One-to-N Wireless Power Transmission System Based on Multiple Access One-Way In-Band Communication

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***Abstract*—For an efficient wireless charging to multiple devices, transmitter (TX) system should be able to control the transmitting power-level by monitoring number of receiver (RX) devices via their identification information and charging status and capacity of each receivers. This work proposes a one-way in-band communication scheme, corresponding system structure, and charging algorithm for efficient one-to-N wireless charging system, which has been verified experimentally.**

I. INTRODUCTION

The resonant magnetic coupling can significantly enhance the efficiency and transfer range of a wireless power transmission (WPT) system [1, 2] and potential applications of the WPT are ranging from mobile charging platform to wireless electric vehicle charging. The magnetic resonance coupling is superior in multiple device simultaneous charging over conventional inductive coupling. Information of device identification and the charging status of devices are needed for supplying suitable power wirelessly to multiple devices. There are two ways to send information of receiver (RX) devices to the power transmitter (TX); in-band and out-of-band communications. The former uses the same frequency with the frequency for the power transfer, while the latter uses other frequency range which is different from that for the power transfer. Although the out-of-band communication is advantageous over the in-band counterpart in its operation stability and extendibility in diverse applications, it tends to make the system more complex and expensive due to additional transceiver system and antennas for the communication. In this work, an in-band communication scheme, corresponding system structure, and its charging algorithm for efficient one-to-N multi-device wireless charging system are proposed and verified.

II. IN-BAND COMMUNICATION OF WIRELESS POWER TRANSMISSION SYSTEM

Fig. 1 shows a schematic diagram of the WPT system with the in-band communication. This system transfers 4-5W power wirelessly via magnetic resonance coupling. The received AC power is rectified by a full bridge rectifier and then converted to the desired DC level by a switching DC-DC converter. This power is delivered to a load and a micro-control unit (MCU). Then the MCU is awakened and generates modulated data by subcarrier, with which the AC power signal can be modulated [3-5].

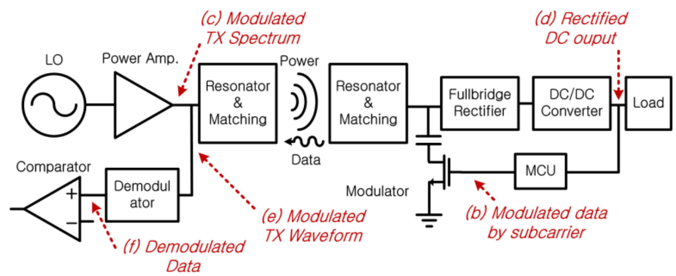
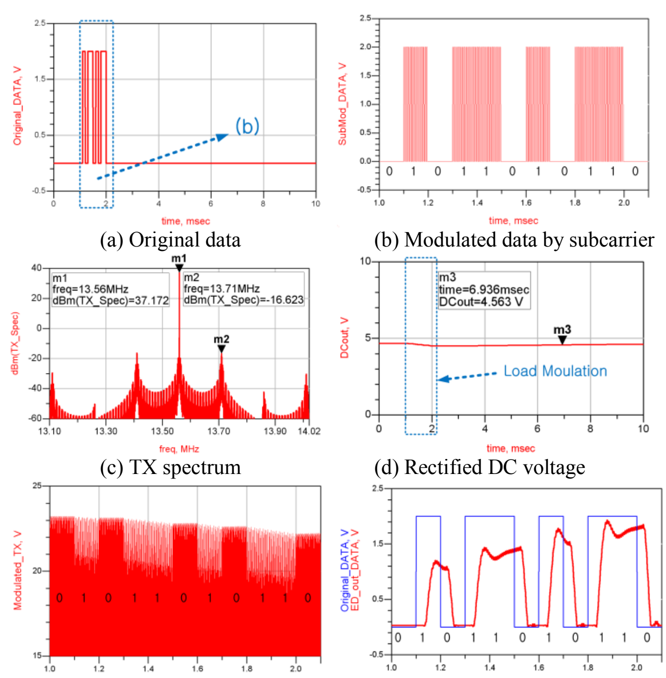


Fig.1. Schematic diagram of the WPT system with in-band communication.



(a) Original data (b) Modulated data by subcarrier

(c) TX spectrum (d) Rectified DC voltage

(e) Modulated TX waveform (f) Demodulated data

Fig. 2. Simulation results of the WPT system for in-band communication by ADS tools.

TABLE I. SPECIFICATION OF THE PROPOSED WPT SYSTEM WITH INBAND COMMUNICATION

Parameters	Specifications of Proposed System
Carrier Frequency	13.56MHz
Data Rate	10kbps
Data Length	11bits
Occurrence Cycle	10ms
Subcarrier	150kHz
Modulation	Load modulation with subcarrier
TX power	5W (Single device), 9W (Multi devices)
RX power	2-3W

Fig. 2 shows the simulation results of the system by using ADS Ptolemy tools. The carrier frequency of the magnetic resonance coupling is 13.56MHz and power transfer efficiency between resonators has been set up to ~80%, which is based on our high-performance resonator set. Fig. 2(a) shows the original data packet including the information of the mobile device identification and a supplying DC voltage level of 2V. It has only 11 bits of data length with the data rate of 10 kbps. The original data packet is generated every 10ms to secure the stable charging time. Then this packet is modulated by 150 kHz subcarrier at MCU as shown in Fig. 2(b), in which the TX power signal is modulated. The spectrum of the TX power signal is shown in Fig. 2(c). The power levels of the TX signal and the subcarrier are 37.17dBm and -16.6dBm, respectively. Fig. 2(d) shows the rectified DC voltage (~4.563V) supplying to a 9Ω load of our mobile device, implying that 2.3W power is transferred to the load. The DC supplying voltage (4.56V) has been maintained with a high-capacity filter capacitor (>100μF) in the load modulation period (1-2ms). Fig. 2(e) shows the modulated TX waveform with peak-to-peak voltage of -23 to +23V. The demodulated data is then recovered as the original data (01011010110) in Fig. 2(f). The specification of the proposed system is summarized in Table I.

III. MULTIPLE ACCESS ALGORITHM

In the proposed one-way in-band communication scheme, the RX system can send data and TX system supply only power based on the received data from the RX system. Because the RX system plays a role of master in performing the in-band communication, simple multiple access algorithm can be feasible to be implemented.

A. One-Way In-Band Communication

Smaller size of RX system is required to be embedded in a mobile device. In this work, one-way in-band communication for concurrent multiple device wireless charging is proposed to reduce the size of the RX system. Fig. 3 shows one-to-N WPT system using one-way in-band communication.

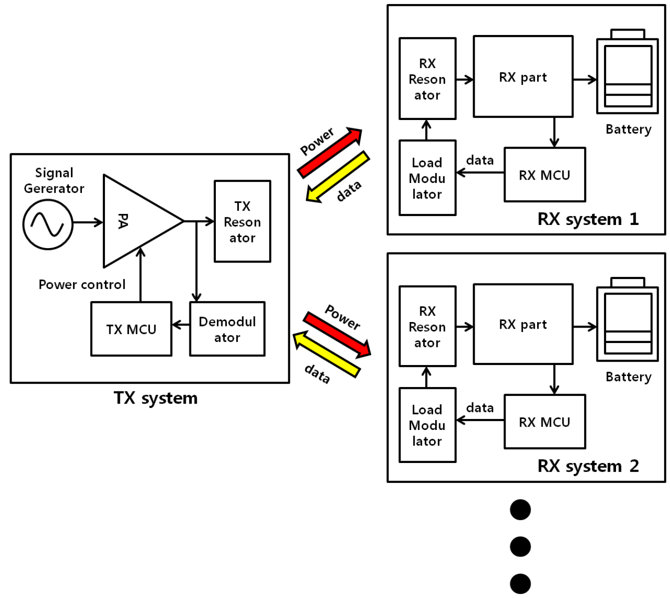


Fig. 3. One-to-N WPT system using one-way in-band communication.

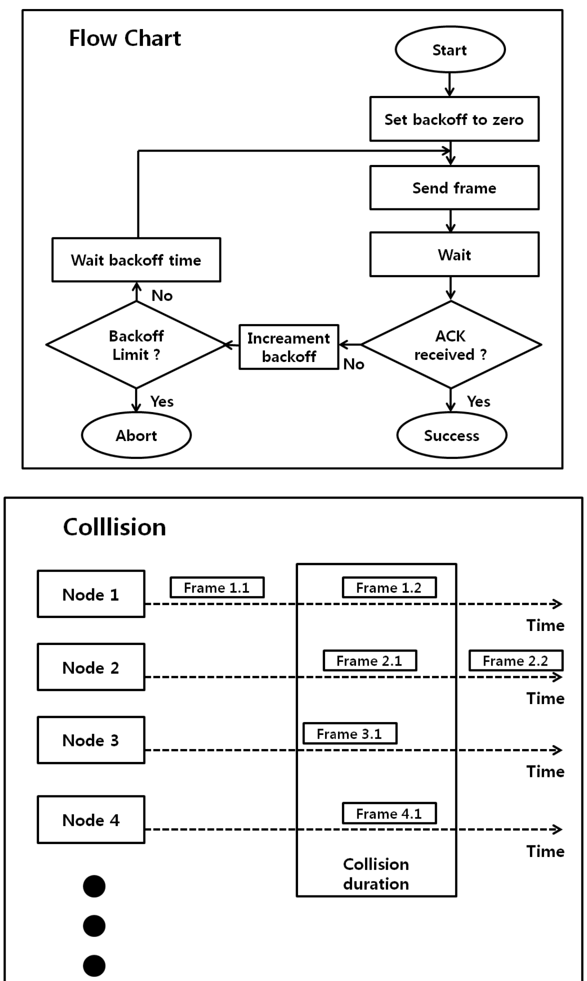


Fig. 4. Multiple access algorithm using ALOHA scheme.

B. One-to-N Multiple Access Algorithm of Wireless Power Transmission System

Wireless power transmission system needs a protocol to avoid a collision by simultaneous multiple access for multiple device charging. The modified ALOHA access scheme is proposed to avoid this collision. The conventional ALOHA access scheme is one of simple multiple access methods that does not make synchronization between nodes and does not check the communication channel before the data transmission. As shown in Fig. 4, if a node has a sending frame, it immediately transfers and waits for ACK (acknowledge) during random time. If ACK is received, the state is "Success". If not, it performs a request repeatedly. When the request continues until reaching the limit, it aborts a sending frame.

C. Proposed Charging Algorithm

Fig. 5 shows the proposed one-way in-band communication algorithm for multi-device wireless charging. At first, TX system transfers a weak power per a period of time. If a valid data is received, it can recognize identification (ID) of RX devices. Next, it increases the count of access (Acc_n) and transfers suitable power to charge RX devices. If not, it decreases the count of access (Acc_n) per a period of time. Then, if the TX system does not receive any ID data from the RX devices, the count of access (Acc_n) becomes '0' and it stops powering. The Tx system waits until new IDs access again.

The RX system sends the data packets of own ID and power capacity per a random delayed time. If the TX system receives the data packets, the RX system would receive the requested power-level. The RX system sends the data packets of own state per a period of time in order to let the TX system know that the RX system is in charging. It sends the data packets of own state until it reaches the state of full-charging. If it becomes the full-charging status, it sends the data packets of full-charging to the TX system to stop powering.

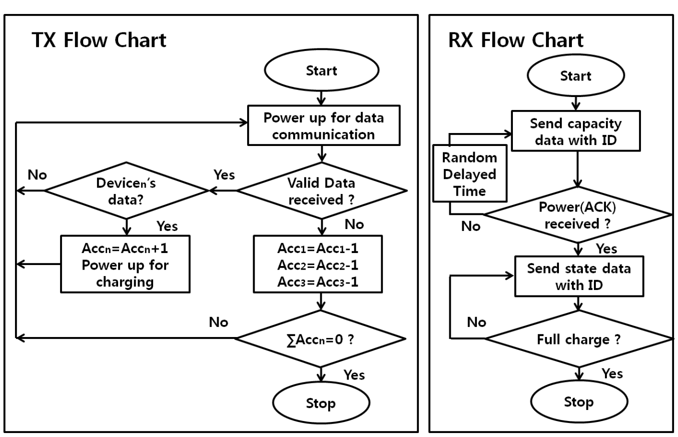


Fig. 5. Proposed charging algorithm with one-way in-band communication

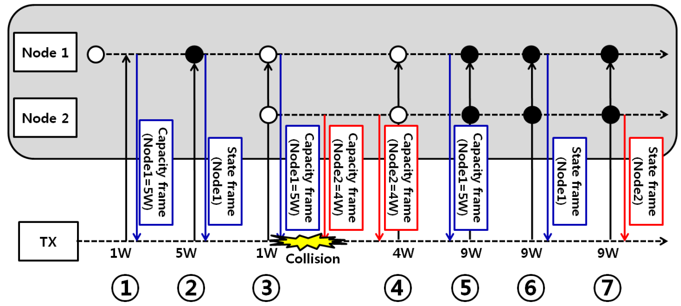


Fig. 6. Scenario of communication and charging for two devices present.

Fig. 6 shows the scenario of communication and charging in case of two RX devices. (1): At first, TX system transfers a weak power, e.g. 1W, per period of time to check the presence of device. (2): If there is node 1, it sends the data packets of own ID and power capacity until it receives the needed power-level. If the TX system receives the data packets successfully, it transfers the required power, e.g. 5W. Then the node 1can receive the needed power level and it send the data packets of own state. (3): At this time, if node 2 is put in, the TX system recognizes the load variation and transfers 1W power to check IDs. In this case, the node 1 cannot receive the needed power and send the data packets of own ID and power capacity. If a collision between these data packets occurs, it retries after a random delayed time. (4): Because the data packets of the node 2 arrive in advance, the TX system transfers 4W power for the node 2. (5): Then, if the data packets of node 1 arrive, the TX system transfers 9W power for the nodes 1 and 2. Both the nodes 1 and 2 are in charging, they send the data packets of their own states. (6), (7): If the data packets of the state are received, the TX system increases the count of access (Acc_n) to prevent from unidentified nodes. If not, it decreases the count of access (Acc_n) per a period of time. If the capacity sum of the nodes is not the same as transmitting power (9W) or the count of access (Acc_n) becomes '0', the TX system stops powering and transfers 1W power to check IDs.

IV. Measurements

Fig. 7 shows the experimental setup for the one-way in-band communication in multi-device wireless charging. The input of the receiver chip was connected to a RX resonator and the output was connected to the battery charger of a mobile phone. The external MCU (ATtiny13) was used to generate the modulated data by subcarrier. The dimension of the RX resonator is 4.5cm×6.5cm and it was embedded in the rear case of a mobile device while a TX resonator with 32cm×22cm was used. The class-E power amplifier was used and its efficiency is about 90% at 13.56 MHz when transmitting power is 9W. The TX system is displaying the ID information of the mobile devices and a supplying DC voltage level while the RX device is in charging.

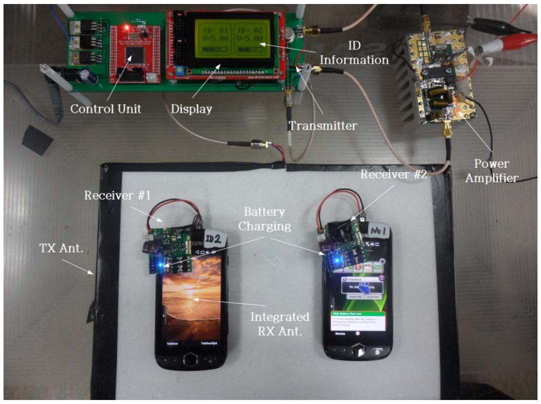
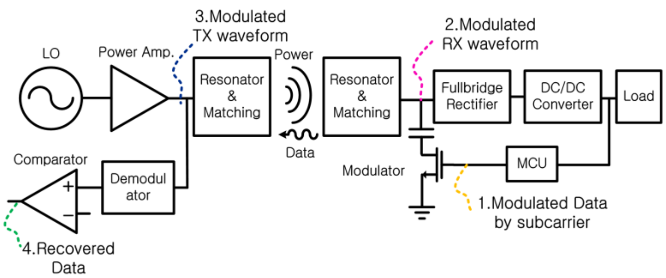
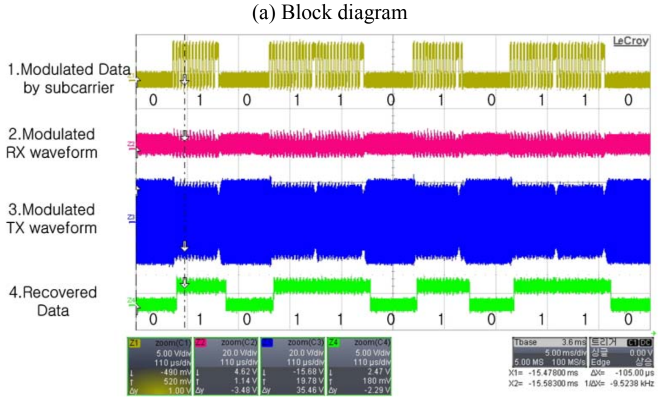


Fig. 7. Eexperimental setup of multiple access one-way in-band communication for one-to-N wireless power transmission system.



(a) Block diagram



(b) Measured waveform

Fig. 8. Block diagram of the WPT system with in-band communication and measured waveform of the recovered data.

Fig. 8(a) shows the block diagram for the data transmission and reception between the power transmitter and the power receiver. The measured waveforms are shown in Fig. 8(b). The modulated data (yellow) packet by subcarrier of 150 kHz is generated from an external MCU. The data packet modulates the gate of the MOS transistor and generates the modulated RX waveform (magenta) by changing the impedance in front of the rectifier. By doing this, the transmitting power signal (blue) can also be modulated output of the power amplifier in the TX. This signal is coupled by a resistor divider and then is fed into the input of a demodulator. The output of a demodulator is compared to a reference level by a comparator and the output of a comparator is the recovered data (green). This is the same as the original data (01011010110). The measured waveform in Fig. 8 is close to the simulated waveform shown in Fig. 2(e) and (f).

V. Conclusion

In this work, we proposed a one-way in-band communication method, a system structure, and a charging algorithm for efficient one-to-N wireless charging system, and this was verified experimentally.

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