Powering the Future: The Latest Breakthrough in Wireless Charging for Electric Vehicles

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***Abstract*—Recently, the Electric Vehicle (EV) market has experienced significant growth and is projected to expand exponentially with the advancement of technology. Major industries are increasingly adopting the concept of producing hybrid or fully electric cars, resulting in electric vehicles becoming a common sight in today's era. This research examines the potential of wireless power transfer systems as an alternative method of charging electric automobiles. Despite the widespread use of traditional plug-in charging, wireless charging proves to be more effective and convenient. The study evaluates various approaches to integrating wireless charging into an electric vehicle prototype, represented by a remote-control car. It also explores the background and advancements of wireless charging technology. By optimising the design of the transmitter and receiver, based on circuits used for mobile phone chargers, the necessary power (5V, 2A) is provided to the remote-controlled car. Voltage regulators are utilized to manage the output voltage of the receiver circuit during simulations, which assess the circuit's performance under different conditions. The results suggest that wireless charging could serve as a practical and environmentally friendly alternative to conventional charging methods.**

Keywords—wireless power transfer, electric vehicle, transmitter, receiver

I. Introduction

Wireless Power Transfer (WPT) is a groundbreaking technique that allows for the seamless migration of energy, eliminating the need for cumbersome cords or wires. This revolutionary approach completely transforms conventional energy utilization practices across a wide array of applications. WPT technology has already been successfully integrated to facilitate the convenient charging of portable electronic devices, including mobile phones. The versatility and portability of WPT systems are among the remarkable attributes that contribute to its exceptional reputation and widespread acclaim [1].

Wireless Power Transfer (WPT) systems serve as a transformative technology for electric vehicles (EVs), as they eliminate the need for user involvement in the charging process. By removing the requirement for physical connections, WPT enables seamless and effortless charging of EVs. It is projected that by the year 2035, the number of EVs on the road will reach an estimated 85 million, further highlighting the growing significance of WPT in the automotive industry [2]. This high demand requires an enormous infrastructure of EV charging points will be demanded [3]. Wireless charging has been an area of discussion and research for quite some time; since the era of Nikola Tesla [4]. Safety concerns surrounding the operation of Wireless Power Transfer (WPT) arose due to the unavailability of necessary resources at the time. However, a significant breakthrough in 2007 changed the landscape entirely. Two researchers successfully demonstrated the ability to power a lightbulb from a distance of two meters using wireless power transfer techniques, resolving the safety issue and paving the way for further advancements in WPT technology [5]. Since achieving this remarkable success, the field of wireless power transfer has witnessed a multitude of significant advancements[6]. The environment is a major concern due to the substantial contribution of internal combustion engine (ICE) vehicles to air pollution through the burning of fossil fuels for power. An effective solution to address this issue involves transitioning to electric vehicles. Rather than relying on fossil fuels, these vehicles are charged using plug-in stations, significantly reducing their environmental impact[7]. Plug-in or conductive charging is the most common way to charge electronic vehicles. Though it is familiar, some issues arise when it comes to using conductive charging, such as the need to connect a cable, galvanic isolation for electronic components that are already on board the vehicle and its durability under poor and wet weather conditions [8]. With the increasing popularity of electric vehicles and their growing presence on the roads, the availability of conductive charging options is limited in various locations. This necessitates the development of a more convenient charging solution. Wireless Power Transfer (WPT) offers a method to address specific challenges associated with plug-in vehicles, particularly the convenience of charging. One such approach involves exploring dynamic wireless power transfer (DWPT) systems that enable charging while the electric vehicles are in motion. Implementing DWPT systems could potentially eliminate concerns related to shorter driving ranges [7]. The integration of Wireless Power Transfer (WPT) into electric vehicles presents inherent challenges. This paper will examine the current state of WPT systems, including their characteristics, parameters, and limitations, while also exploring effective strategies for implementing WPT onto electric vehicles. Wireless charging has gained widespread popularity in the modern world, with the most prevalent application being the wireless charging of mobile devices and other small handheld devices [9]. The initial crucial step towards integrating wireless charging into electric vehicles is the design and prototyping of the circuit. In this report, an analysis will be conducted on various circuit designs used for wireless charging with cellular devices, followed by necessary modifications tailored specifically for the application in a remote-control car.

This study aims to investigate existing WPT systems and evaluate their performance. Design, mode, and conduct numerical simulation of WPT circuits for mobile devices. Apply various techniques and optimize the most suitable technique for wireless charging for a remote-control vehicle. Experiment and prototype the proposed design. In addition, apply the proposed design to integrate on the remote-control vehicles.

This study aims to investigate and assess the performance of existing Wireless Power Transfer (WPT) systems. It involves designing, modelling, and numerically simulating WPT circuits for mobile devices. Various techniques will be explored and optimized specifically for wireless charging in a remote-controlled vehicle. The proposed design will be experimentally tested and prototyped. Furthermore, the design will be applied to integrate onto remote-control vehicles. An extensive literature review will be conducted to examine recent studies on WPT circuits. An initial WPT circuit will be designed, and subsequent developments will be carried out. Various techniques of WPT, tailored for mobile devices, will be optimized through numerical simulations and parametric analysis. The proposed design will be implemented for the mobile WPT circuits, and its application will be extended to the remote-control car. Experimental tests will be conducted on the design to evaluate its performance in wirelessly charging the remote-controlled vehicle through a WPT circuit.

II. Background

Nikola Tesla is known as a pioneer in the electrical engineering field. Tesla was one of the first to work on the realization of alternating current (AC) power. As well as working on the idea of it, he also made it into a reality by conducting work on it himself. A development from working on AC power would be a development in his work on the wireless transmission of electrical power, which at the time was conceived as an impossibility. The motive behind working on WPT was the idea to generate electricity that would be free for all to use. Though many did not believe that creating a WPT system was capable at the time, Tesla put in a lot of energy to materialise this ideology [10].

Amperes' and Faraday's laws were discovered in the early 19th Century and were classified as gateways for other researchers to explore the properties of electricity and electromagnetic fields. Come the 20th Century, WPT research was being conducted by some of the biggest pioneers such as Leblanc, Hutin and Tesla. Tesla made an impact, more than other researchers, on small to mid-range WPT that still has an impact on modern day WPT research [11].

Georgiy Babat was the first engineer to create a plausible application of inductive transmission in 1943 [12]. Babat created an electric vehicle that was supplied via inductive power transmission. The system comprised of copper tubing that formed a series of path buried under asphalt by about 20cm. The receiver of the system was placed on the underneath of the vehicle, positioned above the transmitter. The transmitter produced hundreds of amperes, at a frequency of approximately 50kHz. The current was rectified and fed directly into a 2kW motor. This system was not efficient with a rating of approximately 4% but was a working example on an electric vehicle [13].

The beginning of the 21st Century contained a lack of power standards for many portable devices such as mobile devices [14]. Thus, a collation of different types of plugs, power cables and other forms of powering these devices were introduced, creating more of a problem that a solution. To ensure this did not occur in wireless charging in said devices, a single standard of wireless charging was introduced. The Qi standard was the first standard for wireless energy transfer which was developed by the Wireless Power Consortium and introduced into the market circa 2008 [15]. Nokia was the first company to conform to this standard and was closely followed by other companies such as Toyota, Samsung, Apple, Microsoft as well as many others [16].

III. Methodology

For this project, research was conducted to explore WPT, its applications and how it can be implemented on EVs. The research phase was the first part of this project. Firstly, research was conducted on the different types of WPT, in terms of range, applications and implementation. This part of the research also briefly touched up on the history of electromagnetism and the introduction of WPT from Nikola Tesla and other engineers who worked in this field. The next part of the research was conducted on the coils that can be used in WPT and how the different types of coils can influence certain circuits. Firstly, the coil's parameters were looked at, mentioning how the size of the coil, size of the inner and outer diameters, coil shape and other factors will have and how it affects the circuits in question. The next area of research is conducted for the design phase of the circuits. Several different circuit designs on WPT systems can be found. This part of the research looks at the circuits in depth and compares them. These circuits are rebuilt on circuit design software Multisim, where different parameters are tested. Eventually, this will lead to a final circuit design which can lead to an implementation on a small-scale wireless charger. All research conducted for this project was done using engineering papers, journals, and websites. No independent research was required for this project, therefore outsourced research, such as surveys, was not required for this project report.

IV. Design and Analysis

A. Design Overview

The design process of a WPT is divided into two separate circuits, the transmitter, and the receiver. Assuming the transmitter circuit is connected to a 220V AC power supply, or mains supply, the AC power needs to be converted into DC to regulate the voltage via means of rectification. This DC power is the inverted back into AC power and connected to a compensator networker, which is comprised of capacitors, transistors and in some cases, other coils, or inductors. The compensation network is connected to a resistor and inductor which represent the primary coil. The same happens on the receiver circuit but these components are representations of the secondary or receiver coil.

The coil on the secondary circuit is connected to another compensation network, typically comprised of similar components to the transmitter compensator. This compensation network is then connected to a bridge rectifier, which will act as an AC/DC converter. A DC/DC convertor is directly connected to the rectifier circuit to lower or increase the DC output voltage to provide required power to charge the load device. A reference image for a typical WPT system can be shown in Fig. 1.

As afore mentioned, both circuits require compensation networks that are both directly connected to the coils. Compensation networks are reactive circuits that are constituted from a high frequency inverter which is controlled by using a phase-shift method. Fig. 2 shows an example of a compensation network that is used in certain WPT systems. This compensation network is known as a TT network. It contains three reactance components each side [17].

B. *Initial Designs*

Based on the block diagram in Fig. 1, the circuit in Fig. 3 represents a circuit diagram that follows along the diagram. This circuit was constructed using the software NI Multisim 14.2, which is a familiar program that is easy to use and contains all the components required for most circuit simulation. V1 represents the input voltage which, for this circuit design, will act as a mains supply. The transformer T1 is then connected to decrease the voltage down, this will act as the AC/DC inverter. This rectifier is constructed using 1N4007 general purpose diodes. From the inverter, the compensation network can be shown as three capacitors connected in parallel. This network acts as a smoothing system, allowing the waveform from the inverter to smooth to better represent a DC output. T2 represents where the transmitter coil and receiver coil. The compensation network in the receiver circuit is simply represented as a 1uF capacitor. This is connected to the bridge rectifier 1B4B42. As the output voltage from the bridge rectifier is still too high, the circuit

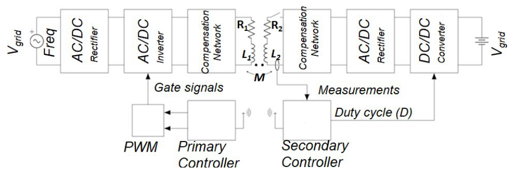


Fig. 1. Typical WPT system.

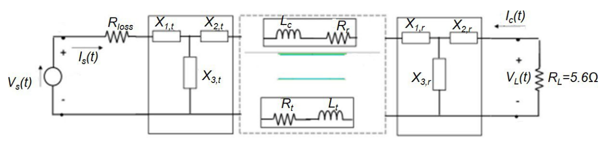


Fig. 2. TT compensation system [17].

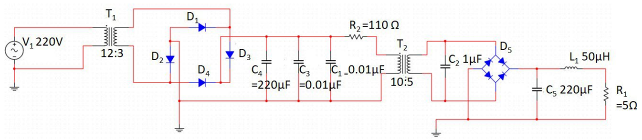


Fig. 3. WPT circuit design used for charging small devices.

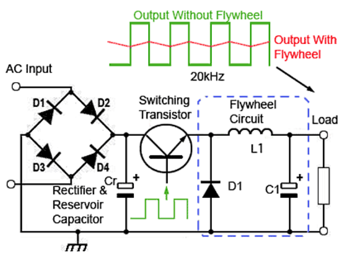


Fig. 4. Buck Converter Circuit Diagram [18].

is connected to a DC/DC buck converter. The buck converter in this circuit is a representation of the DC/DC converter. As this is a system to charge small devices wirelessly, a buck converter is used as this converter is used to decrease the output voltage so that it is lower than the input voltage. Fig. 4 shows a representation of a buck converter in a standard application. R1 is a 5 Ohm resistor that acts as the load resistor. In this case, the load acts as a mobile device. The circuit in Fig. 3 is a circuit that can actively work as a WPT system. However, as this circuit has a primary use for power up low power devices, such as mobile phones, there is a lot of unnecessary parts of the circuit that can be removed due to already existing technologies. Fig. 5 is a plug adapter that converts the AC mains supply into a 5V DC voltage. Fig. 5 also contains a circuit diagram of a circuit contained within the adapter. This adapter is commonly used for many low power devices, if the adapter is implemented, the design of the circuit can be made simpler.

C. *Receiver Circuit*

As aforementioned, evert WPT system is divided into two separate parts, the transmitter and receiver. This section looks at the receiver circuit and its characteristics. Fig. 6 shows block diagram of a typical receiver circuit and the segments of said receiver. The receiver coil acts as the power supply for the receiver circuit, providing an AC power supply. From the power supply, a compensator network is connected from the source into an AC/DC rectifier. The circuit then continues into a DC-DC converter or a regulator. The DC regulation is then connected to the load resistance.

Fig. 7 shows a receiver circuit that has been built and simulated in the Multisim. The 'Rx_COIL' is represented as an inductor, due to Multisim not containing the appropriate components for this circuit. A compensator network is not used in this circuit, due to the voltage already being low enough. The rectifier (D1D4) consists of four 1N4001 diodes connected in a rectifier configuration, allowing the voltage to change from AC to DC. Capacitors are then used to help smooth the AC waveforms into a more appropriate DC wave. The circuit that was constructed in Fig. 4 used a buck

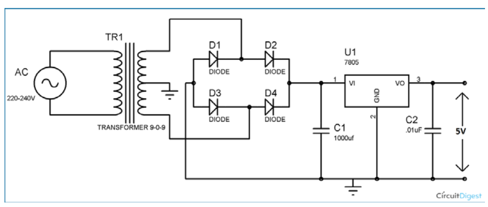


Fig. 5. AC power supply adapter and circuit diagram [19].

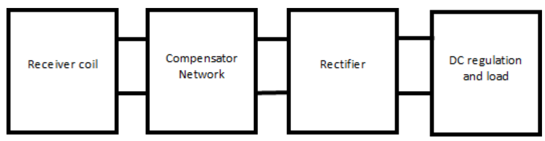


Fig. 6. Receiver Circuit Block Diagram.

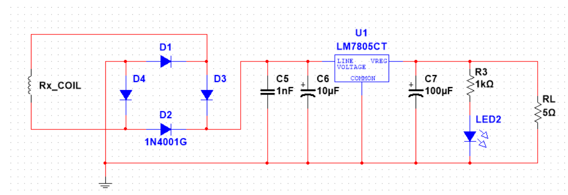


Fig. 7. Receiver Circuit.

converter as the DC/DC converter to help lower the output voltage. In the circuit depicted in Fig. 7, a LM7805 voltage regulator has been used. The voltage regulator outputs 5V which then connected to the load resistor (RL). An LM7805 voltage regulator was used in this instance as it is a more consistent alternative to a DC/DC buck converter. LM7805CT circuits will always output 5V, should the input to the voltage regulator is at least 7V. This differs from the buck converter as the buck would not be able to consistently produce 5V output. Certain parameters of the buck converter would have to be altered carefully to achieve the desired output (find something about voltage regulators).

The receiver circuit from the simulation in Multisim, depicted in Fig. 7 was reconstructed using a breadboard and power supply unit. An LED is connected where the load resistor would be to represent the functionality of the receiver circuit. Using a multi-meter, the output voltage was recorded at different input value, to test the LM7805CT which can be seen into Table I.

The input voltage did not exceed 12V due to other component capabilities as well as the fact the circuit will not need to exceed 12V input from the receiver coil. The table shows that each time, the circuit achieved a 5V output which demonstrates the reliability and consistency of the LM7805CT.

D. *Transmitter Circuit*

When using the adapter in Fig. 5, the needs to use high-cost components, such as transformers, are no longer required, therefore simpler circuit can be created. The transmitter circuit is directly connected to the power source which in this case is a 5V input, the way the rest of the circuit is then designed can vary in different ways.

Fig. 8 shows a basic transmitter circuit. This circuit uses IRF44ZN transistors, which in this instance are labelled Q1 and Q2. These types of transistors are known as MOSFETs. The MOSFET will activate when a certain voltage is achieved across the gate and source pin. The voltage will appear at the terminals of both Q1 and Q2 however only one will be active at a time. For example, if Q1 was turned on first, the voltage at the drain pin will be held at ground. Simultaneously, Q2 will be in a less inductive state, allowing a maximum voltage to be held which will then fall via the capacitor configuration at the end of the circuit. This capacitor system is connected to L3 which represents the transmitter coil in this state.

TABLE I. OPERATION OF LM7805CT

Input Voltage (V)	Output Voltage (V)
5	0
6	0
7	5
8	5
9	5
10	5
11	5
12	5

Other forms of transmitter circuits are shown in Fig. 9. This circuit is simpler to follow and only requires the one MOSFET transistor. The circuit also shows and different configuration of the coil having a connection directly from the power source. This is known as a centre tap, which allows coil to work on both the top and the bottom of the coil. As this is difficult to represent on Multisim a centre tapped coil can be seen in Fig. 9.

E. *Implementation of the Circuit on an EV*

For this experiment, implementing a WPT system on to an actual EV was extraordinarily unrealistic, therefore the construction was completed using a remote-control (RC) car. The remote-control car that was used in this experiment required a rechargeable battery and charges via a USB cable. The prototype circuits that were constructed we unable to be implemented onto the vehicle to time restraints and availability of resources were unavailable for this circuit. Therefore, a transmitter and receiver circuit were purchased and implemented in the vehicle. Fig. 10 shows the WPT block diagram.

The USB cable used for the car was adjusted to a shorter length to allow everything to fit in the compartment underneath the car, which is depicted in Fig. 11. When the transmitter circuit is powered on, the car must park directly over the transmitter cable in parallel to the receiver circuit. When the car is placed over the transmitter circuit, and the car is turned into the off position, the vehicles will begin to charge. There is a light that shines underneath the car that indicates when it is charging. The light underneath the car then

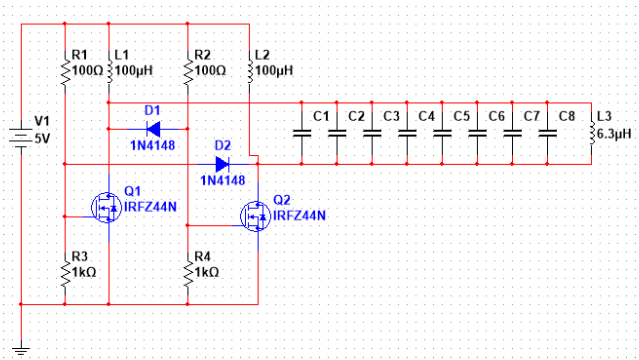


Fig. 8. Transmitter circuit.

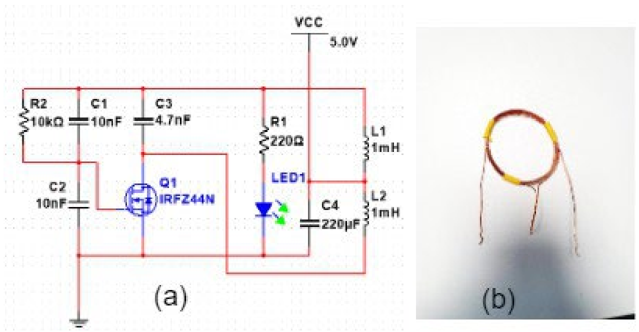


Fig. 9. (a) Transmitter circuit, (b) physically constructed centre tapped coil.

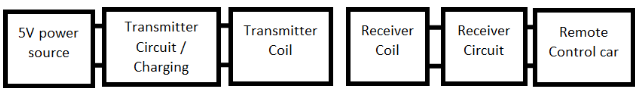


Fig. 10. WPT block diagram.

turns off once the car has finished charging, indicating the battery is full capacity. An example of this can be seen in Fig. 12.

F. Results

After ensuring that the remote-control car could charge under the new charging method it has come under, a few other tests were conducted to experiment under how well the circuit could cope in different circumstances. It was evident that the circuit could operate when the power supply voltage was anywhere between 3V and 12V, however under realistic circumstances, the input voltage would be 5V, should the power source come from a USB-C cable connected to the adapter from the mains supply. The test of the input voltage for the transmitter circuit was tested upon and the results are found in Table II. This was tested when the coils were touching (0cm apart).

Another concern that was presented was how well the car would charge when the coils are different distances apart. On the car, there is approximately 2cm between the two coils which allowed the car to charge under decent conditions. However, the distance does have an effect and will stop after a certain distance. This was tested and the results can be found in Table III. This was tested under a 5V input.

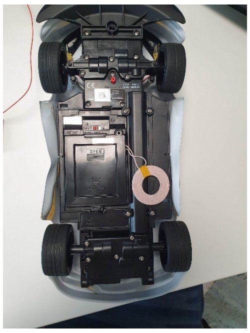


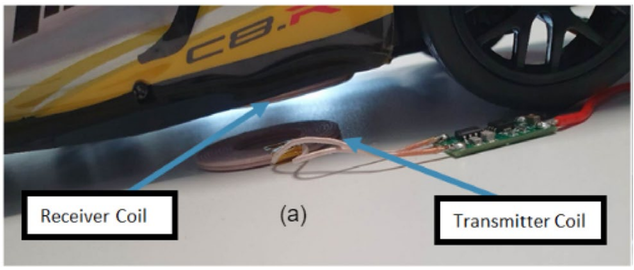
Fig. 11. Receiver coil placed at the bottom of the car.

TABLE II. OUTPUT VOLTAGE UNDER DIFFERENT INPUT VOLTAGE

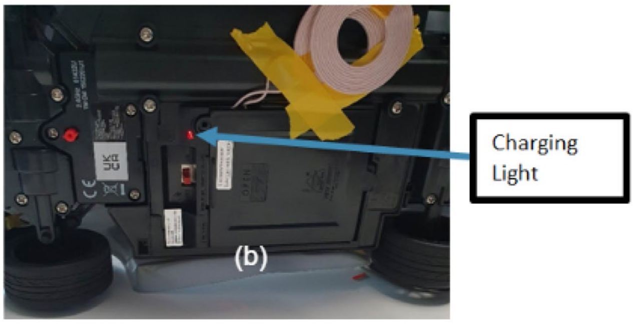
Input Voltage (V)	Output Voltage (V)
0	0
3	5.29
6	5.29
9	5.29
12	5.29

TABLE III. OUTPUT VOLTAGE DEPENDING ON THE DISTANCE BETWEEN TX AND RX COIL

Distance Between Coils (cm)	Output Voltage (V)
0	5.29
1	5.29
2	5.29
3	0
4	0
5	0



(a)



(b)

Fig. 12. (a) Remote Control car parked over Tx circuit, (b) LED light underneath remote-control car to indicate charging.

V. CONCLUSION

This paper showcases an example of wireless power transfer (WPT) charging, providing an efficient and environmentally friendly method for powering cars. Despite facing challenges, the modified remote-control car performed satisfactorily in the given context. The study emphasized specific areas for improvement, with a focus on enhancing circuit simulations. To achieve better outcomes in future advancements, a more thorough analysis will be presented. It was recognized that the transmitter circuit and power source encountered issues, leading to suggestions for potential solutions such as incorporating larger batteries or modifying the circuit design. Despite these obstacles, the operational design strongly validates the feasibility of utilizing WPT for EV charging. This advancement holds great promise in reducing emissions and promoting the adoption of cleaner transportation options. Wireless charging eliminates the need for physical connections, offering the convenience of hasslefree charging while reducing strain on traditional charging infrastructure. Additionally, it creates a visually appealing and clutter-free environment, contributing to the overall appeal of electric vehicles among consumers.

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