Wireless Power Transmission

A Major Project (Planning & Literature Survey)

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Introduction

Wireless power transfer (**WPT**), wireless energy transmission, or electromagnetic power transfer is the transmission of electrical energy from a power source to an electrical load, such as an electrical power grid or a consuming device, without the use of discrete human-made conductors. Wireless power is a generic term that refers to a number of different power transmission technologies that use time-varying electric, magnetic, or electromagnetic fields. In wireless power transfer, a wireless transmitter connected to a power source conveys the field energy across an intervening space to one or more receivers, where it is converted back to an electrical current and then used. Wireless transmission is useful to power electrical devices in cases where interconnecting wires are inconvenient, hazardous, or are not possible.

Wireless power techniques mainly fall into two categories, non-radiative and radiative. In *near field* or *non-radiative* techniques, power is transferred 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 widely used wireless technology; its applications include electric toothbrush chargers, RFID tags, smartcards, and chargers for implantable medical devices like artificial cardiac pacemakers, and inductive powering or charging of electric vehicles like trains or buses. A current focus is to develop wireless systems to charge mobile and handheld computing devices such as cell-phones, digital music players and portable computers without being tethered to a wall plug. In *far-field* or *radiative* techniques, also called *power beaming*, power is transferred by beams of electromagnetic radiation, like microwaves or laser beams. These techniques can transport energy longer distances but must be aimed at the receiver. Proposed applications for this type are solar power satellites, and wireless powered drone aircraft.

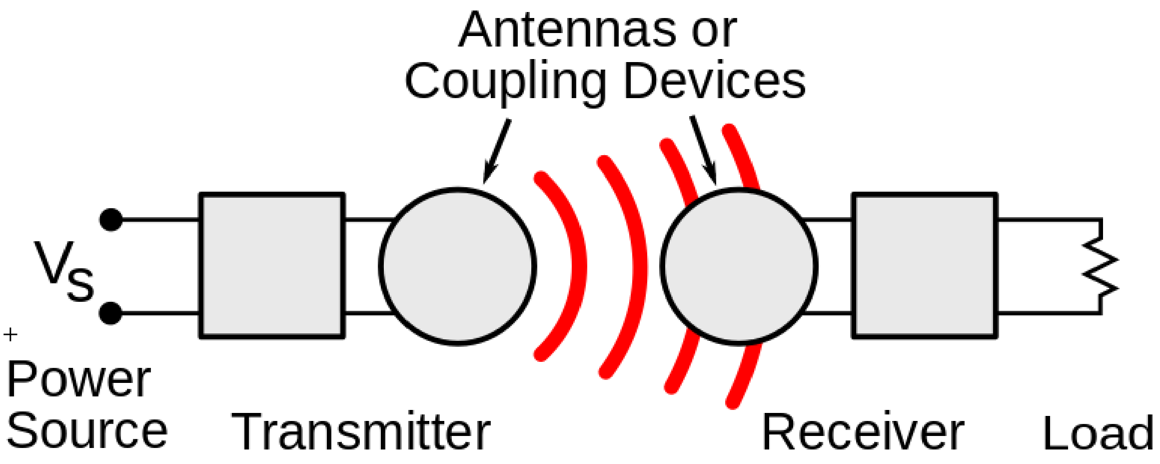
Japan and China both have national ambitions to begin on-orbit testing of solar power satellites by the 2030s which may accelerate both technical and regulatory progress.

An important issue associated with all wireless power systems is limiting the exposure of people and other living things to potentially injurious electromagnetic fields (*see* Electromagnetic radiation and health).

"Wireless power transfer" is a collective term that refers to a number of different technologies for transmitting energy by means of electromagnetic fields. The technologies, listed in the table 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, or infrared or visible light waves.

In general a wireless power system consists of a "transmitter" 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" devices which receive the power and convert it back to DC or AC electric current which 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 generates an electric field, an antenna which 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 f in hertz of the oscillations. The frequency determines the wavelength $\lambda = c/f$ of the waves which carry the energy across the gap, where c is the velocity of light.

Wireless power uses the same fields and waves as wireless communication devices like radio, another familiar technology that involves electrical energy transmitted without wires by electromagnetic fields, used in cell-phones, radio and television broadcasting, and Wi-Fi. In radio communication the goal is the transmission of information, so the amount of power reaching the receiver is not so important, as long as it is sufficient so the signal to noise ratio is high enough that the information can be received intelligibly. In wireless communication technologies, generally, only tiny amounts of power reach the receiver. In contrast, with wireless power the amount 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.



These are the different wireless power technologies:

Technology	Range	Directivity	Frequency	Antenna devices	Current and/or possible future applications
Inductive coupling	Short	Low	Hz – MHz	Wire coils	Electric tooth brush and razor battery charging, induction stovetops and industrial heaters.
Resonant inductive coupling	Mid-	Low	kHz – GHz	Tuned wire coils, lumped element resonators	Charging portable devices (Qi), biomedical implants, electric vehicles, powering busses, trains, MAGLEV, RFID, smartcards.
Capacitive coupling	Short	Low	kHz – MHz	Metal plate electrodes	Charging portable devices, power routing in large-scale integrated circuits, Smartcards.
Magneto-dynamic coupling	Short	N.A.	Hz	Rotating magnets	Charging electric vehicles, busses, biomedical implants.
Microwaves	Long	High	GHz	Parabolic dishes, phased arrays, rectennas	Solar power satellite, powering drone aircraft.
Light waves	Long	High	≥THz	Lasers, photocells, lenses	Powering drone aircraft, powering space elevator climbers.

Need of This Project

Losses in transmission through wires

In India, average T & D (Transmission & Distribution) losses, have been officially indicated as 23 percent of the electricity generated. However, as per sample studies carried out by independent agencies including TERI, these losses have been estimated to be as high as 50 percent in some states. In a recent study carried out by SBI Capital Markets for DVB, the T&D losses have been estimated as 58%. This is contrary to claims by DVB that their transmission and distribution losses are between 40 and 50 percent. With the setting up of State Regulatory Commissions in the country, accurate estimation of T&D Losses has gained importance as the level of losses directly affects the sales and power purchase requirements and hence has a bearing on the determination of electricity tariff of a utility by the commission.

Energy losses occur in the process of supplying electricity to consumers due to technical and commercial losses. The technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub- transmission and distribution of power. These technical losses are inherent in a system and can be reduced to an optimum level. The losses can be further sub grouped depending upon the stage of power transformation & transmission system as Transmission Losses (400kV/220kV/132kV/66kV), as Sub transmission losses (33kV /11kV) and Distribution losses (11kV/0.4kv). The commercial losses are caused by pilferage, defective meters, and errors in meter reading and in estimating unmetered supply of energy.

Experience in many parts of the world demonstrates that it is possible to reduce the losses in a reasonably short period of time and that such investments have a high internal rate of return. A clear understanding on the magnitude of technical and commercial losses is the first step in the direction of reducing T&D losses. This can be achieved by putting in place a system for accurate energy accounting. This system is essentially a tool for energy management and helps in breaking down the total energy consumption into all its components. It aims at accounting for energy generated and its consumption by various categories of consumers, as well as, for energy required for meeting technical requirement of system elements. It also helps the utility in bringing accountability and efficiency in its working.

Transmitting electricity at high voltage reduces the fraction of energy lost to resistance, which varies depending on the specific conductors, the current flowing, and the length of the transmission line. For example, a 100-mile (160 km) 765 kV line carrying 1000 MW of power can have losses of 1.1% to 0.5%. A 345 kV line carrying the same load across the same distance has losses of 4.2%.[17] For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductor. For example, raising the voltage by a factor of 10 reduces the current by a corresponding factor of 10 and therefore the I^2R losses by a factor of 100, provided the same sized conductors are used in both cases. Even if the conductor size (cross-sectional area) is reduced 10-fold to match the lower current, the I^2R losses are still reduced 10-fold. Long-distance transmission is typically done with overhead lines at voltages of 115 to 1,200 kV. At extremely high voltages, more than 2,000 kV exists between conductor and ground, corona discharge losses are so large that they can offset the lower resistive losses in the line conductors. Measures to reduce corona losses include conductors having larger diameters; often hollow to save weight,[18] or bundles of two or more conductors.

Factors that affect the resistance, and thus loss, of conductors used in transmission and distribution lines include temperature, spiralling, and the skin effect. The resistance of a conductor increases with its temperature. Temperature changes in electric power lines can have a significant effect on power losses in the line. Spiralling, which refers to the increase in conductor resistance due to the way stranded conductors spiral about the centre, also contributes to increases in conductor resistance. The skin effect causes the effective resistance of a conductor to increase at higher alternating current frequencies.

Transmission and distribution losses in the USA were estimated at 6.6% in 1997[19] and 6.5% in 2007.[19] In general, losses are estimated from the discrepancy between power produced (as reported by power plants) and power sold to the end customers; the difference between what is produced and what is consumed constitute transmission and distribution losses, assuming no utility theft occurs.

As of 1980, the longest cost-effective distance for direct-current transmission was determined to be 7,000 km (4,300 mi). For alternating current it was 4,000 km (2,500 mi), though all transmission lines in use today are substantially shorter than this.[15]

In any alternating current transmission line, the inductance and capacitance of the conductors can be significant. Currents that flow solely in 'reaction' to these properties of the circuit, (which together with the resistance define the impedance) constitute reactive power flow, which transmits no 'real' power to the load. These reactive currents, however, are very real and cause extra heating losses in the transmission circuit. The ratio of 'real' power (transmitted to the load) to 'apparent' power (sum of 'real' and 'reactive') is the power factor. As reactive current increases, the reactive power increases and the power factor decreases. For transmission systems with low power factor, losses are higher than for systems with high power factor. Utilities add capacitor banks, reactors and other components (such as phase-shifting transformers; static VAR compensators; and flexible AC transmission systems, FACTS) throughout the system to compensate for the reactive power flow and reduce the losses in power transmission and stabilize system voltages. These measures are collectively called 'reactive support'.

Therefore, the future with wireless power transmission is a more efficient future with power being transmitted wirelessly without the transmission loses mentioned above. Also a less use of wires will result in reduced cost of transmission and also the space and volume required by these wires will be reduced to zero.

Literature Review

Field regions

Electric and magnetic fields are created by charged particles in matter such as electrons. A stationary charge creates an electrostatic field in the space around it. A steady current of charges (direct current, DC) creates a static magnetic field around it. The above fields contain energy, but cannot carry power because they are static. However, time-varying fields can carry power. Accelerating electric charges, such as are found in an alternating current (AC) of electrons in a wire, create time-varying electric and magnetic fields in the space around them. These fields can exert oscillating forces on the electrons in a receiving "antenna", causing them to move back and forth. These represent alternating current which can be used to power a load.

The oscillating electric and magnetic fields surrounding moving electric charges in an antenna device can be divided into two regions, depending on distance D_{range} from the antenna. The boundary between the regions is somewhat vaguely defined. The fields have different characteristics in these regions, and different technologies are used for transferring power:

- ***Near-field*** or ***nonradiative*** **region** – This means the area within about 1 wavelength (λ) of the antenna. In this region the oscillating electric and magnetic fields are separate and power can be transferred via electric fields by capacitive coupling (electrostatic induction) between metal electrodes, or via magnetic fields by inductive coupling (electromagnetic induction) between coils of wire. These fields are not *radiative*, meaning 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.

Resonance, such as resonant inductive coupling, can increase the coupling between the antennas greatly, allowing efficient transmission at somewhat 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.
- ***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, $D_{ant} << \lambda$, very little power is radiated. Therefore, the near-field devices above, which use lower frequencies, radiate almost none of their energy as electromagnetic radiation.

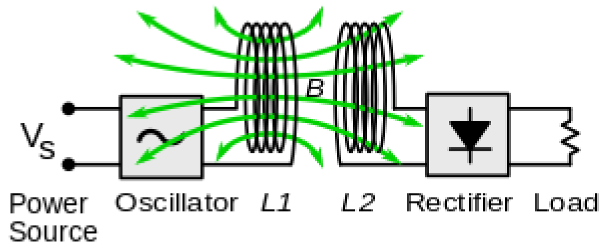
> Antennas about the same size as the wavelength $D_{ant} \approx \lambda$ such as monopole or dipole antennas, radiate power efficiently, but the electromagnetic waves are radiated in all directions (omnidirectionally), so if the receiving antenna is far away, only a small amount of the radiation will hit it. Therefore, these can be used for short range, inefficient power transmission but not for long range transmission.

However, unlike fields, electromagnetic radiation can be focused by reflection or refraction into beams. By 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: $D_{ant} >> \lambda = c/f$. Practical *beam power* devices require wavelengths in the centimetre region or below, corresponding to frequencies above 1 GHz, in the microwave range or above.

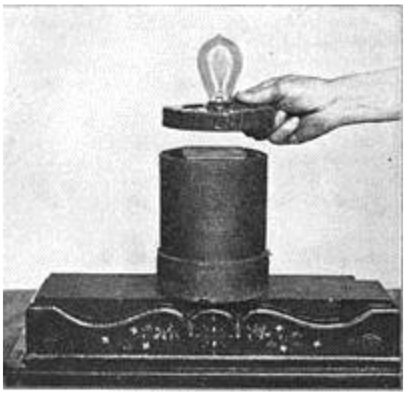
Near-field (nonradiative) techniques

At large relative distance, the near-field components of electric and magnetic fields are approximately quasi-static oscillating dipole fields. These fields decrease with the cube of distance: $(D_{range}/D_{ant})^{-3}$ Since power is proportional to the square of the field strength, the power transferred decreases as $(D_{range}/D_{ant})^{-6}$ or 60 dB per decade. In other words, if far apart, doubling the distance between the two antennas causes the power received to decrease by a factor of $2^6 = 64$. As a result, inductive and capacitive coupling can only be used for short-range power transfer, within a few times the diameter of the antenna device D_{ant}. Unlike in a radiative system where the maximum radiation occurs when the dipole antennas are oriented transverse to the direction of propagation, with dipole fields the maximum coupling occurs when the dipoles are oriented longitudinally.

Inductive coupling



Generic block diagram of an inductive wireless power system.



In inductive coupling (electromagnetic induction or *inductive power transfer*, IPT), power is transferred between coils of wire by a magnetic field. The transmitter and receiver coils together form a transformer *(see diagram)*. An alternating current (AC) through the transmitter coil *(L1)* creates an oscillating magnetic field *(B)* by Ampere's law. The magnetic field passes through the receiving coil *(L2)*, where it induces an alternating EMF (voltage) by Faraday's law of induction, which creates an AC current in the receiver. The induced alternating current may either drive the load directly, or be rectified to direct current (DC) by a rectifier in the receiver, which drives the load. A few systems, such as electric toothbrush charging stands, work at 50/60 Hz so AC mains current is applied directly to the transmitter coil, but in most systems an electronic oscillator generates a higher frequency AC current which drives the coil, because transmission efficiency improves with frequency.

Inductive coupling is the oldest and most widely used wireless power technology, and virtually the only one so far which is used in commercial products. It is used in inductive charging stands for cordless appliances used in wet environments such as electric toothbrushes and shavers, to reduce the risk of electric shock. Another application area is "transcutaneous" recharging of biomedical prosthetic devices implanted in the human body, such as cardiac pacemakers and insulin pumps, to avoid having wires passing through the skin. It is also used to charge electric vehicles such as cars and to either charge or power transit vehicles like buses and trains.

However the fastest growing use is wireless charging pads to recharge mobile and handheld wireless devices such as laptop and tablet computers, cell-phones, digital media players, and video game controllers.

The power transferred increases with frequency and the mutual inductance $\boldsymbol{M}$ between the coils, which depends on their geometry and the distance $\boldsymbol{D}_{\mathbf{range}}$ between them. A widely used figure of merit is the coupling coefficient. This dimensionless parameter is equal to the fraction of magnetic flux through ***L1*** that passes through ***L2***. If the two coils are on the same axis and close together so all the magnetic flux from ***L1*** passes through ***L2***, $\boldsymbol{k} = 1$ and the link efficiency approaches 100%. The greater the separation between the coils, the more of the magnetic field from the first coil misses the second, and the lower $\boldsymbol{k}$ and the link efficiency are, approaching zero at large separations. The link efficiency and power transferred is roughly proportional to $\boldsymbol{k}^2$. In order to achieve high efficiency, the coils must be very close together, a fraction of the coil diameter $\boldsymbol{D}_{\mathbf{ant}}$, usually within centimetres, with the coils' axes aligned. Wide, flat coil shapes are usually used, to increase coupling. Ferrite "flux confinement" cores can confine the magnetic fields, improving coupling and reducing interference to nearby electronics, but they are heavy and bulky so small wireless devices often use air-core coils.

Ordinary inductive coupling can only achieve high efficiency when the coils are very close together, usually adjacent. In most modern inductive systems resonant inductive coupling *(described below)* is used, in which the efficiency is increased by using resonant circuits. This can achieve high efficiencies at greater distances than non-resonant inductive coupling.

Resonant inductive coupling

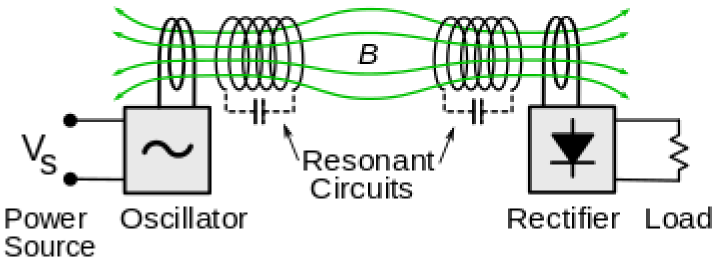


Diagram of the resonant inductive wireless power system demonstrated by Marin Soljačić's MIT team in 2007. The resonant circuits were coils of copper wire which resonated with their internal capacitance (dotted capacitors) at 10 MHz. Power was coupled into the transmitter resonator, and out of the receiver resonator into the rectifier, by small coils which also served for impedance matching.

Resonant inductive coupling (*electrodynamic coupling, strongly coupled magnetic resonance*) is a form of inductive coupling in which power is transferred by magnetic fields *(B, green)* between two resonant circuits (tuned circuits), one in the transmitter and one in the receiver *(see diagram, right)*. Each resonant circuit consists of a coil of wire connected to a capacitor, or a self-resonant coil or other resonator with internal capacitance. The two are tuned to resonate at the same resonant frequency. The resonance between the coils can greatly increase coupling and power transfer, analogously to the way a vibrating tuning fork can induce sympathetic vibration in a distant fork tuned to the same pitch. Nikola Tesla first discovered resonant coupling during his pioneering experiments in wireless power transfer around the turn of the 20th century, but the possibilities of using resonant coupling to increase transmission range has only recently been explored. In 2007 a team led by Marin Soljačić at MIT used two coupled tuned circuits each made of a 25 cm self-resonant coil of wire at 10 MHz to achieve the transmission of 60 W of power over a distance of 2 meters (6.6 ft.) (8 times the coil diameter) at around 40% efficiency.

The concept behind resonant inductive coupling is that high Q factor resonators exchange energy at a much higher rate than they lose energy due to internal damping. Therefore, by using resonance, the same amount of power can be transferred at greater distances, using the much weaker magnetic fields out in the peripheral regions ("tails") of the near fields (these are sometimes called evanescent fields). Resonant inductive coupling can achieve high efficiency at ranges of 4 to 10 times the coil diameter ($\boldsymbol{D}_{\mathbf{ant}}$. This is called "mid-range" transfer, in contrast to the "short range" of non-resonant inductive transfer, which can achieve similar efficiencies only when the coils are adjacent. Another advantage is that resonant circuits interact with each other so much more strongly than they do with non-resonant objects that power losses due to absorption in stray nearby objects are negligible. A drawback of resonant coupling is that at close ranges when the two resonant circuits are tightly coupled, the resonant frequency of the system is no longer constant but "splits" into two resonant peaks, so the maximum power transfer no longer occurs at the original resonant frequency and the oscillator frequency must be tuned to the new resonance peak.

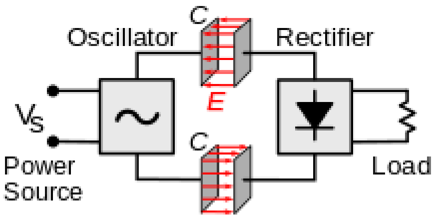
Resonant technology is currently being widely incorporated in modern inductive wireless power systems. One of the possibilities envisioned for this technology is area wireless power coverage. A coil in the wall or ceiling of a room might be able to wirelessly power lights and mobile devices anywhere in the room, with reasonable efficiency. An environmental and economic benefit of wirelessly powering small devices such as clocks, radios, music players and remote controls is that it could drastically reduce the 6 billion batteries disposed of each year, a large source of toxic waste and groundwater contamination.

Capacitive coupling

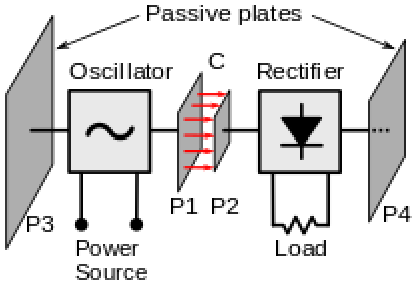
In capacitive coupling (electrostatic induction), the conjugate of inductive coupling, energy is transmitted by electric fields[5] between electrodes such as metal plates. The transmitter and receiver electrodes form a capacitor, with the intervening space as the dielectric. An alternating voltage generated by the transmitter is applied to the transmitting plate, and the oscillating electric field induces an alternating potential on the receiver plate by electrostatic induction, which causes an alternating current to flow in the load circuit. The amount of power transferred increases with the frequency the square of the voltage, and the capacitance between the plates, which is proportional to the area of the smaller plate and (for short distances) inversely proportional to the separation.

Capacitive coupling has only been used practically in a few low power applications, because the very high voltages on the electrodes required to transmit significant power can be hazardous, and can cause unpleasant side effects such as noxious ozone production. In addition, in contrast to magnetic fields, electric fields interact strongly with most materials, including the human body, due to dielectric polarization. Intervening materials between or near the electrodes can absorb the energy, in the case of humans possibly causing excessive electromagnetic field exposure. However capacitive coupling has a few advantages over inductive coupling. The field is largely confined between the capacitor plates, reducing interference, which in inductive coupling requires heavy ferrite "flux confinement" cores. Also, alignment requirements between the transmitter and receiver are less critical. Capacitive coupling has recently been applied to charging battery powered portable devices. and is being considered as a means of transferring power between substrate layers in integrated circuits.

Capacitive wireless power systems



transverse or bipolar coupling



longitudinal or unipolar coupling

Two types of circuit have been used:

- **Bipolar** design: In this type of circuit, there are two transmitter plates and two receiver plates. Each transmitter plate is coupled to a receiver plate. The transmitter oscillator drives the transmitter plates in opposite phase (180° phase difference) by a high alternating voltage, and the load is connected between the two receiver plates. The alternating electric fields induce opposite phase alternating potentials in the receiver plates, and this "push-pull" action causes current to flow back and forth between the plates through the load. A disadvantage of this configuration for wireless charging is that the two plates in the receiving device must be aligned face to face with the charger plates for the device to work.

- **Unipolar** design: In this type of circuit, the transmitter and receiver have only one active electrode, and either the ground or a large passive electrode serves as the return path for the current. The transmitter oscillator is connected between an active and a passive electrode. The load is also connected between an active and a passive electrode. The electric field produced by the transmitter induces alternating charge displacement in the load dipole through electrostatic induction.

Resonant capacitive coupling

Resonance can also be used with capacitive coupling to extend the range. At the turn of the 20th century, Nikola Tesla did the first experiments with both resonant inductive and capacitive coupling.

Magneto-dynamic coupling

In this method, power is transmitted between two rotating armatures, one in the transmitter and one in the receiver, which rotate synchronously, coupled together by a magnetic field generated by permanent magnets on the armatures. The transmitter armature is turned either by or as the rotor of an electric motor, and its magnetic field exerts torque on the receiver armature, turning it. The magnetic field acts like a mechanical coupling between the armatures. The receiver armature produces power to drive the load, either by turning a separate electric generator or by using the receiver armature itself as the rotor in a generator.

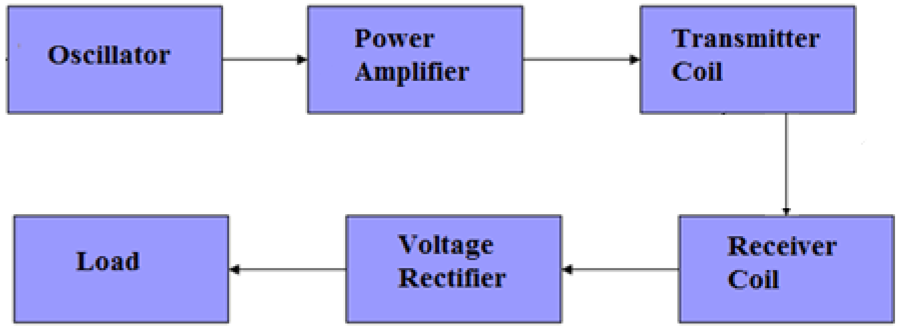
This device has been proposed as an alternative to inductive power transfer for noncontact charging of electric vehicles. A rotating armature embedded in a garage floor or curb would turn a receiver armature in the underside of the vehicle to charge its batteries. It is claimed that this technique can transfer power over distances of 10 to 15 cm (4 to 6 inches) with high efficiency, over 90%. Also, the low frequency stray magnetic fields produced by the rotating magnets produce less electromagnetic interference to nearby electronic devices than the high frequency magnetic fields produced by inductive coupling systems. A prototype system charging electric vehicles has been in operation at University of British Columbia since 2012. Other researchers, however, claim that the two energy conversions (electrical to mechanical to electrical again) make the system less efficient than electrical systems like inductive coupling.

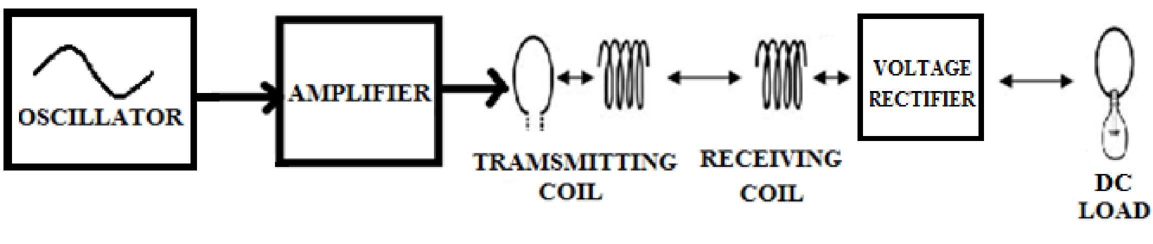
Planning and Methodology

Our primary goal was to be able to wirelessly transfer power (in watts) of an AC oscillating waveform into a DC voltage on the receiving end, which could be used to power an electrical load (in watts) to demonstrate instantaneous power transfer. To do this, we intended to design a tuneable oscillator capable of generating frequency in the RF band (1MHZ – 20 MHz) and a power amplifier to supply enough power to be transmitted for powering the electrical load. In addition to this, we also intended to demonstrate the evanescent waves by the illustration of an exponential relationship of power transmitted to the receiver as a function of distance of separation between the receiver and transmitter coils.

System Design

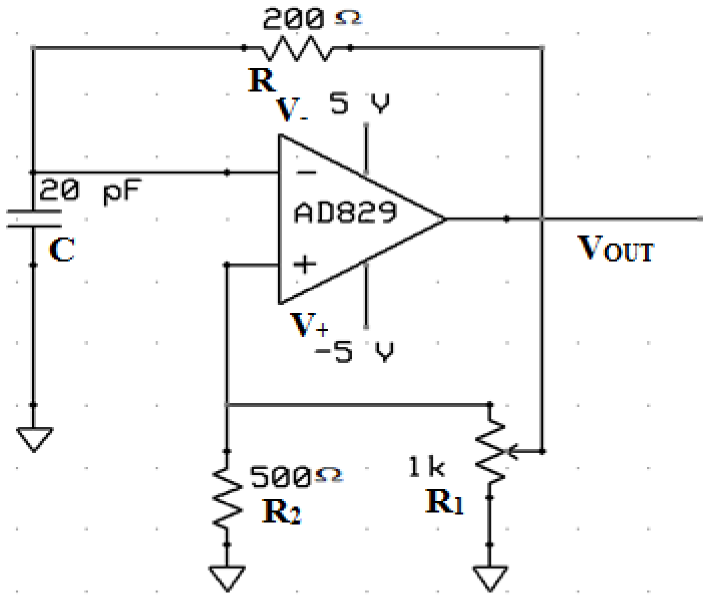
With all the necessary background research completed it became clear what basic design components the entire system would require. First, we needed a method to design an oscillator, which would provide the carrier signal with which to transmit the power. Oscillators are not generally designed to deliver power; thus, it was necessary to create a power amplifier to amplify the oscillating signal. The power amplifier would then transfer the output power to the transmission coil. Next, a receiver coil would be constructed to receive the transmitted power. However, the received power would have an alternating current, which is undesirable for powering a DC load. Thus, a rectifier would be needed to rectify the AC voltage to output a clean DC voltage. Finally, an electric load would be added to complete the circuit design





Oscillator

There are two general classes of oscillators: sinusoidal and relaxation. Op-Amp sinusoidal oscillators operate with some combination of positive and negative feedback to drive the op-amp into an unstable state, causing the output to transition back and forth at a continuous rate. Relaxation Op-Amp oscillators operate with a capacitor, a resistor or a current source to charge/discharge the capacitor, and a threshold device to induce oscillation. The oscillator design that we utilized was a relaxation oscillator using a single Operational amplifier. This oscillator was a Square Wave Generator and could be classified in the category as an astable multivibrator.



Working Principle:

Initially, the non-inverting input at the Op-Amp is biased at a voltage of VOUT * R2 / (R2 + R1) and the op-amp's output is saturated at that particular voltage level. Since the op-amp always attempts to keep both its inverting and the non-inverting inputs, V+ and V- equal to each other, the feedback causes the 20pFcapacitor to charge and make the value of V- equal to V+. When V- reaches the value of V+, a switch to negative saturation at the output occurs and the capacitor begins to discharge. The charging and discharging of the oscillator effectively causes an oscillating signal to the output.

The general equation for charging a capacitor is given by:

$$q = CV (1 - e-t/RC) + q0e-t/RC$$

In this case, V is -VOUT, and if the voltage at V+ is called λVOUT, q0 becomes CVOUT. The charging equation then becomes

$$q = -CVOUT(1 - e-t/RC) + \lambda CVOUTe-t/RC$$

When q gets to -λVOUT, another switch will occur. This time it is half the period of the square wave. Therefore:

$$\lambda CVOUT = -CVOUT (1 - e-t/RC) + \lambda CVOUTe-t/RC$$

Solving for T gives:

$$T = 2RC * \ln\left[\frac{1+\lambda}{1-\lambda}\right] \quad \text{where} \quad \lambda = \frac{R_2}{R_2+R_1}$$

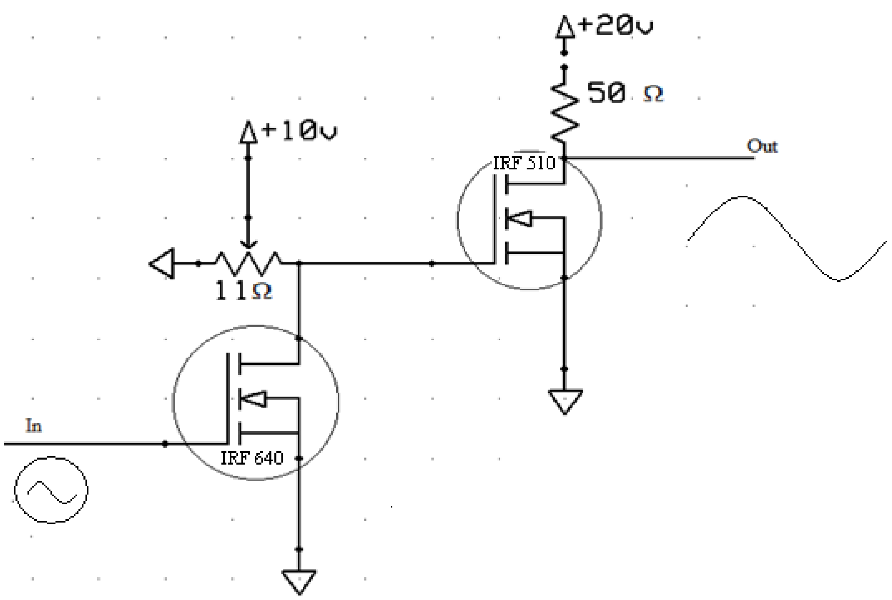
The frequency of oscillation can be determined by 1/T. In our case, the variable resistor R1 could be varied using a 1K pot which was able to tune the frequency from 1.6 MHz to 10.3 MHz.

Power Amplifier

In order to generate the maximum amount of flux which would induce the largest voltage on the receiving coil, a large amount of current must be transferred into the transmitting coil. The oscillator was not capable of supplying the necessary current, thus, the output signal from the oscillator was passed through a power amplifier to produce the necessary current. The key design aspect of the power amplifier was to generate enough current while producing a clean output signal without large harmonic distortions. For this purpose, we utilized a simple switch-mode amplifier design whose design aspects are described below.

Design:

The main idea behind the switch-mode Power Amplifier technology is to operate a MOSFET in saturation so that either voltage or current is switched on and off. The figure below shows the circuit diagram of the switch-mode power amplifier.



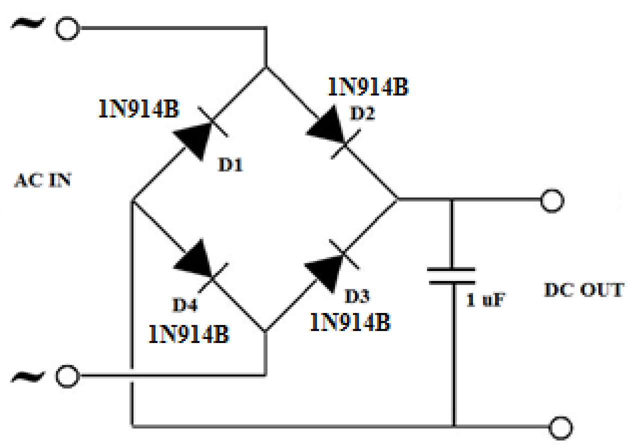
Our switch-mode design consisted of a MOSFET IRF 510, which when turned on allowed large current from the DC power supply to flow through the resistor of 50 Ohms and through the transmitting antenna to transfer current from the power supply through the transmitting coil. The large current from the transmitting coil was able to generate a large flux to induce a high voltage in the receiving coil. The current and voltage required to drive the gate of the MOSFET IRF 510 was supplied by the MOSFET IRF 640 whose gate was driven by the input signal from a Hewlett Packard signal generator. The maximum voltage when the coils were tuned at resonance was recorded to be around 102.3V.

Transmitter and Receiver Coils

The transmitter and receiver circuit combined is called the coupling circuit. It is the heart of the entire system as the actual wireless power transfer is carried out here. The efficiency of the coupling circuit determines the amount of power available for the receiver system.

Voltage Rectifier

A rectifier would be needed to rectify the AC voltage received from the receiver coil to drive a DC load. A type of circuit that produces an output waveform that generates an output voltage which is purely DC or has some specified DC component is a Full Wave Bridge Rectifier. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. The smoothing capacitor connected to the bridge circuit converts the full-wave rippled output of the rectifier into a smooth DC output voltage.



Since the diodes had to rectify AC signals of Megahertz frequencies, fast signal diodes,1N914B, had to be used for the bridge circuit. However, we did not implement this circuit with our final setup as we did not drive a DC load with our setup.

Future Scope

We live in a wireless world. Cell phones, Wi-Fi, Bluetooth, 2G, 3G, 4G — the always on, always connected world of digital devices is driven by the magic of wireless. But all our devices, from smart phones to laptops, still rely on cords and plugs for charging. Everyone's had their cell phone become useless for the day when the battery dies and there's nowhere to charge it. Battery life consistently shows up as a key factor in product ads, feature lists and reviews. As advanced and powerful as phones, tablets and laptops are, when that bar hits 0%, they're as good as worthless without an outlet (the same outlet everyone else in the cafe or the airport wants to use).
Imagine if all you had to do to charge your phone was set it down in the right place. That's the reality wireless power aims to achieve.

"Really, it's about having power everywhere you are, and not having to be limited by the amount of power you can carry with you in a battery or some other matter," explains Joshua Schwannecke, an engineering manager at Fulton Innovation. Fulton is a development and licensing company working on technologies that can improve people's lives — like wireless power. "The idea is that, any device that you have that requires any sort of power right now… should be able to be powered in all of the spaces that you are," explains Schwannecke.

Power is the final cord that needs to be cut for complete wireless freedom. Not only does the technology exist, it's already showing up in consumer technology.

Called magnetic induction, the technology allows power to be transferred without wires. You simply have to set your device — phone, laptop, tablet, or anything else with an embedded receiver — on a charging station, as the technology works best over short distances (the greater the distance the less efficient the transfer is, but there are companies experimenting with transmitting power over further distances, and the limits could change as the technology advances).
However, distance isn't much of an issue because power transmitters can be embedded in places phones and other devices are normally set down, like the tables at a cafe, desks at work, the bedside table at a hotel room, or even the furniture in your own home (which someone has already done with their nightstand). Schwannecke says they're working with furniture manufacturers to make this happen.

Charging stations and cases that work with current phones like the iPhone (the Duracell Powermat, for example) are already available, and eventually the receivers will be built-in to phones and other devices. The recently released Nexus 4 can be charged wirelessly, as well as the Nokia Lumia 920, and there's been speculation for years about wireless charging being built into an upcoming iPhone. Wireless power is already becoming commonplace in Japan. Stateside, Intel has demonstrated a laptop with a wireless charger built-in and the 2013 Dodge Dart is the first car to offer a wireless charging mat inside, and there are now other cars offering the same capability.

An important element of all this is compatibility — all devices and charging stations must interact seamlessly, or the concept would crumble. That's where the Wireless Power Consortium comes in. Dedicated to facilitating a standard for wireless power so that devices and chargers from different companies work together, the WPC has over 100 members, including Fulton Innovation and leading technology brands like HTC, LG, Motorola, Nokia, Panasonic, Philips, Samsung, Sony, Toshiba, and Verizon.

However, the WPC's Qi standard is not universally accepted; the much-talked about WiTricity Corporation has a competing, proprietary standard and many associated patents (WiTricity's technology is designed to work through the air, but the problem of decreased efficiency as the distance increases still exists). But the prospect of a future with less wires is exciting regardless of which standard takes us there.

To Menno Treffers, the WPC's Chairman, a big benefit of wireless power is that it removes a mental barrier to charging frequently — because all you have to do is set your phone down, and if you need to use it, all you have to do is pick it up again.

"So, the psychological barrier of using a plug is gone," he explains, "And that's a significant accomplishment in usability. It may seem trivial, but it makes a big difference because it makes it possible to constantly charge your phone, and top it off."

Bridging the Gaps

Treffers and Schwannecke both expect wireless power to eventually be as ubiquitous as Wi-Fi. Just as nearly every cafe now offers Wi-Fi for free, one day they might all offer wireless charging as well (although unlike Wi-Fi, costs do go up with usage, so cafes and other establishments will have to decide if they want to charge for power or offer it as a perk to lure customers). "We [will] see this appearing in almost everywhere you sit down for a while, so coffee shops, obviously, but also other retails, [like] restaurants, you sit down, you put your phone on the table, and it charges. Without you even thinking about it," says Treffers, "And that's what wireless charging is about."

The obvious application for the technology is with portable devices, but its potential goes far beyond that.

The technology could be used to charge electric vehicles, for example. Transmitters could be embedded in parking lots, or even at stop lights (or along the highway, but the distance would make the transfer less efficient). Charging a car takes a lot of power — but Fulton Innovation's eCoupled technology includes identification, which can be used to create a "secure communication link" to charge money for using power. So you might pull into a parking lot, pull out your smartphone, and buy a certain amount of electricity (cafes or airports could also sell power instead of providing it for free). Then there are medical applications, like charging medical implants wirelessly, which could greatly improve the quality of life of people who rely on medical technology, by avoiding the need for invasive cords.

And Schwannecke assures me it's safe, as he says the magnetic fields produced by the technology don't interact with the body, at least not at the levels present when charging consumer technology. Fulton Innovation is able to use research done for MRIs to ensure that unsafe limits are never exceeded, he explains, and the fields that are generated are "well below [levels] that have ever been shown to have any impact." The eCoupled technology also detects what the power is being transferred into. "We call that foreign object detection," explains Schwannecke, "So one of the things we're doing with wireless power is always looking to see if what's receiving the power [is] the intended receiver — so that's cell phone, laptop, electric vehicle — or is it some foreign object. And we can detect that very very quickly." Then the power supply can be cut off, or the user can be alerted.

As for how it works, the principle is actually simple — at least when Schwannecke explains it.
It's really a principle that's over a hundred years old, originally developed by Nikola Tesla, and what happens is that when you have a coil of wire that you run current through, it creates a magnetic field. So we create that magnetic field, and then we have another coil of wire in the receiver that turns that magnetic field back into an electric current. So that shared magnetic field that we call "induction," "magnetic induction," is taking the electricity from one side, converting it to something that's gonna be able to pass through air, plastic, water, and then converting it back into that usable electricity on the other side.

Which Comes First?

The biggest issue is the classic chicken and the egg dilemma, common to new technologies that require widespread adoption to reach their fullest potential. Wireless power is most appealing when charging stations are everywhere, and yet there's no incentive for businesses to install them until a significant number of people have compatible devices. Unfortunately, this will slow adoption of the technology, but it’s a problem that only time can overcome. “It’s a matter of getting it all organized,” says Treffers, “you have to play with creating infrastructure for charging, getting people to have chargers at home, and introducing it into products. That requires some coordination in the industry.” He doesn’t think it will be a significant problem, however, “because as a consumer you already have the benefits if you just buy the phone and a couple of chargers, for your house, for your office, and you’re already pretty good. And you really see the benefits already.”

Treffers again compares it to Wi-Fi, which took years to become commonplace. He expects wireless power will follow a similar path, and it’s still at the beginning. “Once the install base of phones is significant, and really integrated to phones, it becomes very attractive to offer it in locations where you sit down for a while. Because it will attract customers,” he says, giving the example of a Starbucks where everyone wants the seat by the outlet, which demonstrates that “there’s really a demand for this.”

So, is wireless power the next big thing in technology? A leap that’ll change the way we interact with the devices we use every single day?

“It has the potential to really change people’s lives,” says Treffers, “Because it takes away the anxiety of having an empty battery.”

“In my mind, it’s a big thing that enables a lot of other big things,” says Schwannecke, “Power shouldn’t be something we have to think about. Power should be something that’s just there. So, if you’ve got power for whatever you have, wherever you need it, and you don’t have to think about it anymore, I say that’s a pretty big thing.”

Conclusion

At the end of the research, we were able to design a system for transmitting watts of power wirelessly from the transmitting coil to the receiving coil that was enough to light a 40W bulb. We were able to design discrete components such as the relaxation oscillator, switch mode-power amplifier and a full bridge voltage rectifier for the system design process. We also managed to demonstrate evanescent waves by measuring exponential decay of voltage as an increase in distance between the transmitter and the receiver coils.

There can be significant research work that can be done in the future of this research. Future work includes connecting the relaxation oscillator with the power amplifier using current amplifier chip for providing enough current to drive the gate of the MOSFET to drive the efficient class D H-Bridge power amplifier. Also, reduction in the size of the transmitting and receiving coils and utilizing the regulated signal to power a DC load could be something that could be worked in the future as a means to make this system feasible for practical applications.

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