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INVESTIGATION OF OPTIMIZING EFFICIENCY ON ORIENTATION EFFECTS ON WIRELESS POWER TRANSFER

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Abstract

Several customers want to charge their schemes such as mobile or wearable schemes wirelessly. Wireless power transfer technology using resonant magnetic coupling creates it probable to charge a receiver is distance between the transmitters. Conversely, the receiver can take different orientations over that distance, and this causes problems, such as great shrinkage in power transfer efficiency in certain cases. To solve this problem, we develop a method to control the magnetic field direction of the receiver. The objective of this manuscript is to design a wireless power transfer to charge their smart phones by using resonant magnetic coupling and also increase the efficiency by controlling the direction of the magnetic field corresponding to the different orientations of the receiver.

Keywords:

Wireless Power Transfer, Resonant Magnetic Coupling, Power Transfer Efficiency, Orientation

1. INTRODUCTION

Wireless power transfer is a technique of transfer of electricity without using wires or connectors. It is mainly useful where transfer of electricity is not possible using conductors. It is gaining high attention in the upcoming technical era since they are widely employed in electronic portable devices like cell phones, laptops, smart watches, wearable (or) implanted medical device applications which has internal batteries for its functioning can be recharged anywhere without using cords [6]. This Wireless power can be transferred using various technology is like inductive coupling, capacitive coupling and resonant magnetic coupling. However, the present wireless power transfer technology often based on inductive and resonant magnetic coupling. Because other technologies like magnetic induction leads to narrow efficiency over tiny distances, the receiver devices are placed on, and cannot be removed from the transmitter flat even though cable connections are unnecessary [7]. The inductive charging is also known as wireless or Cordless charging uses an electromagnetic field to transfer power between the transmitter and receiver coil over an electromagnetic induction [8].

Induction charges use an induction coil to create an alternating electromagnetic field from within a charging base, and a receiver coil in portable device takes power from the electromagnetic field and converts it back into the electric current to charge the battery. The distance between the transmitter and receiver coil can be achieved high when the inductive charging system uses resonant inductive coupling [11] [12]. Both the transmitter coil and receiver coil must resonate at the same frequency. Conversely, in cases where the transmitter and receiver coils are far apart, power transfer can still be achieved over resonating of these coils at the same frequency.

In this paper, we will introduce the wireless power transfer system to charge the smartphone in use by using resonant magnetic coupling by controlling the direction of the magnetic field corresponding to various orientations of the receiver.

2. LITERATURE SURVEY

Wireless power transfer [1] via strongly coupled magnetic resonances, to design an efficient non-radiative power transfer over a distance upto 8 times the radius of coil using self-resonant coils in a strongly coupled regime but which is only transfer power 60watts with 40% efficiency [2]. Wireless Power Transfer Using Resonant Inductive Coupling for 3D Integrated ICs, an enhance power transfer efficiency and power transfer density with smaller coils using resonant inductive coupling for 3D ICs. 52% power transfer efficiency is achieved by increasing the coupling coefficient upto 0.887 and the maximum power transfer density is 49mw/mm^2 [3]. An Efficiency Enhancement technique for a Wireless Power Transmission System Based on a Multiple Coil Switching Technique, single loop coil is not enough to charge the mobile schemes efficiently so in this using multiple coils are to obtain the higher power transmission also the system frequency is fixed as 13.56MHz [4]. Analysis and Optimization of Spiral Circular Inductive Coupling Link for Bio-Implanted Applications on Air and within Human Tissue, to design a wireless power transfer for bio-implanted applications using circular spiral inductive coupling link. This is used for medical applications such as brain disorders, paralysis and stimulate nerves and muscle's monitoring using reflected impedance method with 80% efficiency [5]. Wireless power hotspot that charges all of your devices, the paper introduces multispot, a new wireless charging technology that can charge multiple devices. When a user enters the vicinity area, all of the gadgets start to charge automatically upto 50cm.

3. ANALYSIS OF VARIOUS ORIENTATION IN WIRELESS POWER TRANSFER TECHNOLOGY

This proposed model includes the coupling coefficient, resonant frequency of the coil, number of turns, distance between the coils are used to analyse the efficient wireless power transfer in various orientations.

The coupling co-efficient is one of the factor to determine the coupling between the transmitter and receiver coil.

This transmitter and receiver coil parameters such as

- Coil shape
- Outer and inner dimensions ($d_{out.t}$ and $d_{out.r}$)
- Mutual Inductance (M)

- Coefficient factor (K)

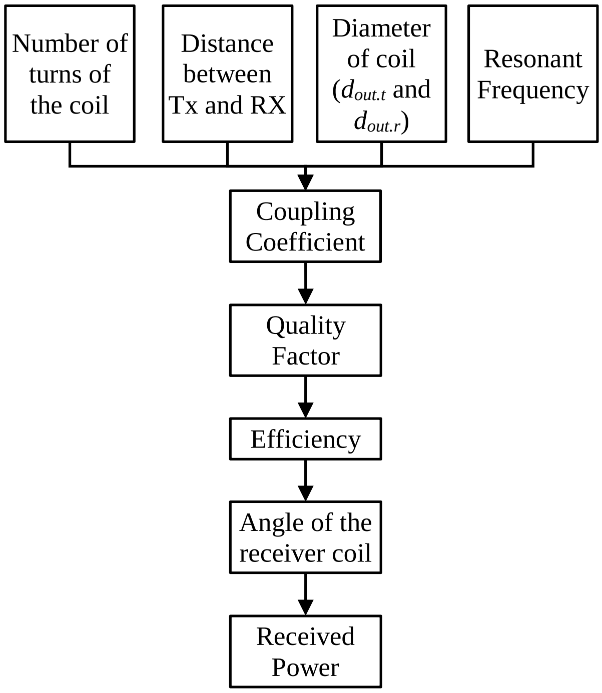


Fig.1. Roadmap to analyse the efficiency of receiver in different orientation

3.1 INPUT PARAMETERS

In this proposed model includes the coupling coefficient, resonant frequency of the coil, number of turns, distance between the coils are used to analyse the efficient power transfer in various orientations. Coupling coefficient is one of the important factor between the transmitter and receiver coils. Because the coupling coefficient desires and predominantly judge the received power in the receiver coil. To analyse the efficiency of the power following input parameters are considered.

- Coil shape or design
- Outer diameter and inner diameter ($d_{out.t}$ and $d_{out.r}$)
- Mutual inductance (M)
- Coupling coefficient (K) and Quality factor (Q).

3.2 MUTUAL INDUCTANCE

The magnetic field through a loop can be changed either by changing the magnitude of the field or by changing the area of the loop. To be able to quantitatively describe these changes, magnetic flux is defined. The Eq.(1) represents the magnetic flux of the coil.

$$\Phi = BA\cos\theta \tag{1}$$

where, θ is the angle between B and the direction perpendicular to the plane of the loop.

Mutual inductance occurs when two circuits are arranged so that the change in current in one causes an EMF to be induced in the other. Imagine a simple circuit of a switch a coil, and a battery. When the switch is closed, the current through the coil sets up a magnetic field. As the current is increasing, the magnetic flux through the coil is also changing. This changing magnetic flux generates an EMF opposing that of the battery. This effect occurs only while the current is either increasing to its steady state value immediately after the switch is closed or decreasing to zero when the switch is opened. This effect is called self-inductance. Eq.(2) represents the mutual inductance of the coil

$$M = \frac{\left(\mu_0 N_t d_{out.t}^2 * N_r d_{out.r}^2 * \Pi\right)}{\left(2\sqrt{d_{out.r}^2 + X^2}\right)^3} \tag{2}$$

where,

N_t - No of turns in Transmitter coil.

N_r - No of turns in Receiver coil.

X - distance between the transmitter and receiver coil.

3.3 COUPLING COEFFICIENT

The coil geometry parameters such as coil shape, outer and inner diameter, coupling coefficient. These are also used for the coupling coefficient. When the coefficient of coupling is equal to 1, such that all the lines of flux of transmitter coil cuts all of the turns of the receiver coil, that is the two coils are tightly coupled together and we obtain an mathematical representation as shown in Eq.(3)

$$K = \frac{\left(a^2 * b^2\right)}{\sqrt{ab} * \left(\sqrt{a^2 + b^2}\right)^3} \tag{3}$$

where,

a - $d_{out.t}/2$ (Outer diameter of transmitter)

b - $d_{out.r}/2$ (Outer diameter of Receiver)

X - distance between the transmitter and receiver.

3.4 QUALITY FACTOR

The quality factor Q is defined as the ratio of the energy stored in the resonator over the energy provided by a generator. Higher Q indicates a smaller rate of system energy loss during power transmission because it supports the low value of Q. Therefore, in a high Q power system, the oscillation/resonance decline slowly. The quality factor is affected by the self-inductance, resistance and intrinsic frequency, which mainly depend on the fabricated materials. The load matching factor mainly hinges on the distance. Since the resonance frequencies of a coil pair change as the gap varies, load matching factor measures how tight the resonance frequencies are matched. To tune the load matching factor for maintaining resonance frequency matching at varying distance existing, literature has proposed various solutions such as coupling manipulation, frequency matching, impedance matching and resonator parameter tuning.

3.5 PERFORMANCE EVALUATION

The efficient wireless power transfer to the mobile devices is achieved by using resonant magnetic coupling to control the direction of magnetic field corresponding to various orientations of the receiver.

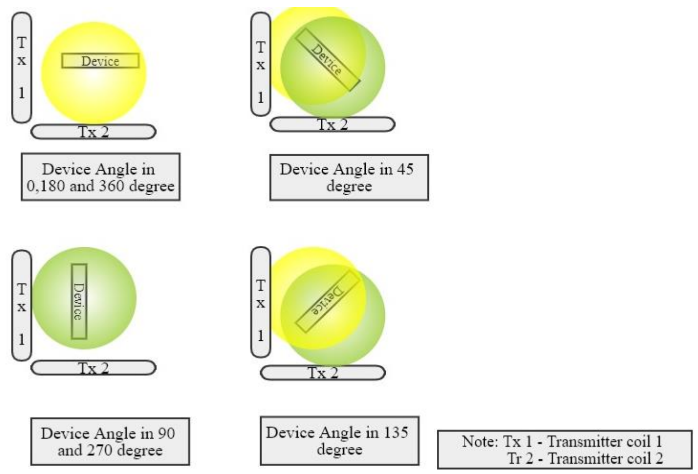


Fig.2. L-Shaped transfer with various orientation effects

4. SIMULATION AND RESULTS

The proposed efficient power transfer by controlling the various direction of a receiver coil for the Wireless Power Transfer system is validated based on simulation results which is done using Matlab 2017b. The design of spiral coil transmitter and receiver have a following specification's.

4.1 COIL DESIGN

The coil design study is divided into two parts. First, the effects on the coil characteristics in free space due to the geometry of the coils are analyzed. They are introduce the conducting and magnetic materials in the geometry for the coil design. This design is depends on the coil windings are placed in a grid pattern with N_r (radial) and N_z (axial) wires. The total number of coil windings is thus $N = N_rN_z$. The optimization varies the geometry of the coils to maximize the coupling coefficient while keeping the magnetic fields within the guidelines decided by ICNIRP. The optimized coil geometry is then used together with the circuit model to optimize the power transfer and efficiency.

4.2 COIL SPECIFICATIONS

The Table.1 has a certain parameters to design the coil with the different formulas such as inductance for simple spiral coil is designed. The resistance of the coil wire can be calculated if the material properties and frequency of operation is known. The skin depth can be used to approximately describe how an alternating current penetrates into a solid conductor. This has a same considerations for transmitter and receiver coils. There are small different may be occur between the coils. The spiral coil design specification as follows.

Table.1. Specifications of transmitter and receiver coil

Component	Parameter	Values
Transmitter Coil (Tx)	Number of turns (N_t)	6.25
	Outer diameter (D_{outt})	0.3m
	Inner diameter (D_{int})	0.1m
	Self-inductance (L_1)	1.2mH
	Resistance (R)	50Ω
	Wire diameter (w_d)	0.0042m
	Turn spacing (w_s)	0.001m
	Resonant frequency (F_r)	3MHz
Receiver Coil (Tx)	Number of turns (N_t)	4.75
	Outer diameter (D_{outt})	0.3m
	Inner diameter (D_{int})	0.1m
	Self-inductance (L_1)	0.9435mH
	Resistance (R)	50 Ω
	Wire diameter (w_d)	0.0042m
	Turn spacing (w_s)	0.001m
	Resonant frequency (F_r)	3MHz
Distance between the transmitter and receiver is upto 30cm		

4.3 INDUCTANCE FOR THE SIMPLE COIL GEOMETRIES

To compute the magnetic fields due to currents flowing in coils when the physical size of the system and its components is much smaller than the wavelength associated with the exciting current, the magnetic field H can be found from the quasi-magnetostatic Ampère's law of induction. This will be represented in the Eq.(4).

$$L = (r^2 * N^2)/((8r+11w)) \quad (4)$$

where,

L - Inductance of the coil

N - Number of turns in the coil

W - Width of the coil

4.4 SELF RESONANT COILS

At low frequency, it is sufficient to model a coil as an ideal inductor in series with a resistance, while the behavior at higher frequencies can be significantly different. Assuming a time-harmonic current excitation, a coil becomes self-resonant when its wire length is approximately equal to half the wavelength in free-space at the excitation frequency. A simplistic model of this behavior is to connect a parasitic capacitor in parallel to the inductor and resistance. It is generally, inductor has a low distributed capacitance between the turns of the wired wound conductor, that distributed capacitance with the inductor resonates at the certain frequency.

4.5 DESIGNED COIL

As per the design specifications in the Fig, the spiral coil is designed in a Matlab with the help of PDE tool, to express the geometry by its boundary points and then the boundary points are imported in PDE tool. Because, spiral is a very popular geometry in resonant coupling type wireless power transfer system for its compact size and highly confined magnetic field. We will use such a spiral as the fundamental element in this example.

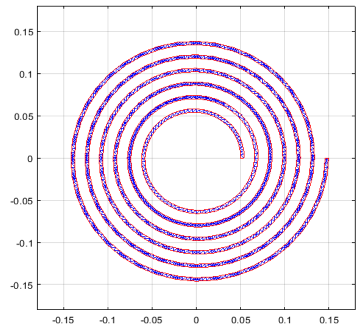


Fig.3. Designed spiral coil

In this, the receiver coil takes a various orientation with respect to transmitter coil. The receiver coil angular is from 0° to 360°. The Fig.4 is the 3 Dimensional model for 450 angle with transmitter, similarly it will take all the orientation angle like 0° to 360°. The complete wireless power transfer system is composed of two parts: the transmitter (Tx) and receiver (Rx). Choose identical resonators for both transmitter and receiver to maximize the transfer efficiency. Here, the wireless power transfer system is modelled as a linear array.

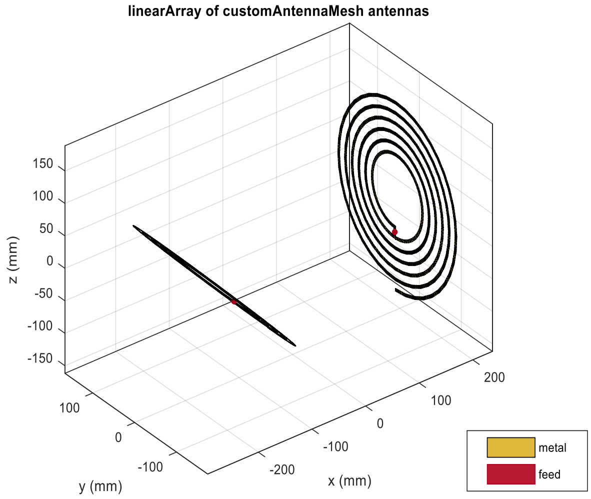
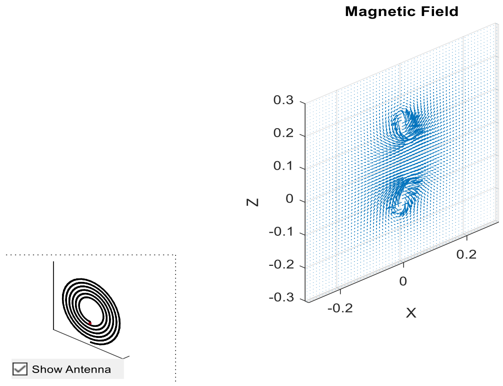


Fig.4. Angular displacement of receiver coil with respect to transmitter coil

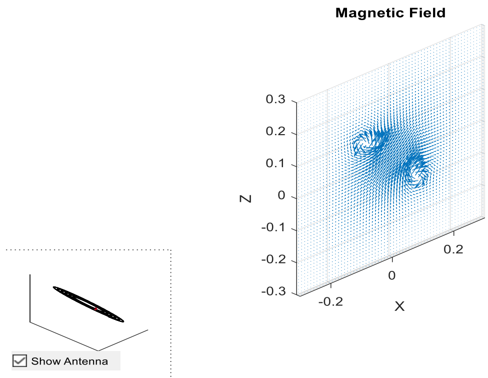
4.6 MAGNETIC FIELD AND IMPEDANCE OF THE COIL

The foremost energy exchange mechanism between the two spiral resonators is over magnetic field. A strongly localized magnetic field is existing at the resonant frequency when the near field is plotted. When the transmitter coil is connected with the power source, it will generate the magnetic field by the moving of electrons in the coil loop. Either an electric current is passed through the wire of the coil to generate a magnetic field, or an external time varying magnetic field through the interior of the coil generates an EMF in the conductor. Generally, an electromagnetic coil is an electrical conductor such as a wire in the shape of a coil, spiral or helix. In this application where electric currents interact with magnetic fields, in devices such as electric motors, generators, inductors, electromagnets and transformers, and sensor coils.

When the electric current through any conductor creates a circular magnetic field around the conductor due to the ampere's law. The advantage of using the coil shape is that it increases the strength of the magnetic field produced by a given current and magnetic field generated by the separate turns of wire all pass through center of the coil and add to produce a field there. The more number of turns of the coil used to produce the strong magnetic field. However, changing external magnetic flux induces a voltage in a conductor. The induced voltage can be increased by winding the wire into a coil, because the field lines intersect the circuit multiple times. Since the spiral is a magnetic resonator, the dominant field component of this resonance is the magnetic field. A strongly localized magnetic field is observed when the near field is plotted.



(a)



(b)

Fig.5. (a) Magnetic field produced in the transmitter and (b) Magnetic field produced in the receiver

The direction of the magnetic field produced by a coil can be determined by the right hand grip rule. If the fingers of right hand are wrapped around the magnetic core of a coil in the direction of conventional current through the wire, the thumb will point in the direction the magnetic field lines pass through the coil. When there are two or more windings around a common magnetic axis, the windings are said to be inductively coupled or magnetically coupled.

4.7 IMPEDANCE OF THE COIL

Strong magnetic fields are existing between the transmitter and receiver coil at resonant frequency. A good technique to find the resonant frequency is to learning the impedance of the two spiral coils resonator, since both spiral coils are magnetic resonator, a Lorentz shaped reactance is expected and observed in the calculated impedance result.

It is important to find the resonant frequency of the designed spiral geometry. A good way to find the resonant frequency is to study the impedance of the spiral resonator. Since the spiral is a magnetic resonator, a Lorentz shaped reactance is expected and observed in the calculated impedance result. In this Fig.6 shows that, the primary coil is fixed with the particular resonant frequency, so that when the frequency resonates at that point only has a high power transfer efficiency. Otherwise, it has a low transfer efficiency. The system is with the out of band frequency, transferred efficiency becomes zero.

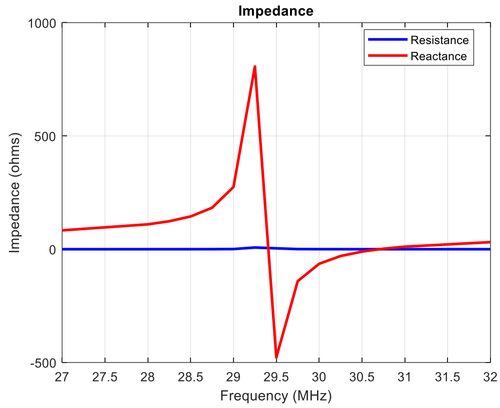


Fig.6. Impedance vs. Frequency

4.7.1 S_{21} Parameter:

One way to evaluate the efficiency of the system is by studying the S_{21} parameter. As presented, and the system efficiency changes rapidly with operating frequency and the coupling strength between the transmitter and receiver resonator. Peak efficiency occurs when the system is operating at its resonant frequency, and the two resonators are strongly coupled. The results for s-parameter analysis has been pre computed and stored in a mat-file. The efficiency of wireless power transfer on orientation effects is calculated using the certain parameters such as S_{21} parameters, coupling co-efficient, mutual inductance.

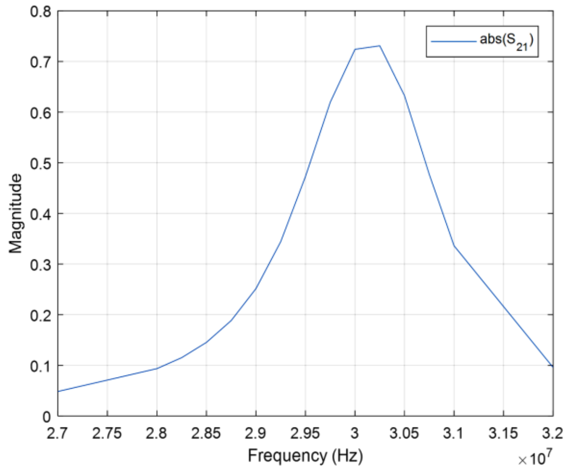


Fig.7. Magnetic vs. Frequency

Critical Coupled Point The coupling between two spirals increases with decreasing distance between two resonators. This trend is approximately proportional to $1/d^3$. Therefore, the system efficiency increases with shorter transfer distance till it reaches the critical coupled regime. When the two spirals are over coupled, exceeding the critical coupled threshold, system efficiency remains at its peak, as shown in Fig.7. We observe this critical coupling point and over coupling effect during modelling the system. Perform a parametric study of the system s-parameters as a function of the transfer distance. The transfer distance is varied by changing the Element Spacing. It is varied from half of spiral dimension to one and half times of the spiral dimension, which is twice of the spiral's outer radius. The frequency range is expanded and set from 25MHz to 36MHz. S_{21} parameter is used to determine the efficiency. The scheme efficiency variations rapidly with operating frequency and the coupling strength between the transmitter and receiver resonator.

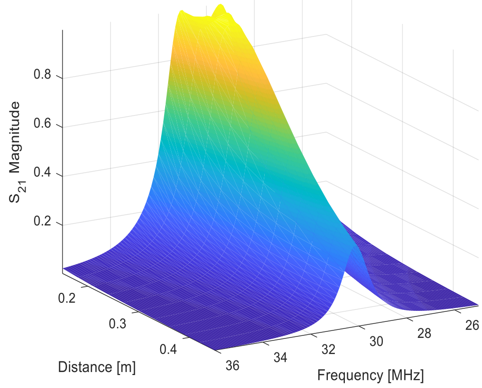


Fig.8. Distance vs. Frequency vs. S_{21} Magnitude

The dominant energy exchange mechanism between the two spiral resonators is through the magnetic field. Strong magnetic fields are present between the two spirals at the resonant frequency.

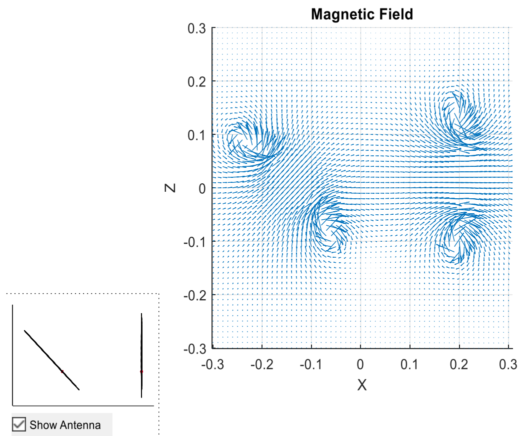


Fig.9. Magnetic field between the transmitter and receiver coil

4.8 COUPLING COEFFICIENT

When the coupling of coefficient (K) is equal to 1, (unity) such that all the lines of flux of one coil cuts all of the turns of the secondary coil. This means that the two coils are tightly coupled together.

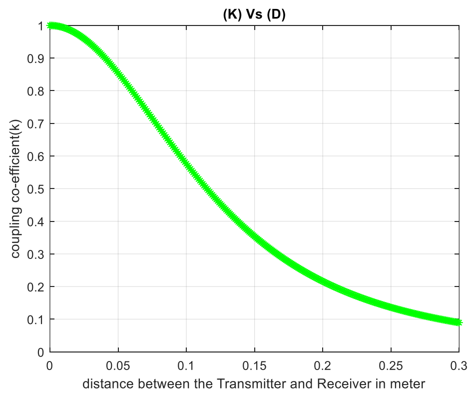


Fig.10. Coupling between the transmitter and receiver coil with respect to distance

When the distance increases between the two coils, it leads to reduce the coupling coefficient. For example, this Fig.10 shows that, when there is coupling coefficient has a range one, the distance between the transmitter and receiver end is close to each other which is used to increase the efficiency of the system.

4.9 MUTUAL INDUCTANCE

Mutual inductance is defined as current flowing in the one coil that induces the voltage in an adjacent coil. The property of mutual inductance is when two are more coils are magnetically linked together by a common magnetic flux. The amount of mutual inductance that links one coil to another coil depends very much on the relative positioning of the two coils. If the one coil is positioned next to the other coil so that their physical distance apart is small, when nearly all of the magnetic flux generated by the primary coil will interact with the coil turns of the secondary coil inducing a relatively large EMF and therefore producing a large mutual inductance value.

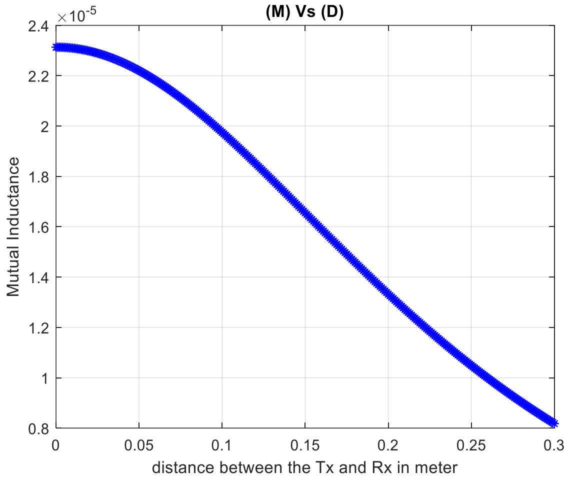


Fig.11. Mutual inductance vs. distance between the Tx and Rx coil

If the two coils are further apart from each other or at different angle, the amount of induced magnetic flux from the primary coil into the secondary coil will be weaker producing a much smaller induced EMF and therefore a much smaller mutual inductance value. So the effect of mutual inductance is very much dependent upon the relative positions or spacing of the two coil. It is the basic operating principle of the transformer, motors, generators and any other electrical component that interact with another magnetic field.

4.10 RECEIVED POWER IN THE SYSTEM

The received power is measured using the Quality factor (Q) of the coils. Because the Q can be very high, even when the low power is fed into the transmitter coil, a relatively intense field builds up over multiple cycle, which increases the power that can be received at resonance far more is in the oscillating field then is being fed into the coil, at the receiver coil receives a percentage of that. The received power is measured in various orientations of the receiver corresponding to the transmitter coil (Received power calculated when the Transmitter placed in horizontal and vertical position). The single transmitter coil is used to analyse the received power such as transmitter placed in horizontal and vertical direction. The following Fig.11 is shown the received power in the secondary coil, when only the horizontal transmitter is ON it only gather the power only in the horizontal transmitter. It has high collected power in the receiver when the receiver or smart phone is flat to the transmitter. For example, when it is in the 0^{o} orientation or flat to transmitter the received power is maximum but when the receiver is vertical to the transmitter it has zero received power.

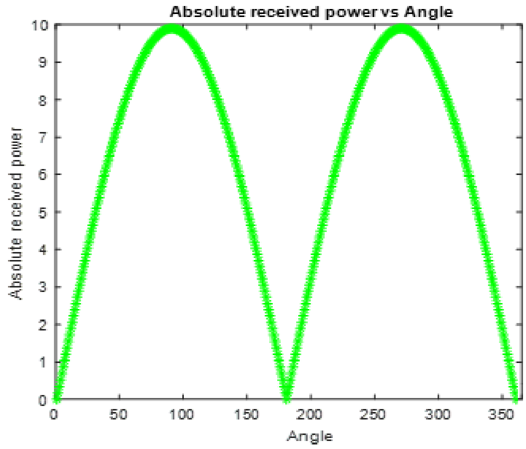


Fig.12. Absolute power received at the receiver when the transmitter in horizontal

When only the vertical transmitter is ON, the secondary coil only collects the power only from the horizontal transmitter. It has high collected power in the receiver when the receiver or smart phone is vertical to the transmitter. For example, when it is in the 90^{o} orientation or vertical to transmitter the received power is maximum but when the receiver is horizontal to the transmitter it has zero received power.

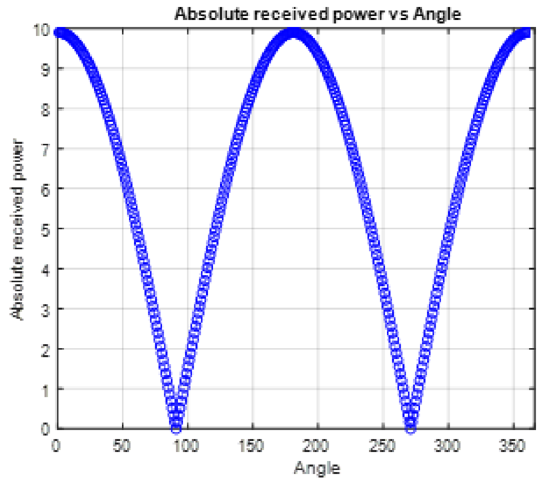


Fig.13. Absolute power received at the receiver when the transmitter in vertical

Here the system has a two transmitter coils which is placed orthogonally it will used to improve the power transfer efficiency. This two transmitter coil is illustrated in the Fig.13.

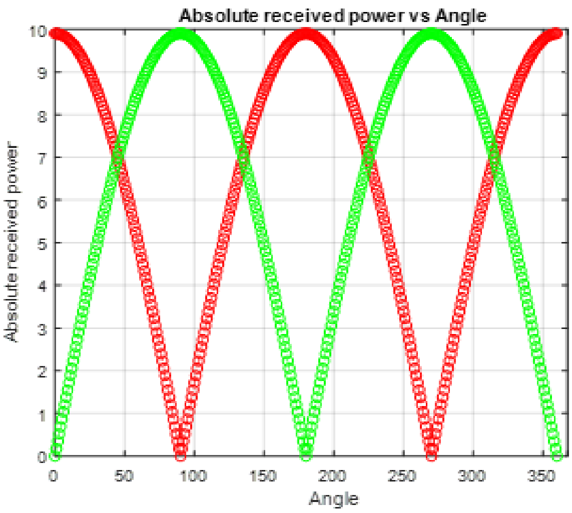


Fig.14. Received power based on orientation of the receiver with Transmitter coil

When the receiver is parallel to the vertical transmitter it only collects the power from the transmitter 1 which is in the vertical direction and this procedure is also similar to the horizontal direction. For the other orientation of the receiver two transmitters are ON and the receiver collects the power from both the transmitter. For example, the receiver in 0^{o} orientation horizontal transmitter is ON, secondary coil receives the maximum power and when the receiver in the 90^{o} orientation vertical transmitter ON this is also having the maximum received power. But in the other orientation of the receiver both the transmitters are ON but received power is less compared to the other situations.

5. EXPERIMENTAL EVALUATION

We used the magnetic resonant coupling method to the wireless power transfer for analysing the various orientation of the receiver. For this experimental evaluation, designed the coil based on the simulated design and placed the transmitter coil under the table and in the partition, and place the receiver coil placed at the back of the smart phone.

To analyse the efficiency of the wireless power transfer with the various orientation of the receiver, we are connecting the transmitter coil with the function generator and the receiver is placed with the spectrum analyser that is the cathode ray oscilloscope (CRO). The general set for analysing the orientation effects of two coil is shown in the Fig.15.

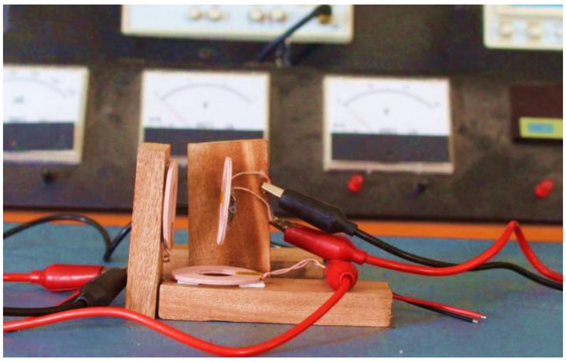


Fig.15. Arrangement of Wireless Power Transmission

5.1.1 Experimental Results for Various Orientation:

Fig.16. Arrangement of WPT *D* = 0cm

The above Fig.16 illustrate the arrangement of WPT with zero distance. In this arrangement used to analyse the power is should be received from the transmitter to receiver when the receiver takes a various orientation.

Table.2. Analysed various orientation (*D* = 0cm, Input Voltage: 5V)

Angles	Frequency (Hz)	Output Voltage (Volt)	Voltage Gain (dB)
0^{o}, 180^{o} and 360^{o}	109KHz	4.4V	1.11dB
45^{o}, 225^{o}	109KHz	2.8V	5.03dB
90^{o}, 270^{0}	109KHz	4.6V	0.72dB
135^{o}, 315^{o}	109KHz	3.1V	4.15dB

Fig.17. Arrangement of WPT (*D* = 1cm, Input Voltage: 5V)

The Fig.17 illustrate the arrangement of WPT with unity distance. In this arrangement used to analyse the power is should be received from the transmitter to receiver when the receiver takes a various orientation.

Table.3. Analysed Various Orientation (*D* = 1cm, Input Voltage: 5V)

Angles	Frequency (Hz)	Output Voltage (volts)	Voltage Gain (dB)
0^{o}, 180^{o}, 360^{o}	109KHz	3.6V	2.85dB
45^{o}, 225^{o}	109KHz	2.0V	7.95dB
90^{o}, 270^{0}	109KHz	3.6V	2.85dB
135^{o}, 315^{o}	109KHz	2.4V	6.37dB

Fig.18. Arrangement of WPT system (*D* = 2cm, Input Voltage: 5V)

Table.4. Analysed various orientation (*D* = 2cm, Input Voltage: 5V)

Angles	Frequency (Hz)	Output Voltage (volts)	Volatge Gain (dB)
0^o, 180^o and 360^o	109 KHz	3.2V	3.87dB
45^o, 225^o	109 KHz	2.4V	6.37dB
90^o, 270^0	109 KHz	2.8V	5.03dB
135^o, 315^o	109 KHz	2.0V	7.95dB

The Table.2-Table.4 shows the results of regression with the various orientation of the receiver by controlling direction of the magnetic field, which is produced by the transmitters. It is based on the resonant magnetic coupling technology.

6. CONCLUSION

In this paper, we proposed and investigate an optimizing efficiency on orientation effects on wireless power transfer scheme that can charge a smart phone in use by applying resonant magnetic coupling. This improve the performance of the scheme. Conversely, in order to increase the absolute power transfer amount, higher coupling coefficient (*K*) and Quality factor (*Q*) are required. It will also increase the distance between the transmitter and receiver coil.

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