Wireless Charging via Strongly Coupled Magnetic Resonance

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***Abstract*— A nonradioactive energy transfer which is devised by two coils spaced by a medium-range distance, using the method of 'inductive coupling' is proposed here to gain efficient transfer of energy. Characteristic size of the resonators will determine the power transfer. It is a field closely related to wireless transmission of energy since it is using two coils that are tuned to resonate at the same frequency. This system requires no complex external controlling system because it relies on impedance for the desired energy. This process completely eliminates the use of traditional wiring in terms of charging or transferring energy.**

I. INTRODUCTION

In recent years, wireless power technology has become the center of attraction and this increased attraction has led to many research and development of this fascinating technology. With the popularity of Wi-Fi going through the roof, there is an indication that cable and wiring will soon become obsolete. Medium to long range, where coverage is equal if not greater for a typical personal-area network, short range, where the coverage is localized within the vicinity of the transmitting device are the two fundamental categories of wireless power system. If the desire is to transmit power compared to a typical wall-mounted dc supply, then violation of RF safety regulations is unavoidable. One way to get around this is to use a large number of transmitters which is an impractical implementation of the technology. Therefore, far-field techniques are most suitable for very low power applications such as charging mobiles, household electronics etc. There is no better choice than inductive coupling when it comes to achieving power transfer at power levels ranging from several microwatts to kilowatts. The block diagram of the wireless power transfer system using inductive coupling is shown in Fig.1

Figure 1: Power Transmission

Though high efficiency is the main concern, another critical thing for the system is able to deliver the required power with respect to the load resistance. The transmitted power should decrease when the load device's impedance increases.

In the following paper, we step-downed the input voltage of 220V to 24V using a transformer and then wirelessly transferred it after converting with a rectifier using two coils. The system has numerous implementation for portable devices of consumer electronics, industrial appliances, and many other applications.

II. ANALYSIS OF OPERATION

A. Inductive Coupling

Power transfer for the system is achieved via magnetic induction between two air core coils. Appropriate shielding at the expense of weight and thickness can be used to make the system more robust in environments where the system's magnetic field is likely to interact with other nearby objects. However, shielding is beyond the scope of this paper, and it is assumed that the system will be working in an environment free of structures and materials that will significantly affect the system performance. Although it would be ideal for both the transmitting coil and the receiving coil to be of the same size to ensure maximum coupling, a practical system uses a receiver coil significantly smaller than the transmitting coil. This allows a user to freely place a device in any orientation as shown in Fig. 16. Therefore, in order to achieve consistent power delivery regardless of the receiving coil's location, the transmitting coil must be able to generate a magnetic field that has relatively even distribution.

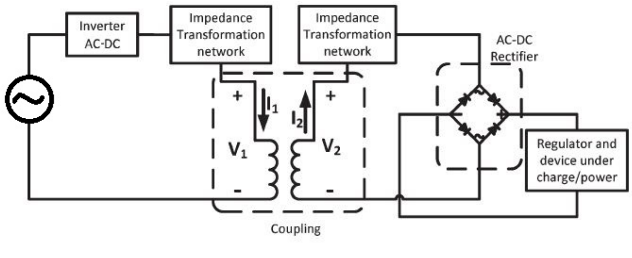


Figure 2: Block diagram of the wireless transfer circuit

The voltage and current characteristics of the transmitting and the receiving coils can be described using the following.

$$V_1 = j\omega M_{11} I_1 + j\omega M_{12} I_2 \quad (1)$$

$$V_2 = j\omega M_{21} I_1 + j\omega M_{22} I_2 \quad (2)$$

$$M_{12} = k\sqrt{M_{11} M_{22}} \quad (3)$$

Where,

V_1	voltage at the transmitting coil	(Fig. 1);
I_1	current at the transmitting coil	(Fig. 1);
V_2	voltage at the receiving coil	(Fig. 1);
I_2	current at the receiving coil	(Fig. 1);
M_{11}	self-inductance of the transmitting coil;	
M_{22}	self-inductance of the receiving coil;	
$M_{12} = M_{21}$	mutual inductance of the two coils;	
k	coupling coefficient between the two coils.	

By Ohm's law,

$$Ztx = Rtx + jXtx = \frac{V_1}{I_1} \quad (4)$$

$$Zrx = Rrx + jXrx = \frac{V_2}{I_2} \quad (5)$$

The earlier analysis of the coupling neglects any second-order effects such as skin depth and proximity effects. A more in-depth analysis accounting for the earlier effects can be performed to improve the accuracy. Alternatively, Litz wires can be used to mitigate such effects.

B. *Impedance Transformation Network*

The purpose of impedance transformation networks on the primary and secondary sides of the coupling is to achieve maximum power transmission and efficiency by operating within the optimum impedance range looking into the transmitter load network over a wide range of load resistance. In consideration of size and efficiency, capacitors instead of resistors and inductors should be used for the network. This is because resistors dissipate power, and the size of a low-loss inductor is generally large. Although a multi element transformation network might achieve a better response, for simplicity and low-component count, the system uses a single element transformation network. The four possible topologies of the single-element transformation network are shown in Fig. 2.

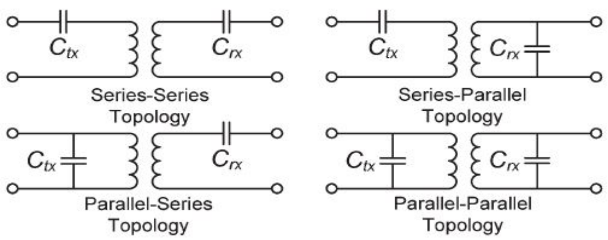


Figure 2: Topologies for a single-element impedance transformation network.

Fundamentally, a series capacitor only introduces a negative reactance and does not change the real part of the impedance. On the other hand, a parallel capacitor changes both the real and imaginary parts of the impedance. To simplify the analysis, the receiver input impedance is modeled using a variable resistor load, and illustrates the transformation performed by the parallel capacitor.

III. DESIGN APPROACH

The design of the proposed wireless power system started with choosing the right wire that was to be used as the transmitter and receiver coil. Then we constructed the transmitter and receiver circuit where we used AC-DC bridge rectifier on both sides, resistors, transistors and voltage regulator.

A. *Component table*

Components	Quantity
Breadboard	2
12ft. X 10ft. Plastic Wood	1
220V – 24V Transformer	1
26 AWG (Insulated) Copper wire	6 ft.
22 AWG Copper wire	8 ft.
D4007 Si diode	8
150 Ω 5Watt Resistor	1
330 Ω 5Watt Resistor	1
TIP35C NPN Transistor	1
220 µF 25V Capacitor	1
6.8 µF 50V Capacitor	2
7805 Voltage Regulator	1
5V Charger Cable with LED	2 ft.

B. *Circuit Diagram*

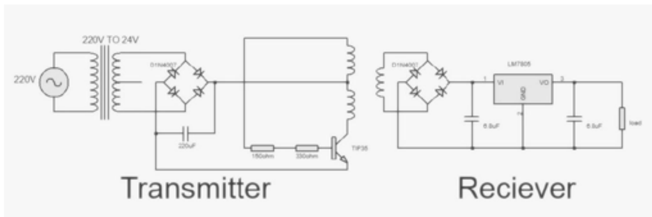
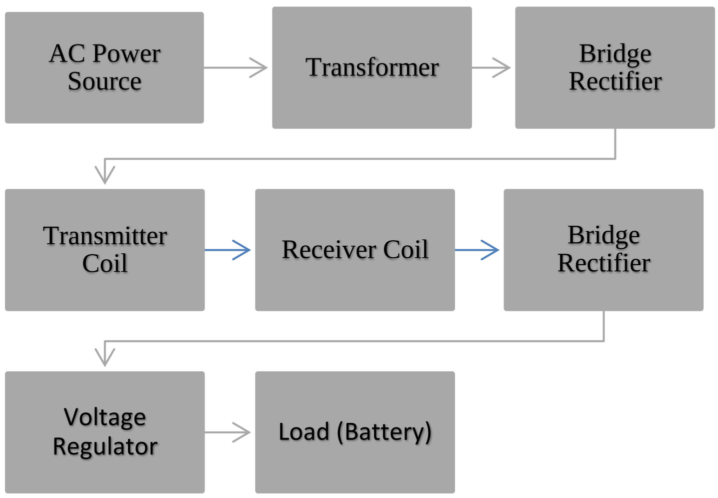


Figure 3: Final Circuit diagram

C. *Block Diagram*



D. *Transmitter and Receiver coils*

We had to use two types of wires for this experiment. We used insulated 26 AWG for constructing the Transmitter coil which is attached to a plastic wood for support. Then we used the 22 AWG Copper wire as the receiver coil. Our reason for using two types of wires is completely based on convenience and our ability to collect the wires. Any type of wires can be used here.

E. *Transmitter circuit*

This part of the build started from connecting a socket to the 220V-24V transformer which converts the 220V AC source to 24V AC source. This AC source is then converted to 24V DC source with AC-DC bridge rectifier. A 220μF capacitor is used in the rectifier for a smoother DC voltage output.

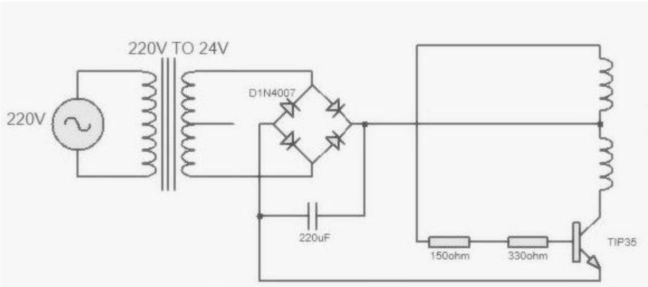


Figure 4: Transmitter Circuit

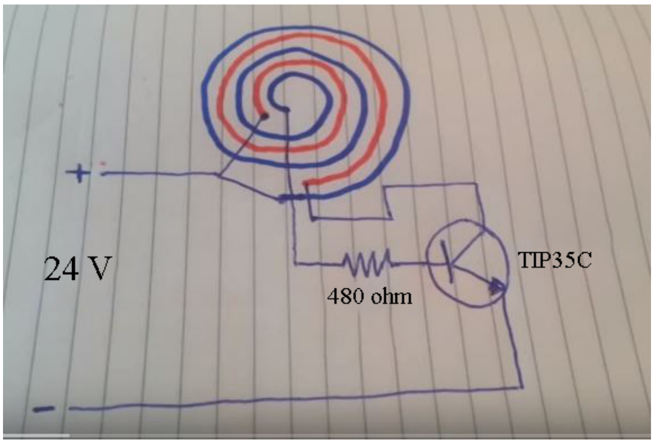


Figure 5: Transmitter Coil Construction

This 24V DC voltage is then supplied to the transmitter pancake coil which is connected to TIP35C transistor and 480Ω resistor like in Fig.5. The 480Ω resistor is constructed using a 150Ω and a 330Ω resistor in series. This resistor is connected to the base of the transistor. The emitter of the transistor is grounded.

F. Receiver Circuit

In this part we used 22 AWG Copper wire as the receiver coil. The coil carries the current to another AC-DC bridge rectifier which eliminates any possibility of backward current flow. This DC current is than carried through a 5V voltage regulator 7805. This regulator confirms the flow of 5V needed for charging the load which is in this case is phone battery. This part can be changed if we need more or less potential.

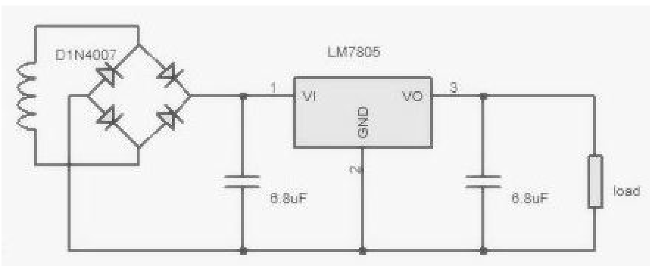


Figure 6: Receiver Circuit

IV. APPLICATIONS

Inductive charging provides a comfortable, reliable and easy way of charging electrical devices. It eliminates physical connection to cables thus allowing more mobility to its user. Wireless technology is not just restricted to consumer applications, it can be very useful in the industrial world too. It is more safe and economic as wires can be dangerous and they have a high maintenance cost. So wireless charging can increase the productivity of a industry. Wireless charging will be extremely useful in medical sector too as medical sectors need many high level electrical devices which run by battery and consist of many wires. They can be contaminated as room conditions are constantly changing. In hazardous situation we often see there is lack of electricity as the wires are damaged so using wireless technology can save a lot of lives in medical sector as its connection does not get affected by such catastrophes. Wireless charging can be very useful for vehicles too. Electrical cars which charge through wireless charging will reduce the pressure from fossil fuel thus saving our mineral resources as well as saving the environment. It will also allow the vehicles to charge while they are moving and they won't have to stop anywhere to charge which will save a lot of time too. Although this technology is not very efficient right now but a lot of research is going on to make these vehicles more efficient. Wireless charging can be used in areas where connecting through wires can be highly dangerous and costly. In jungles or different islands we can use inductive charging when wire is not an option. So wireless charging is safer and more economical to use in any electrical devices.

V. LATEST ADVANCEMENTS

In nineteenth century, Nicola Tesla conceived the transmission mechanism of radio energy. After years of development, wireless power transmission technology has made a great achievement. In 1983, Donaldson's research shows that the optimal electromagnetic coupling coefficient of the transmitter and receiver can be achieved by using the S/P capacitance compensation technique, and the transmission efficiency can reach 50%. Then in 1996, Professor Joun proposed the S/S capacitor compensation technology. Then, the wireless charging hybrid compensation ways has P/P, P/S, S/P-S/SP and so on.

In 2007, Professor Soljacic Marin and the research team proposed resonant WPT principle in Science, it began to step into people's vision and achieved rapid development. MIT successfully put a 2m far away from a 60W light bulb lit, and achieved the efficiency of charging transmission more than 40%. Furthermore, they found that with the distance to shorten the charging efficiency is very rapid rise. When the distance is 125cm, the efficiency is more than 85%. When the distance is 75cm, the efficiency reached a more staggering 95%. In 2009, KAIST was tested on the SUV car, and achieved the output power was 15kW, the efficiency reached 71%. In 2009, Witricity to achieve a 6.4MHz based, transmission distance of 60cm electrical wireless charging, and the efficiency of 95%. In 2011, Witricity achieved a comprehensive transmission efficiency about 90% of the 3.3 kW radio.

2012, Professor Hori of University of Tokyo in Japan realized the high efficiency power transmission based on the automatic group anti-match technology, the transmission distance is 6 - 30cm, the resonance frequency is 13.56MHz, the maximum charge efficiency is 85%. In2013, Professor Mi of Michigan Chris University and his team has achieved the following 200kHz car wireless charging, the transmission power of 2-6 kW, transmission efficiency as high as 94% [12]. From 2012 to 2015, professor Park C and his team has achieved a transmission distance of 5m to achieve the 'bipolar magnetic core coil' wireless power transmission system, and expanding the transmission distance.

Although China's research carried out late, but the development is very rapid. In 2005, the team of Professor Sun Yue began to carry out the related research of frequency stability of contactless power transmission, he also improved the CPT system related voltage output control technology. Then, in 2011, Liu Sucheng of Chongqing University, analyzed the characteristics of the power, efficiency and frequency of the near field magnetic resonance WPT. Professor Chen Qianhong summed up the development of wireless power transmission technology. What is more, Professor Zhang Bo introduced the magnetic resonance WPT about 3 basic ways, and analyzed the limit parameters may occur, not that the transmission efficiency of WPT reached 100%. In 2016, Xi'an University of Technology research team introduced 4 kinds of wireless charging hybrid compensation topology technology, focusing on the analysis of the compensation method of S/P-S/SP. Professor Huang Xueliang, made researched on the development process of radio transmission technology, magnetic resonance series and model, reception device and so on. In addition, many conferences are important ways to promote the development of radio transmission technology. For example, the Chinese Conference on Decision and Control (CCDC), Chinese New Energy Vehicle Charging and Driving Technology Conference (GVCD), silk road international wireless charging union WPC meeting and related meetings held by IEEE.

Imagine a world where we don't have to plug anything in. Your phone, laptop, tablet and headphones are constantly being topped-up whenever they're placed on an inductive surface, so that when you take them out with you into the wider world, your devices are always brimming with battery. Step-by-step, it's what we might be moving toward, if the industry lobbying group The Wireless Power Consortium gets its way. The group's long-in-development wireless charging technology, Qi, is now getting a considerable power boost, which means it will be able to charge more smartphones faster, as well as tablets, which were previously too power hungry for it.

While this a big step forward for Qi, and may lead to wider adoption for the fledgling charging standard, there are other barriers still standing in the way on the road to a wireless power Utopia. First, a note on Qi's progress: the new Qi jumps from its previous 5 watt cap to 15 watts. Most smartphones have traditionally required 5 watts of power to charge. But now, some Android phones have started to feature faster charging through the use of 15 watt chargers. This new Qi standard would allow manufacturers to make phones capable of charging wirelessly at those high speeds, up to 60 percent battery in 30 minutes, according to a Wireless Power Consortium press release. That's compared to normal 5W charging, which according to Kirchhoff's Law, could take more than twice that time. The upgrade also allows Qi to charge more Android tablets, which usually require between 7.5 and 9 watts. The improvement of materials and techniques, like the use Litz wire and a method of “sandwiching” the magnetic field between the receiver and transmitter, allows power transfer to be more efficient and minimizes radiated emissions, says John Perzow, vice president of market development at the Wireless Power Consortium (which champions the Qi standard).

VI. CHALLENGES

While building the experimental version of this proposed design we faced many problems. We had to work with great amount knowledge without knowing much about the things we needed to do. First of all we didn’t know about the limitations of the equipment’s, so selecting the perfect or workable equipment for the job was quit a hassle. We also faced problems when trying to simulate our project in a simulator. We had to redo our circuits several times until we finally found the correct circuit that actually worked. Since it was a project hanging heavily on the coils, choosing the right type of wire for the coil was crucial. We tried few types of wire until we found one that worked for us. The resistors were also hard to select, we had to use resistors capable of supporting higher power. Low level transistors also gave us problems. Finally we used TIP35C transistor which is capable of handling high level of power.

VII. CONCLUSION

A new technique of designing a wireless power transfer system using the operation for transmission via inductive coupling has been proposed. Instead of using complex detection schemes and variable tank circuits to seek resonance and high efficiency, the system is designed to achieve the desired power delivery profile via its natural response across a wide range of load resistances. Finally, a system is fabricated and tested to verify the design. The fabricated system is capable of delivering nearly 300 W with forced air cooling, and the power delivery can be varied via its supply voltage. Higher power delivery can be achieved if a power supply with higher output and transistors with higher breakdown voltages are used. With natural convection cooling, the system achieves a maximum power delivery of 69 W with end-to-end system efficiency of 74%. This is believed to be the highest power and efficiency reported for a loosely coupled wireless power transfer system with a dynamically changing load at the receiver. Depending on the requirements, the system can be reconfigured to transmit power wirelessly to different devices for a wide variety of applications. This technology can be applied to rugged electronics to enable the creation of hermetically sealed units and to eliminate the problem of charging port contamination and corrosion. In environments where sparking and arching hazards exist, this technology can be applied to eliminate an electronic device’s external metallic contacts.

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