Wireless electricity : Dream of a wireless world

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Abstract— It is simply impossible to imagine the world without electricity. And all of us know that the transmission of electricity is being done with the help of wires. The aim of this paper is to introduce a new system of transmitting the power without wires which is called wireless electricity or witricity, a term coined by Dave Gerding in 2005. Imagine juicing up of your laptop, cellphone and other electronic gadgets without plugging them into an electrical socket finally freeing us from that ubiquitous power wire. Some of these devices might not even require their bulky batteries to operate. That's a luxury that could be provided by witricity, a concept that has been bandied for decades but is creeping closer to become viable. Witricity is based upon coupled resonant objects to transfer electrical energy between objects without wires. The system consists of a witricity transmitter(power source) and devices which act as receivers(electrical loads). Using self-resonant coils consisting of an inductor along with a capacitor with it's own resonant frequency, in a strongly coupled regime, efficient non-radiative power transfer over distances upto eight times the radius of the coils can be achieved. This paper originally describes the idea of transmitting power without wires using resonant inductive coupling and also the variation of efficiency of power transmission with the increase in number of receiver coils.

Index Terms— Efficiency variation , power , receiver , resonant inductive coupling , short distance , transmitter , transmission , wireless , witricity.

1 Introduction

When your phone or lapy beeps in hunger of battery , then most likely , many of us wonder isn't there a way to get rid of this 'charging problem'. In the present day-to–day life , the number of electronic devices we use is increasing abruptly , with each family member owning their electronic gadgets . Each of these devices have their own set of chargers, and the drawers are overflowing with all sorts of wires. Well , this is one of the drawbacks of electrical connections. Though it makes the life of people simpler , it can also cause a lot of wiry clutter in the process. So , in order to deal with these clumsy wires , scientist and researchers have been working on the methods to transmit electrical power without wires. Several techniques have been developed but still many of them exist merely as theories or prototypes. The latest technology trends proposed a way to cut the cords by wirelessly supplying power to devices. wireless power transmission is the process that takes place in any system where electrical energy is transmitted from a power source to an electrical load without interconnecting wires in an electrical grid. Wireless transmission is ideal in cases where instantaneous or continuous energy transfer is needed but interconnecting wires are inconvenient , hazardous or impossible.

The witricity is nothing but 'wireless electricity' and the basic concept behind this is magnetic resonance. Two resonant objects of same resonant frequency tend to exchange energy efficiently , while dissipating a little energy in extraneous off-resonant objects. In systems of coupled resonances , there is often a "strongly coupled" regime of operation. If one can operate in that regime in a given system, the energy transfer is expected to be very efficient. Mid-range power transfer implemented in this way can be nearly omni-directional and efficient irrespective of the geometry of the surrounding space with low interference and losses into environmental objects.

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2 History

The idea of wireless power transmission was first proposed by Nikola Tesla in early 1900's. He demonstrated "the transmission of electrical energy without wires" that depends upon electrical conductivity as early as 1891[1]. He was also able to illuminate the vaccum bulbs without using wires at the World Coulumbian Exposition in Chicago. He also designed and constructed "The Wardenclyffe tower" for wireless power transmission.[2]. Another scheme employed for wireless power transmission includes Microwave power transmission proposed by Brown in 1961[3]. Both Tesla's design and the later microwave power were forms of radiative power transfer. Radiative transfer used in wireless communication is not particularly suitable for power transmission due to it's low efficiency and radiative loss due to it's omni-directional nature.

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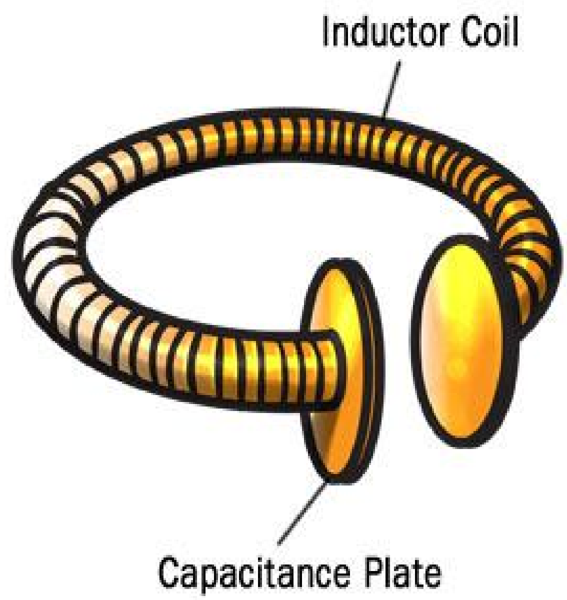
An alternative approach can be some near field interaction between the source and the device so that efficient power transfer was possible.The approach was Evanescent wave coupling. And this evanescent wave coupling method was employed by some Researchers at MIT who transferred power wirelessly to a light bulb placed over seven feet away.

3 RESONANCE AND WIRELESS POWER

In all the technologies based on infra-red , radio-waves , lasers , etc. , the signals are scattered into space before they are received by the corresponding devices. The same method can't be used for transmitting electricity as it is power consuming and dangerous. Also , efficiency is of critical importance here. A better way to transmit electrical power between coils can be obtained by adding resonance to the equation.

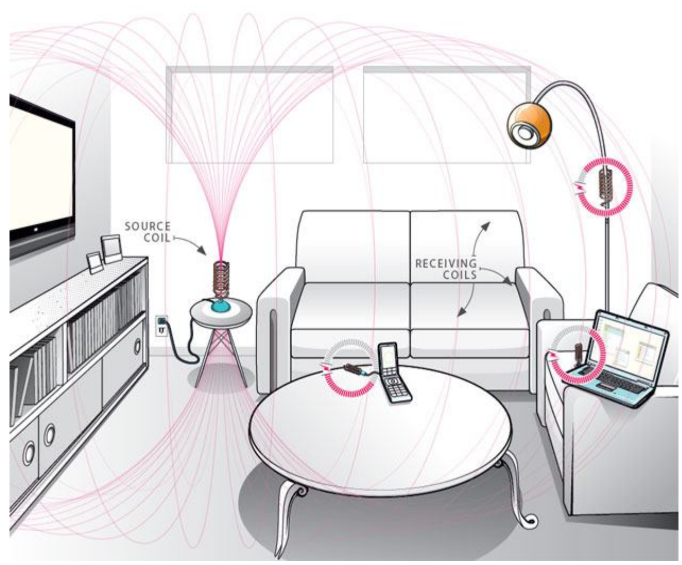
As resonance can be defined as the frequency of a device when it vibrates naturally. The resonance of a device depends greatly upon it's shape and size and the frequency is called resonant frequency. The vibration at resonant frequency can be easily obtained but vibration at other frequencies is difficult and the advantage of this theory was that the power that wasn't utilized remained in the vicinity of transmitter itself and did not radiate to the surrounding environment. Thus , when the magnetic fields have the resonation around the coils , the current will be induced in a different manner and it was proved by placing a curved wire coil as an inductor along with a capacitance plate at each end of the coil and This plate was responsible for holding the charge. When current is passed through the coils , it starts resonating.



The frequency of resonation can be calculated by using the equation given below:-

Resonant Frequency = Inductance of coil*Capacitance of plates. (1)

The transmission is also possible from one transmitter to multiple receivers if the former and the latter coils have the same resonant frequency.



4 EXPERIMENTAL DESIGN

Experimental scheme consists of two Self-resonant coils. One coil(source coil) is coupled inductively to an oscillating circuit; the other(device coil) is coupled inductively to a resistive load. Self-resonant coils rely on the interplay between distributed inductance & distributed capacitance to achieve resonace.

The coils are made of an electrically conducting wire of total length ‘l’ and cross-sectional radous ‘a’, wound into a helix of ‘n’ turns, radius ‘r’, and height ‘h’. There is no exact solution for a finite helix in literature, solutions rely on assumptions that are adequate for this system. So , here the method adopted is simple Quasi-static model to find the parameters. Those are in Electro-magnetic equations.

$$L = \frac{\mu_\circ}{4\pi|I_\circ|^2}\iint dr dr' \frac{J(r)\cdot J(r')}{|r-r'|} \quad (2)$$

$$\frac{1}{C} = \frac{1}{4\pi\varepsilon_\circ|q_\circ|^2}\iint dr dr' \frac{\rho(r)\cdot\rho(r')}{|r-r'|} \quad (3)$$

5 Range and Rate of Coupling

The range and rate of the proposed wireless energy-transfer scheme are the first subjects of examination, without considering yet energy drainage from the system for use into work. An appropriate analytical framework for modeling this resonant energy-exchange is that of the well-known Coupled-Mode Theory(CMT). Here, the field of the system of two resonant objects 1 and 2 is approximated by **$F(r,t)=a_1(t)F_1(r)+a_2(t)F_2(r)$,** here $F_{1,2}(r)$ are the modes of 1 and 2 alone, and then the field amplitudes $a_1(t)$ and $a_2(t)$. The lower order representation of the system is given by:

$$\frac{da_1}{dt} = -i(\omega_1 - i\Gamma_1)a_1 + i\kappa a_2 \quad (4)$$

$$\frac{da_2}{dt} = -i(\omega_2 - i\Gamma_2)a_2 + i\kappa a_1 \quad (5)$$

Where ω1, 2 are the individual frequencies, Γ1, 2 are the Resonance widths (Decay rates) due to the objects‘ intrinsic (absorption, radiation etc.) losses, and **‗κ‘** is the coupling coefficient. The above equation show that at exact resonance (ω1=ω2 and Γ1=Γ2), the normal modes of the combined system are split by 2κ. The energy exchange between the two objects takes place in time Pi/κ and is nearly perfect, apart for losses, which are minimal when the coupling rate is much faster than all loss rates (κ>> Γ1, 2). It is exactly this ratio {κ /sqrt (Γ1, 2)} shows that, it will set as figure-of-merit for any system under consideration for wireless energy-transfer, along with the distance over which this ratio can be achieved. The desired optimal regime {κ/sqrt (Γ1,2)>>1} is called ―Strong-Coupling‖ regime. There is No change in Energy, up to κ/Γ>>1 is true. Consequently, this energy-transfer application requires resonant modes of High Quality factor, Q=ω/2Γ for low (slow) intrinsic-loss rates Γ, so we used here the non-lossy near field. Furthermore, strong (fast) coupling rate κ is required over distances larger than the characteristic sizes of the objects, and therefore, since the extent of the near-field into the air surrounding a finite-sized resonant object is set typically by the wavelength, this mid-range non-radiative coupling can only be achieved using resonant objects of Sub-wavelength size. Such sub-wavelength (λ/r) resonances can often be accompanied with a high radiation-Q, so this will typically be the appropriate choice for the possibly-mobile resonant device-object.[1]

6 Parameters for Designing and Simulation

The coupled mode theory plays a vital role in solving the lower order equations of the system. Using perturbation technique of
x(t)=A cos(ω 0t)+ B sin(ω 0t)
The solution of this equation is by including decay rate due to loss Γ0 is X(t)=C exp(-i ω 0t)exp(-t/ Γ0)
By considering all energy inputs and outputs we can conclude that at resonance condition decay loss by source and device is Γ= ω/2Q. The ratio κ/Γ is proportional to the Quality factor i.e. proportional to the power developed and inversely proportional to decay rate due to loss. so if κ/Γ is high the power output is high. The simulation process is going on in the above way such that to prove in strongly coupled mode at sub-wavelength (λ/r) resonances by considering the following process.

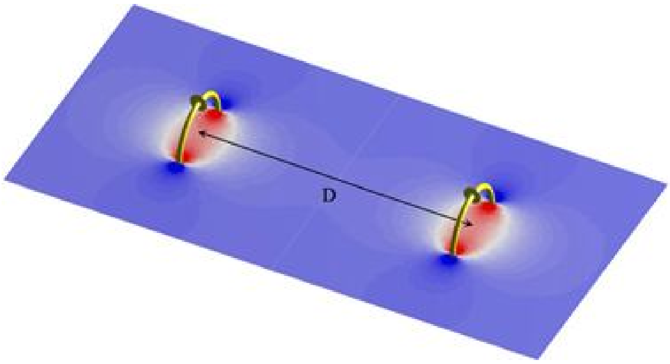
Consider two loops at distance D between their centers, radius r1 and r2 of conducting wire with circular cross-section of radius ‗a‘ and diameter ‗d‘.via a dielectric of relative permittivity ε and everything surrounded by air. To calculate the RLC parameters used the method called Finite-Element Frequency-Domain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

κ= ωM/2*sqrt(L1L2)
L=μ0r[ln(8r/a)]
C=ε0εa/D
η=sqrt(μ0/ ε0) where M is the mutual inductance of the two loops and it is dependent on r1, r2,D.
M={(Pi/2)* μ0* (r1r2)^2}/D^3
Rabs≈ {(Pi/6)η r/a}
Rrad≈{(Pi/6)η r/ λ }
Qabs≈ωL/ Rabs
Qrad≈ ωL/ Rrad

And taking copper wires so that it is having ε=10 other considerations in **COMSOL software** and **Acoustics Module Tool**, designed the system as

Resonant Magnetic Coupling :

Magnetic coupling occurs when two objects exchange energy through their varying or oscillating magnetic fields. Resonant coupling occurs when the natural frequencies of the two objects are approximately the same.

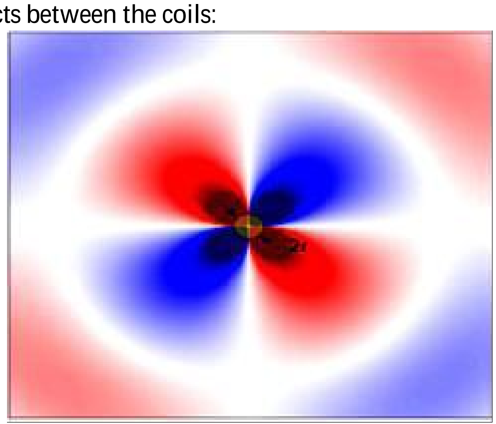


Energy Exchange

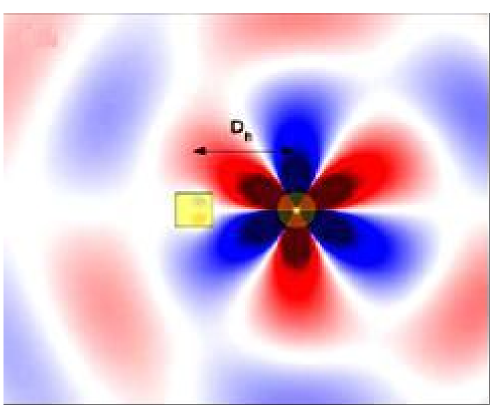
Two idealized resonant magnetic coils, shown in yellow. The blue and red color bands illustrate their magnetic fields. The coupling of their respective magnetic fields is indicated by the connection of the color bands.

Simulation performance:

The results and performance given with and without eternal objects between the coils:



Energy Exchange(with external object)



Energy Exchange(without external objects)

The parameters in the above simulation are designed with FEFD method & from the above two results , we conclude that there is no large variation in ratio with and without the external objects.

7 Efficiency Variation

In the original work, the researchers at MIT fed AC power into a resonating conductive coil, about 2 feet across, creating a magnetic field with a matching coil 7 feet away. The second coil captured energy from the first, converting it into enough power to light up an attached 60W bulb.

Now, if we set up a slightly larger sending coil and two receiving coils having half the size of the original i.e. 12 inches , then the efficiency changes considerably. Powering one device with one receiving coil results in less than 20% efficiency in power transfer. But with two receiving coils, the efficiency jumped to 30%. The probable reason behind this behavior lies in the fact that the two receiving coils, besides resonating with the sending coil, also resonate with each other. This additional resonance strengthens the magnetic field and increases the power transfer efficiency. Now, theoretically, adding still more devices should keep increasing the system's efficiency to 100% but still it is practically being researched.

8 Conclusion

At the end of the research , I could design and simulate a system for transmitting watts of power wirelessly from the transmitting coil to the receiving coil using COMSOL software & Acoustics Module Tool. I could also analyze the variation in energy exchange with and without external objects between the coils. Also , we could predict how the efficiency of energy exchange varies with the number of receiver coils and their size. There can be significant research work that can be done in the future of this research. The above analysis provides mid-range non-radiative energy transfer scheme based on strong coupled resonances. Even very simple designs have promising performance and provides better efficiency with respect to distance. A s a powerful approach , it could enable a wide range of applications. Witricity can be considered as the future technology which will rule the world of transmission of electrical power with all the electronic gadgets taking care of their charing requirement themselves , increased transmission efficiency and a much peaceful, safer and organized world.

9 Safety

Unlike the far field wireless power transmission systems based on travelling EM waves, witricity employs near field inductive coupling through magnetic fields which interact far more weakly with surrounding objects, including biological tissues of the body. Thus , the magnetic field we are using here is basically the same about the earth's magnetic field and of course , we even live in a magnetic field and so are not prone to cause any damage to any living being. Also , limits for human exposure to magnetic fields are set by regulatory bodies such as the FCC, ICNIRP, and are based on broad scientific and medical consensus. Witricity technology is being developed to be fully complaint with applicable regulations regarding magnetic fields and electromagnetic radiation.

10 Applications

- Researchers have outlined a relatively simple system that could deliver power to devices such as laptop, computers or MP3 players without wires.
- A UK company called Splashpower has also designed wireless recharging pads onto which gadget lovers can directly place their phones and MP3 players to recharge them. The pads use EMI to charge devices, the same process used to charge electric toothbrushes.
- Direct wireless power interconnections and automatic wireless charging for implantable medical devices (ventricular assist devices, pacemaker, etc.)
- Direct wireless powering and automatic wireless charging of consumer appliances, mobile robots etc.
- Witricity technology is designed to be directly embedded in the products and systems of Original Equipment Manufacturers(OEM's).

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