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Editorial

Next-Generation Wireless Charging Systems for Mobile Devices

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1. Introduction

Wireless power transfer (WPT) is currently sparking more attention towards the application of wireless charging for mobile devices and electric vehicles. While its fundamental theory was revealed more than 100 years ago [1], there has only recently been a strong demand for WPT technology, and its application has increased in the Fourth Industrial Revolution. The reason for this is that WPT technology makes it possible to use electricity anytime, anywhere. WPT technology is likely to converge with the current high-tech industry, as is the case for new technologies such as smartphones. Currently, the applications of WPT are being extended from the chip scale to room scale.

WPT is generally classified into inductive WPT using magnetic fields [2], magnetic-resonant WPT using magnetic fields [3], microwave and millimeter wave beam-type WPT using beam-type electromagnetic waves [4], and capacitive WPT using electric fields [5]. Based on these methods, many novel applications have been achieved, and various WPT techniques, from chip-scale WPT to room-scale WPT, have been presented [6,7]. Additionally, it is not only consumer electronic devices that can be wirelessly charged but also advanced implantable medical devices and underwater equipment. Smartphone wireless charging technology based on inductive WPT has already become commonplace. Additionally, the cradles of some audio devices, such as Bluetooth earphones, can be wirelessly charged. For next-generation mobile device charging, which is the topic of this Special Issue, WPT based on magnetic-resonant, inductive, capacitive, and beam-type electromagnetic waves will be considered. For example, beam-type WPT will work for low-power and medium-distance applications such as IoT (Internet of Things) sensors, while inductive and magnetic-resonant WPT will be better for high-power and short-distance applications. However, for beam-type WPT, RF safety and electromagnetic interference regulations are likely to prevent industrial applications, even though they could provide long-distance charging.

It should also be noted that magnetic-resonant WPT in the MHz frequency range should be focused on, since it will provide several advantages, such as the ability to simultaneously charge multiple devices, spatial freedom, and compact, planar printed circuit board (PCB) coils in the MHz frequency range. However, a proper and reliable WPT control method for charging multiple devices and achieving spatial freedom has not been standardized. Additionally, electromagnetic interference (EMI) remains an issue.

In this Special Issue, next-generation wireless charging methods for mobile and various other applications are discussed. Additionally, novel WPT techniques to improve previous limitations are presented. Furthermore, magnetic-resonant WPT systems in the MHz frequency range have been proposed for compact wearable IoT devices.

2. A Short Review of the Contributions in This Issue

More than ten important articles are published in this Special Issue. It covers WPT technology for charging mobile devices, as well as other applications, such as wearable IoT devices. For example, the topic of magnetic-resonant WPT for compact wearable IoT devices using a 6.78 MHz frequency range is discussed. Additionally, novel methods for distance improvement and the charging of multiple devices are presented.

In [8], multi-load repeaters for simultaneously providing power to multiple loads were are discussed. For power regulation at each repeater, the MOSFET switches of the repeaters could can turn on and off. Using repeater coils with loads, the proposed method could wirelessly and simultaneously transfer power over a midrange and supply power to multiple devices. In particular, the proposed system can be applied to the IoT in a smart grid.

In [9], a wirelessly rechargeable AA battery using electrodynamic wireless power transmission (EWPT) was explored. For verification, an EWPT system of 238 Hz sinusoidal magnetic charging field was also presented. A low-frequency magnetic field was generated by a Helmholtz coil pair, and a EWPT receiver, including a PMC (power management circuit), was developed. To optimize the PMC, the receiver was analyzed for various load conditions and resistive loads. The proposed system was tested for the ability to wirelessly charge a rechargeable AA battery, which was installed within a wireless computer mouse and a battery powered clock. The expectation was that the proposed system can be effectively applied to low-power IoT devices.

In [10], a dual-band RF WPT system with a thinned Tx array antenna for 2.4 GHz and 5.8 GHz was studied. The shared-aperture dual-band Tx array for a dual band of 2.4 GHz and 5.8 GHz was designed and optimized for maximum efficiency between Tx and Rx antennas in the case of 25 WPT scenarios. Each element antenna for the array had a right-handed circular polarization. Similar to the Tx antenna of a dual band, a dual-band (2.4 GHz and 5.8 GHz) stacked patch Rx antenna was effectively designed. Since the thinned array antenna can simultaneously use two frequencies, the system can be used to charge multiple devices. Additionally, depending on the scenario, it can be used for an Rx target, as explained in the paper.

In [11], a control method for power distribution to two receiver coils without feedback was proposed. The proposed algorithm could control the current ratio of multiple Tx coils. The max–min optimization method was applied to implement the proposed algorithm. The proposed method was verified by a simulation using ANSYS MAXWELL. Since multiple device charging is important, the proposed method will be very useful for effectively charging multiple devices by using multiple Tx coils.

In [12], an effective WPT system supporting optimal impedance matching that used ferrite core transformers was presented. The proposed system was fully analyzed, and experimental verification was provided. As is well-known, optimal impedance matching methods for WPT over a medium distance are important. In the paper, a simple optimal impedance matching method was provided, and the method was verified, showing experimental results of 50% efficiency and 100 W WPT at 1 m.

In [13], a multilayered planar spiral coil was analyzed and optimized for the applications of charging compact in-ear bio-signal monitoring devices based on magnetic-resonant WPT. In the paper, it was shown that magnetic-resonant WPT could effectively and simultaneously charge multiple compact wearable IoT devices. Furthermore, it was shown that the multilayered spiral coil should be optimized for maximum power transfer efficiency according to the number of layers and within the available size. It was expected that the analysis results would be helpful for the application of magnetic-resonant WPT for next-generation mobile devices and compact listening devices.

In [14], a retrodirective system to improve the efficiency and safety of microwave power transmission (MPT) systems in multipath environments was proposed and verified by computer simulation. It was shown that the MPT efficiency in multipath environments was improved through the aid of the automatic target-chasing method. Furthermore, the system could improve the efficiency of MPT systems in the case that an obstacle existed between the transmitter and receiver by avoiding an obstacle and tracking two moving targets. The proposed method will be very helpful for applications of the wireless charging of remote IoT sensors in the future.

In [15], a shielding sensor (SS) coil located over the Tx coil was proposed and verified to solve the misalignment issue and the leakage magnetic field issue of the wireless power transfer (WPT) system for electric vehicles (EVs). By measuring mutual inductance between the SS and Tx coils and adjusting the current phase of the SS coil, the leakage magnetic field can be reduced. The proposed method is also well suited for charging multiple mobile devices.

3. Future Trends in WPT

In the future, the IoT platform infrastructure will play a very important role in our daily lives. IoT mobile and wearable devices will be used for health monitoring, electric transportation, security and metering sensors, and so on. They are not only wired but also wireless. Electric transportation, such as e-mobility, electric vehicles, flying drones, and autonomous robots, will become more and more popular and widespread. The method of wireless power will certainly be suitable for supplying power to IoT devices anytime and anywhere, since these IoT devices will be connected to the internet and able to communicate with one another. With the convergence of the IoT industry and WPT, IoT devices can be easily supplied and easily used.

Up to now, various WPT technologies have been published and lots of applications have been reported. It is expected that future WPT applications based on magnetic induction, magnetic resonance, and microwave beams will converge with various IoT industries, such as wearable sensors, smart mobile devices, and implantable or wearable biomedical devices.

From my own knowledge, the following technical and regulatory issues should be resolved for the effective development of WPT technology:

Spatial freedom;
Multiple device charging;
Device-to-device WPT;
Adaptive impedance matching;
Magnetic field beam forming in near-field and mid-field;
Effective conversion components in the MHz frequency range;
Three-dimensional coils;
Simultaneous wireless information and power transfer (SWIPT);
Global standardization for new products;
Mitigation of EMI (electromagnetic interference) and EMF (electromagnetic fields) safety.

It is believed that several important topics can be explored in addition to the items mentioned above depending on the fields of applications.

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References

1. Tesla, N. *The Tesla Papers: Nikola Tesla on Free Energy & Wireless Transmission of Power*; Childress, D.H., Ed.; Adventures Unlimited Press: Kempton, IL, USA, 2000.
2. Mahesh, A.; Chokkalingam, B.; Mihet-Popa, L. Inductive wireless power transfer charging for electric vehicles: A review. *IEEE Access* **2021**, *9*, 137667–137713. [CrossRef]
3. Houran, M.A.; Yang, X.; Chen, W. Magnetically coupled resonance WPT: Review of compensation topologies, resonator structures with misalignment, and EMI diagnostics. *Electronics* **2018**, *7*, 296. [CrossRef]

4. Rodenbeck, C.T.; Jaffe, P.I.; Ii, B.H.S.; Hausgen, P.E.; McSpadden, J.O.; Kazemi, H.; Shinohara, N.; Tierney, B.B.; DePuma, C.B.; Self, A.P. Microwave and millimeter wave power beaming. *IEEE J. Microw.* **2021**, *1*, 229–259. [CrossRef]
5. Lu, F.; Zhang, H.; Mi, C. A Review on the recent development of capacitive wireless power transfer technology. *Energies* **2017**, *10*, 1752. [CrossRef]
6. Khan, S.R.; Pavuluri, S.K.; Cummins, G.; Desmulliez, M.P.Y. Wireless power transfer techniques for implantable medical devices: A review. *Sensors* **2020**, *20*, 3487. [CrossRef] [PubMed]
7. Sasatani, T.; Sample, A.P.; Kawahara, Y. Room-scale magnetoquasistatic wireless power transfer using a cavity-based multimode resonator. *Nat. Electron.* **2021**, *4*, 689–697. [CrossRef]
8. Hassan, N.U.; Lee, W.; Lee, B.H. Efficient, load independent and self-regulated wireless power transfer with multiple loads for long distance IoT applications. *Energies* **2021**, *14*, 1035. [CrossRef]
9. Smith, S.E.; Halim, M.A.; Chyczewski, S.T.; Rendon-Hernandez, A.A.; Arnold, D.P. A wirelessly rechargeable AA battery using electrodynamic wireless power transmission. *Energies* **2021**, *14*, 2368. [CrossRef]
10. Song, C.M.; Lim, H.J.; Trinh-Van, S.; Lee, K.Y.; Yang, Y.G.; Hwang, K.C. Dual-band RF wireless power transfer system with a shared-aperture dual-band Tx array antenna. *Energies* **2021**, *14*, 3803. [CrossRef]
11. Heo, J.; Park, S.Y.; Kim, S.W.; Cho, I.K.; Hong, S.N.; Park, Y.B. Control of WPT transmitter coils for power distribution to two receiver coils without feedback. *Energies* **2021**, *14*, 6828. [CrossRef]
12. Kim, J.W.; Kim, D.H.; Kim, J.E.; Park, Y.J. Wireless power transfer between two self-resonant coils over medium distance supporting optimal impedance matching using ferrite core transformers. *Energies* **2021**, *14*, 8540. [CrossRef]
13. Park, Y.J.; Kim, J.E.; Na, K.M.; Yang, K.D.; Cho, K.H. Optimization and analysis of multilayer planar spiral coils for the application of magnetic resonance wireless power transfer to wearable devices. *Energies* **2021**, *14*, 5113. [CrossRef]
14. Shinohara, N.; Sasaki, T. A study on automatically target-chasing microwave power transfer systems in multipath environments. *Energies* **2022**, *15*, 2343. [CrossRef]
15. Son, S.H.; Woo, S.; Kim, H.; Ahn, J.; Huh, S.; Lee, S.; Ahn, S. Shielding sensor coil to reduce the leakage magnetic field and detect the receiver position in wireless power transfer system for electric vehicle. *Energies* **2022**, *15*, 2493. [CrossRef]