Wireless Electricity ***Transfer***

for R & D Committee

Submission to IIM

By **WET** Group

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July, 2020

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Dedication/ Declaration/ Preface

- Declaration: Patents, discussions, appendix and companies information are copied.
- Dedicated to IIM for Nigeria; Nigerian President Mohammadu Buhari GCFR, IIM President Amb. Dr. Oyedokun A. Oyewole FIIM and Chairman IIM R & D Committee Dr. Patrick I. Orumbie FIIM
- Preface: IIM request for R & D Committee on June 21st 2020 to come up with solutions to "Benefits of National Citizens' Data Harmonization in Addressing Insecurity" and "Wireless Electricity Transfer (WET) to Homes from Transmission Points without Distribution Problems of Transformers" to government, industries, office complex etc. caused the committee to create two groups to tackle both by research.

- o Compilation of information on Wireless Electricity Transfer was derived from members and the Internet for group A. National Data Harmonization in Nigeria does not exist as a pool for national data collection, but the data can be pulled from all the bodies that collect data for various utilities like Drivers License, International Passport, Voters Card etc.
- o National Citizens' Data Harmonization Collection (group B) and every other service that requires electricity, cannot function without steady electricity (WET group A) which many in ICT should know WET is also part of ICT and run by ICT experts and not only technicians who cannot handle the program of the wireless aspect:-

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Acknowledgement/ Certification (**WET group A Members**):

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Introduction

- Everything produced is given a name, internationally some local governments and individuals have used wireless electricity, but Nigeria will be the first country to use Wireless Electricity Transfer for personal and office use. So as the leader and proposer of WET, I gave it a distinct name because the solutions to do WET has to do with the research materials covering distance to make it safe that is not in WPT, MTP, wireless energy transfer etc. alone.
- Mobile phones made phone calling in Nigeria for everyone because it was not connected to NITEL (erstwhile Nigerian Telecommunication) poles problems and competition exists with more than one GSM distributor; that is why the suggestion for wireless electricity is most important for Nigerians so that the generation companies will be their power problem and choice problem than the distribution companies choosing for Nigerians.

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- WET presents the idea of wireless transmission that is power transmission without using any kind of electrical conductor and/or wires. We have presented a concept that is discussed here about how electrical energy can be transmitted as microwaves/radio-waves so that to reduce the transmission, allocation and other types of losses. Such technique is known as Microwave Power Transmission (MPT). We have also posed and associated several aspects with the currently available Power transmission systems of wires to the related history of wireless power transmission systems and also the compared developmental changes. The basic blueprint, values and demerits, applications of Wireless Power Transmission are also deliberated.

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- Wireless Power Transfer (WPT) is the transmission of electricity without wires and is based on technologies using time-varying electric, magnetic, or electromagnetic fields. Wireless power transfer (WPT), has been around us since nineteenth century in applications such as telemetry, satellite communications, and radio frequency identification (RFID) tags. Many of these applications transfer low amounts of power, in the range of microwatts to milliwatts, for data transfer. For higher-power applications, from few watts to several kilowatts, over adequate distances, the WPT has newly been the focus of the industrial developments. The most common method of high power WPT is through inductive coupling that was conceived by Nikola Tesla more than a hundred years ago. He contemplated of finding a more efficient way than cables to transfer electricity. In 1891 in the Colorado Springs Lab Nicola Tesla succeeded to light some bulbs wirelessly placed 18 meter from the power source and this was the first time to successfully transfer electricity wirelessly. As wireless charging is such a widespread need among both consumers and businesses, the technology is constantly improving and becoming more common in industries across the board.

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- WPT is useful to power electrical devices where they are difficult, or not doable, as is the case of body embedded sensors, actuators, and communication devices. Wireless power transfer (WPT) systems allow power to be transferred from one electrical network to another without the requirement of wires or exposed contacts. For many diverse applications, this aspect is highly advantageous, and in certain cases has enabled new applications to be realized.
- Further, WPT is poised to play a vital role in the worldwide drive to electrify transportation systems and, thus, become ubiquitous throughout technologically advanced future communities. Therefore, knowledge in WPT is increasingly important for the modern power electronics and systems engineer.

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- So how does wireless power work? Ultimately, it uses basic idea most engineers are very familiar with: Faraday's law of induction. This law states that a changing magnetic field causes an AC (alternating current).
- There are two coils involved in wireless power transfer: a receiver and a transmitter. These coils act like inductors. You could think of them as a transformer without a core; crucially, they are just two air coils that are inductively coupled.
- Power can be transferred over short distances (near-field transfer) by alternating magnetic fields and inductive coupling between coils, or by alternating electric fields and capacitive coupling between metal electrodes. Inductive coupling is the utmost common method of WPT and is used in charging devices such as smart phones, electric shavers, visual prostheses, and implantable medical devices (cardiac pacemakers, cochlear implants) (Sun et al., 2013; Moorey et al., 2014). For 20 mm distance separation and size of the coil pair, loop diameter, and frequency play a major role in determining WPT performance (Celik and Aydin, 2017).

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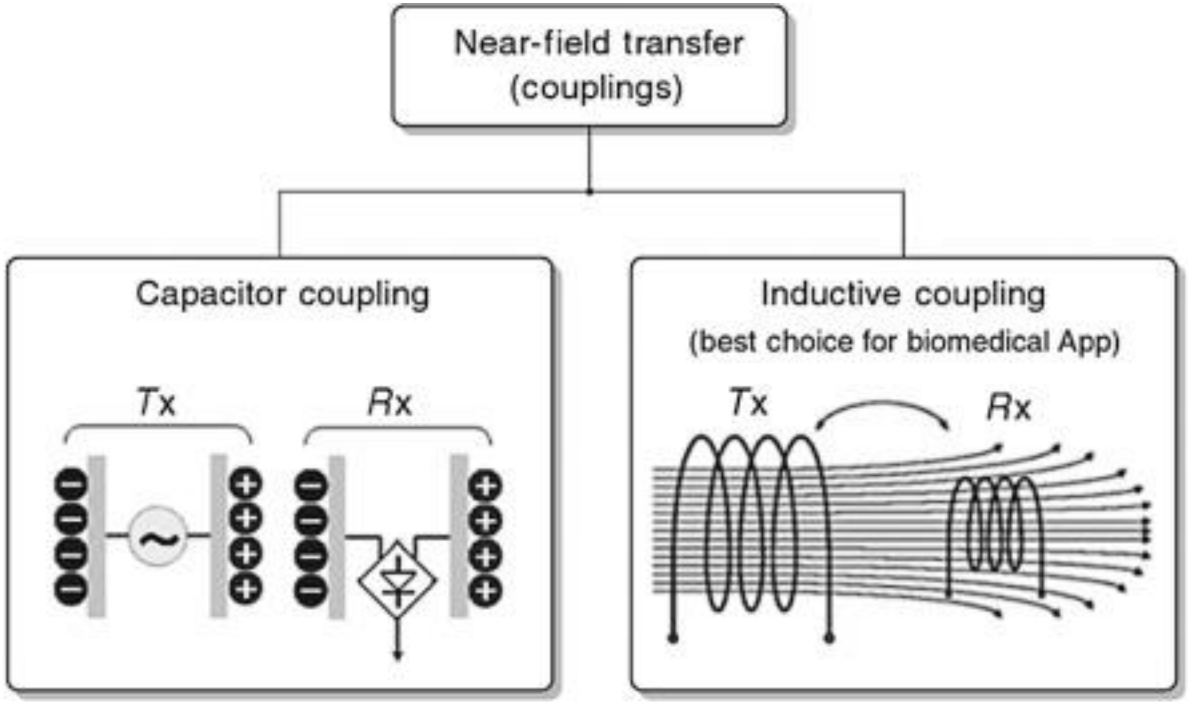

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- ***Wireless power transmission, wireless power transfer** (**WPT**), **wireless energy transmission** (**WET**),* or electromagnetic power transfer are all transmission of electrical energy without wires. In a wireless power transmission system, a transmitter contraption, driven by electric power from a power source, generates a time-varying electromagnetic field, which transmits power across space to a receiver device, which extracts power from the field and supplies it to an electrical load. The technology of wireless power transmission can exclude the use of the wires and batteries, thus increasing the mobility, convenience, and safety of an electronic device for all users. Wireless power transfer is useful to power electrical machines where interconnecting wires are inconvenient, hazardous, or are not possible.

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- Wireless power procedures fall into two categories, near field and far-field. In near field or non-radiative techniques, power is transferred over short distances by magnetic fields using inductive coupling between coils of wire, or by electric fields using capacitive coupling between metal electrodes. Inductive coupling is the most extensively used wireless technology; its applications include charging handheld devices like phones and electric toothbrushes, RFID tags, induction cooking, and wirelessly charging or constant wireless power transfer in implantable medical devices like artificial cardiac pacemakers, or electric vehicles.

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- In *far-field* or *radiative* techniques, also called *power beaming*, power is transmitted by beams of electromagnetic radiation, like microwaves or laser beams. These methods can transport energy at long distances but must be aimed at the receiver. Intended applications for this type are solar power satellites, and wireless powered drone aircraft.
- An important issue acquainted with all wireless power systems is limiting the exposure of people and other living things to potentially injurious electromagnetic fields.

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- In general a wireless power system consists of a "transmitter" device connected to a source of power such as a mains power line, which converts the power to a time-varying electromagnetic field, and one or more "receiver" apparatus which receive the power and convert it back to DC or AC electric current that is used by an electrical load. At the transmitter the input power is converted to an oscillating electromagnetic field by some type of "antenna" device. The word "antenna" is used loosely here; it may be a coil of wire which generates a magnetic field, a metal plate which produces an electric field, an antenna that radiates radio waves, or a laser which generates light. A similar antenna or coupling device at the receiver converts the oscillating fields to an electric current. An important parameter that determines the type of waves is the frequency that determines the wavelength.

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- Wireless power uses the similar fields and waves as wireless communication devices like radio, another familiar technology that involves electrical energy transmitted without wires by electromagnetic fields, used in cellphones, radio and television broadcasting, and WiFi. In radio communication the goal is the transmission of information, so the quantity of power reaching the receiver is not so significant, as long as it is sufficient that the information can be received intelligibly. In wireless communication technologies only tiny amounts of power reach the receiver. In distinction, with wireless power transfer the quantity of energy received is the important thing, so the efficiency (fraction of transmitted energy that is received) is the more significant parameter. For this reason, wireless power technologies are likely to be more limited by distance than wireless communication technologies.

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- Wireless power transfer may be used to power up wireless information transmitters or receivers. These types of communication are known as wireless powered communication (WPC). When the harvested power is used to supply the power of wireless information transmitters, the network is known as Simultaneous Wireless Information and Power Transfer (SWIPT); although when it is used to supply the power of wireless information receivers, it is known as a Wireless Powered Communication Network (WPCN).

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LITERATURE REVIEW

- We start with a concise description of wireless power transfer history, which continues with a discussion on the research done on non-radiative and radiative power transfer, followed by introduction of formation of the first international wireless power standard (Qi) and other standards. The challenges, benefits, applications, and the future of wireless power transfer are conversed.

HISTORY OF WIRELESS POWER TRANSMISSION

- Han Oerested in 1820 during a lecture, noticed a needle deflection of compass when electric current flew in one wire cable which proved magnetic effect of electricity. Andrie-Marie Ampere in 1826, through his circuital law, formulated the relationship between electric current and the produced magnetic field. In 1831 Faraday's law described that the electromagnetic force could be induced in a conductor by varying magnetic flux. Heirnrich Hertz in 1888, confirmed that electromagnetic radiation exists. Nicola Tesla in 1891, improved Hertz's wireless transmitter and registered it in a patent.

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- Hutin and Leblanc’s patent on wireless power transmission at 3 kHz was issued in 1894. In the same year, Tesla successfully energized a light lamp using a pair of coils.

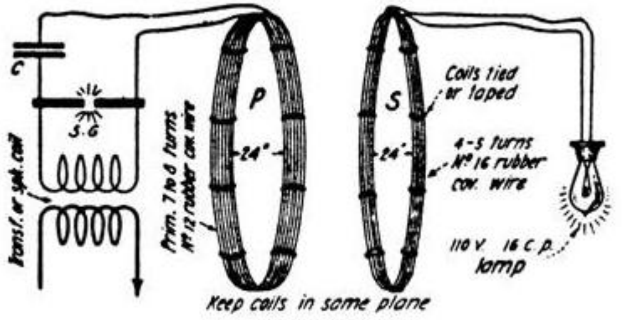

Fig. 1. Diagram shows of one of Tesla's wireless power experiment

- Jagdish Bose in 1895, was able to ring a bell remotely from 75 feet distance through a wall using electromagnetic wave. Marconi successfully sent radio transmission over distance 1.5 miles in 1896. Tesla performed wireless power transmission to 48 km distance.

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- In 1904, a prize was offered for a successful attempt to drive a 0.1 horsepower (745. 5 watts) airship motor by energy transmitted via space at a distance of least 100 feet (3,048 cm). In 1926 Yagi and Uda invented high gain directional array antenna. Before William Brown published his article about possibilities of microwave power transfer and demonstrated a helicopter model that receives the microwave beam. In 1968, Peter Glaser demonstrated the principle of solar power satellite through his suggestion that the wireless energy transmitted from the Sun could be captured. In 1973, the first passive system Radio Frequency Identification (RFID) receivers were energized by electrodynamic induction from a few feet in Los Alamos National Lab.

- In 2007, a physics research group at Massachusetts Institute of technology (MIT), led by Professor Marin Soljacic, presented a coupled magnetic resonance power transfer system and his success to wireless powering of a 60W light bulb with 40% efficiency at a 2m distance using two 60 cm-diameter coils, they called it "Witricity". Recently in 2008, Intel replicated MIT group's experiment that wirelessly powered a light bulb at 75% efficiency, but for a shorter distance.

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- Dr. Rim, a professor of Nuclear and Quantum Engineering at KAIST University in 2015, and his team used inductive power transfer and transmitted electricity to a distance of 3-5m where efficiency is 29%, 16%, 8% for 3m, 4m and 5m, respectively; they used 20kHz signals.
- WPT research between 2001-2013 is summarized in reference, with citation of over 50 papers. According to the most productive author Fu and Imura. As well, the top four active countries in this field are mentioned as USA, South Korea, China, and Japan. Though, New Zealand is developing Wireless Electricity Transmission Network; Electricity Transmission is the bulk movement of electrical energy from the generating site to an electrical substation as grid.

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COMPONENTS OF WIRELESS ELECTRIC TRANSMISSION

Field Region: The fields have diverse physiognomies in these areas, and different technologies are used for transferring power:

- ***Near-field*** or ***non-radiative*** **region** – This means the region within about 1 wavelength (***λ***) of the antenna. In this are the oscillating electric and magnetic fields are separate and power can be transferred through electric fields by capacitive coupling (electrostatic induction) between metal electrodes, or through magnetic fields by inductive coupling (electromagnetic induction) between coils of wire. These fields are not *radiative* implying the energy stays within a short distance of the transmitter. If there is no receiving device or absorbing material within their limited range to "couple" to, no power leaves the transmitter. The range of these fields is short, and depends on the size and shape of the "antenna" devices, which are usually coils of wire. The fields, and thus the power transmitted, decrease exponentially with distance, so if the distance between the two "antennas" D_{range} is much larger than the diameter of the "antennas" D_{ant} very little power will be received. Therefore, these techniques cannot be used for long range power transmission.

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- Resonance, such as resonant inductive coupling, can increase the coupling between the antennas greatly, allowing the efficient transmission at rather greater distances, although the fields still decrease exponentially. Therefore the range of near-field devices is conventionally divided into two categories:
- ***Short range*** – up to about one antenna diameter: $D_{range} \leq D_{ant}$. This is the range over which ordinary non-resonant capacitive or inductive coupling can transfer practical amounts of power.
- ***Mid-range*** – up to 10 times the antenna diameter: $D_{range} \leq 10\ D_{ant}$. This is the range over which resonant capacitive or inductive coupling can transfer practical amounts of power.

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- ***Far-field*** or ***radiative* region** – Beyond about 1 wavelength (**λ**) of the antenna, the electric and magnetic fields are perpendicular to each other and propagate as an electromagnetic wave; examples are radio waves, microwaves, or light waves. This part of the energy is *radiative*, meaning it leaves the antenna whether or not there is a receiver to absorb it. The portion of energy which does not strike the receiving antenna is dissipated and lost to the system. The amount of power emitted as electromagnetic waves by an antenna depends on the ratio of the antenna's size D_{ant} to the wavelength of the waves **λ** which is determined by the frequency: $\lambda = c/f$. At low frequencies f where the antenna is much smaller than the size of the waves, $D_{ant} \ll \lambda$, very little power is radiated. Thus the near-field devices above, which use lower frequencies, radiate almost none of their energy as electromagnetic radiation. Antennas about the same size as the wavelength $D_{ant} \approx \lambda$ such as monopole or dipole antennas, radiate power efficiently, but the electromagnetic waves are radiated in all directions (Omni directionally), so if the receiving antenna is far away, only a small amount of the radiation will hit it. Hence, these can be used for short range, inefficient power transmission but not for long range transmission.

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- Nevertheless, unlike fields, electromagnetic radiation can be focused by reflection or refraction into beams. In using a high-gain antenna or optical system which concentrates the radiation into a narrow beam aimed at the receiver, it can be used for ***long range*** power transmission. From the Rayleigh criterion, to produce the narrow beams necessary to focus a significant amount of the energy on a distant receiver, an antenna must be much larger than the wavelength of the waves used: $D_{ant} \gg \lambda = c/f$. Practical *beam power* devices require wavelengths in the centimeter region or below, corresponding to frequencies above 1 GHz, in the microwave range or above.

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WIRELESS POWER TRANSFER PRINCIPLES

- The working criterion of wireless power transfer is comparable to the power transformer, but with some differences such as transformer have two coils placed very close to each other and usually each coil is wound on a ferrite material to increase the magnetic coupling but in case of wireless power transfer, the core is the open air.
- Wireless power transfer works on the inductive power transfer principle, as seen in the conventional transformers. The main difference is that while in the transformer the two coils are in really close proximity and contain a ferrite material to increase the coupling, inductive chargers have an air gap between the two coils. The process follows the following procedure:

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- The mains voltage is converted into alternating current, preferably, high-frequency AC (Alternating Current).
- This current (the high-frequency AC) is transferred to the coil via transmitter circuit. This AC induces a magnetic field in the transmitter coil.
- The induced magnetic field generates a current in the adjacent receiver coil.
- Conversely, in previous applications, the designers faced a challenge; the strength of a magnetic field decreases with distance. The decrease in strength is proportional to the square of the distance from the origin. It made it hard to regulate power and reduced energy proficiency. To resolve this, the designers introduced resonance. You obtain resonance by multiplying the capacitance of the plates attached to ends of the coil with the coil inductance.

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- Introduction of resonators with same frequency in the sources and receiver coil respectively ensures that both systems couple magnetically, therefore allowing for higher energy transfer efficiency. This means that the power transfer happens over an air gap without the need for metal or other material connection.
- For this to happen, both the transmitter and the receiving coil must resonate at same frequency. The generated alternating current (AC) is converted into direct current for charging the battery.
- Though, in cases where the two objects are far apart, power transfer can still be achieved through resonating the two coils at the same frequency. This eliminates the need for perfect alignment. Greater power transfer distances can be achieved by introducing resonant repeaters between the two components.

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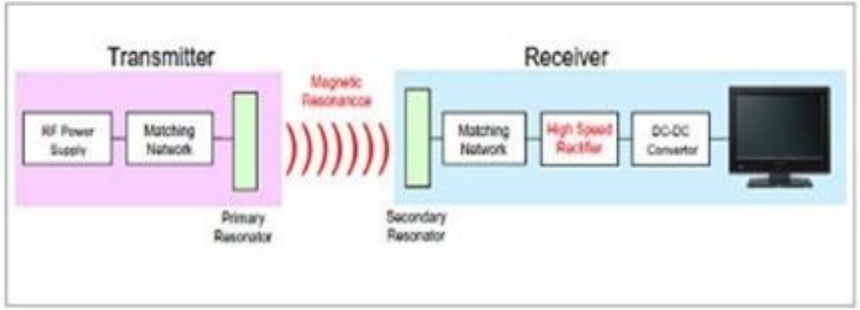
- The basic elements to attain WPT are two, transmitter and receiver. The first one is to have a transmitter that needs circuits to convert the 50 Hz to the optimal WPT frequency to improve efficiency and reduce effects on human body, this frequency is below 10 MHz. This transmitter is connected to a coil that generates a changing magnetic field.



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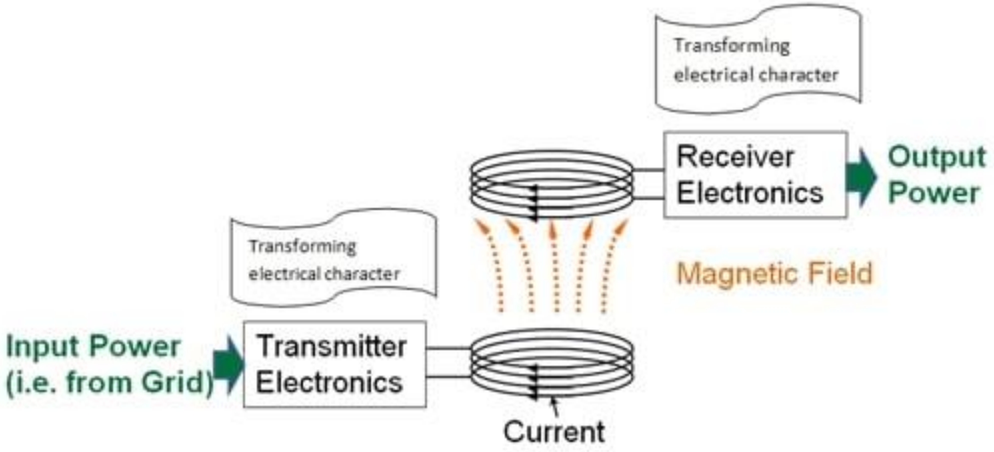

Figure 2 Basic elements of Wireless Power Transfer

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MERITS OF WIRELESS ELECTRIC TRANSMISSION

- **Easy to Use and Maintain:** Unlike traditional electric transmission, WET is easier to use and maintain, distributing electric power to millions of people through wireless transformers and wireless electric meters.
- **Uninterrupted Electric Transmission:** WET distributes electricity even when there is heavy downpour.
- **Absence of Electric Hazards:** Due to its wireless nature, there is lower likelihood of electric accidents such as electrocution.
- **Eliminate Fraud in Electric power fees:** As a result of its wireless nature, it will be difficult to illegally tap electric power and evade electric power usage charges.

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- **Job Creation:** Electric power distribution firms will create jobs as a result of increased margin due to the decline in Electric power fees fraud. This ultimately increase government revenue in the form of corporate tax.

- **DEMERITS OF WIRELESS ELECTRIC TRANSMISSION**
- **Health Concerns:** Wireless electric transmission have the tendency to generate massive radiation which may lead to health hazards in the society.
- **Intensive Capital Involved in Establishing WET:** WET projects may take huge amount of capital for its establishment which most countries such as the developing countries will not afford to undertake and will require proper maintenance overtime.
- **Skilled Manpower Required:** WET requires skilled manpower to maintain its operations. Most countries may lack the needed manpower to manage WET operations.
- This concerns are the purpose of this research on WET that the solutions are below.

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ENERGY HARVESTING

- In the context of wireless power, *energy harvesting*, also called *power harvesting* or *energy scavenging*, is the conversion of ambient energy from the environment to electric power, mainly to power small autonomous wireless electronic devices. The ambient energy may come from stray electric or magnetic fields or radio waves from nearby electrical equipment, light, thermal energy (heat), or kinetic energy such as vibration or motion of the device. Although the efficiency of conversion is usually low and the power gathered often minuscule (milliwatts or microwatts), it can be adequate to run or recharge small micro-power wireless devices such as remote sensors, which are proliferating in many fields. This new technology is being developed to eliminate the need for battery replacement or charging of such wireless devices, allowing them to operate completely autonomously.

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TYPES OF WIRELESS ELECTRIC TRANSMISSION

A. By Technology

i. Near field

Its range is from centimetres to few metres. The power is lost inversely proportional to distance with increase in distance.

1. Conduction: It exploits the process of conduction i.e. energy is transmitted through collisions between neighbouring molecules.

2. Induction: This technique works on the method of electromagnetic induction. Some example of its general usage is in transformers.

3. Resonance: Developed recently by Witricity, this technique works on principle of magnetic resonance i.e. at a particular frequency, inductive and capacitive reactance of a circuit are equal.

ii. Far Field

Its range is from few metres to hundreds of kilometre. The power lost is minimal as long as transmitter and receiver are in line of site with each other.

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1. Microwave/Radio waves: In this technique, the power to be transmitted is converted in microwaves and then transmitted. A Rectenna or solar array could be used as a receiver.

2. Optical: The power transmitted is converted in LASER beams which has much low diffraction in atmosphere, thus minimal power loss.

B. By Sector

1. Consumer Electronics

Automatic wireless charging of mobile electronics as well as direct wireless powering of stationary devices eliminating expensive custom wiring & unsightly cables.

2. Industrial Appliances

Wireless power and communication interconnections across rotating and moving joints (robots, packaging machinery etc.), thus, eliminating costly and failure-prone wiring.

3. Wireless Charging

Charging for existing electric vehicle classes: golf carts, industrial vehicles and for future hybrid and all-electric passenger and commercial vehicles, at home, in parking garages etc.

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4. Military Applications

For high tech military systems (battery powered mobile devices, covert sensors, unmanned mobile robots and aircraft, etc.).

C. By Transmission Types

1. Direct Wireless Power

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 wireless power source.

2. Automatic Wireless Charging

When a device with rechargeable batteries charges itself while still in use or at rest, without requiring a power cord or battery replacement.

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BASIC PARAMETERS AFFECTING WIRELESS ELECTRIC TRANSMISSION

A. Coil Shape

The shape of coil used as antenna will determine the area to which the power will be transmitted.

B. Coil Impedance

Maximum power will be transmitted if transmitting coil's impedance is equal to receiving coil impedance which could be achieved by resonating both sending and receiving coil's at a similar resonating frequency.

C. Distance between coils

The total distance between two coils i.e. sending and receiving coils that also affects the power transmitted too. Usually the transmitted power reduces inversely proportional by the increase in distance.

D. Number of coils

The number of coils used as transmitter and receiver affects the transmitted power directly; with increase in coils used, the complexity of the circuit also increases.

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E. Intermediate Coils, if any

Intermediate coils, if used must be perfectly matched with the impedance of the transmitting and receiving coil impedance, thus providing potential to increase the distance vastly.

PARAMETERS ON WHICH EFFICIENCY OF AN ELECTRIC SYSTEM DEPENDS

The efficiency of an electrical system depends on various parameters. Some of those parameters in this research analyses are :

A. System Performance

One of the most important parameter to calculate efficiency of a system, is the performance of the WPT system in terms of power obtained of which load as well as speed of the system is as whole.

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B. Time

It defines the time taken to switch on the system or the time taken to get power at the receiving terminal from the moment it is transmitted.

C. Cost

It includes the overall cost of the transmission system. For wired system it usually includes all the cables or conductors used as well as cost of distribution system whereas for wireless systems it includes cost of frequency converters, coil and transmitter/receiver circuit.

D. Losses

This considers all the ongoing losses in the systems. For wired system it includes both transmission and distribution losses.

E. Sensitivity and Reliability

It is one of the most, if not the most important parameter to calculate the efficiency of any system. A system should be moderately sensitive as well as very reliable in long run for easing and benefiting the seller and consumer.

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CHALLENGES AND FUTURE WORK

The main challenge that the near-field method is facing is the limitation on its transmission distance. The future work for this technology is focused on improving it to be used in the medical applications; integrating core link driver that will be a way to increase the reliability.

Many challenges face the mid and long-range technologies. Efficiency is very low for these methods, as shown in Fig. 2. It should be noted that the maximum efficiency that could be achieved for mid-range, which requires impedance matching that could not exceed 50%.

Future work in mid-range technology should be considered maximizing the coil's quality factor; designing proper loading of the drive and load loop; and designing a system for impedance matching between the load and transmitter for variable distance, e.g. portable devices. Developing an adaptive rectifier that does not interfere with the operation of magnetically coupled resonant circuit is also desired. Reducing the size of transmitter and receiver to be more suitable for commercial stage and reducing interference with foreign object surrounding the device are other challenges to be addressed.

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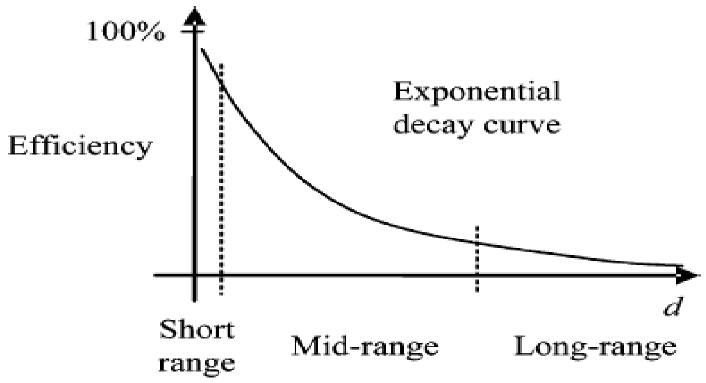

Fig. 2. Decay curve of efficiency

- For both short and mid ranges, the following factor should be considered during design stage. First the emitted magnetic flux should not cause fire. It should not corrupt data in smart card or credit cards. Also, the surrounding metallic objects placed near the charging region shouldn't be heated up. The wireless charging system should be able to locate the position of the load or even make recommendations on how to locate it before starting energy transfer.
- The main focuses for far-field systems are the improvement of directivity and efficiency. Although many systems have been built using microwave with high gain antennas to transfer power over kilometer distance with efficiency of 90%, these systems still suffer from the need for Line of Sight (LOS) (point to point) connection. On one hand there is need to transfer power using omnidirectional antennas to cover more area, on the other hand there is a need for directive antennas to improve the efficiency. The received power density decreases by the factor of square distance from the transmitter to receiver. The transmitter needs to first locate the load and direct the beam towards it.

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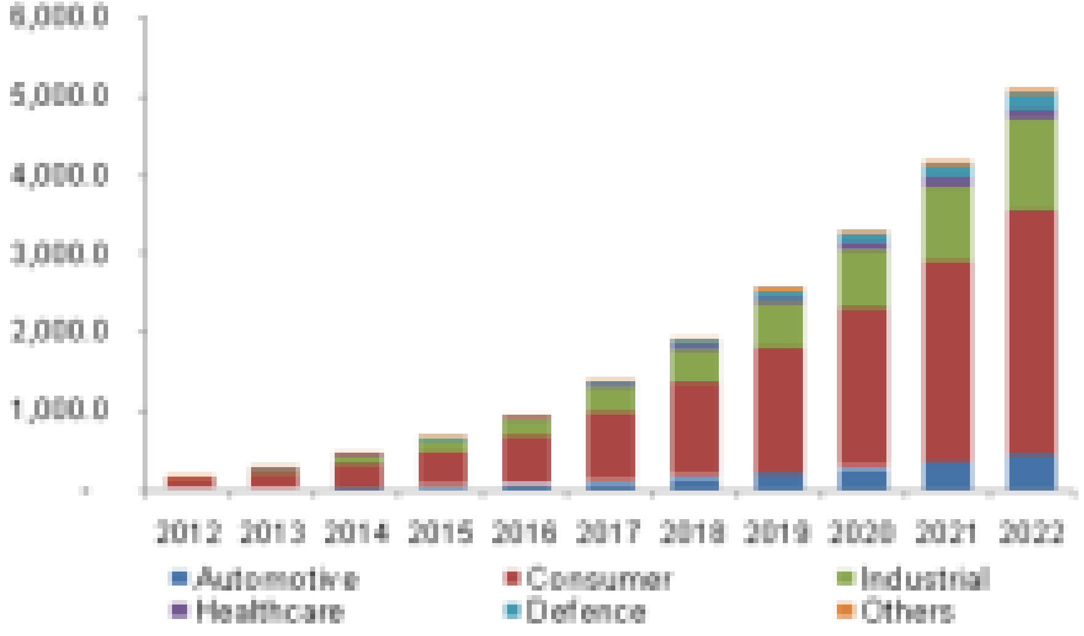
MARKET TRENDS FOR WIRELESS POWER

- Wireless power transfer is still a relatively new phenomenon. In 2012, the market started very small and was comprised entirely of consumer applications (basically phones and tablets). In 2015, the market grew to just under $1 billion. Today, growth for 2016 is projected to exceed $1 billion. By 2022, wireless power is expected to achieve aggressive growth of over $5 billion. It will most likely continue to be dominated by the consumer market, though it is hoped to expand to the industrial and automotive markets



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EXAMPLES OF WIRELESS POWER APPLICATIONS

- There are countless applications for wireless power transfer. Here are just a few examples of what companies are currently trying to achieve:
- Starbucks: phone charging stations at coffee tables
- Qi: cordless kitchen appliances for the home
- Bosch: cordless power drills for construction sites
- Delphi: in-cabin phone charging and infotainment systems for vehicles
- IKEA: integrated furniture and lighting for entirely wireless homes

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APPLICATIONS

- **Industrial Applications:** Wireless power transfer has seen tremendous applications and value addition to industries. The primary applications include wireless sensors on rotating shafts, wireless equipment charging and powering, and safe and watertight equipment through eliminating charging cords
- **Subsea applications:** though subsea vehicles can self-navigate; human assistance is still required for power supply. Due to the rough terrain, as well as the distance, cabled conductors can prove to be a challenge. WPT comes in handy in these instances.
- **Charging mobile devices, unmanned aircraft, home appliances and electric vehicles:** The charging system the smaller gadgets comes in the form of a charging pad and power benches, where the user places the device such as a mobile phone and electric toothbrushes.
- **Charging and operating medical implants:** such as subcutaneous drug supplies, pacemakers, and other implants. WPT, especially with high resonance allows convenient continual charging of these implants without the need for frequent surgeries and the inclusion of external charging ports.

Wireless Electricity *Transfer*

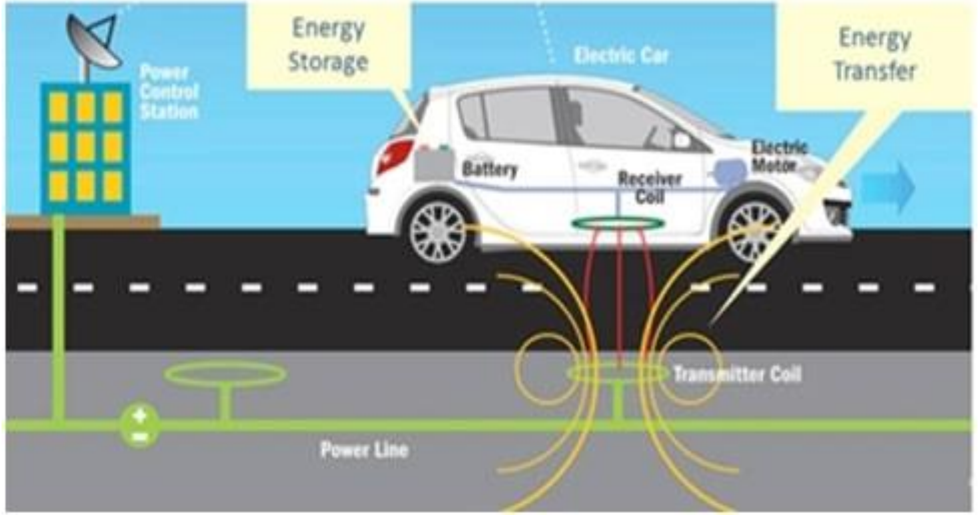
- **<u>Charging wearables</u>:** The convenience of wearables lies in the mobility and convenience. Considering that the wearer must walk around, the primary problem thus is the charging. Wireless power transfer accords the convenience of charging by eliminating the requirement for cables and connectors

BASIC TECHNOLOGIES

- **<u>Inductive Coupling</u>**

This technology is used for small distance WPT and based on two coils only. Used for mobile charging and electric cars charging which will be so effective in electric car industry as cars will not need to stop for charging.

__Figure 3__ Wireless charging for electric cars



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Resonant Inductive Coupling

- Used for small distance Wireless Power Transfer. By using a resonance circuit includes capacitor and inductor, WPT can be more efficient with better magnetic coupling. Nicola Tesla used this method at his first experiment.

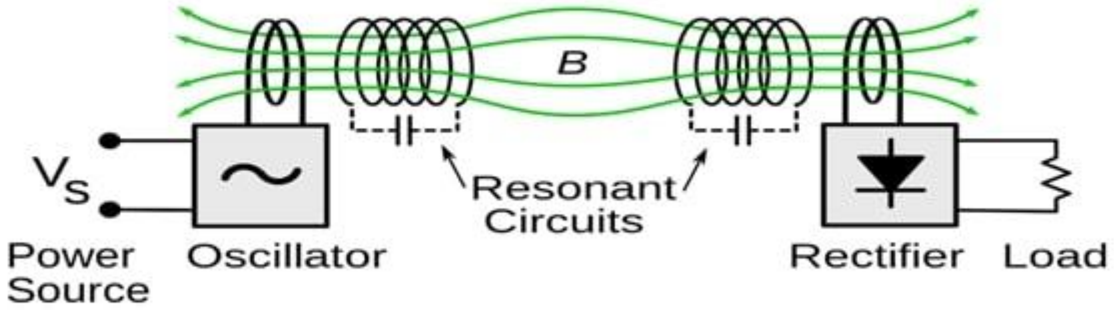

Figure 4 *Wireless Power Transfer using Resonance on secondary side*

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- Magnetic field will energize any metal in its range thus this provides hazards for human.
- A main problem for power station is that in case of WPT, load control will be so hard as the station would act as a transmitter, thus any receiver will be able to receive power and in turns the load shedding and protection will not be that easy.

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BENEFITS OF WIRELESS ELECTRIC TRANSFER

- There are several important benefits of wireless power transfer.
- For one, wireless power allows you to completely seal your device. Whether you are looking to get rid of a power port, remove something you do not want in the system, or advance your product from water-resistant to waterproof, wireless power could be your perfect solution.
- For another, wireless power means less cord clutter. Since each mobile device typically requires its own charging cord, many of us are constantly tripping over (or searching for) chargers in our homes. Wireless power eliminates those problems by providing one universal, cordless power solution for all those devices.
- Another key benefit to wireless power is the highly expandable power range it offers. No longer just a low-power solution, wireless power offers a multitude of real-world applications with anywhere from 0 to over 200W of power transfer. The level of efficiency is thus very high.
- Allows for charging of multiple devices. This is achieved by changing the coil geometry, as well as allocating large charging surface areas such as tabletops and charging benches.

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- High charging speeds: though now wireless charging offers a slower charging rate than the wired option, advances in resonance and induction technology promises an increased charging rate and improved efficiency in the future.
- Wireless power transfer allows for greater spatial freedom between the power source and the device. This means that the two do not have to be precisely aligned for power transfer.
- Eliminating charging cords enables engineers to make compact and watertight devices, thus maximizing on safety, and varied use such as in deep-sea applications.
- Prevents corrosion and sparking by eliminating mechanical connectors and wired contacts.
- Reduces costs associated with maintaining and replacing mechanical connectors.
- wireless power offers a more robust product to design manufacturers.
- The last major benefit of wireless power is increased product life. By eliminating the physical limitations of connectors (like mating cycles, corrosion on contact points, and the likes.

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- Wireless power transfer is a generic term for a number of different technologies for transmitting energy by means of electromagnetic fields. The technologies, listed below, differ in the distance over which they can transfer power efficiently, whether the transmitter must be aimed (directed) at the receiver, and in the type of electromagnetic energy they use: time varying electric fields, magnetic fields, radio waves, microwaves, infrared or visible light waves.

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Material and Methodology

MAGNETIC SHIELD OF WET

Has to do with the magnetic shielding of the field generated by a wireless power transfer (WPT) system at the frequency of 20 kHz.

Diverse shielding techniques are examined and discussed based on the use of conductive and magnetic material panels. The performances of the WPT system and the magnetic field shielding effectiveness (SE) in presence and in absence of shield panels are calculated and measured.

CONVERSION OF WET FOR TRANSMISSION

Conversion of AC to DC for transmission of electricity and the reconversion of DC to AC for use is the safest method of WET that would not harm anyone or interfere with any technology.

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MAGNETIC SHIELD OF WET

- This evaluates how design parameters of a power pad for an electric vehicles wireless charging device have effect on the exposure of people to electromagnetic fields. The effectiveness of magnetic field shielding method by means of conductive panels is analyzed. The shielded coreless transformer has been modelled and examined through Finite Element software. The overall system's behavior was tested in accordance with the International Commission on Non-Ionizing Radiation Protection directives regarding the exposure of people to the risks arising from electromagnetic fields.
- Wireless Power Transfer (WPT) technologies, using inductive coupling, is a technique for contactless power transmission. It is a near-field technology based on the transmission of energy from a transmitter to a receiver through an oscillating magnetic field. This technology is applied to a wide variety of systems, such as small hand-held devices, robotic platforms, and charging electric vehicles.

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The major issue related to this technology is the large air gap between transmitter and receiver coils, resulting in a weak coupling and large leakage flux. There are several problems related to relevant magnetic field in the surrounding environment of WPT systems, such as the safety of people the compliance with the standards for human exposure, the disturbances in other electric and electronic devices, the eddy currents and resulting heating in metallic parts close to the WPT. Consequently, the coil optimized design is an important and challenging task. At the same time, they have to transmit power with a good efficiency and with different relative positions between them, as well as guarantee low exposure of people to electromagnetic fields. In particular, a WPT system for electric vehicles is required to have high efficiency, a large air gap, good tolerance for misalignment in the lateral direction, and to be compact and lightweight.

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AC-DC CONVERTER FOR WIRELESS POWER TRANSMISSION OF ENERGY HARVESTING SYSTEM

- High-efficiency AC-DC converter is improved for a wireless power transmission system that transmits power generated from energy harvesting. RF power is transmitted in the frequency of 10-100 MHz, and power of -10 to 15 dBm is received by the AC-DC converter. A matching network is designed according to the received power from resonant coils and the load resistor is enhanced to obtain maximum output power. As a consequence, conversion efficiency ranging from 50% to a maximum of 87% is achieved in an RF power range of -10 to 15 dBm that has 10-100 MHz frequency. Likened to other converters, the implemented AC-DC converter shows not only 20%-40% higher peak efficiency, but also 20%-50% higher average efficiency. It is appropriate for application in wearable devices or body area networks.
- Wearable devices and Body Area Networks (BANs) are fields in which the most recent wireless power transmission systems can be applied. As wearable devices and BANs require portability and are used with human activity, the means by which power is provided is important.

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For instance, batteries and energy harvesting circuits can be used as power sources. In wearable devices and BANs that are used with human activity, the ideal is to remove the constraints of time available by providing power with an energy harvesting circuit rather than a battery. Moreover, because the recent wireless power transmission systems using resonant coils generally have high power requirements of more than 50 W, the enhancement of such systems in the medium power range (−10 to 15 dBm) is needed for their application in the mentioned fields. In the application of resonant coils on the human body, the coils must transmit power with a resonance frequency of 10–100 MHz because of physical constraints, such as coil diameter, length, etc. When the transmitted RF power is changed to DC power for use in applications, it is very important to fully convert the power with high efficiency because the amount of power generated by energy harvesting is too small. The quantity of power, the frequency, the arrangement of the matching component, the load resistor, and the number of stages of the voltage multiplier are considered for high-efficiency conversion of RF power transmitted to the AC-DC converter. The suggested converter could greatly improve the conversion efficiency in 10–100 MHz band by using matching characteristics according to amount of received power and optimum load resistance. In Section II, the matching network and system design are described in detail. In Section III, the simulation and measured efficiency results designed using large signal analysis will be matched in relation to the amount of power with small signal analysis and large signal analysis in the range from −10 to 15 dBm. Before, the performance of the proposed converter will be compared with that of other converters and analyzed in terms of the average and maximum efficiency.

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PATENTED CLAIMS STARTS excluding figures

“WIRELESS POWER TRANSMISSION APPARATUS AND WIRELESS POWER TRANSMISSION METHOD

The embodiment relates to a wireless power transmission apparatus and a wireless power transmission method. The wireless power transmission apparatus includes a first power converting unit to generate high-frequency AC signals; a second power converting unit to generate low-frequency AC signals; a first coil receiving the high-frequency AC signals and transmitting a wireless power through a first power transmission scheme; a second coil receiving the low-frequency AC signals and transmitting the wireless power through a second power transmission scheme; and a control unit to control the first and second coils, wherein the control unit is configured to transmit a detection signal for the first power transmission scheme to a wireless power reception apparatus through the first coil, detect a reception of a first response signal corresponding to the first detection signal during a first predetermined time, determine a power transmission scheme of the wireless power reception apparatus as the first power transmission scheme in response to a detection of the first response signal, and deactivate the first power converting unit in response to no detection of the first response signal.

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1. A wireless power transmission apparatus comprising: a first power converting unit to generate high-frequency AC signals; a second power converting unit to generate low-frequency AC signals; a first coil receiving the high-frequency AC signals and transmitting a wireless power through a first power transmission scheme; a second coil receiving the low-frequency AC signals and transmitting the wireless power through a second power transmission scheme; and a control unit to control the first and second coils, wherein the control unit is configured to transmit a detection signal for the first power transmission scheme to a wireless power reception apparatus through the first coil, detect a reception of a first response signal corresponding to the first detection signal during a first predetermined time, determine a power transmission scheme of the wireless power reception apparatus as the first power transmission scheme in response to a detection of the first response signal, and deactivate the first power converting unit in response to no detection of the first response signal.

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2. The wireless power transmission apparatus of claim 1, wherein the control unit activates the second power converting unit in response to no detection of the first response signal, transmits a second detection signal to the wireless power reception apparatus through the second coil, detects a reception of a second response signal corresponding to the second detection signal during a second predetermined time, and determines the power transmission scheme of the wireless power reception apparatus as a second power transmission scheme in response to a detection of the second response signal.

3. The wireless power transmission apparatus of claim 2, wherein the control unit switches the first coil or the second coil according to the determined first power transmission scheme or second power transmission scheme, and transmits a power to the wireless power reception apparatus through the switched coil.

4. The wireless power transmission apparatus of claim 1, wherein the first response signal includes information about an amount of charge in the wireless power reception apparatus and a power is transmitted through the first power transmission scheme based on the information about the amount of charge.

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5. The wireless power transmission apparatus of claim 1, wherein the first response signal includes information about a charging scheme of the wireless power reception apparatus.

6. The wireless power transmission apparatus of claim 1, wherein the first coil includes a resonance coil and the second coil includes an induction coil.

7. The wireless power transmission apparatus of claim 3, further comprising: a power supply unit; and a transforming unit to transform a power supplied from the power supply unit into a DC power, wherein the first power converting unit and the second power converting unit receiving the DC power from the transforming unit.

8. The wireless power transmission apparatus of claim 7, further comprising a switch unit which selectively applies the power of the transforming unit to the power converting units according to the first power transmission scheme and the second power transmission scheme determined by the control unit.

9. The wireless power transmission apparatus of claim 7, wherein the transforming unit includes one of a buck converter, a boost converter and a buck-boost converter.

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10. The wireless power transmission apparatus of claim 1, wherein the control unit includes a Bluetooth controller.

11. A wireless power transmission method of a wireless power transmission apparatus having a plurality of power transmission schemes, comprising: activating a first transmission control unit that detects a first power transmission scheme; transmitting a detection signal for the first power transmission scheme to a wireless power reception apparatus; detecting a reception of a first response signal corresponding to the first detection signal during a first predetermined time; determining a power transmission scheme of the wireless power reception apparatus as the first power transmission scheme in response to a detection of the first response signal; and deactivating the first transmission control unit in response to no detection of the first response signal.

12. The wireless power transmission method of claim 11, further comprising: activating a second transmission control unit in response to no detection of the first response signal; transmitting a second detection signal to the wireless power reception apparatus; detecting a reception of a second response signal corresponding to the second detection signal during a second predetermined time; and determining the power transmission scheme of the wireless power reception apparatus as a second power transmission scheme in response to a detection of the second response signal.

13. The wireless power transmission method of claim 12, further comprising: transmitting a power to the wireless power reception apparatus through the determined first power transmission scheme or second power transmission scheme.

14. The wireless power transmission method of claim 12, wherein the second response signal corresponding to the second detection signal includes information about an amount of charge in the wireless power reception apparatus and a power is transmitted through the second power transmission scheme based on the information about the amount of charge.

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15. The wireless power transmission method of claim 12, wherein the second response signal corresponding to the second detection signal includes information about a charging scheme of the wireless power reception apparatus.

16. The wireless power transmission method of claim 11, wherein the first response signal corresponding to the first detection signal includes information about an amount of charge in the wireless power reception apparatus and a power is transmitted through the first power transmission scheme based on the information about the amount of charge.

17. The wireless power transmission method of claim 12, wherein the first response signal corresponding to the first detection signal includes information about a charging scheme of the wireless power reception apparatus.

18. The wireless power transmission method of claim 11, wherein the first power transmission scheme includes an electromagnetic resonance scheme and the second power transmissions scheme includes an electromagnetic induction scheme.

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BACKGROUND

- The embodiment relates to a wireless power transmission apparatus and a wireless power transmission method.
- In general, various electronic devices are equipped with batteries and operated using power charged in the batteries. In this case, the battery is replaceable and rechargeable in the electronic device. To this end, the electronic device is equipped with a connecting terminal for a connection with an external charging device for charging the battery. In other words, the electronic device is electrically connected with the charging device through the connecting terminal. However, because the connecting terminal in the electronic device is exposed to the outside, the connecting terminal may be contaminated with foreign matters or shorted due to moisture. In this case, connection failures occur between the connecting terminal and the charging device so that the battery in the electronic device may not be charged.
- In order to solve the above problem, there has been suggested a wireless power charging system. The wireless power charging system includes a wireless power transmission apparatus and a wireless power reception apparatus. In this case, the electronic device is implemented as the wireless power reception apparatus. In addition, the wireless power transmission apparatus transmits the power through a wireless transmission unit and the wireless power reception apparatus receives the power through a wireless reception unit.
- A scheme of implementing a wireless charging system is typically classified into a magnetic induction scheme and a magnetic resonance scheme.

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- The magnetic induction scheme is a contactless energy transmission technique which applies current to one of two adjacent coils and generates electromotive force in the other coil through a medium of a magnetic flux generated from one coil, and the magnetic induction scheme may utilize a frequency of several hundreds of kHz.
- The magnetic resonance scheme is a magnetic resonance technique which uses an electric or magnetic field without using any electromagnetic waves or electric currents, and the magnetic resonance scheme may have a transmissible distance of several meters or more and use a bandwidth of several tens of MHz.
- If the wireless power transmission apparatus is constructed with the combination of the above charging schemes, the magnetic fields generated from the coils may interfere with each other so that the two charging modes may not normally operate. In addition, if the independent charging scheme is adopted, the high cost and degradation of components may be caused because installation and setting of dedicated hardware and software are required.

Wireless Electricity *Transfer*

SUMMARY

- The embodiment provides a wireless power transmission apparatus representing improved performance.
- The embodiment provides a wireless power transmission apparatus operated with various wireless power transmission schemes.
- The embodiment provides a wireless power transmission apparatus including a first power converting unit to generate high-frequency AC signals; a second power converting unit to generate low-frequency AC signals; a first coil receiving the high-frequency AC signals and transmitting a wireless power through a first power transmission scheme; a second coil receiving the low-frequency AC signals and transmitting the wireless power through a second power transmission scheme; and a control unit to control the first and second coils, wherein the control unit is configured to transmit a detection signal for the first power transmission scheme to a wireless power reception apparatus through the first coil, detect a reception of a first response signal corresponding to the first detection signal during a first predetermined time, determine a power transmission scheme of the wireless power reception apparatus as the first power transmission scheme in response to a detection of the first response signal, and deactivate the first power converting unit in response to no detection of the first response signal.

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- The embodiment provides a wireless power transmission method including activating a first transmission control unit that detects a first power transmission scheme; transmitting a detection signal for the first power transmission scheme to a wireless power reception apparatus; detecting a reception of a first response signal corresponding to the first detection signal during a first predetermined time; determining a power transmission scheme of the wireless power reception apparatus as the first power transmission scheme in response to a detection of the first response signal; and deactivating the first transmission control unit in response to no detection of the first response signal.
- The wireless power transmission apparatus according to the embodiment is a combination type wireless power transmission apparatus equipped with induction and resonance schemes, which can provide maximum power through various schemes with a simple configuration and reduce the cost through the common use of components.

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DETAILED DESCRIPTION OF THE EMBODIMENTS

- Hereinafter, a wireless power transfer system according to an embodiment will be described with reference to accompanying drawings. Although embodiments have been described with reference to a number of illustrative embodiments thereof, it should be understood that numerous other modifications and embodiments can be devised by those skilled in the art that will fall within the spirit and scope of the principles of this disclosure. The thickness and size of an apparatus shown in the drawings may be exaggerated for the purpose of convenience or clarity. The same reference numerals denote the same elements throughout the specification.
- The embodiment selectively uses various types of frequency bandwidths in the range of a low frequency wave (50 kHz) to a high frequency wave (15 MHz) for transmitting wireless power, and requires a support of a communication system which is capable of exchanging data and control signals for system control.

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- The embodiment can be employed in various industrial fields, such as a mobile terminal industry, a smart clock industry, a computer and laptop industry, an electronic device industry, an electric vehicle industry, a medical device industry, a robot industry, etc.
- The embodiment may include a system capable of transmitting power to one or more devices by using one or multiple transmission coils constituting the device.
- According to the embodiment, the problem of low battery for mobile devices such as smartphones, laptops, etc. can be solved. For example, when the smartphone and the laptop are seated and used on a wireless charging pad on a table, the battery is automatically charged and used for a long period of time. In addition, when the wireless charging pad is installed at public areas such as coffee shops, airports, taxis, offices, restaurants, etc., various mobile devices can be charged regardless of charging terminals which may vary depending on the manufacturer of the mobile device. Further, when the wireless power transfer technology is employed in electrical appliances such as vacuum cleaners, electric fans, etc., users may not need to look for the power cable, and tangled electrical cables can be eliminated at home so wirings in buildings can be reduced and space can be more efficiently utilized. In addition, a long period of time is required when an electric vehicle is charged by a typical household power source. However, when a high amount of power is transmitted through the wireless power transfer technology, charging time can be reduced, and when wireless charging equipment is installed at a floor of a parking lot, an inconvenience of preparing a power cable in the vicinity of the electrical vehicle can be relieved.

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- Terms and abbreviations used in the embodiment are as follows:-
- Wireless Power Transfer System: A system for transmitting wireless power in a magnetic field region.
- Wireless Power Transfer System-Charger: An apparatus for transmitting wireless power to a signaler or multiple power devices in a magnetic field region and for managing the entire system.
- Wireless Power Transfer System-Device: An apparatus for receiving wireless power from a wireless power transfer system-charger in a magnetic field region.
- Charging Area: An area in which the wireless power is transmitted in the magnetic field region, and which may vary according to a size of an application product, required power and an operating frequency.
- Scattering parameter: A scattering parameter is a ratio of an input voltage to an output voltage in a frequency distribution, a ratio of an input port to an output port (Transmission; S21) or a self-reflection value of each input/output port, in other words, a value of an output reflecting back by a self-input (Reflection; S11, S22).
- Quality factor (Q): A value of Q in a resonant state designates a quality of frequency selection, in which a resonance characteristic is better when the value of Q is higher, and the value of Q is expressed as a ratio of stored energy to energy loss in a resonator.

Wireless Electricity *Transfer*

- The principle of wirelessly transferring power mainly includes a magnetic induction scheme and a magnetic resonance scheme.
- The magnetic induction scheme is a contactless energy transmission technique which applies current to a source inductor Ls adjacent to a load inductor L1 such that electromotive force is generated in the load inductor L1 through a medium of a magnetic flux generated from the source inductor Ls. In addition, the magnetic resonance scheme generates a magnetic resonance from a natural frequency between two resonators by coupling the two resonators to utilize a resonance scheme for forming an electric field and a magnetic field in the same wavelength range while fluctuating in a same frequency thereby wirelessly transferring energy.
- Ls/Rs=L1/R1 Equation 1
- According to the equation 1, a maximum power transmission is possible when a ratio of an inductance of the transmission coil Ls to the source resistance Rs is the same as a ratio of an inductance of the load coil L1 to the load resistance R1. Because a capacitor for compensating for a reactance does not exist in a system in which only an inductance exist, a self-reflection value S11 of an input/output port at a position on which maximum power is transferred may not be 0, and a maximum transfer efficiency may be varied according to the mutual inductance Ms1. Accordingly, the source capacitor Cs may be added to the wireless power transfer system-charger and the load capacitor C1 may be added to the wireless power transfer system-device for compensation capacitors for the impedance matching. The compensation capacitors Cs, C1, for example, may be serially connected or connected in parallel with each of the reception coil Ls and the load coil L1, respectively. In addition, passive elements such as an additional capacitor and an inductor may be added along with the compensation capacitors to each of the wireless power transfer system-charger and the wireless power transfer system-device for the impedance matching.

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- In the magnetic resonance scheme, most of the energy in the resonator of the wireless power transfer system-charger is transferred to the resonator of the wireless power transfer system-device when the resonance frequency of the two resonators are the same, so that the power transfer efficiency can be improved and the efficiency of the magnetic resonance scheme becomes better when satisfying the following equation 2.
- $k/\Gamma >> 1$ Equation 2
    - (k is a coupling coefficient, Γ is a damping ratio)
- In the magnetic resonance scheme, an element for the impedance matching may be added to improve the efficiency, and the impedance matching element may be a passive element such as an inductor and a capacitor.
- A system for transmitting wireless power, in which power is transferred by the magnetic induction scheme or the magnetic resonance scheme based on the principle for transmitting wireless power, will be examined below.

Wireless Electricity *Transfer*

The transmission side AC/DC converting unit 1100 is a power converter which converts an AC signal received from the outside under the control of the transmission side communication and control unit 1500 to a DC signal, in which the transmission side AC/DC converting unit 1100 may be a sub-system including a rectifier 1110 and a transmission side AC/DC converter 1120. The rectifier 1110 is a system for converting the supplied AC signal to the DC signal, and for an embodiment for implementing the rectifier 1110, a diode rectifier having a relatively high efficiency when operating at high frequencies, a synchronous rectifier prepared as one-chip, or a hybrid rectifier by which cost and space can be reduced and having a high freedom of a dead time may be used. In addition, the transmission side DC/DC converter 1120 controls a level of the DC signal provided by the rectifier 1100 under the control of the transmission side communication and control unit 1500, and for an embodiment for implementing the transmission side DC/DC converter 1120, a buck converter which lowers a level of the input signal, a boost converter which increases the level of the input signal and a buck boost converter or a Cuk converter which lowers or increases the level of the input signal may be used. In addition, the transmission side DC/DC converter 1120 may include a switching device which controls a power conversion, an inductor and a capacitor which smooth the output voltage, and a transformer which modifies a voltage gain or performs an electrical separation (insulation) function, and remove a ripple component or a pulsation component (AC component included in DC component) included in the DC signal. Further, an error between a command value of the output signal of the transmission side DC/DC converter 1120 and an actual output value may be controlled through a feedback scheme, which can be performed by the transmission side communication and control unit 1500.

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- The transmission side DC/AC converter 1200 is a system capable of converting the DC signal outputted from the transmission side AC/DC converting unit 1100 to the AC signal under the control of the transmission side communication and control unit 1500 and controlling a frequency of the converted AC signal, and for an embodiment for implementing the transmission side DC/AC converter 1200, a half bridge inverter or a full bridge inverter may be used. In addition, the transmission side DC/AC converter 1200 may include an oscillator to generate the frequency of the output signal and a power amplifying unit to amplify the output signal.
- The transmission side impedance matching unit 1300 minimizes a reflection wave at a position at which impedances are different thereby improving a flow of the signal. The two coils of the wireless power transfer system-charger 1000 and the wireless power transfer system-device 2000 are spatially separated from each other so a large amount of the magnetic field is leaked, so that an efficiency of power transfer may be improved by compensating for the impedance difference between the two connecting parts of the wireless power transfer system-charger 1000 and the wireless power transfer system-device 2000. The transmission side impedance matching unit 1300 may include an inductor, a capacitor and a resistor, and may modify an impedance value for the impedance matching by varying an inductance of the inductor, a capacitance of the capacitor and a resistance value of the resistor under the control of the transmission side communication and control unit 1500. In addition, when the wireless power transfer system transfers power by the magnetic induction scheme, the transmission side impedance matching unit 1300 may have a serial resonance structure or a parallel resonance structure, and energy loss can be minimized by increasing an induction coupling coefficient between the wireless power transfer system-charger 1000 and the wireless power transfer system-device 2000. Further, when the wireless power transfer system transfers power by the magnetic resonance scheme, the transmission side impedance matching unit 1300 allows the impedance to be matched in real-time according to a change in the distance between the wireless power transfer system-charger 1000 and the wireless power transfer system-device 2000 or mutual influence from metallic foreign substances and various devices, and a multiple matching scheme using a capacitor, a matching scheme using multiple antennas, a scheme using multiple loops may be used for the compensation scheme.

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- The transmission side coil 1400 may be implemented by a plurality of coils or a single coil, and, when the transmission side coil 1400 includes a plurality of coils, the coils may be spaced apart from each other or overlapping, and when the coils are overlapping, an overlapped area may be determined by taking a deviation of the magnetic flux density into consideration. In addition, the transmission side coil 1400 may be produced by taking an internal resistance and a radiation resistance into consideration, and in this case, when the resistance component is small, the quality factor and the transmission efficiency can be improved.
- The communication and control unit 1500 may be a sub-system including a transmission side controller 1510 and a transmission side communication unit 1520. The transmission side controller 1510 may control the output voltage of the transmission side AC/DC converter 1100 by considering an amount of required power, a currently charged amount and a wireless power scheme of the wireless power transfer system-device 2000. In addition, the power to be transmitted may be controlled by generating a frequency and a switching waveform to drive the transmission side DC/AC converter 1200 by taking the maximum power transmission efficiency into consideration. Further, an algorithm, a program or an application required for the control which is read from a storage unit (not shown) of the wireless power transfer system-device 2000 may be used to control an overall operation of the wireless power transfer system-device 2000. Meanwhile, the transmission side controller 1510 may signify a microprocessor, a micro-controller unit or a micom. The transmission side communication unit 1520 may communicate with a reception side communication unit 2620, and for an example of a communication scheme, a Bluetooth scheme may be used. The transmission side communication unit 1520 and the reception side communication unit 2620 may transceive charging status information and charging control command with each other. In addition, the charging status information may include a number of the wireless power transfer system-device 2000, a residual energy of a battery, a number of charging operations, an amount of usage, a capacity of the battery, a ratio of the battery and an amount of transferred power of the wireless power transfer system-charger 1000. Further, the transmission side communication unit 1520 may transmit a charging function control signal to control a charging function of the wireless power transfer system-device 2000, and the charging function control signal may indicate to enable or disable for receiving wireless power of controlling the wireless power transfer system-device 2000.

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- Meanwhile, the wireless power transfer system-charger 1000 may include a hardware different from the transmission side communication unit 1520 so that the wireless power transfer system-charger 1000 may communicate in an out-band type. In addition, the wireless power transfer system-charger 1000 and the transmission side communication unit 1520 may be implemented as single hardware, so that the wireless power transfer system-charger 1000 may communicate in an in-band type. Further, the transmission side communication unit 1520 may be separately provided from the transmission side controller 1510, and the reception side communication unit 2620 may be included in the controller 2610 of the reception device or separately provided from the controller 2610 of the reception device.
- The reception side coil unit 2100 may receive the power through the magnetic induction scheme or the magnetic resonance scheme. Accordingly, the reception side coil unit 2100 may include at least one of an induction coil and a resonance coil according to the power reception scheme. In addition, the reception side coil unit 2100 may further include Near Field Communication. Further, the reception side coil unit 2100 may be same as the transmission side coil unit 1400, and a specification of a reception antenna may vary according to an electrical characteristic of the wireless power transfer system-device 2000.

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- The reception side impedance matching unit 2200 may match the impedance between the wireless power transfer system-charger 1000 and the wireless power transfer system-device 2000.
- The reception side AC/DC converter 2300 generates a DC signal by rectifying the AC signal outputted by the reception side coil unit 2100.
- The reception side DC/DC converter 2400 may control a level of the DC signal outputted by the reception side AC/DC converter 2300 in match with the capacitance of the load 2500.
- The load 2500 may include a battery, a display, an audio output circuit, a main processor and various sensors.
- The reception side communication and control unit 2600 may be activated by a wake-up power from the transmission side communication and control unit 1500, communicate with the transmission side communication and control unit 1500, and control a sub-system of the wireless power transfer system-device 2000.
- A plurality of a single wireless power transfer system-device 2000 may be provided to simultaneously and wirelessly receive energy from the wireless power transfer system-charger 1000. In other words, in the wireless power transfer system using the magnetic resonance scheme, a plurality of the wireless power transfer system-devices 2000 may receive power from one wireless power transfer system-charger 1000. In this case, the transmission side matching unit 1300 of the wireless power transfer system-charger 1000 may adaptively match the impedance between the wireless power transfer system-devices 2000. This may be similarly employed even when the magnetic induction scheme includes a plurality of coil units which are independent from each other.

Wireless Electricity *Transfer*

- In addition, when a plurality of the wireless power transfer system-devices 2000 are provided, the systems may have the same power reception scheme or different power reception schemes. In this case, the wireless power transfer system-charger 1000 may be a system transmitting power in the magnetic induction scheme or the magnetic resonance scheme or a system using both schemes.
- Meanwhile, when a size and a frequency of the signal of the wireless power transfer system are examined, in the case of the magnetic induction scheme, the transmission side AC/DC converting unit 1100 may receive an AC signal of 110 V to 220 V and 60 Hz, convert the AC signal to a DC signal of 10 V to 20 V and output the DC signal in the wireless power transfer system-charger 1000, and the transmission side DC/AC converter 1200 may receive the DC signal and output an AC signal of 125 kHz. In addition, the wireless power transfer system-device 2000 receives the AC signal of 125 KHz and converts the AC signal to a DC signal of 10 V to 20 V, and the reception side DC/DC converter 2400 may output the DC signal, for example a DC signal of 5 V, appropriate for the load 2500 and transfer the DC signal to the load 2500. In addition, in the case of the wireless power transmission using the magnetic resonance scheme, the transmission side AC/DC converter 1100 may receive an AC signal of 110 V to 220 V and 60 Hz, convert the AC signal to a DC signal of 10 V to 20 V and output the DC signal, and the transmission side DC/AC converter 1200 may receive the DC signal and output an AC signal having a frequency of 6.78 MHz in the wireless power transfer system-charger 1000. Further, the reception side AC/DC converter 2300 may receive the AC signal having the frequency of 6.78 MHz, convert the AC signal to a DC signal having a voltage of 10 V to 20 V, and output the DC signal, the DC/DC converter 2400 may output a DC signal, for example the DC signal of 5 V, appropriate for the load 2500 and transfer the DC signal to the load 2500.

Wireless Electricity *Transfer*

- The AC-DC converting unit 3100 may convert AC power received from a power supply unit 30 into DC voltage.
- The transforming unit 3200 may adjust a level of the DC power output from the AC-DC converting unit 3100 based on a control signal.
- Since the operation of the transforming unit 3200 is based on the conversion of a DC input into a DC output, the transforming unit 3200 may be called an SMPS (Switched Mode Power Supply), a DC-DC transformer or a DC-DC converter.
- The transforming unit 3200 may include one of a buck converter of which an output voltage is lower than an input voltage, a boost converter of which an output voltage is higher than an input voltage, and a buck-boost converter having the characteristics of the above-mentioned converters.
- A control unit may include the main control unit 3300 and the transmission control unit 3400.
- The main control unit 3300 may control the level of DC voltage output from the transforming unit 3200 by taking into consideration the maximum power transmission efficiency, the amount of power required by the receiver and an amount of charge in the receiver.
- In addition, the main control unit 3300 may control the transmission control unit 3400 according to the power transmission scheme. The main control unit 3300 may obtain information about the charge scheme from the receiver to control the transmission control unit 3400 according to the power transmission scheme.
- The transmission control unit 3400 may include a first transmission control unit 3410 and a second transmission control unit 3420.
- The first and second transmission control units 3410 and 3420 may control the power transmission according to the power transmission scheme.

Wireless Electricity *Transfer*

The first transmission control unit 3410 may be a control unit to control power transmission through the electromagnetic induction scheme in a first charging scheme. That is, the first transmission control unit 3410 may control the operation for transmitting power to the wireless power reception apparatus through the electromagnetic induction scheme. Preferably, the first transmission control unit 3410 may be a wireless power consortium (WPC) controller. The WPC controller may control the operation for transmitting power to the wireless power reception apparatus located in a near field through the magnetic induction scheme. In addition, when the wireless power reception apparatus is detected within a critical distance, the WPC controller may control the operation to transmit power to the wireless power reception apparatus. In this case, the power transmission frequency may be in the range of 110 KHz to 205 KHz. In addition, the second transmission control unit 3420 may be a control unit to control power transmission through the resonance scheme in a second charging scheme. That is, the second transmission control unit 3420 may control the operation for transmitting power to the wireless power reception apparatus through the resonance scheme of the power transmission schemes. Preferably, the second transmission control unit 3420 may be an alliance for wireless power (A4WP) controller. When compared to the WPC controller, the A4WP controller can control the operation for transmitting power to the wireless power reception apparatus located far from the A4WP controller. In addition, the A4WP controller may include an A4WP Bluetooth (A4WP BLU) controller. Accordingly, when the power is transmitted to the wireless power reception apparatus through the magnetic resonance scheme, the A4WP BLU controller may perform the Bluetooth communication with the wireless power reception apparatus. That is, the A4WPBLU controller may receive wireless charging information and status information of the wireless power reception apparatus through the Bluetooth communication, and controls to transmit an operation control signal to the wireless power reception apparatus. The A4WP BLU controller may set the frequency for the power transmission differently from the frequency for the Bluetooth communication. Preferably, the frequency for the power transmission may be 6.78 MHz, and the frequency for the Bluetooth communication may be 2.4 GHz. The first and second transmission control units 3410 and 3420 may not be limited to the above.

Wireless Electricity *Transfer*

- The first transmission control unit 3410 may detect the wireless power reception apparatus and may be enabled or disabled to transmit the power the wireless power reception apparatus under the control of the main control unit 3300.
- The first transmission control unit 3410 may be activated prior to the second transmission control unit 3420 under the control of the main control unit 3300. In the activation state, the first transmission control unit 3410 may detect the wireless power reception apparatus and may check whether the detected wireless power reception apparatus is wirelessly charged through the first charging scheme. Upon checking the charging scheme of the wireless power reception apparatus, if the first charging scheme is adopted in the wireless power reception apparatus, the first transmission control unit 3410 may control the operation to transmit the power to the wireless power reception apparatus. In addition, the first transmission control unit 3410 may operate based on the information about the charging scheme obtained from the receiver under the control of the main control unit 3300.
- If the detected charging scheme is not the first charging scheme, the enabled first transmission control unit 3410 may be disabled under the control of the main control unit 3300.

Wireless Electricity *Transfer*

- In a state that the first transmission control unit 3410 is disabled, the second transmission control unit 3420 may be enabled under the control of the main control unit 3300. That is, the second transmission control unit 3420 is enabled in a state that the first transmission control unit 3410 is disabled, so that the second transmission control unit 3420 may detect the charging scheme of the wireless power reception apparatus under the control of the main control unit 3300. If the second charging scheme is adopted in the wireless power reception apparatus, the second transmission control unit 3420 may control the operation to transmit the power to the wireless power reception apparatus. In addition, the second transmission control unit 3420 may operate based on the information about the charging scheme obtained from the receiver under the control of the main control unit 3300.
- Although it has been described in that the first transmission control unit 3410 is primarily enabled and the second transmission control unit 3420 is enabled when the first transmission control unit 3410 is disabled under the control of the main control unit 3300, the embodiment is not limited thereto. The first and second transmission control units 3410 and 3420 may be alternately operated.

Wireless Electricity *Transfer*

- The switch unit 3500 may be switched under the control of the main control unit 3300 in such a manner that the power generated from the transforming unit 3200 according to the charging scheme of the wireless power reception apparatus based on the operation of the first and second transmission control units 3410 and 3420 can be transferred to one of a resonance coil or an induction coil.
- When the induction power transmission scheme is adopted, the switch unit 3500 may be switched according to a control signal of the main control unit 3300 in such a manner that the power generated from the transforming unit 3200 can be output to a first power converting unit 3610. In addition, when the magnetic resonance power transmission scheme is adopted, the switch unit 3500 may be switched according to a control signal of the main control unit 3300 in such a manner that the power generated from the transforming unit 3200 can be output to a second power converting unit 3620.
- The switch unit 3500 may include one of an analog switch, a MOSFET and a transistor to perform a switching operation. The switch unit 3500 is not limited to the above, but various devices can be adopted if they can set the path through the switching operation.

Wireless Electricity *Transfer*

- The power converting unit 3600 may convert a DC voltage of a predetermined level into an AC voltage by a switching pulse signal in a band of several tens of KHz to several tens of MHz to generate power. The power converting unit 3600 may convert a DC voltage into an AC voltage to generate “wake-up power” or “charging power” used for the receiver to be charged. The wake-up power may be a micro power of 0.1 mWatt to 1 mWatt. The charging power may be a power necessary to charge a battery of the receiver or consumed to operate the receiver. The charging power may be in the range of 1 mWatt to 200 Watt consumed in the load of the receiver.
- The power converting unit 3600 may include a power amplifier for amplifying the DC voltage output from the transforming 3200 according to a switching signal of the switch unit 3500.
- The power converting unit 3600 may include an inverter. The power converting unit 3600 may convert a DC signal output from the transforming unit 3200 into an AC signal and adjust a frequency of the converted AC signal according to the power transmission scheme and under the control of the control unit. To this end, the power converting unit 3600 may include a full-bridge inverter or a half-bridge inverter. In addition, the transmission side DC/AC converting unit 1200 may include an oscillator for generating a frequency of an output signal and a power amplifier for amplifying the output signal.

Wireless Electricity *Transfer*

- The power converting unit 3600 may include a first power converting unit 3610 and a second power converting unit 3620 according to the charging scheme of the wireless power reception apparatus and may be operated under the control of the main control unit 3300 and the transmission control unit 3400.
- The first power converting unit 3610 and the second power converting unit 3620 may perform the power transmission through mutually different schemes.
- The first power converting unit 3610 may supply power to an induction coil 3810 through the magnetic induction scheme under the control of the first transmission control unit 3410. In addition, the second power converting unit 3620 may supply power to a resonance coil 3820 through the resonance scheme under the control of the second transmission control unit 3420.
- The first power converting unit 3610 and the second power converting unit 3620 may generate AC signals having mutually different frequencies according to transmission schemes, respectively. Preferably, the first power converting unit 3610 may generate an AC signal of 110 KHz to 205 KHz under the control of the first transmission control unit 3410 according to the induction scheme (WPC) which is the first charging scheme. In addition, the second power converting unit 3620 may generate an AC signal of 6.78 KHz under the control of the second transmission control unit 3420 according to the resonance scheme (WPC) which is the second charging scheme.

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- The matching unit 3700 may include at least one of at least one passive element and at least one active element. The matching unit 3700 performs the impedance matching between a wireless power transmission apparatus 3000 and a receiver, so that power transmission efficiency may be maximized.
- The matching unit 3700 may include a first impedance matching unit 3710 and a second impedance matching unit 3720 according to the transmission scheme. The first impedance matching unit 3710 and the second impedance matching unit 3720 may be connected to the first power converting unit 3610 and the second power converting unit 3620 of the power converting unit 3600, respectively.
- The first impedance matching unit 3710 may perform the impedance matching with respect to the power output from the first power converting unit 3610 when the power transmission scheme is the magnetic induction scheme. The second impedance matching unit 3720 may perform the impedance matching with respect to the power output from the second power converting unit 3620 when the power transmission scheme is the resonance scheme.
- The coil unit 3800 may include a first coil unit 3810 and a second coil unit 3820 according to the transmission scheme.

Wireless Electricity *Transfer*

- When the first charging scheme, that is, the magnetic induction scheme is adopted to the wireless power reception apparatus, the first coil unit 3810 may transfer the power output from the first impedance matching unit 3710 to the wireless power reception apparatus.
- In addition, when the second charging scheme, that is, the resonance scheme is adopted to the wireless power reception apparatus, the second coil unit 3820 may transfer the power output from the second impedance matching unit 3720 to the wireless power reception apparatus.
- In addition, the number of the first and second coil units 3810 and 3820 may be singular or plural. When a plurality of first and second coil units 3810 and 3820 are provided, they may overlap each other and the overlapping area is determined by taking into consideration a deviation of magnetic flux density and interference of the magnetic field.
- The wireless power transmission apparatus 3000 may include a communication unit. The communication unit may perform bi-directional communication with a communication unit provided in the wireless power reception apparatus through a predetermined communication scheme, such as NFC (Near Field Communication), Zigbee communication, infrared communication, visible light communication, or Bluetooth communication.

Wireless Electricity *Transfer*

- In addition, the communication unit may transceive power information with the wireless power reception apparatus. The power information may include at least one of a capacity of the receiver, residual energy of a battery, the number of charging operations, an amount of use, a data rate. In addition, the communication unit may transmit a charging function control signal for controlling a charging function of the receiver based on the power information received from the receiver.
- The charging function control signal may be a control signal for controlling the receiver such that a charging function is enabled or disabled.
- The communication unit may perform the out-band communication or in-band communication.
- Hereinafter, the wireless power transmission operation of the wireless power transmission apparatus having the above configuration according to an embodiment will be described with reference to FIG. 6.
- The main control unit 3300 may check whether the receiver is detected based on a response signal from the receiver in response to the output signal (S606).

Wireless Electricity *Transfer*

- In addition, the communication unit may transceive power information with the wireless power reception apparatus. The power information may include at least one of a capacity of the receiver, residual energy of a battery, the number of charging operations, an amount of use, a data rate. In addition, the communication unit may transmit a charging function control signal for controlling a charging function of the receiver based on the power information received from the receiver.
- The charging function control signal may be a control signal for controlling the receiver such that a charging function is enabled or disabled.
- The communication unit may perform the out-band communication or in-band communication.
- Hereinafter, the wireless power transmission operation of the wireless power transmission apparatus having the above configuration according to an embodiment will be described with reference to FIG. 6.
- The main control unit 3300 may check whether the receiver is detected based on a response signal from the receiver in response to the output signal (S606).

Wireless Electricity *Transfer*

- If the response signal from the receiver in response to the output signal is detected, it may be determined that the receiver has the first charging scheme to which the power transmission is performed under the control of the first transmission control unit 3410. Thus, the main control unit 3300 may receive the charging information including an amount of required charge from the receiver (S608).
- Thus, the main control unit 3300 may control the first transmission control unit 3410 based on the charging information to generate power through the first charging scheme and output the power to the receiver (S610).
- Meanwhile, if the response signal is not received from the receiver or if the receiver is not detected even if the first transmission control unit 3410 is activated, the main control unit 3300 may change the status of the first transmission control unit 3410 into the deactivated state (S612).
- Then, the main control unit 3300 may change the status of the second transmission control unit 3420 from the deactivated state into the activated state (S614).
- As the second transmission control unit 3420 is activated, the main control unit 3300 may output a signal for detecting the receiver (S616).

Wireless Electricity *Transfer*

- The main control unit 3300 may determine whether the receiver is detected by checking whether the response signal in response to the output signal is received from the receiver (S618).
- If the response signal from the receiver in response to the output signal is detected, it may be determined that the receiver has the second charging scheme to which the power transmission is performed under the control of the second transmission control unit 3420. Thus, the main control unit 3300 may receive the charging information including an amount of required charge from the receiver (S620).
- Thus, the main control unit 3300 may control the second transmission control unit 3420 based on the charging information to generate power through the second charging scheme and output the power to the receiver (S622).
- In the above embodiment, it has been described in that the receiver is detected by activating/deactivating the transmission control units under the control of the main control unit 3300. However, it is also possible to request the charging scheme information to the receiver through the communication unit to control the transmission control units based on the charging scheme information received from the receiver by receiving the response signal."

PATENTED CLAIMS END

Wireless Electricity *Transfer*

Materials & Methodology Results & Discussion

We have presented wireless transmission of power without electrical conductor and/or wires. We have presented and discussed here about how electrical energy can be transmitted as microwaves of radio waves so that to reduce the transmission, allocation and other types of losses. Such technique is known as Microwave Power Transmission (MPT). We presented and correlated several aspects with the current available Power transmission systems to the related history of wireless power transmission systems and also the related developmental changes. The basic design, merits and demerits, applications of Wireless Power Transmission are discussed.

Wireless communication is the transmission of energy spanning a distance without usage of wires or cables, where distance is short or long. Wireless operations permits services, for instance, long-range communications, which are merely unfeasible using wires. Wireless energy transfer or wireless electricity transfer or wireless power transmission may be the transmittance of electric power from your power source for electrical load without interconnecting wires. Wireless transmission is advantageous in occasions where interconnecting wires are inconvenient, hazardous, or impossible. The situation of wireless power transmission is different from that of wireless telecommunications, like radio. Finally, the percentage of those received becomes critical on circumstance that it can be too low for that signal being distinguished on the ground noise. By wireless power, efficiency is the more significant parameter. Perhaps the energy sent out by the generating plant must arrive at the receiver(s) for making the system economical. The most common form of wireless power transmission is completed using direct induction and then resonant magnetic induction. Other methods under consideration include radio waves such as microwaves or beam of light technology. Wireless communication is mostly regarded as a branch of telecommunications. Wireless operations permits services, illustrating long-range communications, which can be impossible and impractical in conventional methods.

Wireless Electricity *Transfer*

Conventional Power System

One of the main problems in existing power system is the losses occurring in the transmission and allocation of energy to the end users. As demand drastically increases daily, the power generation increases and also the power loss can be increased. The percentage of loss of power during transmission and distribution is approximated as 26%. The key reason for power loss during transmission and distribution may be the resistance of wires used for grid. The efficiency of power transmission may be improved to a particular level by employing high strength composite over head conductors and underground cables who use warm super conductor. But, the transmission is inefficient.

Methods of Wireless Power Transmission Transformer

Coupling or Induction

Energy transfer between two coils via magnetic fields conversely in this technique, distance between two coils really should be too close. The criterion of mutual induction between two coils can be used to the transfer of electrical energy without using wires. The best demonstration of how mutual induction works would be the transformer, where there isn't a physical contact between primary plus the secondary coils. The transfer of energy develops due to electromagnetic coupling relating to the two coils.

Wireless Electricity *Transfer*

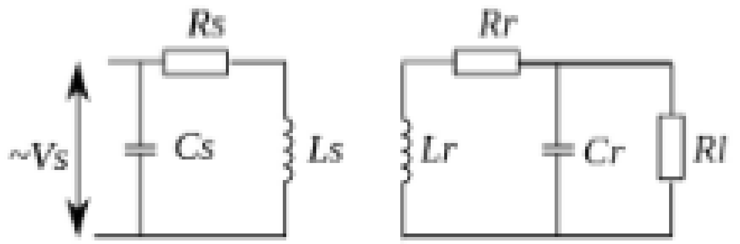


Figure 1: *Transformer Coupling or Induction*

Resonant Induction Coupling / Evanescent Wave Coupling

Researchers at Massachusetts Institute of Technology (MIT) have discovered a substitute way of wirelessly transferring power using non-radiative electromagnetic energy resonant tunneling. Subsequently electromagnetic waves would tunnel, they would not propagate through the air for being absorbed or wasted, and would not normally disrupt electronics or cause injuries like microwave or radio transmission. Researchers anticipate around 5 meters of range. According to them, an electro-magnetic wave in a very high angular waveguide is called as evanescent waves which carry no energy, when if a proper resonant waveguide is brought at the transmitter then the tunnel is formed towards power drawing waveguide and this can be converted into DC using rectifier circuits. A prototype model is achieved with 5 meters of ranges using this method.

Wireless Electricity *Transfer*

Radio/Microwave Electricity Transfer

It is possible to attain a long range using this method. In this technique, microwave is sent to long distances which are received through rectenna. Rectenna extracts microwave energy back to electrical energy. The main problem with this particular strategy is how the diameter of antenna needs to be order of kilometer. Power transmission through radio waves can be produced more directionally, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, archetypally in the microwave range. Rectenna transformation efficiencies surpassing 95% are definitely achieved.

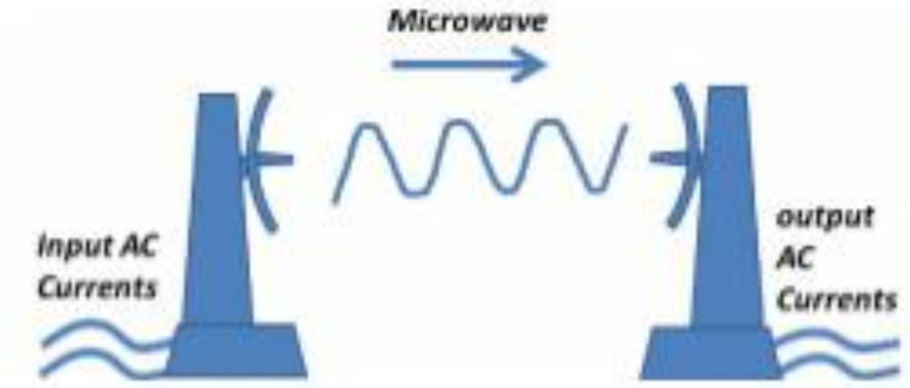


Figure 2: *Radio/Microwave Energy Transfer*

Wireless Electricity *Transfer*

LASER Beam Transfer

In this precise system, laser is beamed for the photovoltaic cells that extract the electrical energy. This process is quite challenging to execute and manage.

Figure 3: *Radio/Microwave Energy Transfer*

Moderate Distance Power Transmission

A capable method to transfer power between coils separated by a few meters is the fact that we're able to extend the length involving the coils with the help of resonance on the equation. Another way to understand resonance would be to think it is in terms of sound. An object's organic structure much as configuration of a trumpet determines the frequency from which it naturally vibrates. This really is its resonant frequency.

Wireless Electricity *Transfer*

Electrostatic Induction and Electro-dynamic Induction

Universally known as capacitive coupling can be an electric field gradient or differential capacitance between two elevated electrodes over the conducting ground plane for wireless energy transmission involving high frequency alternative current potential differences transmitted between two plates or nodes.

Furthermore referred to as resonant inductive coupling resolves the notable error in connection with non-resonant inductive coupling for wireless energy transfer; specifically, dependence of efficiency on transmission distance. Once resonant coupling is applied by transmitter and receiver inductors are tuned for mutual frequency as well as the drive current is modified from the sinusoidal into a non-sinusoidal transient waveform. Pulse power transfer occurs over multiple cycles. This means significant power can be transmitted spanning a distance all the way to a number of times how big the transmitter.

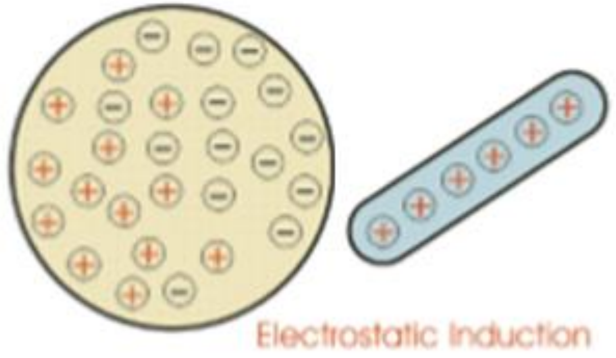


Figure 4: *Electrostatic Induction*

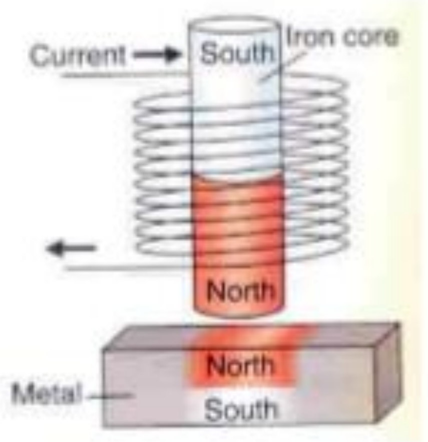


Figure 5: *Electro-dynamic Induction*

Wireless Electricity *Transfer*

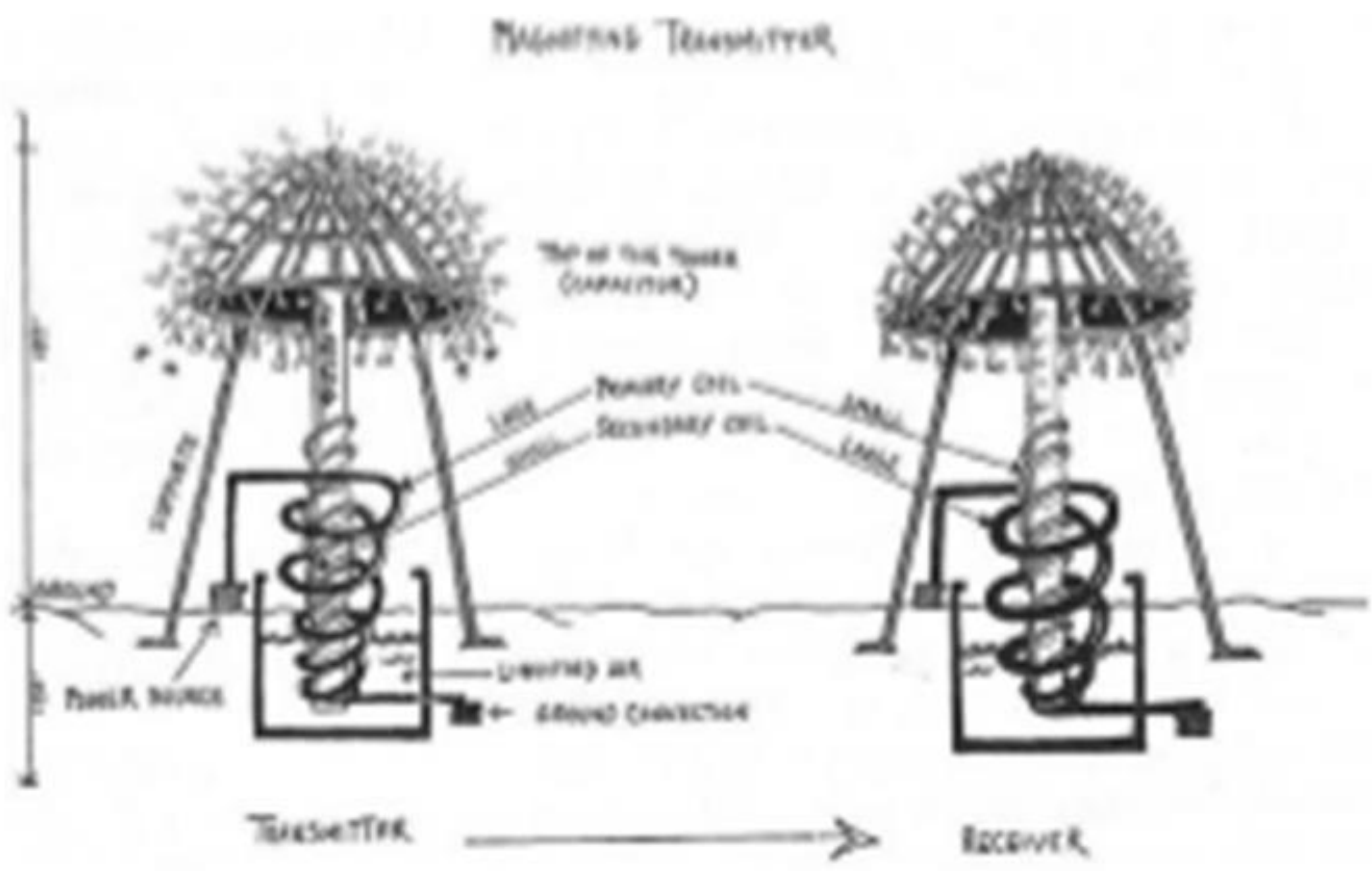


Figure 6: *Tesla Wireless Power Transmission*

The Splash Power Recharging Mat and Edison Electric's Power desk the two of which use coils to generate a magnetic field. Electronics use matching built-in or plug-in receivers to recharge while purchasing the mat. These receivers have compatible coils as well as circuitry needed to supply electricity to devices' batteries. A Splash power mat uses induction to recharge several devices simultaneously.

Figure 7: *Splash Power Recharging Mat*

Wireless Electricity *Transfer*

Canada's Communications Research Centre developed a small aircraft that could abscond power beamed in the Earth. The unmanned airplane, referred to as Stationary High Altitude Relay Platform (SHARP), was formed to be a communications relay.

Figure 8: *Stationary High Altitude Relay Platform (SHARP)*

Microwave Transmitters: - Probably the most current research and proposals use microwaves as the frequency ranges of choice for transmission. An efficiency of 76% may be possible using current technology for microwave power transmission. The transmission efficiency of the waves have to be focused to ensure each of the energy transmitted from the source is incident around the wave collection device.

Wireless Electricity *Transfer*

Advantages and Disadvantages

Some of the advantages are as follows:

1. Different ways of transmitting power wirelessly have been illustrious for centuries. The main widely known model is non-particulate radiation, for instance radio waves. Though such radiation is extremely good for wireless transmission of knowledge, it’s not at all possible to apply it for power transmission. As radiation spreads in all directions, a massive tastes power would become wasted into free space.

2. WPT system would completely eliminates preceding high-tension power transmission line cables, towers and sub stations including the generating station and consumers and facilitates the interconnection of electrical generation plants with a global scale.

3. It’s extra freedom of both receiver and transmitters. Similarly mobile transmitters and receivers might be chosen to the WPT system.

4. The power might possibly be transmitted towards places the location where the wired transmission is not practicable. Reduction of transmission is a negligible level from the Wireless Power Transmission; hence, the efficiency with this way is a lot higher than the wired transmission.

5. Power can be purchased with the rectenna provided that the WPT is operating. Power failure as of short and fault on cables could not exist from the transmission and power theft will be not likely in any regard.

Wireless Electricity *Transfer*

Some of the disadvantages are as follows:

1. High capital cost for practical application of wireless power transmission.

2. Another probable disadvantage is the interference of the microwaves with the present wireless communication system.

3. The effect of microwave radiations at high doses received is not suitable to human health.

Applications of Wireless Power Transmission

1. Moving targets for instance fuel free airplanes, fuel free electric vehicles, moving robots and fuel free rockets. Another applying WPT are wireless power source, wireless sensors and RF power adaptive rectifying circuits (PARC).

2. Mobility - user device might be moved easily in the wireless range.

3. Neat and easy Installation - since no cable running occasionally, just start-up the wireless device and you’re ready to rumble.

4. Generating power by placing satellites with giant solar arrays in Geosynchronous Earth Orbit and transmitting the power as microwaves on the earth called Solar Power Satellites (SPS) will be largest application of wireless power transmission.

Wireless Electricity *Transfer*

The ideas of Wireless Power Transmission (WPT), its history, technological advancements, merits, demerits and applications are deliberated in this white paper. So, we are able to know the greater possibilities for transmitting power with negligible losses, simple transmission and zero health risk by electromagnetic shielding or RF/EMI shielding for a long time. It really is imagined that wireless energy would be really accomplished using advantage of easy implementation and less expensive that is, tariff of transmission and distribution overhead would dwindle and moreover it is crucial that the tariff of electrical power on the consumer would even be reduced when compared with existing systems.

Wireless Electricity *Transfer*

Electromagnetic shielding

Electromagnetic shielding is the practice of decreasing the electromagnetic field in a space by blocking the field with barriers prepared from conductive or magnetic materials. Electromagnetic shielding that blocks radio (microwave) frequencies and electromagnetic radiation is also known as RF shielding. The shielding can reduce the coupling of radio waves, electromagnetic fields and electrostatic. Conductive inclusion used to block electrostatic fields is also known as a Faraday cage. The reduction depends more on the used materials, its thickness, size of the shielded volume and the frequency of the fields of interest. The material thickness decides which frequencies will be blocked to get in or out Faraday cage. For low frequencies as 10kHz is a soft steel layer of 6mm that is needed to get a reduction of 80dB, but a frequency of 30MHz can be shielded by copper foil with a 0.03 mm thickness.

Wireless Electricity *Transfer*

Materials used in RF shielding

Copper based RF shields are easy to make and mold into preferred shapes. Its high conductivity feature makes it an efficient shield against RF. Mu-metal is a nickel iron soft ferromagnetic alloy with extremely high permeability that is used for shielding sensitive electronic equipment against static or low-frequency magnetic fields (such as hard disks inductive proximity sensors). Aluminium is a versatile constituent when it comes to RF shielding. It can be used as a foil to block low frequency radio fields or it can be integrated in the manufacturing to offer a built-in shield that is an anti-radio frequencies.

Fig. 1 RF shielding

Wireless Electricity *Transfer*

How to create best EMI shielding

There are many ways to create optimum EMI (electromagnetic interference) shielding:

1. The RF (Radio Frequency) part on PCB (Printed Circuit Board) will be shielded by a can.

2. The whole PCB will be shielded by foils , wrappers or a box.

3. Or the outmost housing is also shielded.

Shielding electronic goods housed in plastic inclusions can be done by coating the inner side of the enclosed space with a metallic ink or related substance. The ink comprises of a carrier substance loaded with a suitable metal, typically copper or nickel in the form of extremely small particles.

Wireless Electricity *Transfer*

Ceiling Radiation Damper example from Panasonic

Product Details:

UL (Underwriter Laboratories) Classification (UL Standard 555C) and Warnock Hersey Listed for use in non-combustible 1, 2 or 3 hour fire-rated floor / ceiling and roof / ceiling designs.

Key features:

- ceiling Radiation Damper can be used with select Panasonic vent fans to deliver fire and heat radiation protection in 1, 2 or 3 hour fire-rated floor/ceiling, roof/ceiling designs;
- congruent with 50-150 CFM fans, fans with motion/condensation sensor and select fan/lights;
- meets UL, Warnock Hersey and National Fire Protection Agency standards.

Wireless Electricity *Transfer*

Electromagnetic shielding

Electromagnetic shielding cages inside a disassembled mobile phone.

Electromagnetic shielding is the praxis of decreasing the electromagnetic field in a space by blocking the field with barriers created of conductive or magnetic materials. Shielding is distinctively applied to enclosures to isolate electrical devices from their surroundings, and to cables to isolate wires from the environment via which the cable runs. Electromagnetic shielding that blocks Radio Frequency (RF) electromagnetic radiation is also known as RF shielding.

The shielding can downgrade the coupling of radio waves, electromagnetic fields, and electrostatic fields. A conductive inclusion used to block electrostatic fields is also known as a Faraday cage.

Wireless Electricity *Transfer*

The extent of reduction hangs very much upon the material used, its chunkiness, the size of the shielded volume and the frequency of the fields of concern and the size, shape and orientation of apertures in a shield to an incident electromagnetic field.

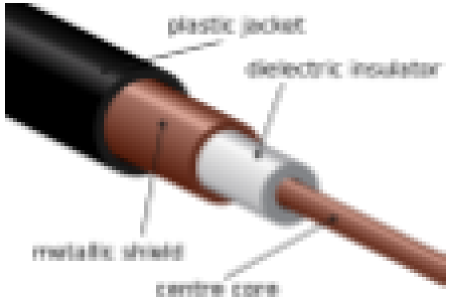
Materials used

Archetypal materials used for electromagnetic shielding include sheet metal, metal screen, and metal foam. Regular sheet metals for shielding comprise copper, brass, nickel, silver, steel, and tin. Shielding effectiveness, that is how well a shield reflects or absorbs/suppresses electromagnetic radiation, is affected by the physical materials of the metal. These may consist of conductivity, solderability, permeability, thickness, and weight. A metal’s properties are an important contemplation in material selection. For instance, electrically dominant waves are reflected by highly conductive metals like copper, silver, and brass, while magnetically dominant waves are absorbed/suppressed by a less conductive metal such as steel or stainless steel. Additionally, any holes in the shield or mesh must be significantly smaller than the wavelength of the radiation that is being kept out, or the enclosure will not effectively approximate an unbroken conducting surface.

Wireless Electricity *Transfer*

Alternately familiarly used shielding method, especially with electronic goods housed in plastic enclosures, is to coat the inside of the inclosure with a metallic ink or similar material. The ink consists of a carrier material loaded with a suitable metal, typically copper or nickel, in the form of very small particulates. It is sprayed on to the inclosure and, once dry, produces a continuous conductive layer of metal that can be electrically connected to the chassis ground of the equipment, thus providing active shielding.

Electromagnetic shielding is the procedure of lowering the electromagnetic field in an area by barricading it with conductive or magnetic property. Copper is used for radio frequency (RF) shielding as it absorbs radio and other electromagnetic waves. Properly designed and constructed RF shielding enclosures fulfill most RF shielding requirements, from computer and electrical switching rooms to hospital CAT-scan and MRI facilities.



Cross-section through a coaxial cable showing shielding and other layers

Wireless Electricity *Transfer*

A model is a shielded cable that has electromagnetic shielding in the form of a wire mesh surrounding an inner core conductor. The shielding inhibits the escape of any signal from the core conductor, and also prevents signals from being added to the core conductor. Some cables have two separate coaxial screens, one connected at both ends, the other at one end only, to maximize shielding of both electromagnetic and electrostatic fields.

The door of a microwave oven has a screen built into the window. From the perspective of microwaves (with wavelengths of 12 cm) this screen finishes a Faraday cage formed by the oven's metal housing. Visible light, with wavelengths ranging between 400 nm and 700 nm, passes easily via the screen holes.

RF shielding is also used to prevent access to data stored on RFID chips embedded in innumerable devices, such as biometric passports.

NATO specifies electromagnetic shielding for computers and keyboards to prevent passive monitoring of keyboard emissions that would allow passwords to be captured; consumer keyboards do not offer this protection primarily because of the prohibitive cost.

RF shielding is also used to protect medical and laboratory equipment to provide protection against interfering signals, including AM, FM, TV, emergency services, dispatch, pagers, ESMR, cellular, and PCS. It can also be used to protect the equipment at the AM, FM or TV broadcast facilities.

Wireless Electricity *Transfer*

Numerous issues serve to limit the shielding capability of real RF shields. One is that owing to the electrical resistance of the conductor, the excited field does not totally terminate the incident field. Furthermore, most conductors exhibit a ferromagnetic response to low frequency magnetic fields, so that such fields are not fully weakened by the conductor. Any holes in the shield force current to flow around them, so that fields passing through the holes do not excite opposing electromagnetic fields. These effects reduces the field-reflecting capability of the shield.

In the event of high-frequency electromagnetic radiation, the abovementioned adjustments take a non insignificant amount of time, yet any such radiation energy, as far as it is not reflected, is absorbed by the skin (unless it is extremely thin), so in this case there is no electromagnetic field inside either. This is one aspect of a greater occurrence called the skin effect. A measure of the depth to which radiation can penetrate the shield is the so-called skin depth.

Wireless Electricity *Transfer*

Magnetic shielding

Equipment sometimes needs isolation from external magnetic fields. For static or slowly diverging magnetic fields (below about 100 kHz) the Faraday shielding explained above is ineffective. In these cases shields made of high magnetic permeability metal alloys can be used, such as sheets of permalloy and mumetal or with nanocrystalline grain structure ferromagnetic metal coatings. These properties do not block the magnetic field, as with electric shielding, but rather draw the field into themselves, providing a path for the magnetic field lines around the shielded Magnetic shielding volume. The best shape for magnetic shields is thus a closed container encircling the shielded volume. The effectiveness of this type of shielding depends on the property's permeability that generally drops off at both very low magnetic field strengths and at high field strengths where the material becomes saturated. So to realize low residual fields, magnetic shields often consist of numerous enclosures one inside the other, each of which successively reduces the field inside it.

Wireless Electricity *Transfer*

For the above constraints of inert shielding, an alternative used with static or low-frequency fields is active shielding; using a field generated by electromagnets to rescind the ambient field within a volume. Solenoids and Helmholtz coils are varieties of coils that can be used for this objective.

Superfluously, superconducting materials can expel magnetic fields through the Meissner effect.

Wireless Electricity *Transfer*

We cannot envisage the world without electricity. Usually the power is transmitted through wires. This white paper describes original concepts to eliminate the dangerous usage of electrical wires that involve lot of confusion in precisely organizing them. Envision a future in which wireless power transfer is possible: cell phones, household robots, mp3 players, laptop computers and other portable electronics capable of charging themselves without ever being plugged in, freeing us from that last, pervasive power wire. Nearly all of these devices may not even need their bulky batteries to work. The methods of transmitting power without using wires with a proficiency of about 95% with non-radiative techniques. Due to which it does not effect the environment surrounding. These techniques consist of resonating inductive coupling in sustainable modest range. The coupling comprises of an inductor along with a capacitor with its own resonating frequency. In any method of coupled resonators there often subsists a so-called “strongly coupled” system of action. If one ensures to operate in that method in a given system, the energy transfer can be extremely efficient. Alternative technique includes transfer of power via microwaves using rectennas. This is principally appropriate for long range distances ranging kilometers. With this we can evade the misunderstanding and danger of having long, hazardous and tangled wiring. This is an effective high performance method that can efficiently transmit the power to the required area varying in distances.

Wireless Electricity *Transfer*

Except you are precisely organized and good with tie wrap, you probably have a few dusty power cord tangles around your home. You may have even had to follow one specific cord through the seemingly unfeasible growl to the outlet hoping that the plug you pull will be the right one. This is one of the downfalls of electricity. While it can make people's lives easier, it can add a lot of clutter in the process.

By these logics, scientists have tried to remodel techniques of wireless power transmission that could cut the clutter or lead to clean sources of electricity. Researchers have developed numerous methods for moving electricity over long distances without wires. Some exist only as hypotheses or models, but others are already in use. This white paper delivers the methods used for wireless power transmission. These systems are concisely classified into three depending on the distance between the transmitter and receiver. These are: short range, moderate range and long range.

Short distance induction: These techniques can reach at most a few centimetres. The action of an electrical transformer is the simplest instance of wireless energy transfer. The primary and secondary circuits of a transformer are electrically isolated from each other. The transfer of energy (electricity) takes place by electromagnetic coupling via a process known as mutual induction. (An added benefit is the ability to step the primary voltage either up or down.) The electric toothbrush charger is a model of how this principle can be used.

Wireless Electricity *Transfer*

A toothbrush's daily exposure to water makes a traditional plug-in charger potentially hazardous. Normal electrical connections can also let water to seep into the toothbrush, damaging its components. For this, most toothbrushes recharge via inductive coupling. You can use the same principle to recharge several devices at once. For instance, the Splash-power recharging mat and Edison Electric's Power desk both use coils to generate a magnetic field. Electronic devices use corresponding built-in or plug-in receivers to recharge while resting on the mat. These receivers contain compatible coils and the circuitry required to deliver electricity to devices' batteries.

A Splashpower mat uses induction to recharge multiple devices simultaneously.

Wireless Electricity *Transfer*

Sufficient distance Resonance and Wireless Power Household devices manufacture comparatively small magnetic fields. For this purpose, chargers sustain devices at the distance required to induce a current that can only happen if the coils are near together. A larger, stronger field can induce current from farther away, but the process would be extremely inefficient. Subsequently a magnetic field spreads in all directions, making a larger one would waste a lot of energy. An efficient way to transfer power between coils separated by a few meters is that we could extend the distance between the coils by adding resonance to the equation. A good method to comprehend resonance is to ruminate of it in terms of sound. An object's physical structure -- like the size and shape of a trumpet -- ascertains the frequency at which it naturally vibrates. This is its resonant frequency. It's easy to get objects to vibrate at their resonant frequency and hard to get them to vibrate at other frequencies. This is why playing a trumpet can cause a nearby trumpet to begin to vibrate. Both trumpets have similar resonant frequency.

Induction could take place slightly differently if the electromagnetic fields around the coils resonate at the same frequency. The theory uses a curved coil of wire as an inductor. A capacitance plate that can hold a charge, fixes to each end of the coil. As electricity moves through this coil, the coil starts to resonate. Its resonant frequency is a produce of the inductance of the coil and the capacitance of the plates.

Wireless Electricity *Transfer*

Electric power, moving along an electromagnetic wave, can tunnel from one coil to the other as far as they both have the same resonant frequency. In a brief theoretical analysis they show that by propelling electromagnetic waves around in a highly angular waveguide, evanescent waves are created which carry no energy. An evanescent wave is nearfield enduring wave exhibiting exponential decay with distance. If a proper resonant waveguide is brought near the transmitter, the evanescent waves can allow the energy to tunnel (precisely evanescent wave coupling, the electromagnetic equivalent of tunneling to the power drawing waveguide, where they can be rectified into DC power. Since the electromagnetic waves would tunnel, they would not spread through the air to be absorbed or dissipated, and would not disrupt electronic devices. As long the two coils are out of range of one another, nothing will happen, since the fields around the coils aren't strong enough to affect much around them. Similarly, if the two coils resonate at different frequencies, nothing will happen. Yet if two resonating coils with the same frequency get within a few meters of each other, streams of energy travel from the transmitting coil to the receiving coil. According to the theory, one coil can even send electricity to several receiving coils, as long as they all resonate at the same frequency. The researchers have named this non-radiative energy transfer given that it involves stationary fields around the coils rather than fields that spread in all directions.

Wireless Electricity *Transfer*

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Wireless Electricity *Transfer*

Giving to the theory, one coil can recharge any device that is in range, as long as the coils have similar resonant frequency. "Resonant inductive coupling" has key effects in solving the two main problems associated with non-resonant inductive coupling and electromagnetic radiation, one of which is caused by the other; distance and efficiency. Electromagnetic induction works on the theory of a primary coil generating a predominantly magnetic field and a secondary coil being within that field so a current is induced within its coils.

This cause the relatively short range due to the quantity of power needed to produce an electromagnetic field. Over greater distances the non-resonant induction technique is inefficient and wastes much of the transmitted energy only to increase range. This is where the resonance comes in and helps efficiency dramatically by "tunneling" the magnetic field to a receiver coil that resonates at the same frequency. Dissimilarly the multiple-layer secondary of a non-resonant transformer, such receiving coils are single layer solenoids with closely spaced capacitor plates on each end that in combination let the coil to be tuned to the transmitter frequency thus eliminating the wide energy wasting "wave problem" and allowing the energy used to focus in on a specific frequency escalating the range.

Wireless Electricity Transfer

Long-distance WET: if or not it integrates resonance, induction universally sends power over relatively short distances. Yet some plans for WET involve moving electricity over a span of miles. A few proposals even involve sending power to the Earth from space. In the 1980s, Canada's Communications Research Centre (CCRC) created a small airplane that could run off power beamed from the Earth. The unmanned plane, called Stationary High Altitude Relay Platform (SHARP), was designed as a communications relay. Preferably flying from point to point, the SHARP could fly in circles two kilometers in diameter at an altitude of about 13 miles (21 kilometers). Very importantly, the aircraft could fly for months at a time. The clandestine to the SHARP's long flight time was a big, ground-based microwave transmitter. The SHARP's circular flight path fixed it in range of this transmitter. A great, disc-shaped rectifying antenna, or rectenna, just behind the plane's wings changed the microwave energy from the transmitter into direct-current (DC) electricity. As of the microwaves' interaction with the rectenna, the SHARP had a constant power supply as long as it was in range of a functioning microwave array. Rectifying antennae are central to many WPT theories. They are usually made of an array of dipole antennae that have positive and negative poles. These antennae connect to Schottky diodes. Here's what happens:

1. Microwaves that are RF, which are part of the electromagnetic spectrum reach the dipole antennae.
2. The antennae collects the microwave energy and transmits it to the diodes.

(SHARP) unmanned plane

3. The diodes act like switches that open or close as well as turnstiles that let electrons flow in only one direction. They direct the electrons to the rectenna's circuitry.
4. The circuitry transmits the electrons to the parts and systems that need them.

Wireless Electricity ***Transfer***

Effectiveness: The Proficiency of wireless power is the ratio between power that reaches the receiver and the power distributed to the transmitter. Researchers successfully demonstrated the skill to power a 60 watt light bulb from a power source that was seven feet (2 meters) away using resonating coils. This type of setup could power or recharge all the devices in one room. Some adjustments would be essential to send power over long distances, like the length of a building or a city. Power transmission through radio waves can be made more directional, letting longer distance power beaming, with shorter wavelengths of electromagnetic radiation, normally in the microwave range. A rectenna may be used to convert the microwave energy back into electricity. Rectenna conversion productivities exceeding 95% have been realized. Wireless Power Transmission (using microwaves) is well established. Experiments in the tens of kilowatts have been done.

Requirement for wireless power transmission: Wireless transmission is employed in cases where immediate or continuous energy transfer is required, but interconnecting wires are inconvenient, precarious, or unfeasible.

Wireless Electricity *Transfer*

The essential advantage of using the non-radiative field lies in the detail that most of the power not picked up by the receiving coil remains bound to the vicinity of the sending unit, in its place of being radiated into the environment and lost. Through such a design, power transfer for laptop-sized coils are more than sufficient to run a laptop can be transferred over room-sized distances nearly omni-directionally and efficiently, regardless of the geometry of the surrounding space, even when environmental objects entirely obstruct the line-of-sight between the two coils. As far as the laptop is in the room equipped with a source of such wireless power, it would charge automatically, without having to be plugged in. In reality, it would not even need a battery to operate inside of such a room." In the long run, it can decrease our society's dependence on batteries that are currently heavy and expensive. Similarly, for the long range power transmission, power can be sent from source to receivers instantaneously without wires, decreasing the cost.

Number of household points receives electricity at the same frequency using single transmitting coil as long as they all are at resonance. So this setup could recharge all the devices in a room at once.

Wireless Electricity *Transfer*

Alternative model of the practical use of electromagnetic shielding would be defense applications. As technology progresses, so does the predisposition to various types of nefarious electromagnetic interference. The conception of encasing a cable inside a grounded conductive barrier can deliver mitigation to these risks.

How it works

Electromagnetic radiation contains coupled electric and magnetic fields. The electric field harvests forces on the charge carriers (i.e., electrons) within the How it works conductor. As soon as an electric field is applied to the surface of a standard conductor, it induces a current that initiates displacement of charge inside the conductor that cancels the applied field inside, at which point the current stops.

Likewise, varying magnetic fields generate eddy currents that act to rescind the applied magnetic field. (The conductor does not respond to static magnetic fields unless the conductor is moving relative to the magnetic field.) The result is that electromagnetic radiation is reflected from the surface of the conductor: internal fields stay inside, and external fields stay outside.

Wireless Electricity *Transfer*

DISCUSSIONS @ Mail Online Science

Most objects in the room - such as people, desks and carpets - would be unaffected by the electromagnetic field. But any objects designed to resonate with the electromagnetic field would absorb the energy. It sounds complicated, but the result demonstrated by the American team this month was a dramatic success. Using two coils of copper, the team transmitted power 7ft through the air to a light bulb, which lit up instantly. The scientists say the technique works only over distances of up to 9ft. However, they believe it could be used to charge up a battery within a few yards of the power source connected to a receiving coil. Placing one source in each room could provide enough power for an entire house.

The receiver and transmitter would not have to be in view of each other. Professor Peter Fisher, another of the researchers, said: "As long as the laptop is in a room equipped with a source of wireless power, it would charge automatically without having to be plugged in. In fact, it would not even need a battery to operate inside such a room." The researchers believe there is little to worry about on safety grounds, saying that magnetic fields interact weakly with living organisms and are unlikely to have any serious side effects. Dr. Soljacic said: "When my son was about three years old, we visited his grandparents' house. They had a 20-year-old phone and my son picked up the handset asking, 'Dad, why is this phone attached with a cord to the wall?' That is the mindset of a child growing up in a wireless world.

Wireless Electricity *Transfer*

DISCUSSIONS @ ResearchGate WEBSITE

Topic: **Coil Design and Control Method of Independent Active Shielding System for Leakage Magnetic Field Reduction of…**

The shielding technique by active coils is proposed to mitigate the magnetic field produced by a wireless power transfer (WPT) system based on near field coupling. General guidelines are provided for the active shielding design to shield the source for emission reduction or to shield the victim for immunity enhancement. Then, a method is proposed to identify the suitable excitation of the active coils. The proposed method permits the mitigation of the magnetic field in a specific point or of the induced effects in a loop area. Furthermore, the influence of the active shielding on the performance of a WPT system is also investigated. Finally, the proposed solution for active shielding is validated by measurements. A shielding effectiveness (SE) of about 20 dB on the considered area is obtained with a negligible degradation of the WPT system efficiency.

Wireless Electricity *Transfer*

- ... a) E-mail: sahn@kaist.ac.kr fields are eliminated each other in terms of the phasor. The power supply methods of the active shielding systems can be classified into two types as 1) dependent power source, and 2) independent power source [15] [16]. The dependent active shielding is to use partial turns of transmitting (TX) and receiving (RX) coils for shielding by designing reversed coil turns [15]. ...
- ... The independent active shielding system is to supply shielding power from the independent power source [16]. This method can control appropriate shielding current in terms of the current strength and phase. ...
- ... This method can control appropriate shielding current in terms of the current strength and phase. The independent active shielding method proposed in [16] was the method to reduce electromagnetic field in specific area for protecting electronic device. This method provides the SE for the electronic device that is situated far from the IPT system. ...

Discussants: Jedok Kim · Jangyong Ahn · Sungryul Huh · Seungyoung Ahn

Wireless Electricity *Transfer*

Active Shielding Applied to an Electrified Road in a Dynamic Wireless Power Transfer (WPT) System

- ... They are similar to passive coils, but independently excited in such a way that the current flowing into them is able to produce an opposite field that can almost cancel the incident field. Obviously, the shielding performance of active coils can be very good, but they have to be adequately powered, increasing the complexity of this application [15] [16] [17] [18] [19]. ...
- ... where bk,x, bk,y and bk,z are the x, y, z components of the magnetic flux density generated by a unit current flowing in the kth coil, with k = 1,…,m and m = 3 [15] . Equation (4) can be rewritten in matrix form: ...
- ... Minimizing Equation (11) we find the value of α such that the average value of B over the n considered points is minimum. The value of the unknown term α that minimizes Equation (11) can be then obtained applying the pseudoinverse as [15] : ...

Discussants: Silvano Cruciani · Tommaso Campi · Francesca Maradei · Mauro Feliziani

Wireless Electricity *Transfer*

Numerical Analysis Applying the AMSL Method to Predict the Magnetic Field in an EV with a WPT System

- ... The use of ferrite plates, disks or blocks can reduce the magnetic flux leakage and diminish consequently eddy current losses in the metal parts. The ferrite acts as a magnetic shield diverting the magnetic flux lines and it can be also seen as a part of a magnetic core improving the coupling between the WPT coils and the electrical performances of the WPT system [8]. ...
- ... In the proposed test case, the bodyshell has been modeled using both traditional FEM and AMSL method discretizations. The presence of the metal bodyshell can affect the WPT system performances altering the values of the circuit lumped parameters, i.e., mainly self and mutual inductances [7]- [8]. The frequency variation of the equivalent circuit lumped parameters has been calculated by Ohm's law [8] for frequencies from 10 kHz to 10 MHz, as shown in Fig. 7. ...
- ... The presence of the metal bodyshell can affect the WPT system performances altering the values of the circuit lumped parameters, i.e., mainly self and mutual inductances [7]- [8]. The frequency variation of the equivalent circuit lumped parameters has been calculated by Ohm's law [8] for frequencies from 10 kHz to 10 MHz, as shown in Fig. 7. The obtained results using the AMSL method are in excellent agreement with those obtained by a conventional FEM solution using a very fine discretization. ...

Discussants: Tommaso Campi · Silvano Cruciani · Valerio De antis · Mauro Feliziani

Wireless Electricity *Transfer*

Magnetic shielding design of wireless power transfer systems

- ... To this aim, shielding techniques should be used. However, the presence of the shield can alter the magnetic field with possible degradations of the WPT performances [2]- [3]. In order to efficiently design a WPT system with reduced emission, shielding solutions must be included in the WPT coil design. ...
- ... The FEM analysis permits extracting the lumped circuit parameters. It should be noted that the inductances L 1, L 2 and M, are strongly dependent on the configurations of the shield and the coils [2]- [3]. Therefore, the WPT system must be re- tuned at any shield configuration by calculating new values of C 1 and C 2. ...
- ... The planar stacked coils have 5 turns, internal radius R int = 70 mm, external radius R ext = 83.5 mm, distance between the stacked coils d = 40 mm. The coils are close to two aluminum surfaces which can alter the WPT performances [2]- [3]. To avoid any WPT degradation, a limited use of ferrite is examined. ...

Discussants: Tommaso Campi · Silvano Cruciani · Francesca aradei · Mauro Feliziani

Wireless Electricity *Transfer*

Near field shielding of a wireless power transfer (WPT) current coil

- ... Nowadays, growing interest is directed to EMF safety concerns about magnetic fields in applications related to the emerging technology of the Wireless Power Transfer (WPT) based on magnetic resonant coils [13] [14] [15] [16] [17] [18] [19] [20]. WPT for battery recharging is spreading in a number of applications such as automotive, biomedical devices, and consumer electronics. ...
- ... The tangential components of the magnetic field, H ρ, are calculated along the radial distance ρ at ζ = t at four different frequencies, 100 Hz, 1 kHz, 10 kHz and 100 kHz, of relevant interest for power and WPT automotive applications [15,16]. The results are obtained considering a copper shield with t = 1 mm and coil/shield separation d = 10 mm, as shown in Fig. 6. ...

Discussants: Mauro Feliziani · Silvano Cruciani · Tommaso ampi · Francesca Maradei

Wireless Electricity *Transfer*

Wireless Power Transfer Charging System for AIMDs and pacemakers

- ... In test case #3, the inductive coupling between the two coils is negatively affected by the presence of metallic objects in the surrounding (e.g., the titanium case of a pacemaker). Indeed, the magnetic field produced by the WPT system produces eddy currents in the metallic case modifying the magnetic field behavior and, consequently, the values of the self and mutual inductances [23]- [25]. On the contrary, the ferrite layer in test case #4 acts as a magnetic shield diverting the magnetic flux lines before they meet the metallic pacemaker case [24], [25]. ...
- ... Indeed, the magnetic field produced by the WPT system produces eddy currents in the metallic case modifying the magnetic field behavior and, consequently, the values of the self and mutual inductances [23]- [25]. On the contrary, the ferrite layer in test case #4 acts as a magnetic shield diverting the magnetic flux lines before they meet the metallic pacemaker case [24], [25]. As a consequence, the magnetic field behavior is modified, but the WPT performances are not necessarily lessened since the ferrite shield can be considered as a portion of magnetic core that reduces the total magnetic reluctance. ...

Discussants: Tommaso Campi · Silvano Cruciani · Federica alandrani · Mauro Feliziani

Wireless Electricity *Transfer*

Design of UAV wireless power transmission system based on coupling coil structure optimization

- ... The lithium battery limits the length of UAV possible running length [12] [13] [14] [15]. It is necessary for UAV continuously conduct inspections and detection under working condition [16] [17] [18]. Therefore, it is important to elongate the running time of UAV [19]. ...

Discussants: Xin Yan · Wan Shi · Xiaobing Zhang

Wireless Charging of Electric Vehicles: Planar Secondary Coil position vs. Magnetic Field

- ... losses the coil is realized using a Litz wire composed by 1650 strands of 38 AWG copper wires cable to mitigate the skin and proximity effects at the considered frequency. Two ferrite disks cover the coils to improve the inductive coupling and to reduce the magnetic field in the environment [9] . The ferrite disks have the same thickness tfe1 = 3 mm, while their radius are rfe1 = 300 mm for the primary circuit and rfe2 = 250 mm for the secondary coil. ...

Discussants: Tommaso Campi · Silvano Cruciani · F. Maradei · Mauro Feliziani

Wireless Electricity *Transfer*

Challenges of Future High Power Wireless Power Transfer for ght-Duty Electric Vehicles—Technology and Risk…

- ... Typically, aluminum is employed as a passive shielding material for low power WPT with the advantages of low weight and low resistance, which generates a reactive eddy current as well as the magnetic flux to cancel the EM emission. Since eddy currents are induced in the aluminum plate, losses are also unavoidable, with a typical percentage of 1e2% [37, 38]. The SAE J2954 recommended practices document provides the recommended backing aluminum shielding design adopted in WPT1(3.7 kW), WPT2(7.7 kW), and WPT3 (11 kW) [39,40], with a recommended shielding dimension design of 800 mm Â 800 mm x 0.7 mm or larger. ...

Discussants: Zhang · Richard B. Carlson · John G. Smart · Bor Hann Liaw

Comparative Verification of Radiation Noise Reduction Effecting Spread Spectrum for Inductive Power Transfer System

- ... This regulation is basically corresponding to CISPR 11 Group 2, Class B [8]. In previous studies, suppression methods using a magnetic material or metal shield have been proposed [9] [10] [11] [12]. In order to suppress the radiation noise, transmission coils are surrounded by plates composed of magnetic material or metal plate. ...

Discussants: Lusaka · Inoue · Itoh

Wireless Electricity *Transfer*

Feasibility Study of a Wireless Power Transfer System Applied a Leadless Pacemaker

- ... Note that this type of coil is also convenient for the usage of some ferrites inside the helical coil. The high permeability ferrite modifies the incident magnetic field produced by the primary coil whose flux lines are deflected inside the secondary coil [13]. This trend increases the coupling between coils since the magnetic flux lines are almost parallel to the secondary coil axis. ...

Discussants: Tommaso Campi · Silvano Cruciani · Valerio Deantis · Mauro Feliziani

Analysis and Performance Improvement of WPT Systems in one Environment of Single Non-Ferromagnetic Metal Plates

- This paper deals with the magnetic shielding of the field generated by a wireless power transfer (WPT) system at the frequency of 20 kHz. Different shielding techniques are examined and discussed based on the use of conductive and magnetic material panels. The performances of the WPT system and the magnetic field shielding effectiveness (SE) in presence and in absence of shield panels are calculated and measured. © 2014 The Institute of Electronics, Information and Communication Engineer.
- .. At present, few researches have been conducted on the characteristics of magnetic coupling resonance WPT systems under the influence of metal objects. To address the problem caused by the existence of metal objects, an experimental analysis method is the one most frequently used to study the influences of external metal objects [12, 13]. However, this method has great limitations, that is, it doesn't effectively play a guiding role in system design and is only used as an auxiliary means to analyze the performance. ...

Wireless Electricity *Transfer*

- ... Therefore, the existence of metal objects breaks down system's original "electric resonance" At present, few researches have been conducted on the characteristics of magnetic coupling resonance WPT systems under the influence of metal objects. To address the problem caused by the existence of metal objects, an experimental analysis method is the one most frequently used to study the influences of external metal objects [12, 13]. However, this method has great limitations, that is, it doesn't effectively play a guiding role in system design and is only used as an auxiliary means to analyze the performance. ...
- ... By defining a SE formula, a University of L'Aquila in Italy work analyses absorption loss, reflection loss and additional effects of multiple reflections and transmissions, and finally draws the conclusion that the magnetic material helps to improve the coupling. The conclusion is verified by experiments and simulation in a 20 kHz system [12, 20]. Based on the TEM wave theory, Lawson and others [21] analyzed how the PTE of a WPT system varies with the frequency when a ferrite material exists in the system. ...

Discussants: Tan · Jiacheng Li · Chen Chen · Xueliang Huang

Wireless Electricity *Transfer*

Coupled Electromagnetic Field Canceling Coil for Wireless Power Transfer System

- ... For stationary EV wireless charging applications, no matter what coil structure is, the basic circular pad [3], [10], DD pad [11], DDQ pad [12], bipolar pad [13], or even H-shape [14], the Al-plate passive shielding [9] is widely used. However, side effects caused by the Al-plate shielding are often underestimated and evaded, like decreasing coupling coefficient [9], [15] between the WPT coils and increasing the coil resistance [9], [15], [16] which could greatly reduce the WPT efficiency of the applied system. Different from the passive Al-plate shielding, active EMF cancelling [17] and reactive shielding [9], [18] measures have also been proposed for EV wireless charging application. ...

- ... For stationary EV wireless charging applications, no matter what coil structure is, the basic circular pad [3], [10], DD pad [11], DDQ pad [12], bipolar pad [13], or even H-shape [14], the Al-plate passive shielding [9] is widely used. However, side effects caused by the Al-plate shielding are often underestimated and evaded, like decreasing coupling coefficient [9], [15] between the WPT coils and increasing the coil resistance [9], [15] , [16] which could greatly reduce the WPT efficiency of the applied system. Different from the passive Al-plate shielding, active EMF cancelling [17] and reactive shielding [9], [18] measures have also been proposed for EV wireless charging application. ...

- ... Here, by utilizing a combination of this decoupling characteristic with the aforementioned reactive shielding idea, we present a kind of simple but effective null-coupled cancelling (NCC) coil for EMF shielding in this paper. On the one hand, the proposed NCC coil does not have the defects of the passive conductive shielding measure as in [9], [15], [16]. On the other hand, due to the decoupling characteristic, analyses of the original WPT system and analyses of the additional NCC coil could be separated, thus it does not add to the complexity of parametric design. ...

Discussants: Qingwei Zhu · Yun Zhang · Chenglin Liao · Lifang Wang

Wireless Electricity *Transfer*

Comprehensive overview of inductive pad in electric vehicles stationary charging

- ... By reducing the leakage flux, a simple shielding can be for the system to comply the standard safety limits. Also, the adverse impact of the shield on the system's performance will be minimal [105]. The literature is full of studies related to the core design, including used material, shape and dimensions which are covered in this section. ...around the system. Magnetic passive shielding is manufactured from nonconductive materials with a high magnetic permeability, to direct magnetic flux lines to travel in a specific path leading to enhance self and mutual inductance, improve the system performance and reduce the leakage flux [105, 158]. The magnetic shield is achieved by the magnetic core installed in the pad, which can be a plate, multiple bars or multiple tiles, as was explained in Section 2.2.2. ...
- ... These eddy currents produce magnetic fields that oppose the original fields and partially cancel them. This helps to minimize the leakage flux around the system, but adversely affects the system performance by reducing the coupling factor and efficiency [105, 159,162,163]. Several studies are presented in the literature to optimize the shield design for reducing its negative impact on the system efficiency, considering different materials, such as copper [164], and aluminum [165,166], different dimensions [167,168], and different positions [153,169,170]. ...

Discussants: Ahmed A. S. Mohamed · Ahmed A Shaier · Hamed · Sameh Selem

Wireless Electricity *Transfer*

Comprehensive Overview of Inductive Pad in Electric Vehicles Stationary Charging

- ... By reducing the leakage flux, a simple shielding can be for the system to comply the standard safety limits. Also, the adverse impact of the shield on the system's performance will be minimal [106]. The literature is full of studies related to the core design, including used material, shape and dimensions which are covered in this section. ...
- ... Passive shielding is achieved by adding a passive component (conductor or/and magnetic) that helps to block and/or shape EMFs to reduce the leakage fields around the system. Magnetic passive shielding is manufactured from nonconductive materials with a high magnetic permeability, to direct magnetic flux lines to travel in a specific path leading to enhance self and mutual inductance, improve the system performance and reduce the leakage flux [106, 161]. The magnetic shield is achieved by the magnetic core installed in the pad, which can be a plate, multiple bars or multiple tiles, as was explained in section 2.2.2. ...
- ... These eddy currents produce magnetic fields that oppose the original fields and partially cancel them. [106, 162,165,166]. Several studies are presented in the literature to optimize the shield design for reducing its negative impact on the system efficiency, considering different materials, such as copper [167], and aluminum [168,169], different dimensions [170,171], and different positions [123,156,172]. ...

Discussants: Ahmed A. S. Mohamed · Ahmed A Shaier · Hamed etwally · Sameh Selem

Wireless Electricity *Transfer*

Wireless power transfer (WPT) system for an electric vehicle V): How to shield the car from the magnetic field generate…

- ... The wireless power transfer (WPT) based on the magnetic resonant coupling between two or more coils is a very promising technology to transfer electrical energy without wires [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [11] [12] [13]. For this technology to become widespread in the next future, it is necessary that the magnetic field generated in the environment by WPT systems must be compliant with: † electric and magnetic field (EMF) safety standards for human exposure [14]; † electromagnetic compatibility (EMC) regulations to avoid disturbances with other electric and electronic apparatuses and devices [15]. ...
- ... However, the WPT system is an intentional source of magnetic field. Thus, any field reduction using improperly active or passive shields could dramatically reduce the performances of the WPT itself that becomes unable to transfer the nominal power to the load [1, 2]. ...
- ... The considered WPT system is composed of two parallel coupled coils: the primary placed outside the EV on the road, while the secondary is located in the vehicle underbody in close proximity of many metallic objects as chassis, platform, engine, electrical wiring system, etc. The coupled coils are modeled by an equivalent two-port network whose circuit lumped parameters are depending not only on the configurations of the coils but also on the conductive and magnetic materials in the surrounding environment [1, 2]. ...

Discussants: Tommaso Campi · Silvano Cruciani · Valerio De antis · Mauro Feliziani

Wireless Electricity *Transfer*

Wireless Power Transfer for Vehicular Applications:

Overview and Challenges

- ... The WPT system should be compliant with different electromagnetic interference (EMI) and EMC standards [51]. Also, time-varying magnetic field induces eddy currents in the metal object which is located on or in the vicinity of the transmitter coil, leading to additional losses and possible object heating [88]. Shielding measures that redirect or absorb the magnetic field incur losses and reduce the efficiency of the WPT system. ...
- ... are not illustrated). The presence of shielding affects the performance of the system by reducing coil inductance and increasing losses which requires further capacitance compensation to achieve resonance condition [88] - [90]. Shielding can reduce the efficiency of a system by 1%-2% [88]. ...
- ... The presence of shielding affects the performance of the system by reducing coil inductance and increasing losses which requires further capacitance compensation to achieve resonance condition [88]- [90]. Shielding can reduce the efficiency of a system by 1%-2% [88]. Typically, aluminum or copper is employed as a shielding material, as both of the material are highly conductive such that eddy currents induced in the material counteract the incident flux but also lead to losses in the shielding. ...

Discussants: Devendra Patil · Matthew Mcdonough · John Miller · Poras Balsara

Wireless Electricity *Transfer*

Impact of Ferrite Shield Properties on the Low-Power Inductive Power Transfer

- ... In addition to its contribution to the shielding ability, the introduction of soft magnetic substrates in IPT systems contributes to the enhancement of magnetic coupling between the transmitter (Tx) and receiver (Rx) inductors, finally yielding higher power efficiency. This beneficial performance of ferrite substrates has been experimentally verified for different powering systems in [10] and [11]. As the IPT constitutes a near-field transmission technique, high transfer efficiency also necessitates the accurate alignment of the Tx and Rx coils. ... ... The highest A dB values are In this case, we expect that the normal component of the magnetic field finally decays in the conductor. Aluminum-loaded assemblies outperform the copper-loaded ones by ∼10 dB due to aluminum's larger thickness, which exceeds the skin depth in the region of the test frequency [10]. On this account, Al sheet as separate shield provides a 44.6 dB

Discussants: Charalampos A. Stergiou · V. T. Zaspalis

Wireless Electricity *Transfer*

Design efficiency and lightweight wireless charging system for one batteries

- ... A circuital simplified representation of a WPT system is shown in Fig. 4. The considered system is composed by two coupled coils that are characterized by selfinductances L1 and L2, and mutual inductance M. The power losses in the windings are modeled by the resistances R1 and R2 [10]. For the Series-Series (SS) compensation topology the capacitor C1 and C2 are connected in series with the coils. ...
- ... The extraction of the lumped circuit parameters is carried out by the solution on the magneto quasi-static (MQS) field equations in the considered domain. Thus, the lumped self and mutual inductances are calculated applying Ohm's law [10]. To calculate the selfinductance of the coil it is sufficient to feed the coil with a time-harmonic current and measure the voltage drop on it. ...

Discussants: F. Maradei · Tommaso Campi · Silvano Cruciani · Mauro Feliziani

Wireless Electricity *Transfer*

Wireless Power Transfer Technology Applied to an autonomous Electric UAV with a Small Secondary Coil

- ... Low frequency magnetic fields are difficult to mitigate as the field diffusion through conductive barriers are relevant. Furthermore, in the case of near-field WPT technology based on inductively coupled coils, the eddy currents in conductive materials can negatively affect the performance of the WPT system [4], [5]. ...
- ... Contrary to the majority of magnetic near field sources, the WPT coil currents are an intentional source. It means that any reduction of the magnetic field without taking particular care on WPT operation can negatively affect the performance of the same WPT system [4], [5]. Thus, extreme attention must be paid to shield the WPT coils, and the shielding design is definitely very challenging. ...

Discussants: Silvano Cruciani · Tommaso Campi · F. Maradei · Mauro Feliziani

Wireless Electricity *Transfer*

- ... Capacitance compensation networks are added on transmitting and receiving sides to obtain resonance condition [21] and to improve the electrical performances of the system. There are several compensation network configurations that can be used in a WPT system. ...

- ... At the transmitting side, a full bridge inverter made by MOSFETs (M1, M2, M3, M4) is adopted to generate a high frequency square wave voltage V1 from the DC source VIN. At the receiving side the high Capacitance compensation networks are added on transmitting and receiving sides to obtain resonance condition [21] and to improve the electrical performances of the system. There are several compensation network configurations that can be used in a WPT system. ...

Discussants: Tommaso Campi · Silvano Cruciani · Mauro Feliziani

Wireless Electricity *Transfer*

Active Shielding Applied to an Electrified Road in a Dynamic

- ... It means that a relatively large amount of the incident field can pass through the conductive shield if the thickness of the shield (or bodyshell) is around 1-3 mm. Furthermore, conductive shields are sites of eddy currents that produce losses decreasing the power transfer efficiency [6, 13]. For these reasons the conductive materials are not widely used on board EVs to mitigate the magnetic field. ...
- ... The considered region to be shielded is in centimeters $\{-80 \leq x \leq 80, -125 \leq y \leq -90, -5 \leq z \leq 45\}$ that is discretized in $n = 6750$ points. In this region, shown in Figure 4 by a green box, the minimization is done on the average value of the norm of B. The constant value of the delivered power is ensured via (13) varying the input voltage. After applying the method described in Section 2, we have calculated the magnetic field without, and with, the active shield. ...

Discussants: Silvano Cruciani · Tommaso Campi · Francesca aradei · Mauro Feliziani

Wireless Electricity *Transfer*

Magnetic Field during Wireless Charging in an Electric Vehicle according to Standard SAE J2954

- ... The goal of this study was to numerically predict the magnetic field in the environment [11] [12] [13] [14] [15] [16] [17] [18] [19] [20] [21] [22] [23] [24]. The numerical simulations were carried out by a hybrid technique based on the solution of an electromagnetic (EM) field/circuit coupled problem. ...
- ... For a given WPT class, the magnetic field is maximum for small size vehicles with maximum ground clearance and maximum offset. The goal of this study was to numerically predict the magnetic field in the environment [11] [12] [13] [14] [15] [16] [17] [18] [19] [20] [21] [22] [23] [24]. The numerical simulations were carried out by a hybrid technique based on the solution of an electromagnetic (EM) field/circuit coupled problem. ...

Discussants: Francesca Maradei · Tommaso Campi · Silvano · Mauro Feliziani

Wireless Electricity *Transfer*

Comparative Analysis and Design of the Shielding Techniques WPT Systems for Charging EVs

- ... However, the core and shielding structure and dimensions should carefully be designed [18]. In [19], magnetic field mitigation techniques for the WPT system are investigated. Three types of different material sheets are used as shielding including: aluminum, copper, and ferrite with different thickness. ...

Discussants: Ju · Linlin Tan · Elnail Kamal Eldin · Xueliang

Design of a Patterned Soft Magnetic Structure to Reduce agnetic Flux Leakage of Magnetic Induction Wireless Pow…

- ... Leakage magnetic field reduction method in wireless magnetic material shield (high μ r), which uses the path of magnetic fields to be induced inside the magnetic material. Aluminum is mainly used for Conductive shield, and Mn-Zn ferrite is mainly used for magnetic shield [18], [19]. ...

Discussants: -Gon Lee · Nam Kim · In-Kui Cho · Ic-Pyo Hong

Wireless Electricity *Transfer*

Design of a High-Frequency Wireless Power Transfer System or a Rotating Application

- ... Consequently, shielding techniques are applied in order to mitigate undesirable effects of the magnetic field. Inclusion of the shielding technique in the design phase is crucial, since the performance might degrade significantly [5]. The Finite Element Method (FEM) is often applied during the design phase [1], [2], [4]. ...

Discussants: Koen Bastiaens · D. C. J. Krop · Mitrofan Curti · E.A. ...omonova

Wireless Charging System Integrated in a Small Unmanned Aerial Vehicle (UAV) with High Tolerance to Planar Coil...

- ... A simplified electrical circuit of a WPT system is reported in Fig. 3. The two coupled coils are characterized by self-inductances L1 and L2, mutual inductance M and self-resistances R1 and R2 that model the losses in the coils [13]. The coupling factor k is given by: The resonance condition is obtained by using compensation network both on the primary and secondary side. ...

Discussants: Tommaso Campi · Silvano Cruciani · F. Maradei · Mauro Feliziani

Wireless Electricity *Transfer*

Edge Effect and Coil Optimization of Wireless Power Transmission System for Electric Vehicle Charging

- ... If the electromagnetic field is too high, produce heat in the nonmetallic shielding and cause the loss of energy [7, 8]. ...

Discussants: Wang · Xin Huang · Zhiguo Kong · Xian Zhang

Near field Wireless Powering of Deep Medical Implants

- ... The results reported in Table 2 show that the presence of the ferrite strongly improves the coil coupling and the tolerance to misalignment conditions. This is due to the ferrite layer that acts as a magnetic shield creating a preferential path for the flux lines [23, 24]. When only a titanium housing is present, the incident magnetic field produced by the transmitting coil generates eddy currents that lead to a reduction of the magnetic coupling. ...

Discussants: Tommaso Campi · Silvano Cruciani · Valerio De antis · Mauro Feliziani

Wireless Electricity *Transfer*

- ... Therefore, the existence of metal objects breaks down system's original "electric resonance" At present, few researches have been conducted on the characteristics of magnetic coupling resonance WPT systems under the influence of metal objects. To address the problem caused by the existence of metal objects, an experimental analysis method is the one most frequently used to study the influences of external metal objects [12, 13]. However, this method has great limitations, that is, it doesn't effectively play a guiding role in system design and is only used as an auxiliary means to analyze the performance. ...
- ... By defining a SE formula, a University of L'Aquila in Italy work analyses absorption loss, reflection loss and additional effects of multiple reflections and transmissions, and finally draws the conclusion that the magnetic material helps to improve the coupling. The conclusion is verified by experiments and simulation in a 20 kHz system [12, 20]. Based on the TEM wave theory, Lawson and others [21] analyzed how the PTE of a WPT system varies with the frequency when a ferrite material exists in the system. ...

Discussants: Tan · Jiacheng Li · Chen Chen · Xueliang Huang

Coupled Electromagnetic Field Canceling Coil for Wireless Power Transfer System

- ... For stationary EV wireless charging applications, no matter what coil structure is, the basic circular pad [3], [10], DD pad [11], DDQ pad [12], bipolar pad [13], or even H-shape [14], the Al-plate passive shielding [9] is widely used. However, side effects caused by the Al-plate shielding are often underestimated and evaded, like decreasing coupling coefficient [9], [15] between the WPT coils and increasing the coil resistance [9], [15], [16] which could greatly reduce the WPT efficiency of the applied system. Different from the passive Al-plate shielding, active EMF cancelling [17] and reactive shielding [9], [18] measures have also been proposed for EV wireless charging application. ...

Wireless Electricity *Transfer*

Frequently Asked Questions

Q. *What is wireless power transfer (WPT)*?

A. Wireless Power Transfer (WPT) is the process where electrical energy is transmitted from a power source to an electrical load across an air gap using induction coils. These coils produce an electromagnetic field which sends energy from a charging base station (transmitter) to a coil on a portable device (receiver) with complete galvanic isolation. The receiver coil takes power from the electromagnetic field and converts it into electrical power.

Q. *How do you calculate efficiency*?

A. Efficiency is calculated as battery charge power divided by transmitter DC input power at rated load.

Q. *Are there any health risks associated with this technology*?

A. Power by Proxy has conducted studies at leading medical universities and found no adverse health effects as a result of their wireless power technology. Each Proxy transmitter system has been tested against international standards that dictate maximum magnetic field exposure levels, and all have produced results well below the allowable limits.

Q. *What is DC and AC*?

DC (Direct Current) is electrical current that flows in only one direction and has a fairly constant average value.

AC (Alternating Current) is electric current that regularly reverses direction; that causes electric shock to touch.

Wireless Electricity *Transfer*

Results

- Top Wireless power transfer Companies

- Rolls Royce (/organisation/Rolls Royce/35a04adc
- Founded 1906
- United Kingdom
- Rolls-Royce Holdings plc is a British multinational public holding company that, through its various subsidiaries, designs, manufactures and distributes power systems for aviation and other industries. Rolls-Royce Holdings is headquartered in City of Westminster, London. It is the world’s second-largest maker of aircraft engines, and also has major businesses in the marine propulsion and energy sectors. Rolls-Royce was the world's 16th-largest defence contractor in 2011 and 2012 when measured by
- http://www.witricity.com (http://www.witricity.com)

Wireless Electricity *Transfer*

- WiTricity (/organisation/WiTricity/e5876139-5c7e
- Private Company
- Founded 2007
- USA
- WiTricity is the industry leader in wireless electricity delivered over distance. The company was founded in 2007 to commercialize an exciting new technology for wireless electricity. With a growing list of global clients in industries including consumer electronics, automotive, medical devices and defense, WiTricity has emerged as the leader for IP and expertise in highly resonant wireless power transfer.
- (https://www.ventureradar.com/home)

Wireless Electricity *Transfer*

- http://velmenni.com/ (http://velmenni.com/)
- Velmenni (/organisation/Velmenni/f680c976
- Private Company
- Founded 2013
- Estonia
- Jugnu is the next generation of smart LED bulbs that can transfer data through visible light. We are implementing the Li-Fi technology in our new range of LED bulbs. It refers to the wireless communication system which uses light as a medium of transport instead of traditional radio frequencies. Although the use of light in order to transmit data can be limited in comparison to radio waves, there is a great amount of possibilities that can be developed with the proper use of this technology.

Wireless Electricity *Transfer*

- http://www.energous.com/ (http://www.energous.com/)
- Energous Corporation (/organisation/Energous
- Listed Company
- Founded 2012
- USA
- Energous Corporation is the developer of WattUp®—an award-winning, wire-free charging technology that will transform the way consumers and industries charge and power electronic devices at home, in the office, in the car and beyond. WattUp is a revolutionary radio frequency (RF) based charging solution that delivers intelligent, scalable power via radio bands, similar to a Wi-Fi router. WattUp differs from older wireless charging systems in that it delivers power at a distance, to multiple devices – thus

Wireless *Electricity* ***Transfer***

- http://www.ossia.com/ (http://www.ossia.com/)
- Ossia (/organisation/Ossia/5ca1af2c-97c5-4107
- Private Company
- Founded 2013
- USA
- Ossia is challenging people’s core assumptions about what is possible with wireless power. Ossia’s Cota technology redefines wireless power by safely delivering targeted energy to devices at a distance. Ossia’s patented RF smart antenna technology automatically keeps multiple devices charged without any user intervention, enabling an efficient and truly wire-free, powered-up world, that is always on and always connected. The Cota technology does not involve pads or other induction or contact-based charging.

Wireless Electricity *Transfer*

- http://www.maxentric.com (http://www.maxentric.com)
- MaXentric Technologies LLC
- Founded date unknown
- USA
- http://nucurrent.com (http://nucurrent.com)
- NuCurrent (/organisation/NuCurrent/83ae288b
- Founded 2009
- USA
- NuCurrent is a leading developer of high-efficiency antennas for wireless power applications. Compliant across Alliance for Wireless Power (A4WP), Wireless Power Consortium (Qi) and Power Matters Alliance (PMA) standards, NuCurrent works closely with electronic device OEMs and integrators to customdesign, rapid-prototype and integrate the optimal antenna for a broad range of applications. NuCurrent's patented designs, structures and manufacturing techniques mitigate typical high frequency effects…

Wireless Electricity *Transfer*

- http://www.sigfox.com/ (http://www.sigfox.com/)
- Sigfox (/organisation/Sigfox/f6018b6d-f901
- Founded 2009
- France
- SIGFOX is the first and only company providing global cellular connectivity for the Internet of Things, fully dedicated to low-throughput communications. SIGFOX is re-inventing connectivity by radically lowering prices and energy consumption for connected devices. The SIGFOX connectivity solution is based on an antenna & base station infrastructure that is completely independent of existing networks, such as the telecommunications networks. This low-throughput only network is being rolled out in 60 countries

Wireless Electricity *Transfer*

- http://www.voltserver.com (http://www.voltserver.com)
- VoltServer (/organisation/VoltServer/50044178
- Founded 2011
- USA
- VoltServer's innovative and patent-protected Digital Electricity™ remote powering solutions speed installation, significantly reduce equipment, cable and labor costs, and more efficiently power the equipment needed to densify 4G LTE and WiFi service in buildings and venues. VoltServer began shipping in early 2015, and is powering 4G/LTE mobile services in many large sports stadiums, office towers, hotels, condominiums and medical buildings. According to Cisco Systems, 80% of all mobile traffic now

Wireless Electricity *Transfer*

- http://www.snaptonic.net/ (http://www.snaptonic.net/)
- snapTonic (/organisation/snapTonic/ede3cb9d
- Founded 2013
- Belgium
- The best wireless communication solution is the one that fits your use case. We make IoT happen. Any succesful Internet of Things product needs reliable wireless communication technology. We focus on (custom) wireless hardware and software solutions to make this happen, from initial idea to prototyping and production. snapTonic provides products and services to connected product makers, OEMs and semiconductors.

Wireless Electricity ***Transfer***

- TWI Technology Centre (Wales)
- Private Company
- Founded 1946
- United Kingdom
- TWI is one of the world’s foremost independent research and technology organisations, with expertise in solving problems in all aspects of manufacturing, fabrication and whole-life integrity management technologies. Established in Cambridge, UK in 1946 and with facilities across the globe. TWI Technology Centre (Wales) specialises in the development and application of state of the art non-destructive testing (NDT) methods. Through applied research and development in response to requests for assistance from
- http://www.twi-global.com/about/twi-group/twi-technology-centre-wales/

Wireless Electricity *Transfer*

- http://www.creare.com (http://www.creare.com)
- Creare Inc. (/organisation/Creare
- Private Company
- Founded 1961
- USA
- Creare LLC is an engineering research and development firm located in Hanover, New Hampshire. Founded in 1961, we provide industrial and government clients in the medical, aerospace/defense, energy, process, and manufacturing industries with services ranging from applied research to prototype design, fabrication and testing. Core areas of expertise include fluid dynamics, heat and mass transfer, electronics and software development, sensors and control systems, and CFD/FEA analysis.
- http://www.idt.com/ (http://www.idt.com/)

Wireless Electricity *Transfer*

- Integrated Device Technology, Inc.
- Listed Company
- Founded 1980
- USA
- Integrated Device Technology, Inc. develops system-level solutions that optimize its customers' applications. IDT's market-leading products in RF, timing, wireless power transfer, serial switching, interfaces and sensing solutions are among the company's broad array of complete mixed-signal solutions for the communications, computing, consumer, automotive and industrial segments. These products are used for development in areas such as 4G infrastructure, network communications, cloud

Wireless Electricity *Transfer*

- Swiss Center for Electronics and Microtechnology
- Founded 1984
- Switzerland
- CSEM is a private non-profit-making organization for research and development. Its operation is based on five strategic programs; Microsystems (Design & process Integration & packaging), Systems (Scientific instrumentation, Medical device technology, Automation), Photovoltaics & Energy Management, UltraLow-Power Integrated Systems (System-on-chips, Wireless, Vision) and Surface Engineering (Nanotechnology, biotechnology, printable electronics).
- http://www.csem.ch/ (http://www.csem.ch/)
- http://www.intelesens.com/ (http://www.intelesens.com/)

Wireless Electricity *Transfer*

- Intelesens (fka ST&D) (/organisation/Intelesens
- Founded 2000
- United Kingdom
- Intelesens is an internationally recognised, leading innovator in targeted non-invasive vital signs monitoring. Wireless telemetry, Low power consumption electronics, Embedded software, Cardiology, Body sensors and low level signal processing, Screen printing solid gel electrode manufacture, Science of the skin including long term non-irritant materials, Defibrillation techniques and recovery, Medical systems approval - FDA and CE.

Wireless Electricity *Transfer*

- http://www.indianamicro.com (http://www.indianamicro.com)
- Indiana Microelectronics LLC
- Founded date unknown
- USA

Wireless Electricity *Transfer*

- http://www.ferrosi.com (http://www.ferrosi.com)
- FERRO SOLUTIONS, INC. (/organisation/FERRO
- Founded 2002
- USA
- Ferro Solutions develops Wireless Power Transfer Systems, Magnetic "Through The Earth

Wireless Electricity *Transfer*

- http://www.avanto.tech (http://www.avanto.tech)
- Avanto Technologies (/organisation/Avanto
- Private Company
- Founded 2016
- Finland
- AVANTO® specializes in the seamless integration of the electronics and clothing. We offer our infrared heating technology to sports, outdoors and professional equipment manufacturers as a B2B solution. AVANTO® aims to co-operate with partner companies from the beginning of the product development all the way to the production. We help our customers create heated clothing that is up to twice as energy efficient as competing resistance heated products. This in turn allows us to use smaller batteries and…

Wireless Electricity *Transfer*

- Blu Wireless Technology (/organisation/Blu
- Founded 2009
- United Kingdom
- Blu Wireless designs and licenses silicon IP for 60GHz applications. The 60GHz band enables multigigabit data transfer and is vital for the emerging, and rapidly growing WiGig (802.11ad WiFi) and 4G backhaul markets. By using our IP, baseband chip manufacturers can quickly and cost-effectively develop
- http://www.bluwirelesstechnology.com (http://www.bluwirelesstechnology.com)
- and launch industry leading wireless ICs with 60GHz functionality.

Wireless Electricity *Transfer*

- http://www.draysontechnologies.com/ (http://www.draysontechnologies.com/)
- Drayson Technologies (/organisation/Drayson
- Founded 2007
- United Kingdom
- Drayson Technologies Ltd has pioneered environmentally sustainable technologies since 2007, latterly focusing on the emerging field of electric vehicles and wireless technology. The business owns the Drayson Technologies automotive R&D business and a majority stake in the newly formed Drayson Wireless business in collaboration with Imperial Innovations.

Wireless Electricity *Transfer*

- http://www.maptech.co.kr/ (http://www.maptech.co.kr/)
- MAPTech co., ltd (/organisation/MAPTech
- Founded date unknown
- USA
- 1. Mid-power range (10~15W) wireless power transfer system 2. Advanced charging area by moving coil enabled motor and gear mechanism 3. Adaptive device track system for intelligent wireless charger 4. Cost competitive dual mode USB charging connecter as fast as a wall adapter Primary Application Area: Electronics, Sensors & Communications Technology. Development Status: Prototype. Technology Readiness Level: TRL 4 FIGURES OF MERIT. Value Proposition: 1. Provide higher charging power(15W)

Wireless Electricity *Transfer*

- Optimos Apto (/organisation/Optimos
- Founded 2011
- Netherlands
- Optimos Apto makes wireless access to power supplies possible. PhD student and entrepreneur, Frank van der Pijl (MSc), developed his own version of contactless power transfer, instead of doing away with cables and sockets altogether, the device of Optimos Apto allows you to extract power at any point along
- http://optimosapto.com/ (http://optimosapto.com/)
- the cable at any AC or DC voltage you would require without making an electrical connection.

Wireless Electricity *Transfer*

- http://www.wfs-tech.com/ (http://www.wfs-tech.com/)
- WFS Technologies (/organisation/WFS
- Founded 2003
- United Kingdom
- WFS Technologies is the world's leading supplier of subsea wireless technology for communication, control, navigation and power transfer. Combining radio, acoustic and wireless power transfer technologies, our field proven expertise in wireless connectivity is delivering cost savings and new capabilities to the Subsea, Oil & Gas, Environmental and Consumer industries worldwide. WFS' wireless technology enhances monitoring systems in subsea industries by enabling "real-time" data transmission

Wireless Electricity *Transfer*

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(2014). Magnetic shielding of wireless power transfer systems. IEEE International Symposium on Electromagnetic Compatibility.

Wireless Electricity *Transfer*

Conclusion/ Abstract

- Wireless electricity is safe for implantable medical devices that are in the body, which shows that it is very safe when safety measures are done. Wireless Electricity Transfer can cover long distances and does not loose electricity like wired electricity cables do loose electric current by twenty something percent for each point from generation to transmission to distribution; New Zealand is building wireless electricity devices to transfer electricity across the country, this is in an appendix below this conclusion of the white paper. Electricity will be converted from AC to DC before wireless transmission to eliminate any public worry or GSM interference by WET, before it will be converted from DC to AC; radio waves are safer than micro waves and laser beam, so radio waves that were first to be used will be used to carry electricity across long distances that will reduce the number of transmission points that will be scattered around to transmit electricity wirelessly to homes and offices.

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Laser beam can be used with dampeners to reduce risks in grid long distances outside cities to transfer electricity to the radio waves electricity transmission. Companies that have done WPT etc. can combine with companies that have done protective measures to produce WET. Cost of doing WET is less than cost of doing GSM; because it is private companies that have done WPT etc. that should be invited via policy to do WET like the Federal Government let in private companies to do wireless mobile services. GSM services cost more because NITEL services had to be adjusted to wireless services, but there is no need for power Generating Companies or Transmissions Stations to be adjusted by Government, so that makes it is much cheaper. As government makes money via tax from WET companies they invited who profit from charges on customers that are the citizenry of Nigeria.

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- People will always speculate about cost and safety like if all should be done by Government when GSM was not done that way, that was why it worked; Government is only to have green paper done. Privatization has already been done. it is only to invite the companies that have done it and they will do it. There is no cost for infrastructure on the Government of Nigeria, only Nigerians will have to pay for the wireless Electricity Receiver and Emitter (WERE). Safety is always a priority with Quality Control (QC), in which they have international bodies like WAIPO to monitor bodies that do. WET will therefore be converted to DC for grid and home transfer for better safety than the GSM does because the standard of medical devices in the body is the standard WET will be to the committee that will make it harmless.
- Information Management is not only for Communications but also for Power. Thank you.

Wireless Electricity *Transfer*

Contributors to Research:

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- Mr. Kingsley Amah SPIIM
- Mr. Agbedo Ojore Godday Associate

Wireless Electricity *Transfer*

Appendix

Power Management in Wireless Networks

Abstract

This paper presents a survey on the various power saving techniques used in wireless networking today. The work presented covers topics ranging from the use of energy harvesting techniques at the physical layer to partitioning the load of power hungry computations across multiple devices at the application layer. While research in this area continues to grow, few standards have yet to emerge that incorporate the use of each of these techniques. De facto standards do exist, however, and tend to be driving the development of power aware devices in industry at the moment. This paper explores the various techniques used for preserving the energy consumed at each layer of a wireless networking protocol stack. The types of wireless networks considered include Wireless Local Area Networks (WLANs), Wireless Personal Area Networks (WPANs), and Wireless Sensor Networks. Existing standards for performing power management in each of these networks are discussed, and their effective use is analyzed. The role that these standards play in industry as well as the role played by current research in this area is also introduced.

Wireless Electricity *Transfer*

1. Introduction

Many differences exist between wireless networks and tradition wired ones. The most notable difference between these networks is the use of the wired medium for communication. The promise of a truly wireless network is to have the freedom to roam around anywhere within the range of the network and not be bound to a single location. Without proper power management of these roaming devices, however, the energy required to keep these devices connected to the network over extended periods of time quickly dissipates. Users are left searching for power outlets rather than network ports, and becoming once again bound to a single location. A plethora of power management schemes have been developed in recent years in order to address this problem. Solutions exist at every layer of the traditional network protocol stack, and each of them promises to provide their own level of energy savings. This paper takes a look at the different techniques used at each layer and examines the standards that have emerged as well as products being developed that are based on them. It focuses on the subset of wireless networking that deals with Wireless Local Area Networks (WLAN) and Wireless Personal Area Networks (WPAN). As a subset of WPANs known as LR-WPANs that require very low power operation at very low data rates, techniques used in Wireless Sensor Networks (WSNs) are given particular focus. The rest of this paper is organized as follows. Section 2 provides a brief overview of WLANs, WPANs, and WSNs, including a discussion of how each type of network differs in terms of their requirements for performing power management. Section 3 follows with an introduction to the different power management techniques used within the various network protocol layers in each type of network. Section 4 discusses standards for each type of network that have been developed to use these different techniques. Section 5 talks about the recent advances that have been made in the field of power management, followed by a short description of the products available from industry which take advantage of this research in Section 6. Finally, Section 7 provides a summary of the entire paper, with references and a list of the abbreviations used throughout the paper following at the end.

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2. Power Constrained Wireless Networks

Wireless networks have been a hot topic for many years. Their potential was first realized with the deployment of cellular networks for use with mobile telephones in the late 1970's. Since this time, many other wireless wide are networks (WWANs) have begun to emerge, along with the introduction of wireless Metropolitan Area Networks (WMANs), wireless Local Area Network (WLANs), and wireless Personal Area Networks (WPANs). Fig. 1 shows a number of standards that have been developed for each of these types of networks.

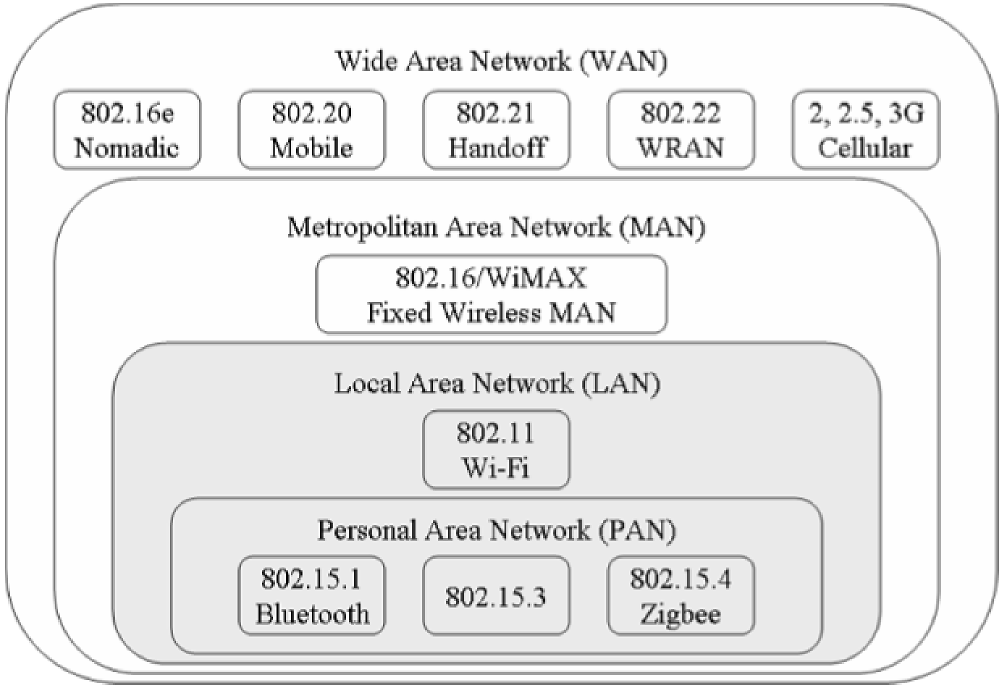

Fig. 1: Wireless Standards

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If they are to have any hope of long term usability, the power consumed by individual nodes in each of these networks needs to be managed efficiently. Although performing this power management is important for each of these types of networks, this paper focuses primarily on the power management schemes used by WLANs and WPANs. The following two subsections give a brief overview of these two types of networks, along with a description of how they differ from one another in terms of their power management requirements. The final subsection is dedicated to the introduction of a subset of WPANs, known as wireless sensor networks (WSNs). Wireless sensor networks are specifically designed for very low power operation and thus deserve this degree of special attention. Fig. 2 shows how these different types of networks compare in terms of data rate and power consumption. The [Ieee802.15.4] standard shown in the figure is the one most widely used by wireless sensor networks.

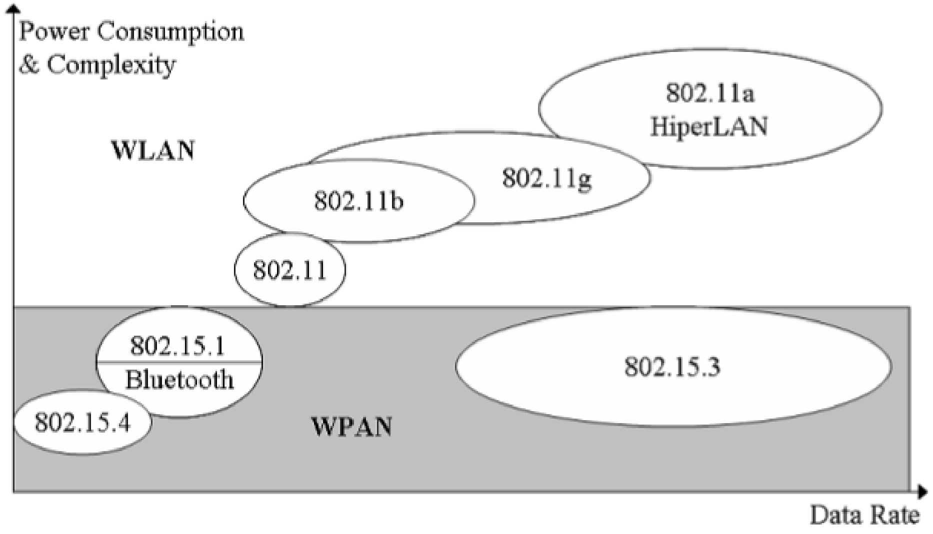

Fig. 2: Power Consumption in IEEE 802 based networks

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2.1 Wireless LANs

Most wireless LANs are based on the IEEE 802.11 standard [Ieee802.11] depicted in Fig. 1 and Fig. 2. This standard is also known as WiFi (Wireless Fidelity), and provides functionality for wireless devices to communicate in a way similar to the way they would on a traditional wired LAN. Devices in these networks normally operate at a higher data rate than for devices existing in a WPAN. They are usually made to communicate over longer distances as well. Because of this higher data rate and longer communication range (higher transmission power), they also tend to consume more power. To reduce the power consumed, a power management scheme known as PSM is built into the 802.11 standard. Section 4.1 talks about this power management scheme in more detail. Many variations of the 802.11 standard have begun to emerge over the past few years, each with its own set of enhancements over the original 802.11 standard. Some of these improvements are for enhanced Quality of Service (802.11e), Security (802.11i), Throughput (802.11n), as well as dynamic frequency selection and transmission power control (802.11h). Of all the variations, however, only [Ieee802.11h] deals with improving the power management capabilities of 802.11 in any way. As will be shown in Section 3.3, transmission power control is a method of controlling the topology of a network by reducing the power at which certain nodes in the network are allowed to transmit. However, the 802.11h enhancement standard does not explicitly define a policy for implementing a transmission power control policy; it only provides the facility for doing so.

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2.2 Wireless PANs

PAN technology was primarily developed in order to allow personal devices to communicate wirelessly with one another. While devices in a WLAN are able to communicate with one another over relatively long distances and at relatively high data rates, devices in a PAN communicate within a much smaller range, and at a much lower data rate. The primary standards for WPANs include 802.15.1 [Bluetooth], [Ieee802.15.3], and [Ieee802.15.4] (Zigbee). While 802.15.3 operates at data rates comparable to those in an 802.11 WLAN, the range at which devices in these networks can communicate is much smaller. Because of these smaller transmission powers and lower data rates, devices in a WPAN inherently consume much less power than those in a WLAN. The 802.15.1 standard includes a power management scheme to further reduce the power consumed. This scheme is discussed in more detail in Section 4.2

2.3 Wireless Sensor Networks

While it is desirable for devices in a WLAN or a WPAN to consume as little power as possible it is imperative for devices in a wireless sensor network to do so. WSNs are made up of a large number of tiny low-cost, low-power, multi-functional devices used for extracting data from the environment around them. They are capable of taking sensor readings from the environment, processing that data, and communicating it back to some central location for further processing. They can essentially be thought of as extensions of the Internet into the physical world. In many situations it is desirable that the devices making up a WSN are deployed into the environment and left to run on their own accord for many months or even years. Without careful power management of these devices, such deployments would not be possible.

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The WPAN standard designed to work with WSNs is 802.15.4 [Ieee802.15.4]. As shown is Fig. 2, 802.15.4 is not only the standard that consumes the least amount of power, but also the one having the lowest data rate. Many of the power management techniques discussed later on in this paper have been developed specifically with WSN applications in mind. Section 4.2 discusses the [Zigbee] specification developed to work on top of the 802.15.4 standard to further reduce the power consumed in WSNs.

3. Power Management Techniques

The previous section discussed WLANs and WPANs and the various standards that exist for them. The differences between each type of network were introduced with an emphasis put on their requirements for performing power management that each of them have. This section discusses the various power management techniques used by these standards for reducing the power consumed in each type of network. Many of the techniques introduced in this section do not appear in any of these standards, but are used in common practice to reduce the power of devices in both WLANs and WPANs. These techniques exist from the application layer all the way down to the physical layer of a traditional networking protocol stack. Techniques specific to a particular type of network are annotated as appropriate.

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3.1 Application Layer

At the application layer a number of different techniques can be used to reduce the power consumed by a wireless device. A technique known as load partitioning allows an application to have all of its power intensive computation performed at its base station rather than locally [Jones01]. The wireless device simply sends the request for the computation to be performed, and then waits for the result. Another technique uses proxies in order to inform an application to changes in battery power. Applications use this information to limit their functionality and only provide their most essential features. This technique might be used to suppress certain "unnecessary" visual effects that accompany a process [Jones01]. While these techniques may be adapted to work with any application that wishes to support them, a number of techniques also exist for specific classes of applications. Some applications are so common that it is worth exploring techniques that specifically deal with reducing the power consumed while running them. Two of the most common such applications include database operations and video processing [Jones01]. For database systems, techniques are explored that are able to reduce the power consumed during data retrieval, indexing, as well as querying operations. In all three cases, energy is conserved by reducing the number of transmissions needed to perform these operations. For video processing applications, energy can be conserved using compression techniques to reduce the number of bits transmitted over the wireless medium. Since performing the compression itself may consume a lot of power, however, other techniques that allow the video quality to become slightly degraded have been explored in order to reduce the power even further. Please refer to [Negri04] for a more complete list of application specific power management schemes.

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3.2 Transport Layer

The various techniques used to conserve energy at the transport layer all try to reduce the number of retransmissions necessary due to packet losses from a faulty wireless link [Jones01]. In a traditional (wired) network, packet losses are used to signify congestion and require backoff mechanisms to account for this. In a wireless network, however, losses can occur sporadically and should not immediately be interpreted as the onset of congestion. The TCP-Probing [Tsaoussidis00] and Wave and Wait Protocols [Zhang01] have been developed with this knowledge in mind. They are meant as replacements for traditional TCP, and are able to guarantee end-to-end data delivery with high throughput and low power consumption. 3.3 Network Layer

Power management techniques existing at the network layer are concerned with performing power efficient routing through a multi-hop network [Jones01] [Manoj04] [Karl03]. They are typically either backbone based, topology control based, or a hybrid of them both. In a backbone based protocol (sometimes also referred to as Charge Based Clustering), some nodes are chosen to remain active at all times (backbone nodes), while others are allowed to sleep periodically. The backbone nodes are used to establish a path between all source and destination nodes in the network. Any node in the network must therefore be within one hop of at least one backbone node, including backbone nodes themselves. Energy savings are achieved by allowing non-backbone nodes to sleep periodically, as well as by periodically changing which nodes in fact make up the backbone.

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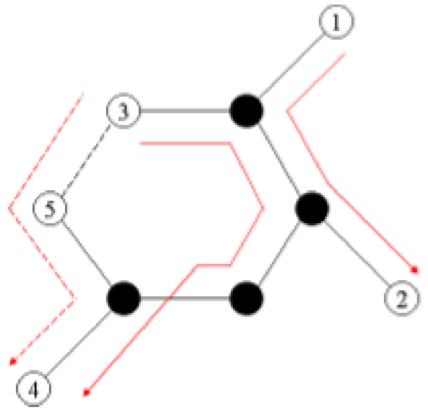

Fig. 3: Backbone based routing

Fig. 3 shows how packets would be routed from node 3 to node 4 and from node 1 to node 2 using the backbone that has been established. Black nodes signify backbone nodes, while numbered nodes signify non-backbone nodes. Solid lines indicate paths along which a packet may travel, while dashed ones show paths that will not be followed. Given this backbone structure, packets traveling from node 3 to node 4 will have to travel through 4 different backbone nodes before reaching their destination. If node 5 had been chosen as a backbone node as well, packets would only have had to traverse through 2. Topology based routing protocols achieve energy savings in a different way. Their goal is to reduce the transmission power of all nodes in a network such that the network remains connected, but all nodes operate with the lowest transmission power possible. In a homogeneous network, this means that the transmission powers of all nodes are adjusted so that they are just within range of their nearest one-hop neighbor. In heterogeneous networks (i.e. networks with nodes of different type, power limitations, etc.) the transmission powers may be adjusted according to the needs of that network. A summary of the different types of topology based protocols that exist can be seen in Fig. 4.

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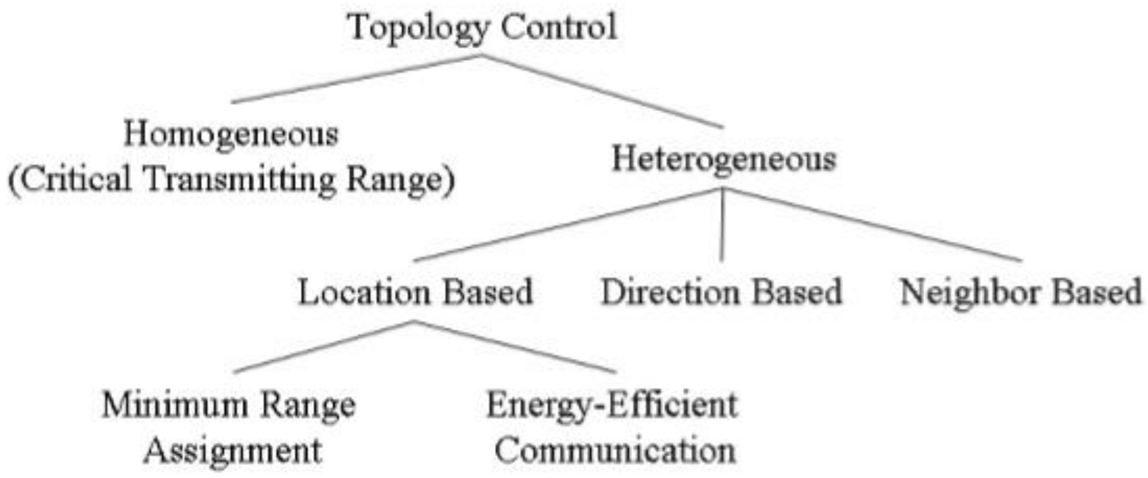

Fig. 4: Topology based routing protocols

As seen in the figure, certain location based topology control protocols attempt to use the topology of the network to provide the most energy efficient communication path possible. These protocols produce a sort of "Localized Power-Aware Routing" mechanism for the network. In some cases, providing this path means taking a larger number of hops through the network than would otherwise be taken when transmitting directly from one node to another. While this may seem counterintuitive at first, it makes sense if the amount of energy expended in transmitting to a node very far away is significantly greater than the energy expended when transmitting between a large number of nodes that are within closer range of one another. The rational behind the other topology based protocols found in Fig. 4 can be found in [Bao03]. Transmission power control schemes are combined with backbone based ones to produce a hybrid of them both. Using hybrid based protocols, the benefits of both backbone based and topology based routing protocols can be achieved simultaneously. Section 5.1 explores a number of different power efficient routing protocols that use the ideas presented in this section.

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3.4 Data Link Layer

The two most common techniques used to conserve energy at the link layer involve reducing the transmission overhead during the Automatic Repeat Request (ARQ) and Forward Error Correction (FEC) schemes. Both of these schemes are used to reduce the number of packet errors at a receiving node. By enabling ARQ, a router is able to automatically request the retransmission of a packet directly from its source without first requiring the receiver node to detect that a packet error has occurred. Results have shown that sometimes it is more energy efficient to transmit at a lower transmission power and have to send multiple ARQs than to send at a high transmission power and achieve better throughput. Integrating the use of FEC codes to reduce the number of retransmissions necessary at the lower transmission power can result in even more energy savings. Power management techniques exist that exploit these observations [Jones01]. Other power management techniques existing at the link layer are based on some sort of packet scheduling protocol [Alghamdi05]. By scheduling multiple packet transmission to occur back to back (i.e. in a burst), it may be possible to reduce the overhead associated with sending each packet individually. Preamble bytes only need to be sent for the first packet in order to announce it presence on the radio channel, and all subsequent packets essentially "piggyback" this announcement. Packet scheduling algorithms may also reduce the number of retransmissions necessary if a packet is only scheduled to be sent during a time when its destination is known to be able to receive packets. By reducing the number of retransmissions necessary, the overall power consumption is consequently reduced as well.

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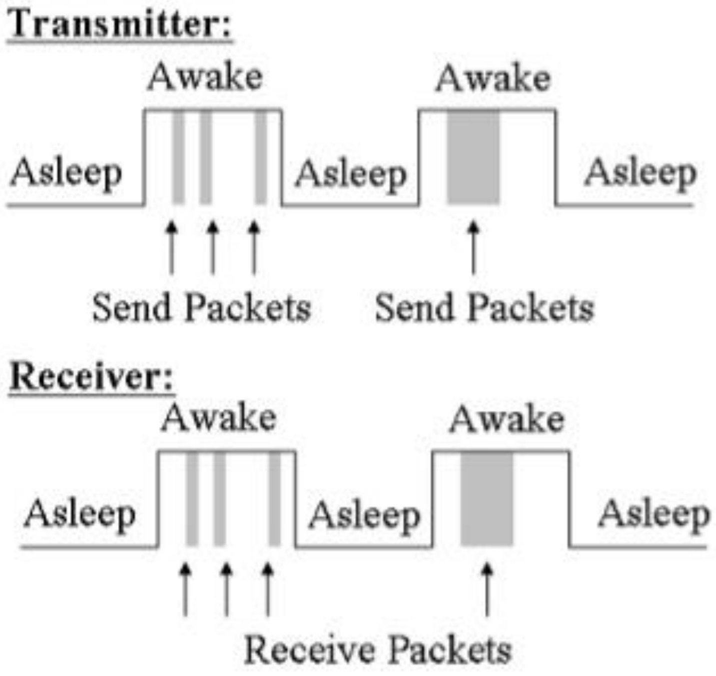

Fig. 5: Synchronous sleep scheduler

Asynchronous sleep scheduling, on the other hand, does not rely on any clock synchronization between nodes whatsoever. Nodes can send and receive packets whenever they please, according to the MAC protocol in use. Fig. 6 shows how two nodes running asynchronous sleep schedulers are able to communicate.

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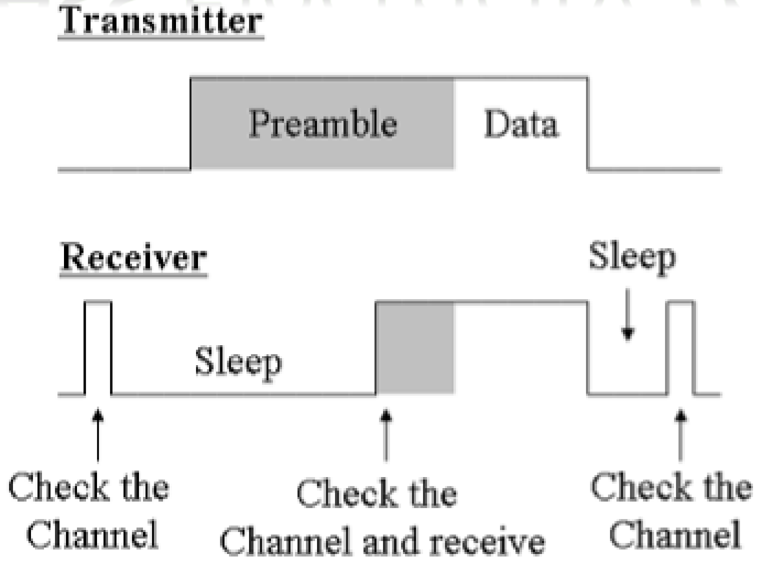

Fig. 6: Asynchronous sleep scheduler

Nodes wake up and go to sleep periodically in the same way they do for synchronous sleep scheduling. Since there is no time synchronization, however, there must be a way to ensure that receiving nodes are awake to hear the transmissions coming in from other nodes. Normally preamble bytes are sent by a packet in order to synchronize the starting point of the incoming data stream between the transmitter and receiver. With asynchronous sleep scheduling, a significant number of extra preamble bytes are sent per packet in order to guarantee that a receiver has the chance to synchronize to it at some point. In the worst case, a packet will begin transmitting just as its receiver goes to sleep, and preamble bytes will have to be sent for a time equal to the receiver's sleep interval (plus a little more to allow for proper synchronization once it wakes up). Once the receiver wakes up, it synchronizes to these preamble bytes and remains on until it receives the packet. Unlike the power efficient routing protocols introduced in section 3.3, it doesn't make sense to have a hybrid sleep scheduling protocol based on each of the two techniques. The energy savings achieved using each of them varies from system to system and application to application. One technique is not "better" than the other in this sense, so efforts are being made to define exactly when each type should be used. Section 5.2 explores this concept further.

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3.6 Physical Layer

At the physical layer, techniques can be used to not only preserve energy, but also generate it. Proper hardware design techniques allow one to decrease the level of parasitic leak currents in an electronic device to almost nothing [Jacome03]. These smaller leakage currents ultimately result in longer lifetimes for these devices, as less energy is wasted while idle. Variable clock CPUs, CPU voltage scaling, flash memory, and disk spin down techniques can also be used to further reduce the power consumed at the physical layer [Jones01] [Manoj04]. A technique known as Remote Access Switch (RAS) can be used to wake up a receiver only when it has data destined for it. A low power radio circuit is run to detect a certain type of activity on the channel. Only when this activity is detected does the circuit wake up the rest of the system for reception of a packet. A transmitter has to know what type of activity needs to be sent on the channel to wake up each of its receivers. [Manoj04] Energy harvesting techniques allow a device to actually gather energy from its surrounding environment. Ambient energy is all around in the form of vibration, strain, inertial forces, heat, light, wind, magnetic forces, etc. [Brown06]. Energy harvesting techniques allow one to harness this energy and either convert it directly into usable electric current or store it for later use within an electrical system. In section 5.3 the latest technological advances in both low power design and energy harvesting techniques will be introduced.

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4. Existing Standards

In the previous section, various techniques were explored that enable energy to be conserved at various layers within the wireless networking protocol stack. Some techniques were looked at in greater detail than others, and some techniques existing at the overall system level were not discussed at all. These power management schemes involve controlling the power state for peripheral devices such as the display or hard disk on a laptop computer. Others include cycling through the use of multiple batteries on a device in order to increase the overall lifetime of each individual one. Since these techniques do not explicitly exist at any single layer within the wireless networking protocol stack itself, they have been left out of this discussion. For more information on these and other power management techniques not discussed in the previous section, please refer to chapter eleven of [Manoj04] and its corresponding list of references. The following section focuses on the use of the techniques introduced in the previous section for defining the various power management schemes built into the IEEE 802 standards discussed in section 2. As the IEEE standards body only concerns itself with defining the various MAC layer protocols for the 802 family of wireless networks, the standards discussed in this section only make use of the sleep scheduling protocols discussed previously. The standards that exist for WLANs (802.11-PSM), WPANs (Bluetooth), and WSNs (802.15.4/Zigbee) are all introduced separately.

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4.1 Wireless LANs

The IEEE 802.11 standard specifies how communication is achieved for wireless nodes existing in a Wireless Local Area Network (WLAN). Part of this standard is dedicated to describing a feature known as Power Save Mode (PSM) that is available for nodes existing in an infrastructure based 802.11 WLAN [Ieee802.11-PSM]. PSM is based on a synchronous sleep scheduling policy, in which wireless nodes (stations) are able to alternate between an active mode and a sleep mode. As a wireless station using PSM first joins an infrastructure based WLAN, it must notify its access point that it has PSM enabled. The access point then synchronizes with the PSM station allowing it to begin running its synchronous sleep schedule. When packets arrive for each of these PSM stations, the access point buffers them until their active period comes around again. At the beginning of each active period, a beacon message is sent from the access point to each wireless station in order to notify them of these buffered packets. PSM stations then request these packets and they are forwarded from the access point. Once all buffered frames have been received, a PSM station resumes with its sleep schedule wherever it left off. Whenever a PSM station has data to send, it simply wakes up, sends its packet, and then resumes its sleep schedule protocol as appropriate. Although this feature of 802.11 networks is readily available on all devices implementing the full 802.11 specification, it is not very widely used. Many studies have been done to investigate the effects of using PSM and other power saving techniques for WLANs [Simunic05] [Bononi01] [Molta05] [Gruteser01] [Anastasi04] [Chen04]. They all conclude that the throughput achieved with these techniques is significantly less than with them disabled. While PSM may significantly reduce the energy consumed by a wireless station, many users prefer to sacrifice these power savings for an increase in performance.

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4.2 Wireless PANs

The 802.15.1 standard [Bluetooth] provides provisions for power management as well. Wireless nodes in a Bluetooth network are organized into groups known as piconets, with one node dedicated as the master node and all others as slave nodes. Up to seven active nodes can exist in a piconet at any given time, with up to 256 potential members (249 inactive). All nodes operate using a synchronous sleep scheduling policy in order to exchange data. A beacon messaging system similar to the one described in Section 4.1 for 802.11 based networks is used to exchange messages between slave nodes and their master. All nodes are able to communicate with all other nodes within the Piconet, but messages between slaves must be sent exclusively through the master node. Bluetooth defines eight different operational states, 3 of which are dedicated to low power operations. These three low power states are known as Sniff, Hold, and Park. While in the Sniff state, an active bluetooth device simply lowers its duty cycle and listens to the piconet at a reduced rate. When switching to the Hold state, a device will shut down all communication capabilities it has with a piconet, but remain "active" in the sense that it does not give up its access to one of the seven active slots available for devices within the piconet. Devices in the Park state disable all communication with the piconet just as in the Hold state, except that they also relinquish their active node status.

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4.3 Wireless Sensor Networks

The 802.15.4 [Ieee802.15.4] wireless networking standard provides low data rate, low power communication that is ideal for wireless sensor networking applications. It too is based on a synchronous sleep scheduling policy that periodically wakes nodes up and puts them to sleep in order to exchange data. The difference between this standard and the others is in the frequency with which nodes wake up, and the data rate (and correspondingly the required transmission power) with which they transmit data. A low power protocol stack called [Zigbee] has been developed on top of the 802.15.4 MAC layer in order to provide low power solutions for WSNs. As will be seen in section 6, many products for WSNs are being developed in industry with "Zigbee" compatibility as a very strong marketing point.

5. Current Research Efforts

In addition to the standards that have been developed for low power communication in wireless networks, ongoing research continues to provide innovative solutions to this problem. This section discusses some of the more recent advances and provides references to some of the older ones. Since it is impossible to list every single power management protocol that has ever been developed for warless networking, only the most representative ones have been provided here.

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5.1 Power Aware Routing

Backbone based protocols such as ASCENT [CerpaXX] and SPAN [Chen02], utilize local rules to assess a node's connectivity with its neighbors and decide whether the node should stay active to join a communication backbone. These protocols focus on maintaining network connectivity, and are best suited for ad-hoc multihop networks running at high data rates. In a wireless sensor network setting, nodes are not just concerned with communicating with one another, but also in maintaining proper sensing coverage. A number of hybrid based protocols for wireless sensor networks that achieve this goal have been explored most recently in PEAS [Ye03].

5.2 Sleep Scheduling

A number of different sleep scheduling protocols exist, each with their own set of advantages and disadvantages for different types of wireless networking systems/applications. While both 802.11 PSM [Ieee802.11-PSM] and S-MAC [Ye02] are synchronous sleep scheduling policies, they are targeted towards two very distinct wireless networking domains. 802.11 PSM targets high data rate wireless devices existing in an infrastructure based WLAN, while S-MAC targets very low data rate wireless sensing devices existing in a wireless sensor network. As stated before, however, even with these types of policies available, users tend to prefer higher throughput to the power savings they can achieve. One solution known as PAMAS (Power Aware Multi-Access Signaling) has proven to be very effective in reducing the power consumed in both types of networks [Singh98]. Using PAMAS, nodes are able to detect when a packet on the channel is destined for someone else and put themselves to sleep. PAMAS can be combined with some of the other sleep scheduling protocols discussed below to produce even more power savings.

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An asynchronous sleep scheduling protocol known as Low Power Listening (LPL) [Polastre05] is quickly becoming the de facto standard for sleep scheduling policies in the world of wireless sensor networks. LPL operates just as any other asynchronous sleep scheduling protocol with one key difference. When LPL turns the radio on to check the channel for incoming packets, it does so very quickly (and reliably) so as to go back to sleep as quickly as possible. The time between each of these checks is known as a check interval. LPL only achieves significant power savings if many check intervals are allowed to pass before a packet is actually detected on the channel. This makes LPL ideal for the low data rate environment pertinent in wireless sensor networks. While the protocols described above only scratch the surface on the number of sleep scheduling protocols that have been developed to date, they do provide a good reference to the different domains in which different types of sleep scheduling protocols are most applicable. 5.3 Energy Harvesting

Traditionally, energy has been harvested through the use of solar panels attached to the periphery of a wireless device. These solar panels are made up of photovoltaic cells that convert sunlight directly into electrical current [Brown06]. The primary disadvantage of solar panels, however, is that they are large and that they require sunlight in order to work. In most wireless networking situations (but not all), it is not practical to be limited by such constraints. Laptops should not have bulky solar panels attached to them and only be operational outdoors, while nodes deployed for a wireless sensor network to take wind measurements in the Sahara desert may welcome such a technology. Most recently, advances have been made with a technology involving the use of piezoelectric materials. Piezoelectricity is the ability to create an electric current by suppressing certain types of crystal to mechanical stress. The primary advantages that piezoelectric materials have over solar panels is that they are small, do not require access to direct sunlight, and they operate with about a 70% mechanical to electrical transduction efficiency. Solar panels achieve only about 16-18% efficiency [Brown06]. While the science behind both solar energy harvesting and piezoelectric materials has been well understood for quite some time, their potential in the wireless networking domain are just now being realized. Section 6 discusses some of these applications and what products are being manufactured to support them.

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6. Industry developments

Products are being developed that exploit the power conserving techniques discussed in the previous sections. Products that make use of both the standards as well as cutting edge research efforts are beginning to hit the market. Most of the newer products are within the realm of WPANs and WSNs, but some new power saving devices for WLANs keep appearing as well. This section discusses some of these products, and how they use the standards and protocols discussed in the previous section to achieve energy savings. 6.1 Wireless LANs

As stated previously, the PSM built into the 802.11 standard is not very widely used. Because of this fact, many of the products that claim to be completely 802.11 compliant do not even include this feature in their distribution. Products exploiting the techniques discussed throughout this paper for reducing the power consumed in WLANs is mostly being done at the application layer or system level. Wireless networking cards for use in WLANs are beginning to appear that claim to be more power efficient than their predecessors . Laptops are designed to shut down their displays and networking cards after a certain period of inactivity. Many applications are now being designed to implement the load partitioning algorithms discussed in Section 3.1. While these products do not exploit the full capability of the power management techniques discussed in this paper, they do allow an application to save as much power as possible, while still maintaining a high level of throughput. As time moves forward, it is anticipated that more and more products will begin to appear that find ways to balance these two conflicting needs.

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6.2 Wireless PANs

Bluetooth devices have become increasingly popular over the last 10 years. A huge part of their success has been due to the extended battery life made possible through their 3 different low power modes of operation. Almost every computer, cell phone, PDA, GPS system, etc. that one can buy nowadays comes equipped with bluetooth technology enabled. The 802.15.3 standard has been developed to provide higher data rates than bluetooth for use with streaming multimedia applications. Products with this technology built into them are just now beginning to appear, and will most likely not begin to dominate the market until a few years from now. The power saving techniques used in these devices is based on the bluetooth technology and therefore employs some of the same power management techniques. Special purpose boots exploiting the use of piezoelectric materials are also being developed by the military in order to allow a soldier to simply click their heels together in order to power up the entire set of communications gear that they have within their PAN [Brown06]. 6.3 Wireless Sensor Networks

Products aimed at structural health monitoring, industrial monitoring, home automation, etc., have been made possible by the use of the extremely low power 802.15.4/Zigbee standards. Chipcon [Chipcon]radio manufacturers produce radio chips with the 802.15.4 standard built into them. Companies such as Crossbow Technologies [Xbow] and Motiv [Motiv] lead the market in the manufacturing small wireless devices called motes for use in wireless sensor network applications. Intel has recently released a low power wireless sensor network platform that is ideal for monitoring manufacturing equipment in an industrial setting. As the field of WSNs is still fairly young, it is expected that many new application and products will begin to emerge over the next few years that exploit the research done in the field of power management for wireless networking in unprecedented ways. As long as the demand for lower power wireless devices is present, products will never stop being produced.

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7. Summary

In this survey, a variety of different energy conserving techniques for wireless networks have been explored. Although the scope of this paper has been limited exclusively to WLANs and WPANs, many of the techniques presented are universal and can be used to perform power management in any type of network. A brief overview of each type of network has been given, including a description of a subset of WPANs known as Wireless Sensor Networks. It was shown that while WLANs and traditional WPANs may achieve longer lifetimes through the use of the power management techniques presented, low power design in WSNs is an essential feature and thus required particular focus in this paper.

The various power saving techniques used at each layer in the traditional networking protocol stack have been presented, and their applicability to each type of network has been analyzed. It was shown that all types of networks can benefit from sleep scheduling protocols, topology control mechanisms, and energy harvesting techniques. However, certain application specific power management schemes are strictly meant for either WLANs or WPANs exclusively.

The integration of some of the techniques into the IEE 802 standards that exist for WLANs and WPANs was presented, and a brief overview of how these techniques are used has been given. The 802.11 PSM has been shown to reduce the power consumed by nodes within a WLAN. In practice, however, the PSM feature provided by this standard is not used, as consumers prefer to have higher throughput rather than longer battery life on their wireless devices. Bluetooth devices on the other hand benefit greatly from the power saving features they provide, and have thus become very widely used over the past few years. Although the industry standard known as "Zigbee" has been developed to work on top of 802.15.4 enabled WSNs, research continues in this area due to the stringent power requirements that these types of networks impose.

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It has been shown that the current research being conducted for power management in wireless networks has been focused developing better topology maintenance protocols, sleep scheduling protocols, and energy harvesting techniques. While each of these techniques provides power savings on their own, they can all be combined to achieve better performance than any one of them individually.

Products are just now being manufactured that exploit the use of these types of techniques. Bluetooth devices have achieved the most success in industry, with devices designed for WSNs following close behind. Power aware devices for WLANs have not achieved as much success because of the need for very high throughput in these types of networks. No one seems to want to save power if it means sacrificing performance.

The quest for the everlasting battery source has not yet produced any results. As long as there is the need to continue driving down the amount of energy consumed by a wireless device, more and more research will continue to be done in this field, more and more standards will continue to emerge, and more and more products will continue to be manufactured.

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List of Acronyms

ARQ: Automatic Repeat reQuest

BAMAC: Battery Aware Medium Access Control

FEC: Forward Error Correction

GPS: Global Positioning System

LPL: Low Power Listening

LR-WPAN: Low Rate Wireless Personal Area Network

MAC: Medium Access Control

PAMAS: Power Aware Multi-Access Signaling

PSM: Power Save Mode

RAS: Remote Access Switch

TCP: Transmission Control Protocol

WiFi: Wireless Fidelity

WLAN: Wireless Local Area Network

WMAN: Wireless Metropolitan Area Network

WPAN: Wireless Personal Area Network

WSN: Wireless Sensor Network

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Appendix 2

New Zealand to trial world-first commercial long-range, wireless power transmission.

Emrod's wireless power transmission devices can beam large amounts of electrical power between two points, with line of sight between relays the only limit on distance.

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A New Zealand-based startup has developed a method of safely and wirelessly transmitting electric power across long distances without the use of copper wire, and is working on implementing it with the country's second-largest power distributor.

The dream of wireless power transmission is far from new; everyone's favorite electrical genius Nikola Tesla once proved he could power light bulbs from more than two miles away with a 140-foot Tesla coil in the 1890s – never mind that in doing so he burned out the dynamo at the local powerplant and plunged the entire town of Colorado Springs into blackout.

Tesla's dream was to place enormous towers all over the world that could transmit power wirelessly to any point on the globe, powering homes, businesses, industries and even giant electric ships on the ocean. Investor J.P. Morgan famously killed the idea with a single question: "where can I put the meter?"

It has taken 120 years, but New Zealand company Emrod appears to have finally convinced a major power distributor to have a crack at going wireless in a commercial capacity. Powerco, the second-biggest distributor in New Zealand, is investing in Emrod, whose technology appears to be able to shift large amounts of electricity much more efficiently, between any two points that can be joined with line-of-sight relays.

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"We're interested to see whether Emrod's technology can complement the established ways we deliver power," said Powerco's Network Transformation Manager Nicolas Vessiot. "We envisage using this to deliver electricity in remote places, or across areas with challenging terrain. There's also potential to use it to keep the lights on for our customers when we're doing maintenance on our existing infrastructure."

Emrod currently has a working prototype of its device, but will build another for Powerco, with plans to deliver by October, then spend several months in lab testing before moving to a field trial. The prototype device will be capable of delivering "only a few kilowatts" of power, but can easily be scaled up. "We can use the exact same technology to transmit 100 times more power over much longer distances," said Emrod founder and serial entrepreneur Greg Kushnir. "Wireless systems using Emrod technology can transmit any amount of power current wired solutions transmit."

The system uses a transmitting antenna, a series of relays and a receiving rectenna (a rectifying antenna capable of converting microwave energy into electricity). Each of these components appear in these images to simply look like big ol' squares on poles. Its beams use the non-ionizing Industrial, Scientific and Medical band of the radio spectrum, including frequencies commonly used in Wi-Fi and Bluetooth.

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Unlike Tesla's globally-accessible free power dream, the power here is beamed directly between specific points, with no radiation around the beam, and a "low power laser safety curtain" immediately shuts down power transmission before any object, like a bird, drone, power thief or helicopter, can touch the main beam. There will be no difficulties this time working out where to place the meter.

Emrod says it works in any atmospheric conditions, including rain, fog and dust, and the distance of transmission is limited only by line of sight between each relay, giving it the potential to transmit power thousands of kilometers, at a fraction of the infrastructure costs, maintenance costs and environmental impact a wired solution imposes.

Indeed, Emrod sees wireless transmission as a key enabling technology for renewable power, which is often generated far from where it's needed. This kind of system could be terrific for getting the products of offshore and remote renewable energy generation into the city grids without the need for giant storage batteries and the like.

Crude render of a temporary power transmission truck Emrod

It'll also be handy in certain unplanned outage events; a truck can be fitted out with a rectenna, and then driven anywhere in visual range of a relay to create a temporary wireless power connection.

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The company has been liaising with the Radio Spectrum Management authorities in New Zealand throughout its development process, with a view to meeting every safety standard even once the technology scales right up to high power levels, a process Kushnir says has also helped Emrod develop guidelines for the companies that will be using the technology.

We've contacted Emrod to ask more about efficiency, the size, shape and state of the current prototype, future plans and what indeed would happen if you stuck your hand in the middle of the beam, and will bring you more information when we can.

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