

Advancing Portable Telephone Battery Chargers with Contactless Electrical Energy Transmission Systems

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ABSTRACT

In the era of portable electronics, the demand for efficient and convenient charging solutions has led to the exploration of innovative technologies such as contactless electrical energy transmission systems. This comprehensive review examines the principles, design methodologies, challenges, and applications of contactless electrical energy transmission systems for portable telephone battery chargers. By delving into the intricacies of contactless charging, this review aims to shed light on its potential to revolutionize the way we power our portable devices, offering insights into advancements, limitations, and future directions in this rapidly evolving field.

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INTRODUCTION

Portable telephones, commonly known as mobile phones or cell phones, have become indispensable companions in modern life, serving as communication devices, entertainment hubs, and productivity tools.^[1-16] However, the need for frequent charging poses challenges in terms of convenience, accessibility, and portability. Contactless electrical energy transmission systems offer a promising solution to these challenges by enabling wireless charging of portable telephone batteries, eliminating the need for physical connectors and cables. This review explores the evolution, principles, and applications of contactless charging systems for portable telephone battery chargers, aiming to elucidate their significance in addressing the evolving needs of mobile users.^[17-19]

Contactless electrical energy transmission systems, also known as wireless power transfer (WPT) systems, represent a revolutionary approach to transmitting electrical power over short distances without the need for physical connectors or wires. This technology enables the efficient and convenient transfer of electrical energy between a power source and a receiver device using electromagnetic fields.^[20-26]

The introduction of contactless electrical energy transmission systems has paved the way for a wide range of applications across various industries, including consumer electronics, automotive, healthcare, and

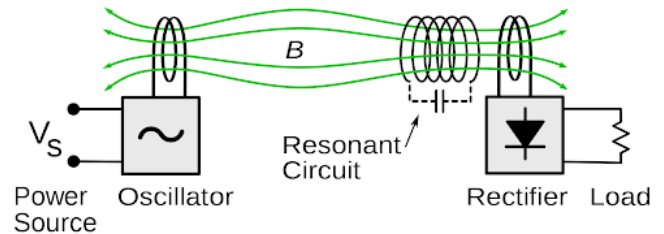


Fig. 1: Contactless Power Transfer

industrial automation. These systems offer several advantages over traditional wired power transmission methods, including increased convenience, reduced wear and tear, enhanced safety, and improved aesthetics given in the Fig. 1.

One of the key components of contactless electrical energy transmission systems is the transmitter, which generates an alternating electromagnetic field. The receiver, typically located within the device being powered, captures this electromagnetic field and converts it back into electrical energy, which is then used to charge batteries or power electronic circuits.^[27-33] Contactless electrical energy transmission systems can operate using various principles, including magnetic induction, magnetic resonance, and radio frequency (RF) energy harvesting. Each principle has its unique advantages and limitations, depending on factors such as distance, efficiency, and power requirements.

Overall, contactless electrical energy transmission systems offer a promising solution for powering electronic devices and systems wirelessly, eliminating the need for physical connectors and enabling greater flexibility and convenience in power delivery. As technology continues to advance, contactless WPT systems are expected to play an increasingly important role in enabling new applications and driving innovation in power transmission and distribution.

EVOLUTION OF CONTACTLESS ELECTRICAL ENERGY TRANSMISSION SYSTEMS

Contactless electrical energy transmission systems have a rich history dating back to the early experiments in wireless power transmission by Nikola Tesla in the late 19th and early 20th centuries. Tesla's pioneering work laid the foundation for modern wireless charging technologies, which have evolved significantly over the decades. The advent of electromagnetic induction, resonant coupling, and magnetic resonance technologies has led to the development of efficient and reliable contactless charging systems for a wide range of applications, including portable telephone battery chargers.

The evolution of contactless electrical energy transmission systems, also known as wireless power transfer (WPT) systems, has been marked by significant advancements in technology and application. This evolution can be traced back to the pioneering work of Nikola Tesla in the late 19th and early 20th centuries, who envisioned a world where electrical energy could be transmitted wirelessly over long distances using electromagnetic fields.^[34-39]

In the decades that followed, researchers and engineers continued to explore various methods and techniques

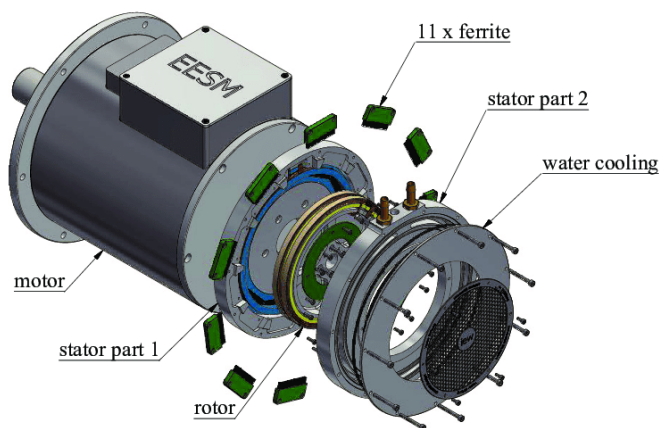


Fig. 2: Exploded view of a rotating contactless energy transfer system

for wirelessly transferring electrical energy. Early experiments focused on magnetic induction, where electrical energy is transferred between coils through mutual induction. While effective for short-range applications, magnetic induction had limited efficiency and range given in the Fig. 2.

The development of magnetic resonance technology in the mid-20th century revolutionized wireless power transfer, enabling more efficient and flexible energy transmission over longer distances. Magnetic resonance systems utilize resonant coupling between coils to transfer energy at specific frequencies, allowing for greater power transfer efficiency and improved range.^[40-46]

In recent years, advancements in semiconductor technology, materials science, and electromagnetic theory have further propelled the evolution of contactless electrical energy transmission systems. New techniques such as beamforming, metamaterials, and capacitive coupling have expanded the capabilities of wireless power transfer, enabling higher power levels, longer distances, and improved efficiency.^[47-53]

Today, contactless electrical energy transmission systems find applications across a wide range of industries, including consumer electronics, automotive, healthcare, and industrial automation. These systems are used to wirelessly charge smartphones, electric vehicles, medical implants, and electronic devices, offering increased convenience, safety, and efficiency compared to traditional wired power transmission methods given in the Fig. 3.

Looking ahead, the evolution of contactless electrical energy transmission systems is expected to continue, driven by ongoing advancements in technology and increasing demand for wireless power solutions. As wireless power transfer becomes more ubiquitous, it has the potential to revolutionize the way we power and interact with electronic devices, leading to new opportunities for innovation and growth in the global economy.

PRINCIPLES OF CONTACTLESS ELECTRICAL ENERGY TRANSMISSION

Contactless electrical energy transmission relies on the principles of electromagnetic induction, resonant coupling, or magnetic resonance to transfer power wirelessly from a transmitter to a receiver. In electromagnetic induction-based systems, alternating current (AC) is passed through a primary coil, generating a time-varying magnetic field. This magnetic field induces an electromotive force (EMF) in a secondary coil placed in close proximity, resulting in

the transfer of electrical energy. Resonant coupling and magnetic resonance technologies enhance the efficiency and range of contactless charging systems by matching the resonant frequencies of the transmitter and receiver coils, enabling efficient power transfer over longer distances. Contactless electrical energy transmission, also known as wireless power transfer (WPT), operates on the fundamental principles of electromagnetic induction and resonance. These principles enable the efficient transfer of electrical energy between a transmitter and a receiver without the need for physical connectors or wires.

At its core, electromagnetic induction involves the generation of an alternating electromagnetic field by the transmitter coil. This alternating magnetic field induces an electromotive force, or voltage, in the receiver coil through mutual induction. The induced voltage generates an electric current in the receiver circuit, which can be used to charge batteries or power electronic devices given in the Fig. 4.

In magnetic resonance-based WPT systems, resonance plays a crucial role in enhancing power transfer efficiency and extending the range of transmission. Resonance occurs when the natural frequencies of the transmitter and receiver coils are closely matched. When operating at resonance, the transmitter coil generates a strong electromagnetic field, which is efficiently coupled to the receiver coil, enabling efficient power transfer over longer distances.

Another principle commonly used in contactless electrical energy transmission is radio frequency (RF) energy harvesting. RF energy harvesting systems capture ambient RF signals from sources such as Wi-Fi routers, cellular towers, and radio transmitters and convert them into electrical energy using specialized antennas and rectifiers. This harvested energy can then be used to power low-power electronic devices or recharge batteries.

Overall, the principles of electromagnetic induction, resonance, and RF energy harvesting form the basis of contactless electrical energy transmission systems.

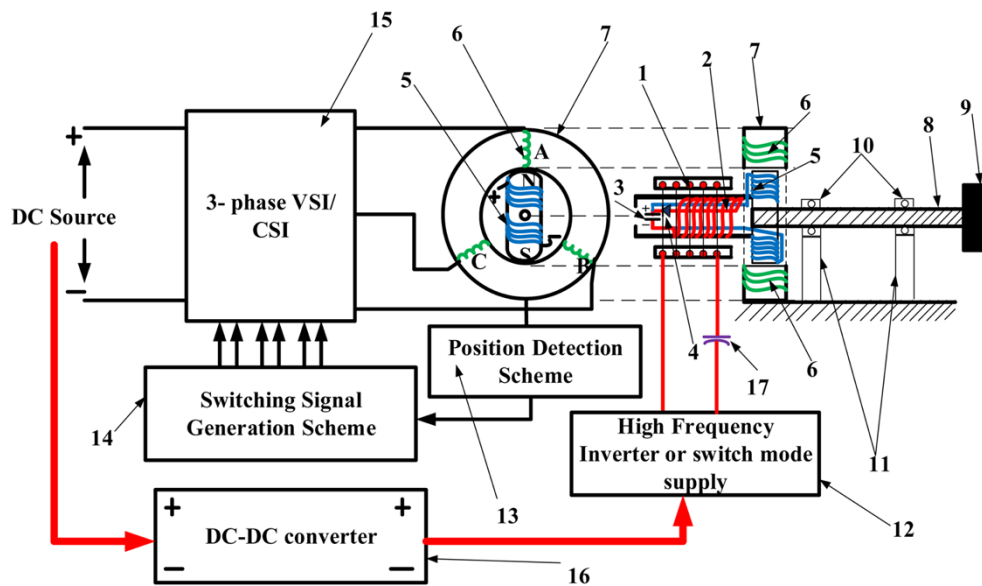


Fig. 3: A low-power prototype of contactless field power

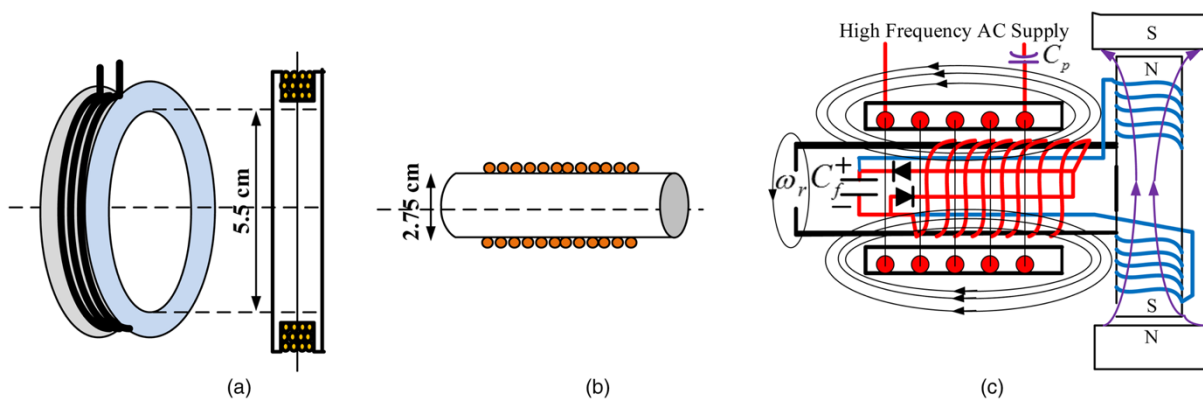


Fig. 4: Field power controlled BLAC and BLDC motors

By leveraging these principles, WPT systems enable the wireless transfer of electrical energy over short to moderate distances, offering increased convenience, flexibility, and efficiency compared to traditional wired power transmission methods. As technology continues to advance, contactless electrical energy transmission systems are expected to play an increasingly important role in powering a wide range of electronic devices and applications, driving innovation and enabling new possibilities in energy delivery and distribution.

DESIGN METHODOLOGIES FOR CONTACTLESS CHARGING SYSTEMS

Designing efficient and reliable contactless charging systems requires careful consideration of various factors, including coil geometry, resonance frequency, power conversion efficiency, and electromagnetic compatibility. Coil design plays a critical role in optimizing the magnetic coupling between the transmitter and receiver, maximizing power transfer efficiency while minimizing electromagnetic interference and heating effects. Advanced design methodologies, such as finite element analysis (FEA), electromagnetic simulation, and optimization algorithms, are employed to optimize coil geometries, impedance matching networks, and power management circuits for contactless charging systems. Designing contactless charging systems involves several key methodologies aimed at optimizing efficiency, reliability, and safety while meeting the specific requirements of the application. These methodologies encompass various aspects of system design, including coil configuration, resonant frequency selection, power management, and electromagnetic field optimization given in the Fig. 5.

One crucial aspect of contactless charging system design is coil configuration. The arrangement and geometry of transmitter and receiver coils play a significant role in

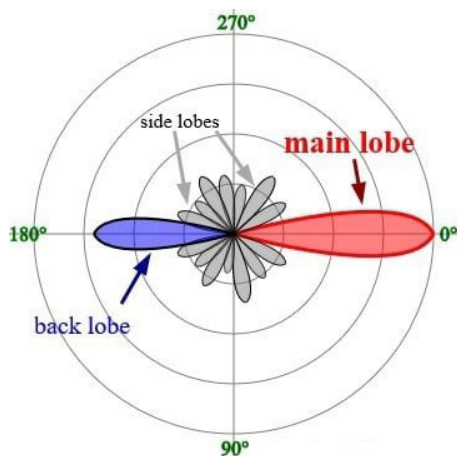


Fig. 5: Radiation Patterns

determining the efficiency and range of power transfer. Designers often employ analytical modeling, simulations, and experimental testing to optimize coil geometry and spacing for maximum coupling efficiency and power transfer.

Resonant frequency selection is another important consideration in contactless charging system design. By operating at resonance, the system can achieve higher power transfer efficiency and extend the range of transmission. Design methodologies involve tuning the resonant frequency of the transmitter and receiver coils to match each other, either through manual adjustment or automatic frequency tracking algorithms.

Power management is a critical aspect of contactless charging system design, particularly in applications with stringent power requirements or limited energy resources. Designers must implement efficient power conversion, regulation, and control techniques to ensure optimal energy transfer and minimize losses during power transmission.

Moreover, optimizing the electromagnetic field distribution is essential for ensuring uniform power delivery and minimizing electromagnetic interference (EMI). Design methodologies involve analyzing electromagnetic field patterns, adjusting coil geometry and orientation, and implementing shielding techniques to mitigate EMI and ensure safe operation of the charging system.

Furthermore, safety considerations are paramount in contactless charging system design, particularly concerning electromagnetic radiation exposure, thermal management, and fault detection. Design methodologies include compliance with relevant safety standards and regulations, implementing temperature monitoring and cutoff mechanisms, and incorporating fault detection and isolation features to prevent system damage or harm to users given in the Fig. 6.

Overall, the design methodologies for contactless charging systems involve a multidisciplinary approach, combining expertise in electromagnetic theory, power electronics, control systems, and safety engineering.

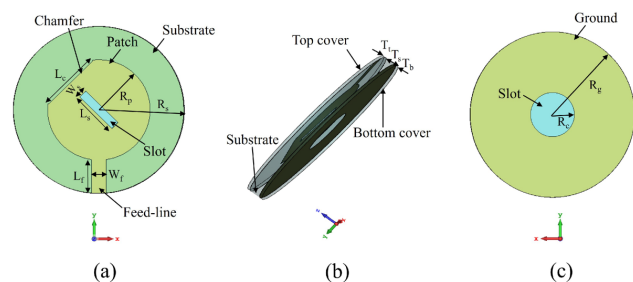


Fig. 6: Flexible and Transparent Circularly Polarized Patch Antenna

By employing these methodologies, designers can develop contactless charging systems that offer efficient, reliable, and safe wireless power transfer for a wide range of applications.

CHALLENGES AND LIMITATIONS

Despite the advantages of contactless electrical energy transmission systems, several challenges and limitations must be addressed to realize their full potential in portable telephone battery chargers. These include:

- **Efficiency and Power Losses:**Contactless charging systems may suffer from power losses due to factors such as coil misalignment, electromagnetic interference, and parasitic losses. Improving power conversion efficiency and minimizing losses are critical challenges in contactless charging system design.
- **Range and Alignment:**The range of contactless charging systems is limited by the strength of the magnetic field and the distance between the transmitter and receiver coils. Achieving efficient power transfer over longer distances without compromising safety and performance remains a significant challenge.
- **Interference and Compatibility:**Contactless charging systems may generate electromagnetic interference (EMI) that can interfere with other electronic devices and communication systems. Ensuring electromagnetic compatibility (EMC) and compliance with regulatory standards are essential considerations in contactless charging system design.
- **Safety and Health Concerns:**Contactless charging systems may raise concerns regarding electromagnetic radiation exposure and potential health risks. Addressing safety concerns, implementing shielding techniques, and conducting rigorous testing are critical steps in ensuring the safety and reliability of contactless charging systems.

APPLICATIONS OF CONTACTLESS ELECTRICAL ENERGY TRANSMISSION SYSTEMS

Contactless electrical energy transmission systems have diverse applications in portable telephone battery chargers, offering convenience, flexibility, and mobility for mobile users. Some common applications include:

- **-Smartphones and Mobile Devices:**Contactless charging systems enable wireless charging of smartphones, tablets, and other mobile devices, eliminating the need for physical connectors and

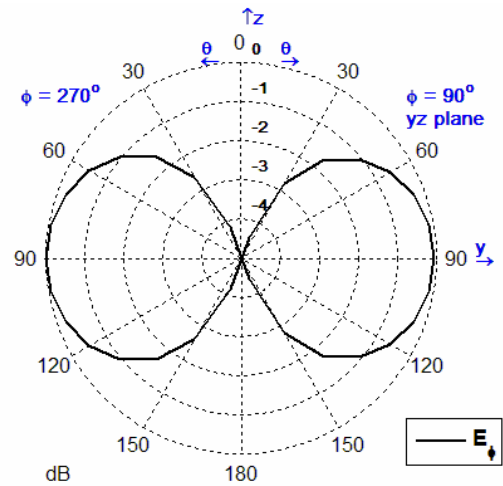


Fig. 7: Simulated far-field radiation patterns for thin-wire

cables. Wireless charging pads, stands, and furniture embedded with contactless charging technology provide convenient charging solutions for mobile users given in the Fig. 7.

- **Wearable Devices:**Contactless charging systems are used to power wearable devices such as smartwatches, fitness trackers, and wireless headphones. Wireless charging modules integrated into wearable accessories enable hassle-free charging without the need for docking stations or charging cables.
- **Automotive Applications:**Contactless charging systems are increasingly being adopted in electric vehicles (EVs) and hybrid vehicles for wireless charging of onboard batteries. Wireless charging pads installed in parking spaces and garages allow EV owners to recharge their vehicles conveniently and efficiently.
- **Industrial and Medical Devices:**Contactless charging systems find applications in industrial automation, robotics, and medical devices, where reliability, safety, and convenience are paramount. Wireless charging technology enables seamless integration of battery-powered devices into complex systems and environments.

FUTURE DIRECTIONS AND EMERGING TRENDS

The field of contactless electrical energy transmission systems for portable telephone battery chargers is evolving rapidly, driven by advancements in coil design, power electronics, and wireless communication technologies. Emerging trends and future directions in contactless charging systems include:

- High-Efficiency Resonant Coupling: Advancements in resonant coupling technologies, such as magnetic resonance coupling and capacitive coupling, are expected to improve power transfer efficiency and range in contactless charging systems.
- Multi-Device Charging: Multi-device contactless charging solutions capable of charging multiple devices simultaneously are gaining popularity, offering convenience and flexibility for users with multiple devices.
- Integration with IoT and Smart Home Systems: Contactless charging systems are being integrated into IoT devices, smart home systems, and connected appliances, enabling seamless energy transfer and communication between devices.
- Standardization and Interoperability: Efforts to standardize contactless charging technologies and establish interoperability between different devices and manufacturers are underway, aiming to enhance compatibility, reliability, and user experience.
- Energy Harvesting and Wireless Power Transfer: Contactless charging systems are being combined with energy harvesting technologies, such as solar panels and piezoelectric devices, to enable self-powered and autonomous operation of portable devices.

CONCLUSION

Contactless electrical energy transmission systems represent a promising solution for powering portable telephone battery chargers, offering convenience, flexibility, and mobility for mobile users. Despite the challenges and limitations, advancements in coil design, power electronics, and wireless communication technologies are driving innovation in contactless charging systems, opening new possibilities for wireless charging in diverse applications. By addressing technical barriers, ensuring safety and compatibility, and embracing emerging trends, contactless charging systems have the potential to revolutionize the way we charge and power our portable devices, ushering in a new era of wireless convenience and connectivity.

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