Power Transfer Efficiency for Distance-Adaptive Wireless Power Transfer System

Dong-Geun Seo [1], Seong-Hyeop Ahn [1], Ji-Hong Kim [1], Seung-Tae Khang [2], Soo-Chang Chae [2], Jong-Won Yu [2], and Wang-Sang Lee [1*]

[1] Department of Electronic Engineering/Engineering Research Institute
Gyeongsang National University, 501 Jinju-daero, Jinju, Gyeongnam, 52828, Republic of Korea
*wsang@gnu.ac.kr

[2] School of Electrical Engineering, Korea Advanced Institute of Science and Technology (KAIST)
291, Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea

Abstract — In this paper, a highly efficient distance-adaptive wireless power transfer system with automatic impedance tuning control at variable distances is proposed, and we compare the power transfer efficiency of wireless power transfer system at different operating conditions using the method of moments (MoM) technique. By sensing a reflected power and controlling impedance tuning networks, the proposed wireless power transfer system achieves the high and stable efficiency with regard to the variable operating distances. According to adaptive impedance matching algorithms under the minimum reflected power conditions, the proposed system achieves an improved power transfer efficiency of approximately maximum 160% within the operating distance.

Index Terms — Distance-adaptive, Power Transfer Efficiency (PTE), variable distances, Wireless Power Transfer (WPT).

I. INTRODUCTION

Wireless power transfer (WPT) technology transfers electrical energy using electromagnetic waves without electrical wires in various industries related to remote energy transfer, μ-sensors, digital IT consumer devices, and electric vehicles (EV) [1]. Due to the impedance matching characteristic of WPT systems that use coupled resonant antennas, WPT systems with different operating distances, variable impedance loads, and lateral misalignment between the transmitting and receiving antennas result in a significant degradation in power transfer efficiency (PTE) [2]–[4]. To achieve a highly efficient WPT, it is necessary for the system to be able to detect the location of the receiving device. In addition, in order to improve PTE for any transfer distance, adaptive frequency tracking was proposed, but it is not practical due to frequency regulation [5]. In this paper, a highly efficient WPT system with automatic impedance tuning control at variable operating distances is presented and by comparing the impedance matching algorithms under different conditions, its optimal performance is verified.

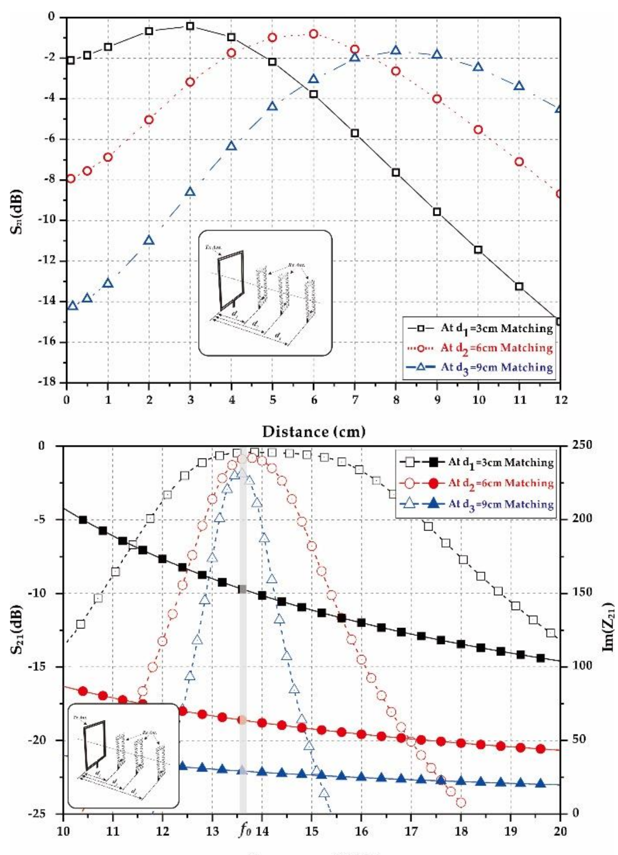

Fig. 1. The simulated transmission coefficient (S_{21}, related to the PTE) between the transmitting and receiving antennas with regard to the operating distance (a), and the operating frequency (b).

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II. PROPOSED WPT SYSTEM CONFIGURATIONS

The practical applications for the WPT with regard to the different mutual couplings between the transmitting and receiving antennas (i.e., variable operating distance and misalignments) are near-field communication (NFC), wireless charging pad, wireless electric vehicle charging, and medical implant. Using a method of moments (MoM) technique, the simulated transmission coefficient (S_{21}, related to the PTE) between the transmitting and receiving antenna with regard to the operating distance and the operating frequency in Fig. 1, respectively. The maximum PTE is obtained at the matching distance, and at other distances due to the impedance mismatching, the PTE is drastically degraded at operating distance. For a highly efficient WPT system, it is necessary to have a distance-adaptive impedance variation characteristic. By controlling an impedance tuning network, an impedance matching characteristic is obtained, and the PTE can be improved.

To improve the WPT efficiency with variable distances, the distance-adaptive WPT system with automatic impedance tuning control is proposed in Fig. 2. The proposed system consists of resonant antennas for magnetic field generation, an impedance tuner (lumped network), a reflectometer to measure the reflection coefficient by detecting the reflected power, a matching algorithm for maximum PTE, and a signal source of 13.56 MHz (ISM band) with a Class-E power amplifier in Fig. 2.

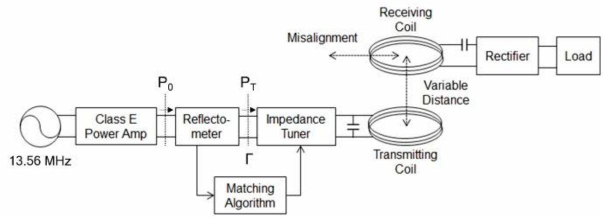

Fig. 2. The overall system block diagram for the proposed WPT system.

III. RESULTS AND DISCUSSION

To verify the PTE of the proposed WPT system with regard to the operating distances, we designed and implemented the proposed distance-adaptive WPT system with automatic impedance matching networks in Fig. 3. The simplified receiving device has a receiving antenna and a rectifying circuit with load. To investigate the power transfer link efficiency between the transmitting and receiving antennas, the coil antennas are designed and fabricated on an FR4 printed circuit board (PCB) substrate with a dielectric constant of 4.4 and thickness of 0.8 mm.

Table 1: The PTE comparison with regard to the operating conditions

Conditions (Dist: 3cm)	Γ	**Voltage (V)**	$\mathbf{P_{in}}$ **(mW)**	$\mathbf{P_{out}}$ **(mW)**	**Efficiency (%)**
Initial (Ref.)	0.691	10.5	163	110	68
Γ_{min}	0.541	11.6	149	135	90
$P_{0,\,max}$	–	10.2	1556	104	7
$P_{T,\,max}$	0.594	15.4	391	237	61

Conditions (Dist: 6cm)	Γ	**Voltage (V)**	$\mathbf{P_{in}}$ **(mW)**	$\mathbf{P_{out}}$ **(mW)**	**Efficiency (%)**
Initial (Ref.)	0.832	5.55	133	31	23
Γ_{min}	0.499	9.95	204	99	48
$P_{0,\,max}$	–	7.25	1409	53	4
$P_{T,\,max}$	0.574	9.95	201	99	49

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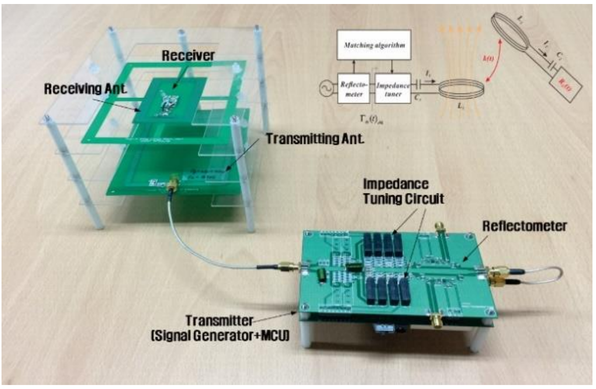

Fig. 3. The prototype of the proposed distance-adaptive WPT system.

Table 1 shows the received DC voltage and overall PTEs with regard to the fixed matching and proposed adaptive tuning conditions for the operating distance. The adaptive tuning conditions represent the maximum output power ($P_{0,max}$) at the output of the power amplifier, the maximum transmitting power ($P_{T,max}$), and the minimum reflection coefficient (minimum reflected power, min). If the WPT transmitting system has the maximum transmitting power condition ($P_{T,max}$), it can increase the received DC in the receiving device, but the overall PTE is less than the fixed matching condition of the impedance tuner. Within an operating distance of 3 cm to 9 cm, the minimum reflection coefficient condition displays an improved PTE of maximum approximately 160%.

IV. CONCLUSION

We propose a highly efficient wireless power transfer system with automatic impedance tuning control for practical applications with variable operating distances. Under misalignment between the transmitting and receiving antenna or any operating distance, the proposed distance-adaptive WPT system achieves an improved PTE of maximum 160% by minimizing the reflection coefficient in the transmitting system. It can be useful in wireless charging without the response of the portable receiving device.

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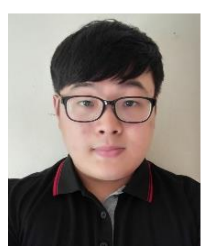
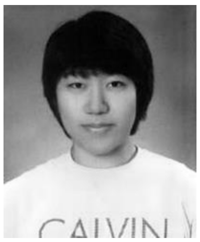
Dong-Geun Seo received the B.S. degree in Electronic Engineering from Gyeongsang National University (GNU), Jinju, South Korea, in 2016, where he is currently pursuing the M.S. degree. His current research interests include near-field wireless power transfer and communication systems, beamforming antenna array and its feeding network for UAV communications, and RFID/IoT sensors.



Seong-Hyeop Ahn received the B.S. degree in Electronic Engineering from Gyeongsang National University (GNU), Jinju, South Korea, in 2018, where he is currently pursuing the M.S. degree. His research interests include near-field wireless power transfer and communications systems, RFID/IoT sensors, and RF/microwave circuit and antenna designs.

Ji-Hong Kim received the B.S. and M.S. degrees in Electronic Engineering from Gyeongsang National University (GNU), Jinju, South Korea, in 2016 and 2019, respecttively, where he is currently pursuing the Ph.D. degree. His current research interests include RF system interference analysis, small antenna miniaturization, RFID/IoT sensors, and RF/microwave circuit and antenna designs.



Seung-Tae Khang received the B.S. degree in Electronic Engineering from Chung-Ang University, Seoul, South Korea, in 2012, and the M.S. degree in Electrical Engineering from the Korea Advanced Institute of Science and Technology, Daejeon, South Korea, in 2014, where he is currently pursuing the Ph.D. degree in Electrical Engineering. His current research interests include frequency-modulated continuous-wave (FMCW) radar system, millimeter-Wave transceiver design, and wireless power transfer system.

Soo-Chang Chae received the B.S. and M.S. degrees in Electrical Engineering from the Korea Advanced Institute of Science and Technology, Daejeon, South Korea, in 2014 and 2016, respectively, where he is currently pursuing the Ph.D. degree in Electrical Engineering. His current research interests include near-field wireless charging system and coil design, active array antenna, and RF/microwave circuit design.

Jong-Won Yu received the B.S., M.S., and Ph.D. degrees in Electrical Engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, in 1992, 1994, and 1998, respectively. From 2000 to 2001 and 2001 to 2004, he was also with Wide Telcom Head and Telson, South Korea. From 2004 to 2013, he was with KAIST, initially as an Assistant Professor of Electrical Engineering and as an Associate Professor. He is currently a Professor in KAIST. His research interests emphasize microwave/millimeter-wave circuits (monolithic microwave integrated circuits (MMICs), hybrid), wireless communication systems, and RFID/ubiquitous sensor network.

Wang-Sang Lee received the B.S. degree from Soongsil University, Seoul, South Korea, in 2004, and the M.S. and Ph.D. degrees in Electrical Engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, in 2006 and 2013, respectively. From 2006 to 2010, he was with the Electromagnetic Compatibility Technology Center, Digital Industry Division, Korea Testing Laboratory (KTL), Ansan, South Korea, where he was involved in the international standarization for RFID and Photovoltaic Systems as well as EMI/EMC analysis, modeling, and measurements for IT devices. In 2013, he joined the Korea Railroad Research Institute (KRRI), Uiwang, South Korea, as a Senior Researcher in the position detection for high-speed railroad systems and microwave heating for low-vibration rapid tunnel excavation system. He is currently an Associate Professor with the Department of Electronic Engineering, Gyeongsang National University (GNU), Jinju, South Korea. His current research interests include the nearfield communication and power systems, RF/microwave circuit and antenna design, RFID/IoT sensors, and EMI/EMC. Lee was a recipient of the Best Paper Award at the 7th Annual IEEE International Conference on RFID in 2013.