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Wireless Mobile Charging: A Revolution

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Abstract: *Wireless charging is an advancement that allows power to be sent through the air to devices, with the main goal of recharging energy. Recent developments in wireless charging methods and improvements in related technologies have provided a promising solution to the energy limitations of many battery-powered devices. However, the circuits used in wireless charging systems also bring up challenges related to performance, design, and power delivery. In this article, a comprehensive overview of wireless charging techniques is provided, along with improvements in specific areas and some system applications. Overall, the system applications of these methods are connected to medical implants and flexible chargers for various electrical and electronic devices. Additionally, the open challenges in implementing wireless charging technologies have been examined. In this article, a general overview of wireless charging advancements has been introduced.*

Keywords: Wireless charging, Wireless Power Transfer, Resonance coupling. Acoustic Power transfer, Ultrasonic Resonance

I. INTRODUCTION

Wireless charging, also known as Wireless force move, is an innovation that allows a source to send electromagnetic energy to an electrical device through the air without requiring wires. This technology is gaining popularity for a wide range of uses, from a low-power toothbrush to high-power vehicles, due to its convenience and improved user experience. Now a-days, this development is quickly moving from theoretical concepts towards becoming a standard feature in everyday products, especially with the rise of advanced devices. Major companies like Samsung, Apple, and Huawei have started releasing new smartphones that include built-in wireless charging capabilities. According to IMS Research, the wireless charging market was expected to reach 4.5 billion by 2016, and it has already surpassed those predictions. Pike Research estimated that the market for cordless charging devices would grow significantly by 2020, reaching a value of 20 billion. Compared to traditional charging methods, wireless charging offers several advantages. First, it improves convenience by eliminating the need to connect cables. Second, it allows multiple brands and models to be charged using the same charger. Third, it increases flexibility, especially for devices that require battery replacements or cable connections. Fourth, it enhances durability, particularly for contactless devices, offering better water and dust resistance. Fifth, wireless charging provides greater control over the charging process, making it more versatile and efficient. However, wireless charging typically has higher production costs compared to wired charging. Initially, a wireless charger must replace a traditional charging cable. Additionally, a device must be equipped with a wireless power receiver. Moreover, wireless chargers often generate more heat than wired chargers, which may lead to increased material costs.

The development of wireless charging is primarily moving in:

A. Radiative Wireless Charging (RF or radio frequency-based wireless charging)
B. Non-radiative Wireless Charging (coupling-based wireless charging)
C. Acoustic Wireless Charging (ultrasonic resonance-based wireless charging).

Radiative wireless charging uses EM waves, specifically RF waves or microwaves, for power transfer through the air. The energy transfer is based on the electric field of the EM wave, which is radiative. Due to health concerns related to RF exposure, these chargers generally operate in low-power environments. Non-radiative wireless charging, on the other hand, relies on the coupling of magnetic fields between two coils within a certain distance for energy

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transmission. Since the magnetic field of the EM wave diminishes faster than the electric field, the range for energy transfer is limited in this method. Because of its non-radiative nature, this method is commonly used in gradual charging processes. In addition to these developments, there is another emerging technology called Acoustic Power Transfer, which uses ultrasonic vibrations for energy transfer. This method has a good potential to enter the market as it is both efficient and environmentally friendly. This article provides a comprehensive overview of the latest wireless charging technologies, their structures, and their applications in communication systems. The article is organized based on the following structure: it begins by explaining the origin of wireless charging and the fundamental principles of wireless power transfer. It also covers the different types of wireless charging technologies that have been developed so far, including inductive coupling, magnetic resonance coupling, RF/microwave radiation, and Acoustic (ultrasonic resonance). The article will also discuss the types of wireless charging technologies, including diagrams, system flows, functionality, applications, advantages, and disadvantages.

II. HISTORY

Electromagnetism is the foundation of wireless power transfer, where electromagnetic waves carry energy. The study of electromagnetism began in 1819 when H.C. Oersted discovered that electric current creates a magnetic field around it. Later, scientists like Ampère, Biot, and Savart developed laws that explained key properties of magnetic fields. In 1864, James Clerk Maxwell introduced a set of equations that described how electric and magnetic fields are generated and change together. His book, "A Treatise on Electricity and Magnetism," published in 1873, unified electricity and magnetism into one theory. From that point on, electricity and magnetism were understood as two aspects of the same fundamental force.In the late 1800s, Nikola Tesla, known for creating the rotating magnetic field used in modern power systems, was the first to experiment with wireless power transfer using microwaves.He worked on long-distance wireless power transmission and demonstrated the transmission of microwave signals over a distance of about 48 kilometers in 1896. Another major development in 1899 was transmitting 108 volts of high-frequency electric power over a distance of 25 miles to light 200 bulbs and run an electric motor. However, Tesla's method had limitations, as sending such high voltages through the air could be harmful to people and electrical equipment nearby.

Around the same time, Tesla also worked on improving the magnetic field for wireless power transfer by developing the famous "Tesla coil," illustrated in 1901.

He built the Wardenclyffe Tower, which was intended to transmit electrical energy without wires through the atmosphere. However, due to technical limitations, such as low system efficiency caused by large-scale electric fields, the idea was never widely adopted or promoted. Alongside Tesla, W.C. Brown, an engineer, developed a device called Rectenna [4], which is used to convert microwave power into electricity. Improvements have been made to the Rectenna setup to increase the efficiency of power transfer. This is the real basis of modern wireless charging technology.

III. FUNDAMENTAL PRINCIPLE OF WIRELESS CHARGING

Wireless force move? It's basically kinda like, um, your typical communication system stuff. Power, specifically, has gotta get from one spot– the transmitter– to another, the receiver. We're talking different methods, ya know? Like coupling or RF stuff. So, it's pretty similar to how a message signal moves from, like, a transmitter to a receiver in, um, normal communication systems, where they use different modulation schemes. These schemes help the signal get there effictively. So, in a nutshell, wireles charging technologies? They're kinda like modulation schemes... in, you know, regular old communication systems.

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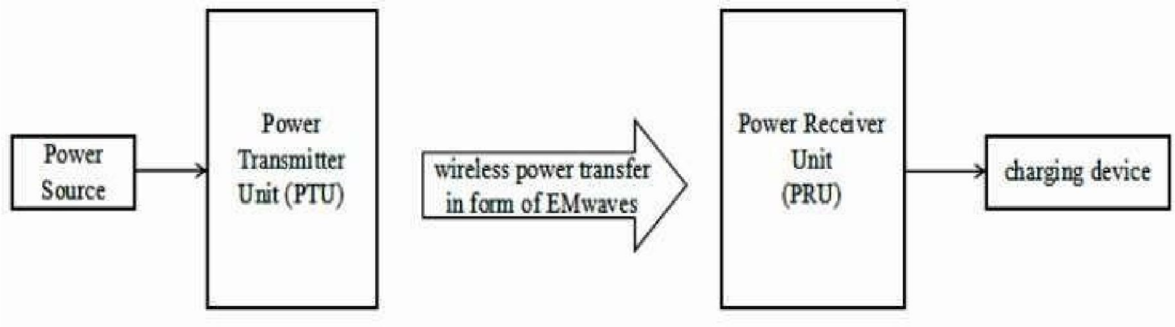

Fig.1. Block Diagram of Basic Wireless Charging Device

Above Figure 1 shows the basic square graph of the key Wireless charging technology. The first square represents the power source, which is commonly used and provides the electrical power. The next square is the Power Transmitting Unit (PTU), which includes an energy amplifier, matching circuits, A-D converters, a communication module, and a resonator (primary) or transmitter. In this square, electrical energy is converted into electromagnetic (EM) waves. These EM waves carry the electrical energy through the air gap to the next part. This PTU square has a similar function to the modulator in a communication system. Alongside the PTU, there is the Power Receiving Unit (PRU), which includes a resonator (secondary) or receiver, rectifiers, DC-DC converters, and a communication module. Here, DC-DC converters are used instead of DC-AC converters because the main loads are batteries. Batteries store the energy in the form of DC. Regardless of the DC input provided, the battery can take in the energy and store it [5]. This is one of the key features of good wireless charging, as mentioned in Section 1.

IV. WIRELESS CHARGING TECHNOLOGIES

In this section, the main data related to wireless charging is discussed, covering the standards of development and how this technology is currently being used. It also looks into the design of the charging system in engineering, the hardware components, and their usage.

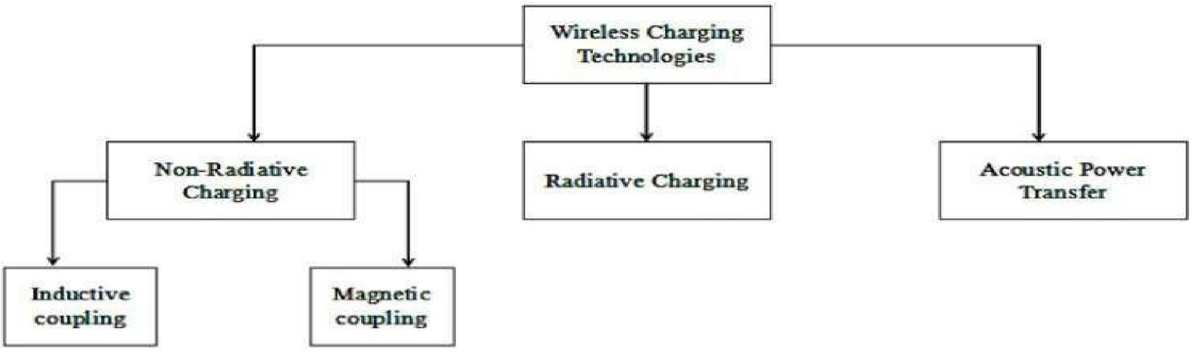

Fig.2. Classification of the Wireless Charging Technologies

As shown in the figure above, wireless charging can be broadly divided into three types: non-radiative coupling-based charging, radiative RF-based charging, and acoustic ultrasonic-based charging.

Non-Radiative Charging: The basic structure of a general non-radiative wireless charging system includes a transmitter side with three main components:

i) An AC/DC rectifier that converts alternating current (AC) to direct current (DC);

ii) A DC/DC converter that adjusts the voltage level of a DC source;

iii) A DC/AC inverter that converts DC back to high-frequency AC power.

The wireless charging process works as follows: Initially, a power source is needed to operate the AC/DC rectifier. Since standard AC operates at either 50Hz or 60Hz, which is too low for wireless charging, the charger first converts AC to DC, increases the voltage, and then converts the DC back to high-frequency AC. This high-frequency AC passes

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through the transmit coil, creating a magnetic field around it. The AC is then induced in the receive coil, which is located away from the transmit coil by an air gap. The energy receiver converts this induced AC back to DC and adjusts it to the required voltage for the device. The battery of an electronic device can then be charged at this point.

This process is further categorized into three types based on the coupling between the coils for transferring power: inductive coupling, magnetic coupling, and capacitive coupling.

In capacitive coupling, the coupling capacitance depends on the area covered by the device. However, for a typical-sized mobile electronic device, it is difficult to achieve the required power density.

Due to this limitation, non-radiative charging is typically carried out using two methods: magnetic inductive coupling and magnetic resonant coupling. These methods are used in near-field applications where the electromagnetic field dominates the area close to the transmitter and receiver. In far-field applications, the absorption of the radiation does not affect the receiver. On the other hand, for near-field applications, the load is significantly affected by the field produced by the transmitter. This is because, in far-field applications, the transmitter and receiver are not part of the energy receiver's loop, which is within the field and usually at a frequency lower than the field's frequency. In near-field applications, the current or voltage is induced in the secondary coil of the energy receiver within the field. This induced voltage can be used to charge wireless devices or energy systems. The frequency of this method is up to kilohertz. The secondary coil should be tuned to the working frequency to improve charging efficiency. In reality, the quality factors of these circuits are low because the transferred power decreases quickly with higher quality factors. Due to the lack of high-quality components, the effective charging distance is limited to centimeters.

Highlights: The advantages of inductive coupling include ease of implementation, good performance, high efficiency (especially in close-range applications where the distance is within the loop's range), and guaranteed safety.

Therefore, it is suitable and commonly used for devices. This technology is currently being used in continuous applications and was first introduced in the mobile industry by Samsung. It is only suitable for near-field applications, and this is the main drawback of this technology.

Magnetic Resonance Coupling: In this method, energy is transmitted between resonant loops through varying or influencing magnetic fields.

Since both loops operate at the same resonant frequency, they are tightly coupled, resulting in high energy transfer efficiency with minimal loss to non-resonant externalities. Due to the property of resonance, magnetic resonance coupling is well-suited for resistance to the area and for efficient energy transfer. Magnetically coupled resonators show the ability to transmit power for longer distances than inductive coupling, with higher efficiency compared to the RF radiation approach. Additionally, one transmitter resonator can be coupled to multiple receiver resonators, allowing for simultaneous charging of different devices.

Highlights: As magnetic resonance coupling usually operates in the megahertz frequency range, the quality factor of the resonators is high.

However, as the charging distance increases, the coupling efficiency of the resonator decreases sharply, leading to a reduction in charging efficiency. Since magnetic resonance coupling can charge different devices simultaneously by tuning the coupled resonators of various receiving loops, proper tuning of the resonators is essential to avoid interference between the receiving loops.

Radiative Charging: In this method, RF radiation uses diffused RF/microwave waves as the medium to carry the energy.

RF waves travel through space at the speed of light. The power transmission process starts with an AC-to-DC conversion, followed by a DC-to-RF conversion using a magnetron at the transmitter side. After being transmitted through the air, the RF/microwave waves are received by the rectenna and converted back to power through a RF-to-DC conversion. The efficiency of the RF-to-DC conversion depends on the received power at the receiving device, the accuracy of the impedance matching between the antenna and the voltage multiplier, and the efficiency of the voltage multiplier that converts the received RF signals to DC voltage.

Features: RF energy can be sent in all directions or focused in a particular direction using a technique called beam forming. This method is commonly used in applications like point-to-point communication and broadcasting. Beam forming transmits electromagnetic waves, known as beamforming energy, which helps improve the efficiency of power transmission. A beam is created using an array of receiving wires. The sharper the beamforming energy, the more receiving wires are used. Using large receiving antenna arrays can enhance the sharpness of the beam. Recent developments have led to the creation of large radio wire arrays, such as power transmitter and power receiver systems.

Microwave radiation also has the advantage of being compatible with existing communication systems.

Microwaves can carry both energy and data. While the efficiency and duration of microwaves carry the data, their radiation and vibrations are used to deliver the energy. The process of receiving both power and data is called Simultaneous Wireless Information and Power Transfer (SWIPT). To support SWIPT, advanced smart radio wire technologies have been developed to achieve a good balance between system performance and complexity. However, the transmission of dedicated power reference points overlaps with the existing communication system. Considering the issues of RF radiation, these power reference points need to follow some RF exposure regulations. In this way, the dense organization of power signals is needed to manage handheld mobile devices with low power and shorter ranges.

Acoustic Power Transfer: This technology uses ultrasonic waves, which are sound waves, to transmit power through dielectric air media.

This is a newer method to achieve biocompatible wireless power transfer for use in bio-clinical implants, such as implantable medical devices. The main principle involved is "Ultrasonic Resonance." The initiation of ultrasonic waves is much lower than that of electromagnetic waves used in inductive coupling or radiative methods. The ultrasonic wireless power transmission device can be easily designed and proposed to operate at a short frequency with a relatively low operating frequency. Therefore, using ultrasonic waves makes it possible to transmit power over significant distances while keeping the device size smaller compared to electromagnetic waves.

The ultrasonic waves are generated using Magnetostrictive or piezoelectric techniques.

These waves are used not only for power transfer but also for data transmission. The process of power transfer using ultrasonic waves is as follows:

First, electrical energy is used to produce ultrasonic waves from a piezoelectric part or transducer.

The ultrasonic waves are transmitted through the medium.

They can travel 10-50 meters indoors (for implantable devices) and 100-200 meters outdoors. The transmitted ultrasonic waves are received by the receiver, where the piezoelectric part converts the ultrasonic waves into electrical energy. The entire system involves the piezoelectric effect and transverse piezoelectric effect. Unlike other systems, there are no transmitting and receiving radio wire pairs in the power transfer process. Instead, there are transmitting transducers and receiving transducers. In this technology, power is transmitted from the transmitter to the receiver in different forms of energy.

The transmitter has a section designed to ensure proper alignment between the transmitting transducer and the receiving transducer, which delivers the ultrasonic waves at the required frequency.

Auxiliary transmitting efficiency can be achieved by using transducers of the same type, which may help in achieving better matching efficiency. The transmitter design is similar to that of a rectifier circuit, where electrical energy is converted into mechanical vibration energy, which is then used to generate acoustic energy (i.e., ultrasonic waves).

The receiver design is simpler than that of the transmitter and includes a receiving transducer and a Power Management System (PMS).

The acoustic energy received by the transducer is converted into electrical energy. This energy is then passed to the PMS, which controls the delivery of power to the load.

Features: The benefits of this technology are: the device (i.e., power transfer system) is smaller compared to other methods.

It is free from electromagnetic interference and absorption. It is possible to transmit power through air as well as through conveyors and in submerged environments where electromagnetic wireless transmission is difficult. The table shows the relationship between wireless charging technologies. It also includes the advantages and disadvantages of each method. By looking at the table, acoustic power transfer is best suited for continuous applications. Other charging systems may not be as effective.

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V. ENERGY CONVERTION EFFICIENCY

Wireless force move? It's pretty much just like, uh, the regular communication system process. Kinda. Power needs to, like, be moved from the transmitter to the receiver. We do this by, um, using different technologies, or, schemes. Like , coupling or RF stuff. It's sorta like how a message signal, you know, gets sent from the transmitter to the receiver in, like, a basic comm system. They use different modulation schemes and stuff to move the message signal effectively, ya know?

So, like, in a simple way? Wireless charging tech is kinda like modulation schemes in communication systems, i guess!

VI. CONCLUSION

Wireless charging technology is a big step forward in how we transfer power, giving a safer, easier, and smarter option compared to using wires. It removes the need for plugs and cables, making things more comfortable, longer-lasting, and dependable for devices like smartphones, wearables, electric cars, and medical equipment. A lot of research and development has made wireless charging more efficient, more reliable, and easier to align, while standards like Qi and SAE J2954 have made it easier for different devices to work together. Combining wireless charging with smart grids, renewable energy, and self-driving systems is a major move toward a sustainable and connected energy system. Even though there are still issues like energy loss, high costs, and limited range, new technologies such as resonant coupling, dynamic charging, and AI-based controls are helping to create more efficient, long-distance, and fully automatic wireless power systems. In the future, wireless charging will not just charge small gadgets but also be a key part of transportation, healthcare, and smart city systems, helping create a world that's cable-free, efficient, and environmentally friendly.

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