Research of wireless power transmitter sub-system based on Qi Specification

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Abstract. This paper summarizes the technique comparison among wireless power transfer methods and related specifications, combined with a designed case of wireless power transmitter sub-system based on Qi specification.

1. Introduction
The transmission of power has been carried out by direct contact with conductors for a long time. With the unitization of the wireless standards and specifications related to power transfer technology, as well as the cost and efficiency of wireless power transfer are approaching the wired mode’s, the technical bottleneck is gradually overcome. As the expansion of the market, a growing demand from users for terminal product battery standby time and charging flexibility, and tailless requirements are greatly increasing; on the other hand, due to the limitations such as farraginous cable connections, incompatible interface protocols in the wired power transfer, wireless power transfer technology has been paid more and more attention because of its advanced performance, and huge amount of enlightened experiments and explorations have been obtained.

2. Wireless Power Transfer Mode and Related Organizations
Wireless power transfer realizes the power delivering via electric field, magnetic field, microwave, laser and other conductive media. Theoretically, it can be classified into 3 types with accordance to the different transmission mode, which is Electromagnetic Induction Mode, Magnetic Coupling Resonance Mode and Radio Wave Mode respectively.

The electric can be delivered between two tightly closing coils, based on electrical/magnetic interaction. Alternating magnetic field is created by primary coil of transmitter, which electrified with AC; meanwhile the secondary coil in the receiver picks up the alternating magnetic field and generate induction current accordingly, then a power transfer process from transmitter to receiver is fully accomplished. The power transfer flow shows as follow.
As illustrated in Figure 1, initially the transmitter outputs the AC current to the driver through rectifier inverter, then controller actuates the driver applying AC in the primary coil. Inversely, the receiver recognizes an alternating magnetic field through a secondary coil and generates current, then output the required DC voltage by the back-end rectifier. During this period, the controllers at both ends monitor and adjust the voltage and current of their own respectively, and modulated communication signal will be added simultaneously, aims to realize control and communication at both ends. Throughout the entire process of control and communication, all parts must work cooperatively, including transmitter driver design and control, the receiver pickup design and control, coil design and improvement and many other works, to make power transfer more efficient, the stability and security of the system better.

The principle of magnetic coupling resonance is adopted in the magnetically resonance mode. When the magnetic field at both ends of the power transfer device varies at the identical frequency, the efficiency of energy transfer will climb up to the peak, power can be transferred. The most different feature compared to Electromagnetic Induction Mode is that a certain space is allowed between the transmitter and receiver, no need to pursue a complete match between the relative positions between the coils.

The devices of Magnetic Coupling Resonance Mode is mainly composed of power transmitter and power receiver. When the frequency of the primary coil is the identical as that of the secondary coil, the system is in strong coupling, high efficiency power transfer at long distance can be realized in medium and high frequency magnetic field, while the interaction between the devices which deviated from the resonant frequency is weak. Obstacles can be avoided during the long distance power transfer by this mean, thus it has a wide application prospects.
The principle of radio wave power transfer is by converting electric energy into microwave or laser, using antenna to transmit or receive power, this method is more suitable for ultra-long distance transmission. The essence of radio wave technology is to replace the wired power supply cable with the directional electromagnetic beam. When the electromagnetic wave propagates, the shorter the wavelength, the less easily it is dispersed, therefore, long distance transmission can be realized. But because the laser can't get around the obstacle, in addition to the existence of dust particles in the atmosphere reduces the propagation efficiency, radio wave mode is confined to low power transfer. Besides, if the power lost is large, it may hazardous to the living things in the environment.

![Radio Wave Power Transfer Scheme](image)

**Figure 3.** Radio Wave Power Transfer Scheme

Well-known enterprises in the field of wireless power transfer formed 3 technical organizations in the two directions, named Wireless Power Consortium (WPC), PWA and A4WP, which represent magnetic induction and magnetic resonance. Things never go easy in the progress of development, so does the wireless power transfer. The main problems focus on the chaotic standards and specifications, low efficiency, etc. At this stage, these barriers have been gradually broken through: 3 major technical organizations (WPC, PWA and A4WP) merged into 2 organizations (WPC, AirFuel) in 2015, and the standards collision has been alleviated to some extent. Specifically, WPC was founded in 2008, which is the world's first organization to promote wireless power transfer technology. After decade’s development, as of June 2018, it has 628 members and 2523 certified products, being in an absolute leadership in the market. The Qi specification led by WPC is also the most widely used wireless power transfer specification in the world at present. In this paper, the research and test of magnetic induction wireless power transfer will be based on Qi specification.

### 3. Design of Wireless Power Transfer System based on Qi Specification

The Qi Specification is perfectly suitable for small electronic devices, which support single and multiple coil designed transmitters, and has simple communication interface protocol and low standby power consumption. The specification defines and specifies the transmitter, receiver, system communication, control mode, algorithm and related structure. This paper will describe the overall design, transmitter hardware design, control communication design, etc.

#### 3.1. System Overall Design

The transmitter and receiver transfers electric energy between parallel-closed coupled coils based on electromagnetic induction in wireless power transfer. According to the Qi specification, transmitters are defined as the base station and receivers as the mobile device. The power flow is always from the base station to the mobile device, the data communication is controlled by the receiving device. From this perspective, the base station is the actual transmitter, its coil is named as the primary coil; the mobile
device is receiver, its coils is named as secondary coil. The primary coil and the secondary coil constitute 1/2 empty core transformer respectively, energy transfer through coupling of primary coil and secondary coil.

3.2. Transmitter Hardware Design

As shown in Figure 4, the design of power transmitter consists of 2 main functional modules, which is power conversion module and communication control module. Specifically, the primary coil is the magnetic field generating device in the power conversion module, the communication control module adjusts the transferred power according to the requirements of the power receiver. The system module mainly includes the conversion of AC input power supply and user interface. The design of power receiver mainly includes energy pickup module and communication control module. Similarly as transmitter, the secondary coil is the magnetic field receiving device of the power pickup module, the communication control module manipulates the energy transfer according to the output load of the receiver.

![Transmitter Hardware Design Scheme](image)

**Figure 4. Transmitter Hardware Design Scheme**

In this paper, a certain type transmitter chip is selected. The chip realizes reliable communication in noisy environment through improved demodulation algorithm, integrates all the features required to comply with Qi 1.2.4 and 5V dedicated transmitter. The mechanism of the chip is searching a receiver that needs power supply by Ping operation to the environment, and securely coupled with the target after successfully pinged. Then accept communication packets of the receiver and transfer power based on Qi 1.2.4 Specification. Furthermore, the chips possesses the functions including dynamic power limitation and foreign object detection (FOD) to prevent over heating between coils of transmitter and receiver.

Generally, as shown in Figure 5, different output power will affect the efficiency of the system. When the output power of the transmitter is greater than 2W, the efficiency can be stable around over 70%, thus this chip is perfectly suitable for the lower power consumption scenarios such as smart phone, wearable devices, small medical devices, etc. The maximum working efficiency of the hardware scheme design can reach more than 75% in this paper.
Figure 5. Wireless Power Transfer Efficiency Curve

The main structure of the chip is shown in the Figure 6,

Figure 6. Chip Structure

The appearance of the sub-system is shown in the following Figure 7a&7b.
3.3. **System Communication Control Design**

The receiver encodes the transmission information by adjusting the electric signal picked up from the transmitter, the change of electric signal will cause the change of coil current, and the transmitter decodes the information by detecting the amplitude of the coil current. Hence, the communication between the transmitter and receiver is realized by amplitude modulation.

3.3.1. **Bit Encoding Scheme.** The receiver uses differential biphase coding to complete the signal modulation. The transmitter ensures that each bit sent corresponds to one cycle of the internal clock, that is, the start of each digit corresponds to the rising edge of the internal clock. The Qi specification specifies that the internal clock frequency is 2 kHz, a transition represents of 1 in each clock cycle by the coding rule, and otherwise it represents 0. The coding example is shown in Figure 8.

![Figure 8. Example of Bit Encoding Scheme](image)

3.3.2. **Byte Encoding Scheme.** A byte consists of 11 bits, which includes a start bit, the 8 data bits, a parity bit and a single stop bit. The start bit is a ZERO, the order of the data bits is LSB first and the parity bit is odd. The stop bit is ONE. Figure 9 shows a data byte format example.

![Figure 9. Example of Byte format](image)

3.3.3. **Packet Structure.** The receiver shall communicate to the transmitter using Packets. As shown in Figure 10, a Packet consists of 4 parts, namely a preamble, a header, a message and a checksum. The preamble consists of a minimum of 11 and a maximum of 25 bits, all sets to ONE. The preamble enables transmitters to synchronize with the incoming data and precisely detect the start bit of the header.
4. Implementation and Verification of Sub-system Communication process

The communication process of a sub-system mainly includes three phases. In the Ping phase, the packets sent by the transmitter are Signal Strength Packets or End Power Packets. In the Identification and Configuration phase, the packets are Identification and Configuration Packets. In the Power Transfer phase, the packets are End Power Packets, Control Error Packets, etc.

4.1. Ping phase

In the Ping phase, the transmitter communicates at an operating frequency of 175 kHz. If the transmitter detects the start bit of a Signal Strength Packet within $t_p$ time after the power transfer is started and the Signal Strength Packet is received correctly, then process enters into Identification and Configuration phase; otherwise, the End Power Packets are sent and power transfer terminated. An example of communication process shown in Figure 11.

At this phase, the transmitter mainly monitors whether Foreign Objects placed or removed on its surface. Qi Specification provides a method for monitoring based on current change. When the transmitter detects a receiving coil on the surface, the next step will be taken. If the transmitter detects multiple objects at the same time, the transmitter attempts to confirm whether these objects support free positioning firstly, and select a receiving coil to transfer power; if the transmitter does not get the required information during the Ping phase, the process will automatically repeat the Ping phase, this repetition will be continued till an optimal coil for power transfer is selected. Then Foreign Object Detection will be triggered, if foreign objects such as keys, coins are detected, the power transfer will be end instantly.

4.2. Identification and Configuration phase

At this phase, the transmitter has locked the receiver, and obtained the complete configuration information such as potential power. The transmitter can establish the corresponding protocol according to the obtained configuration information, including voltage, maximum power, duty cycle, frequency, etc, and prepare for the power transfer phase.

4.3. Power Transfer phase

At this phase, the transmitter will carry out continuous power transfer and adjust the coil current according to the feedback returned from the receiver. During the entire power transfer phase, the
transmitter monitors and adjusts the relevant parameters of the system by using the complete configuration information data obtained from the previous phase, if any abnormal parameter or fault appeared, the power transfer will be stopped immediately and turn into the Ping phase. Some common faults including 0x01(charge complete), 0x05(over current), 0x08(no response). Under normal circumstances, it is also possible for the receiver to send request to end the power transfer, turn the process into Ping, Identification and Configuration phase for new power transfer. The working status of this phase is shown in the Figure 12.

Figure 12. Example of Power transfer log

5. Summary

Wireless power transfer sub-system as a mature modular product is getting more popular in the market, its advantage lies in its superior expansion performance, can be quickly deployed in various electronic communication product application scenarios. By the detecting to the charging state, the maximum charging current of the wireless power transfer sub-system designed in this paper is up to 980mA, the maximum power can reach 4W. By testing the samples of the wireless power transfer sub-system, the test data verify the feasibility of the design scheme.

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