AN3441

Qi Wireless Power Micro-Receiver Reference Design

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INTRODUCTION

Qi charging is a standard for wireless power transfer promoted by the Wireless Power Consortium (WPC). Currently, this standard is supported by many companies and products that conform to the standard, making it the wireless charging choice for portable consumer electronics.

Handheld devices like smartphones are frequently used and need to be recharged daily, plugging and unplugging the charging cable every time. As an added inconvenience if receiving a call while the device is charging, the plugging and unplugging of the cable action is repeated. To charge Qi wireless devices, place the device on the Qi charger pad and it automatically starts charging. Additionally, during charging, the device is not plugged and it can be picked up and used at any time.

The growing number of Qi wireless chargers and devices can also reduce the need for manufacturer-specific cables and accessories because the Qi standard ensures interoperability. Using wireless charging simplifies the process for the user and significantly reduces the frequent mechanical failures of the portable device connector.

Not only smartphones, but other common battery powered devices can benefit from wireless charging as well. By implementing wireless charging, truly weatherproof or waterproof devices can be manufactured as it is much easier to encapsulate if there are no connectors. This also opens very interesting opportunities regarding medical equipment which sometimes needs to be aggressively cleaned or disinfected. In general, wireless charging can be taken into consideration for any portable device featuring a small rechargeable battery.

Wireless charging uses the principle of magnetic induction to transfer power. It is fairly similar to a conventional AC transformer, the receiver (PRx) and the transmitter (PTx) coils representing the transformer windings. However, it is different when it comes to the coupling between the two coils. While a transformer has strongly coupled coils on a magnetic core, the wireless charging coils are loosely coupled (coefficient <0.5) and the magnetic field transfers through air or other non-metallic, non-ferrous materials (plastic, wood, glass).

OVERVIEW

The Microchip Wireless Power Micro-Receiver allows users to quickly add wireless charging functionality to their projects without having to deal with complex specific protocols or state machines. This receiver is implemented using a general purpose 8-bit microcontroller and is a flexible, low-cost alternative to the common wireless charging solutions based on ASICs. The receiver is compatible with the Qi 1.1 (5W) standard and can be used in conjunction with any Qi 1.1 - compatible wireless charging transmitters (all Qi 1.2 or higher compliant base stations are also backwards compatible with Qi 1.1).

The simplified block diagram of the Microchip Wireless Power Micro-Receiver is presented in Figure 1. The wireless charger specific protocol (Qi 1.1) and the state machine are implemented in firmware on a PIC16F15313 8-bit microcontroller. This part was selected for the best feature/cost ratio, but basically any microcontroller with the required program memory, RAM and peripherals can be used. The high-frequency signal at the output of the resonant tank (L_S, C_S and C_D) is rectified by a simple full-bridge rectifier implemented with four Schottky diodes. The output voltage of the rectifier ($V_{RECTIFIER}$) is monitored by the microcontroller through a simple resistive divider. The rectified voltage is applied at the input of a Low Drop-Out voltage regulator (LDO) which supplies the 5V voltage for the battery charger and the microcontroller. The battery charging functionality is provided by the MCP73830 Single-Cell Li-Ion/Li-Polymer Battery Charge Management Controller (see Data Sheet at www.microchip.com/DS20005049). The input current is measured by the microcontroller using a shunt resistor and an MCP6001 amplifier (see Data Sheet at www.microchip.com/DS20001733). Measurement of the input current is necessary to accurately calculate input power and is further needed to implement *Foreign Object Detection* (FOD) using the power loss method.

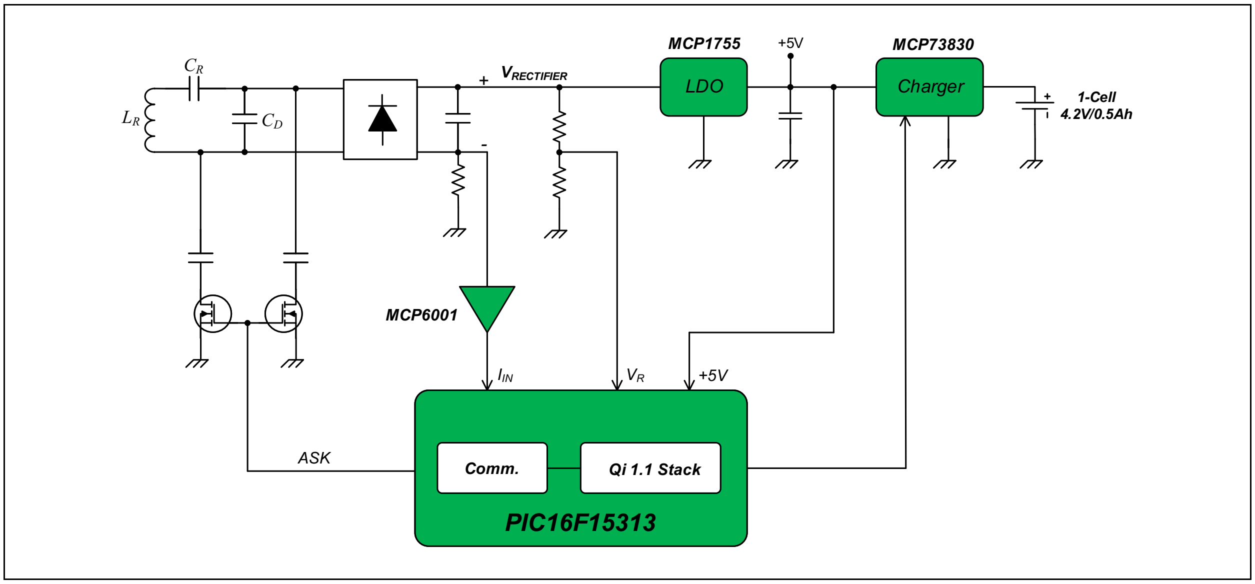

FIGURE 1: *The Simplified Block Diagram.*

The communication with the base transmitter is implemented using *Amplitude Shift Keying* (ASK) as recommended by the Qi 1.1 standard. Two low-power MOSFETs and two capacitors are used to modulate the absorbed power.

In order to minimize the power losses and the power dissipated by the LDO, the rectified voltage value is controlled in a closed loop manner, and the voltage at the output of the rectifier is regulated at a value that is slightly higher than the typical dropout voltage (in this case around 0.5V). At fixed intervals, the power receiver sends error packets to the transmitter, steering the input voltage to the desired value.

The values of the resonant tank components (L_S, C_S and C_D) are critical and must be carefully selected. The values of the resonant capacitors are in general recommended by the manufacturer of the wireless charger inductor. However, these values can be determined using the following recommendations from part 1 of the WPC Version 1.2 specifications. The specifications can be downloaded for free from https://www.wirelesspowerconsortium.com/knowledge-base/specifications/download-the-qi-specifications.html. Additionally, the zipped file containing the specifications can be accessed from https://www.wirelesspowerconsortium.com/data/downloadables/2/2/0/5/qi-wireless-power-specification-non-confidential.zip. The simplified receiver resonant system is presented in Figure 2.

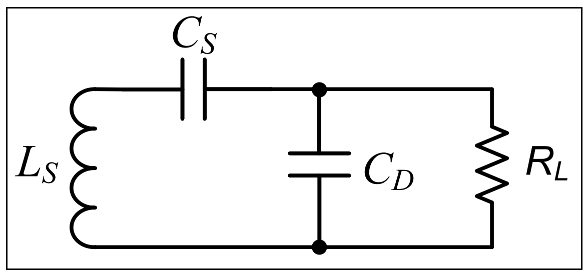

FIGURE 2: *The Equivalent Resonant System of the Receiver.*

The main resonance frequency used during the power transfer phase is given by L_S and C_S and must be set close to 100 kHz. Equation 1 determines the value of the series resonant capacitor.

EQUATION 1: RESONANT CAPACITOR

$$C_S = \frac{1}{(2\pi \times f_S)^2 \times L'_S}$$

Where:

f_S = must be 100 kHz (+5%/-10%)

L'_S = the equivalent inductance of the receiver inductor

L'_S is measured using a specific setup recommended by the WPC Version 1.2 specifications. The setup for measuring L'_S is shown in detail in the WPC Qi specifications, Part 1 and 2, section 3.1.1, page 28.

The second resonant frequency, set by L_R, C_S and C_D, is used for the detection of the receiver by the transmitter using the Q-method (quality factor method). The second resonance is used only during the detection phase and the frequency of this resonance must be set to 1 MHz. The value of C_D capacitor is calculated using the formula in Equation 2.

EQUATION 2: DETECTION CAPACITOR

$$C_D = \frac{1}{(2\pi \times f_D)^2 \times L_S - \frac{1}{C_S}}$$

Where:

f_D = must be 1 MHz (±10%)

L_S = the equivalent inductance of the receiver inductor in free space

The quality factor (Q) of the resonant tank at the detection frequency (1 MHz) must be higher than 77. The quality factor is estimated using Equation 3.

EQUATION 3: QUALITY FACTOR

$$Q = \frac{2\pi \times f_D \times L_S}{R}$$

Where:

R = DC resistance of the loop that includes the receiver inductor, C_S and C_D. R is measured with C_S and C_D short-circuited.

HARDWARE DESCRIPTION

The schematic of the Microchip Wireless Power Micro-Receiver is presented in Figure 3. L4 is the receiver coil and is connected on two specific pads. C1 and C2 form the series resonant capacitor, C_S. C3 is the detection capacitor C_D. The full-wave rectifier is implemented by four Schottky diodes, D1-D4. The rectified voltage is filtered with capacitor C6 and measured by the microcontroller using the resistive divider formed by R4 and R5.

The input current is sensed using the R2 shunt resistor (100 mΩ) and an amplifier stage (U4 amplifier, R10-R12 and C12). The gain of this amplifier is set to 10.

The MCP1755 LDO (U1) provides 5V to the microcontroller and to the charging controller, up to 300 mA (see www.microchip.com/DS25160).

MCP73830 provides fully featured Li-Ion charging functionality. The charging current is set by an external resistor (R9) and the STAT pin connected to an LED informs the user of the charging state. The CE pin allows the chip to be enabled externally by the PIC, which is very useful since the input rectifier voltage needs to reach a certain value before starting to charge the battery. Pre-charging current is 10% of the charging current and internal time limits exist on both pre-charging and charging. Depending on the MCP73830 version (see www.microchip.com/DS20005049), the end of charge current is either 7.5% or 10% of the charging current.

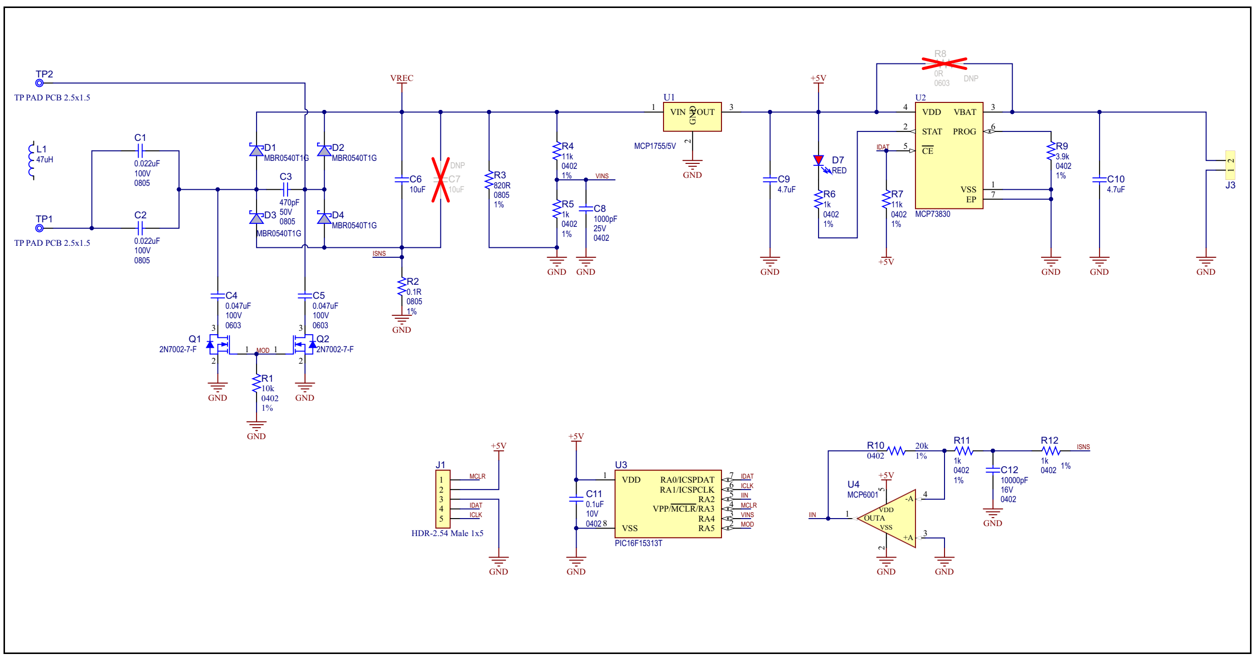

FIGURE 3: *The Schematic of Microchip Wireless Power Micro-Receiver.*

FIRMWARE DESCRIPTION

The firmware is provided as an MPLAB® X Integrated Development Environment (IDE) project and the user has the option to add custom functionality and modify some parameters related to the wireless charging functionality.

These parameters are located in the `qi.h` file. These parameters are related to:

- Circuit input voltage (after LC resonant tank with a diode rectifier, hardware dependent)
- Manufacturer code (2 bytes code)
- Basic identification code (4 bytes, split into HI and LO words)
- Input diode rectifier voltage drop (ADC units, hardware dependent)
- Received power calculation coefficient (hardware dependent)

As required by the application, additional functionality may be added to the core firmware, but any modifications must take the initial peripheral configuration into consideration.

The first requirement is that the PIC runs at 16 MHz, not 32 MHz as the input voltage can drop under 3V in certain conditions. As stated in PIC16(L)F18313/18323 Data Sheet (see www.microchip.com/DS40001799), 32 MHz operation is not guaranteed with a voltage supply under 3V over the whole temperature range.

Another requirement related to input voltage variations is the ADC reference voltage which is provided by the FVR. The ADC reference should be set to 2.048V, allowing it to accurately measure the input voltage even if it drops below 3V.

The main loop timer which is also the base timer for the ADC channel read function and the Qi state machine timing is TMR0 running at 4 kHz. Modifying the timer frequency modifies the Qi data packet intervals and has a functionality breaking potential. Any additional functionality introduced by the user needs to use non-blocking code and take into account the time needed to execute. Any code needing longer than 200-250 μs to execute should be split into smaller chunks and executed sequentially.

The ADC reading function uses the TMR0 overflow as a trigger and is set to read the input voltage and input current. Any additional ADC channels can be added into the reading chain as required by the application. Obviously too many channels can slow down the update rate for each parameter and cause the firmware to react slower to changes.

The PIC is equipped with a PPS peripheral allowing peripheral input/outputs to be remapped. Also, ADC channels can be changed as needed by the application as long as the correct channel values are used in the reading chain (ensure the correct values end up in the input voltage and input current variables).

The Qi data packets transmitted by the receiver to the base station use a biphasic Manchester coding (BMC) and ASK modulation. The data rate specified by the standard is 2 kbps, leading to a half bit frequency of 4 kHz. Data modulation is performed on the TMR2 interrupt to ensure minimal disturbance of the bit timing by the main loop. It is highly recommended not to modify any TMR2 related settings. Any additional code handling interrupts should be non-blocking and execute as quickly as possible; otherwise, transmission errors may occur.

Alternately, applications not needing to run tasks during the Qi charging process may use a routine that monitors input rectifier voltage and can switch between Qi charging functionality and user application when appropriate. In this case the user application has no coding restrictions, but needs to quickly switch to Qi charging when detecting a certain input voltage level ($V_{RECTIFIER}$).

QI PARAMETERS

Identification Packet Customization

Qi major and minor versions are fixed to 1 to reflect the basic 5W Qi 1.1 capabilities of the device. The Manufacturer Code and Basic Device Identifier are customizable.

MANUFACTURER CODE

The Manufacturer Code is defined in the Qi standard as a bit string that identifies the Power Receiver as specified in the Power Receiver Manufacture Codes, Wireless Power Consortium. The code is a 16-bit value found in the identification packet data transmitted by the receiver. It can be modified by changing the `MANUFACTURER_CODE` define in the `qi.h` file.

BASIC IDENTIFICATION CODE

The Basic Device Identifier is a 32-bit string that contributes to the identification of the Power Receiver. The manufacturer should ensure that each device has a sufficiently unique combination of Basic Device Identifier and Manufacturer ID codes. Embedding a serial number of at least 20 bits in the Basic Device Identifier is sufficient for this task. Table 1 shows the identification packet bit fields taken from the Qi 1.2.3 standard. For more information, refer to the recommendations from the WPC Version 1.2 specifications.

The EXT field of the Basic Device Identifier should be set to zero since the current implementation does not support extended identification packets. The Basic Device Identifier can be modified by changing the `BASIC_IDENT_CODE_HI` and `BASIC_IDENT_CODE_LO` defines in the `qi.h` file. Both are 16-bit values.

Note that both the Manufacturer Code and the Basic Device Identifier are in big endian format. The PIC firmware will handle inverting the byte order in each word when transmitting the packet.

TABLE 1: IDENTIFICATION PACKET BIT FIELDS

	b7	b6	b5	b4	b3	b2	b1	b0
B0	Major Version				Minor Version			
B1 B2	(MSB) Manufacturer Code (LSB)							
B3 B4 B5 B6	Ext	(MSB) Basic Device Identifier (LSB)						

Input Voltage Regulation

Voltage regulation at the receiver input is regulated using control error packets that are sent to the base station. These packets contain a number showing the relative deviation of the current voltage value compared to the desired input voltage. In this case the input voltage is read after the diode rectifier bridge, so it does not include losses on the diodes. The PIC firmware calculates the error for the control packets and sends the data. The voltage set point can be modified by changing the `VIN_SETPOINT_LP` define in the `qi.h` file. Note that the value is in ADC units and must be calculated using the ADC resolution, voltage reference and input voltage divider. A second `no-load` value for the set point can be used before starting to charge the battery. It is usually higher than the normal value and can be useful when connecting loads at full power to avoid undervoltage conditions. This value can be modified by changing `VIN_SETPOINT_START` define in the `qi.h` file.

For the Qi 1.1 5W Micro-Receiver, the ADC resolution is 10 bits, voltage reference is 2.048V, input divider is 1:12 and set voltage is 5.5V. See Equation 4.

EQUATION 4: INPUT VOLTAGE SET POINT CALCULATION

$$V_{SET\_ADC} = \frac{V_{IN} \times 2^{ADC\_BITS}}{V_{IN\_DIV} \times V_{REF}} = \frac{5.5V \times 1024}{12 \times 2.084} = 229.166$$

Input Rectifier Diodes Compensation

The voltage drop on the input diodes is not measured and must be compensated in order to accurately calculate the input power. A simple way to achieve this is to add the voltage drop (at full current) to the input voltage before calculating power. In a rectifier bridge there are usually two diodes conducting, so considering a 0.5V drop per diode, the ADC unit value is calculated in a similar way to the voltage set point. See Equation 5.

EQUATION 5: DIODE VOLTAGE DROP CALCULATION

$$V_{DROP\_ADC} = \frac{(V_f \times 2) \times 2^{ADC\_BITS}}{V_{IN\_DIV} \times V_{REF}} = \frac{1.0V \times 1024}{12 \times 2.084} = 41.66$$

The input diodes voltage drop can be modified by changing the `RECT_DROP_CORR` define in the `qi.h` file.

Received Power Calculation Coefficient

A Qi Power Receiver must periodically transmit a calculated received power value based on measuring the input values and estimated losses. The base station compares this value to the locally measured transmitted power and uses this information for the FOD (Foreign Object Detection) functionality.

Power is transmitted to the base station normalized to 5W and scaled to a value between 0 and 128. See Equation 6. For the 15W version, the scaling factor is 32768.

EQUATION 6: QI RECEIVED POWER VALUE

$$P_{Qi} = \frac{P_{measured}}{5W} \times 128$$

To calculate the power value for the power packet from ADC values, all constants (like input voltage divider, current shunt and amplification) can be combined in one coefficient. See Equation 7 and Equation 8.

EQUATION 7: VOLTAGE AND CURRENT FROM ADC UNITS

$$V_{in} = \frac{V_{IN\_ADC} \times V_{IN\_DIV} \times V_{REF}}{2^{ADC\_BITS}}$$

$$I_{in} = \frac{I_{IN\_ADC} \times V_{REF}}{2^{ADC\_BITS} \times R_S \times A}$$

The Qi 1.1 5W Micro Receiver uses a 0.1Ω shunt resistor and x10 amplification.

EQUATION 8: QI RECEIVED POWER CALCULATION

$$P_{Qi} = \frac{P_{measured}}{5W} \times 128 = \frac{(V_{in} + 2V_f) \times I_{in} \times 128}{5W} =$$

$$(V_{IN_{ADC}} + V_{DROP\_ADC}) \times I_{IN_{ADC}} \times 0.0012288$$

The result is scaled by 2E18 to maintain accuracy: $0.0012288 \times 2^{18} = 322.1225472$. See Equation 9.

EQUATION 9: QI RECEIVED POWER FROM ADC UNITS

$$P_{Qi} = \frac{(V_{IN_{ADC}} + V_{DROP\_ADC}) \times I_{IN_{ADC}} \times 322}{2^{18}}$$

CONCLUSION

The Microchip Wireless Power Micro-Receiver is a simple, robust, low-cost implementation of the Qi 1.1 5W wireless charging standard with the added functionality of a fully featured Li-Ion charging controller. The design offers a lot of flexibility compared to the existing ASICs because the Qi state machine and communication routines are implemented on a PIC micro. Additional functionality can be added by the user by modifying the provided MPLAB X IDE project.

Adding wireless charging capabilities to an application has multiple benefits. Besides the obvious comfort benefits related to plugging and unplugging the device every time it is used or charged, it can minimize cost and extend product life by reducing mechanical failures from connectors and allowing to manufacture devices that are truly resistant to water and dust.

REFERENCES

1. MCP73830(L) Data Sheet - "*Single-Cell Li-Ion/Li-Polymer Battery Charge Management Controllers in 2x2 TDFN*" (DS20005049), Microchip Technology Inc.
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5. PIC16(L)F18313/18323 Data Sheet - "*Full-Featured, Low Pin Count Microcontrollers with XLP*" (DS40001799), Microchip Technology Inc.

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