Freescale Low Power Wireless Charger
APF-IND-T0804

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System and Application
Industrial & Multi-Market Operation
MCU, Freescale Semiconductor

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Session Objectives

After completing this session you should:

• Have a good understanding of basic wireless charging theory and basic WPC "Qi" communication.

• Be familiar with FSL solutions of different types of Wireless Charger Transmitter & Receiver.

• Be familiar with FSL Roadmap.

• Understand the advantages of FSL wireless charging solutions and be able to introduce them to customer.

• Be able to support customer when they met problem.
Agenda

This session introduces wireless charging, Qi protocol, and Freescale’s solutions

• What is Wireless Charging?
• How Qi works
• Introduction to FSL Solutions
• Freescale Wireless Charging Roadmap
What is wireless charging?
What is Wireless Charging

Wireless charging is the transfer of power through non-conductive means.

Types:

• Inductive – Transmitter coil that creates a magnetic field; receiver coil picks up the magnetic field and generates an electric current

• Magnetic resonance – Both a transmitter and receiver coil operating at resonance

• Capacitive – Transmitter plate generates an electric field via high voltage; receiver plate receives this voltage and rectifies this as a DC output
# What is Wireless Charging

## Comparison:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Inductive</th>
<th>Resonance</th>
<th>Capacitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Comparable to traditional</td>
<td>Comparable to traditional</td>
<td>Comparable to traditional</td>
</tr>
<tr>
<td>Power Scalability</td>
<td>Highly</td>
<td>Slightly</td>
<td>Constrained by charge surface area</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>&lt; 500kHz</td>
<td>kHz – MHz range</td>
<td>Varies</td>
</tr>
<tr>
<td>Thermal Footprint</td>
<td>Dependent on efficiencies</td>
<td>Dependent on efficiencies</td>
<td>None</td>
</tr>
<tr>
<td>Multiple Devices</td>
<td>One to One relationship</td>
<td>Yes</td>
<td>One to One relationship</td>
</tr>
<tr>
<td>Z - Spatial Freedom</td>
<td>&lt; 1cm</td>
<td>&lt; 4cm</td>
<td>&lt; 1cm</td>
</tr>
<tr>
<td>Cost Points</td>
<td>Micro &amp; coils</td>
<td>Complex Rx</td>
<td>Electrodes, amplifiers, transformers</td>
</tr>
</tbody>
</table>
Why Qi? The WPC: 137* companies cooperating

- All major consumer electronics companies
- All major mobile phone manufacturers
  - except Apple
- Component suppliers
  - Semiconductors / ICs
  - Magnetic shielding
  - Coils

[Diagram showing various companies and regions]

WPC members per region:
- North America: 29
- Japan: 19
- Taiwan-HK-Macao: 22
- Europe: 28
- China (mainland): 24
- Korea: 14
- South East Asia: 1

*Note: WPC stands for Wireless Power Consortium.
Existing Low Power Wireless Charger Rx Solutions

- **Sleeves**
- **Contactor**
- **Back Cover**
- **Battery Pack Charger**
Freescale Activities
“Qi” & How it works
How it works

• Main application
  – Battery charging, or other suitable loads
  – For wide range of mobile devices
    ▪ Mobile phone, camera, mp3 player, headset, …

• Up to 5W of power delivery
  – More power at later versions

• Power transfer via magnetic induction
  – Loosely coupled transformer
  – At short distance (few mm)
System Overview (Top View)

• Base Station
  - Contains one, or more transmitters
  - Transmitter provides power to receiver

• Mobile Device
  - Contains a receiver that provides power to a load (e.g. a battery)
  - Receiver provides control information to transmitter
System Overview (Power Conversion)

- Power Conversion Unit converts electrical power to wireless power signal
- Power Pickup Unit converts wireless power signal to electrical power
System Overview (Control)

- Receiver controls the power to the output load
  - To the need of the mobile device (required power)
  - To the desired operation point (e.g. output current, voltage)
- Transmitter adapts power transfer
  - To the need of the receiver (required power)
  - To the desired operation point (e.g. primary coil current)
System Overview (Communication)

- Receiver sends messages
  - To provide control information to the transmitter
  - By load modulation on the power signal
- Transmitter receives messages
  - To receive control information from the receiver
  - By de-modulation of the reflected load
Power Conversion (Transmitter)

- Primary coil ($L_p$) + serial resonance capacitor ($C_p$)
- Inverter: e.g. half bridge
- Coil array implementation
- Controlled by e.g. frequency or voltage
Power Pick Up (Receiver)

- Secondary coil ($L_s$)
- Serial resonance capacitor ($C_s$) for efficient power transfer
- Parallel resonance capacitor ($C_d$) for detection purposes
- Rectifier: full bridge (diode, or switched) + capacitor
- Output switch for (dis-)connecting the load
Communication (Modulation)

- Receiver modulates load by
  - Switching modulation resistor ($R_m$), or
  - Switching modulation capacitor ($C_m$)

- Transmitter de-modulates reflected load by
  - Sensing primary coil current ($I_p$) and/or
  - Sensing primary coil voltage ($V_p$)

\[ C_p, L_p, C_d, L_s, C_s, C_m, R_m \]
“Qi” Communication & Power Transfer
Communication (Data-Format)

- Speed: 2 Kbit/s
- Bit-encoding: bi-phase
- Byte encoding:
  Start-bit, 8-bit data, parity-bit, stop-bit
- Packet Structure
  - Preamble (>= 11bit)
  - Header (1 Byte)
    - Indicates packet type and message length
  - Message (1 .. 27 Byte)
    - One complete message per packet
    - Payload for control
  - Checksum (1 Byte)
Communication & Control

- **Start**
  - Transmitter provides signal and senses for presence of an object (potential receiver)
  - Receiver waits for signal

- **Ping**
  - Receiver indicates presence by communicating received signal strength
  - Transmitter detects response of receiver

- **Identification & Configuration**
  - Receiver communicates its identifier and required power
  - Transmitter configures for power transfer

- **Power Transfer**
  - Receiver communicates control data
  - Transmitter adapts power transfer
Power Transfer Control

Transmitter
- Interpret desired control point from
  - Control error message
  - Actual control point
- Adapt power towards zero difference between
  - Desired control point
  - Actual control point

Receiver
- Calculate control error
  \[ = \text{difference between} \]
  - Desired control point
  - Actual control point
- Communicate control error message
Coupling between Coils

- Good Coupling between coils is achieved by
  - Choosing appropriate dimensions of coils (matching size)
  - Keeping the distance between coils small (flat interface surface)
  - Adding magnetic permeable material (shielding)
  - Aligning the coils (next page)
Coil Alignment (Design Freedom)

- Guided positioning with tactile feedback
- Free positioning with moving coil
- Free positioning with selective activation of coils in coil array
Standby Power

- Transmitter can enter standby power mode when
  - No device is present, or
  - Present devices need no power (battery charged)
- Transmitter can apply various methods to react on a receiver
  - Capacitance change
    - To detect the placement of a potential receiver
    - E.g. 0.1 mW
  - Resonance detection, or
  - Resonance change
    - To detect the presence and location of a potential receiver
    - E.g. 5 mW per primary coil when applied every 0.5s
  - Digital ping
    - To detect the presence and location of a receiver
    - To check for power need of a receiver

Example Standby Behavior

- Capacitance Change
  - Wake up
  - Rx Object
- Resonance Detection
  - No Response
- Digital ping
  - Power need
  - Normal Mode

[Diagram showing the relationship between Capacitance Change, Resonance Detection, Digital ping, and Normal Mode]
Foreign Object Detection

- The presence of foreign objects can absorb energy from the magnetic field, causing heating of the object.
- The system must account for all power to detect the presence of a foreign object.
General Power Loss Equations

• The overall power loss in the system can be calculated using the following equation:

\[ P_{loss} = P_{transmittal} - P_{received} \]

• Further, the transmitted power can be calculated using the following equation:

\[ P_{transmittal} = P_{in} - P_{txlosses} \]

• And the received power can be calculated as follows:

\[ P_{received} = P_{load_{meas}} + P_{rxlosses} \]

• Characterization of “expected” system losses make foreign objects easily identifiable
Freescale B type Wireless Transmitter

Key Features:
- Freescale first low power wireless transmitter compatible with Qi specs
- Wide input voltage support from 5V to 16V
- Free positioning with primary coil array (B1 type coil)
- Single-stage full-bridge inverter with phase shift control
- Low cost and robust analog demodulation solution (single channel)
- Low standby power with enable button
Block Diagram

FSL B Type Transmitter
Primary coil composition

Contain 7 coils enable free position

To obtain maximum transfer efficiency, one to three coils on different layers may operate due to the position of secondary coil.

FSL B Type Transmitter

Red
Green
Blue

Layer1
Layer2
Layer3

Coil 1, Coil4 and Coil6 operate

Coil 2 and Coil4 operate

Coil4 operate
System Control Loop

FSL B Type Transmitter
System State Machine

FSL B Type Transmitter

- Idle (Stand-by)
  - Waiting push button pressed
  - Charging end, and detection timer out
  - Push button pressed
  - Detection fail, and detection timer out
  - Localization fail, and detection timer out

- Charging
  - Repeats N3

- Object detection (Analog ping)
  - Repeats N1

- Object localization (Digital ping)
  - Repeats N2
  - Success
  - Repeats >= N1
  - Fail

- Charging fail

- Success
- Fail
Board Description

FSL B Type Transmitter

- Primary Coils
- Power Stage
- Sensing Circuit
- Power Source
- Communication Demodulation Circuit
- Resonant Bank Selection Circuit
- HMI
- MC56F8006

Diagram of the board with labeled components.
Efficiency Test

Power Efficiency FSL Tx/FSL Rx E&E Round Coil

- 5V
- 9V
- 12V
- 16V
- 19V

Output Power (W)

Efficiency

0% 10% 20% 30% 40% 50% 60% 70%

0 1 2 3 4 5 6
Freescale Axx type Wireless Transmitter

Key Features:
- Freescale low cost low power wireless transmitter compatible with Qi specs
- 5V input voltage
- Guided positioning with single primary coil (A11 type coil)
- Single-stage full-bridge inverter with phase shift control
- Low cost and robust analog demodulation solution (single channel)
Freescale A11 type Wireless Transmitter

Key Features:
- Freescale high performance low power wireless transmitter compatible with Qi specs
- 5V input voltage
- Guided positioning with single primary coil (A11 type coil)
- Single-stage full-bridge inverter with frequency and duty cycle control
- Low standby power with TSI
- Basic FOD function
Working Principle

Change the operation frequency to reach the suitable V scale on Lp.
WCT1000 and Touch

Communication  Power Inverter  Coil
Efficiency Test

1. Stable working with different type RX (Runways coil and Round coil)
2. High system efficiency

Power Efficiency FSL Tx A11 / Mr T Runway-L Coil

Power Efficiency FSL Tx A11 / Mr T Runway-S Coil
Freescale A13 type Wireless Transmitter

*Pop-option to use DSC for Vrail control

Other functions: antenna coupling, LED, User Interface,…

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Freescale A13 type Wireless Transmitter

Key Features:
- Freescale automotive low power wireless transmitter compatible with Qi specs
- 6-16V input voltage support
- Free positioning with three primary coils (A13 type coil)
- Two-stage power stage (BUCK + full-bridge) with rail voltage control
- Low standby power with TSI (ver. 2)
- Coil temperature sensing (ver. 2)
- Key FOB avoidance (ver. 2)
- Basic FOD function (ver. 3)
- CAN support (ver. 3)
- NFC co-existence (ver. 3)
- Digital demodulation algorithm (ver. 3)
Board Description

- **Coil Buck DC/DC**
- **FET Driver**
- **H-Bridge**
- **Coil drive**
- **MC33903**
- **NFC Transceiver**
- **WCT1001A**
- **MPR121**
- **Demod / Sense**

FSL A13 Type Transmitter

- **Airfast**, **BeeKit**, **BeeStack**, **CoreNet**, **Flexis**, **Layerscape**, **MagniV**, **MXC**, **Platform in a Package**, **QorIQ Qonverge**, **QUICC Engine**, **Ready Play**, **SafeAssure**, **SMARTMOS**, **Tower**, **TurboLink**, **Vybrid** and **Xtrinsic** are trademarks of Freescale Semiconductor, Inc. All other product or service names are the property of their respective owners. © 2013 Freescale Semiconductor, Inc.
Freescale 30W*4 Wireless Transmitter

Key Features:

- Freescale medium power (30W) wireless transmitter compatible with Qi specs (low power version)
- 18-22V input voltage support
- Guided positioning with single primary coils
- Single-stage power stage (half-bridge) with frequency and duty cycle control
- 4 channels in one base station with one DSC silicon
Freescale 30W Wireless Transmitter

Key Features:
- Freescale medium power (30W) wireless transmitter compatible with Qi specs (low power version)
- 18-22V input voltage support
- Guided positioning with single primary coils
- Single-stage power stage (half-bridge) with frequency and duty cycle control
Freescale Low Power Wireless Receiver

Key Features:
- Freescale first low power wireless receiver compatible with Qi specs
- 5V/1A output
- Load capacitors modulation
- Half SR plus BUCK converter (linear LDO for ver. 2) for power pick up
- Output disconnection
- Basic FOD function
- Small size (32x18x2mm)
Block Diagram

FSL Low Power Receiver

Resonant&Rectifier circuit

AOZ1280
DC/DC
5V/1A
NO SYN

Protection Circuit

3V3 VCC

5VOLTAGE
5V CURRENT

DISCHARGE
VBUS
COMMUNICATION

MC9RS08KB12

Communication circuit
Demodulation circuit will pike up the communication signal.

Change the RX resonant C value will affect the TX LC resonant curve.
Rx Board Description

Figure-11 Test Points on Wireless Power Receiver Board Rev1.2
Freescale 30W Wireless Receiver

Key Features:

- Freescale medium power (30W) wireless receiver compatible with Qi specs (low power version)
- 18V/1.1A output
- Load resistor modulation in AC side
- Full SR for power pick up
- Output disconnection
- Coil temperature sensing
### Existing Freescale Solutions Summary

<table>
<thead>
<tr>
<th>Key IPs</th>
<th>B1</th>
<th>Axx</th>
<th>A11</th>
<th>A13</th>
<th>30W (Bat)</th>
<th>30W (Tab)</th>
<th>Rx (5W)</th>
<th>Rx (30W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freescale</td>
<td>Freescale</td>
<td>on Fulton</td>
<td>on Fulton</td>
<td>on Fulton</td>
<td>on Fulton</td>
<td>Freescale</td>
<td>With Fulton</td>
<td></td>
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<tr>
<td>Processor</td>
<td>MC56F8006</td>
<td>MC56F8006</td>
<td>MC56F82723</td>
<td>MC56F82748</td>
<td>MC56F8257</td>
<td>MC56F8257</td>
<td>MC9RS08KB12</td>
<td>MC9S08QBB8</td>
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<tr>
<td>Power trans.</td>
<td>5V-16V input Full-bridge Phase-shift</td>
<td>5V input Full-bridge Phase-shift</td>
<td>5V input Full-bridge Frequency &amp; duty cycle</td>
<td>6V-16V input Full-bridge &amp; BUCK Rail voltage</td>
<td>18-22V input Half-bridge Frequency &amp; duty cycle</td>
<td>18-22V input Half-bridge Frequency &amp; duty cycle</td>
<td>5V/1A output Half SR &amp; BUCK</td>
<td>18V/1.1A output Full SR</td>
</tr>
<tr>
<td>Safety</td>
<td>NA</td>
<td>NA</td>
<td>FOD</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>FOD</td>
<td>NA</td>
</tr>
<tr>
<td>HMI</td>
<td>FreeMASTER, enable button</td>
<td>FreeMASTER</td>
<td>FreeMASTER, eCouple console</td>
<td>FreeMASTER, eCouple console</td>
<td>FreeMASTER, eCouple console</td>
<td>FreeMASTER, eCouple console</td>
<td>FreeMASTER</td>
<td>eCouple console</td>
</tr>
<tr>
<td>EMC</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Yes, meet car requirements</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Built quantity</td>
<td>100 pcs</td>
<td>NA</td>
<td>30 pcs</td>
<td>10 pcs</td>
<td>30 pcs</td>
<td>30 pcs</td>
<td>50 pcs</td>
<td>150 pcs</td>
</tr>
<tr>
<td>Others</td>
<td>Free position</td>
<td>Co-work with distributors</td>
<td>Low standby power with TSI</td>
<td>Low standby power with TSI</td>
<td>4-ch in one chip</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Freescale Value Proposition

• **Broad Flexibility**
  - Configurable hardware for added features
  - Modular software to select only what’s necessary
  - Ability to add differentiating features via software add-ons

• **Application-Specific Technology**
  - DSC core technology optimized for wireless charging transmitters
  - Software IP focused on efficiency & X/Y/Z freedom

• **Speed Time-to-Market**
  - Market-focused solutions
  - Productized software components
  - Wireless charging expertise
Wireless Charging Roadmap

Features

Low Power Rx
- Qi Protocol
- Charging Algorithms

Medium Power +
- Quad-Channel
- Free Position

Low Power +
- Dual-Channel
- Medium Power
- Single-Channel
- Fixed Position

Low Power
- Single-Channel
- Fixed Position
- Free Position

2012 2013 2014 2015

Production
First Sample Date (left edge)

Execution
Product Qualification (right edge)

Proposal

64LQFP
48LQFP
32LQFP
KB12 24QFN

WCR1010
WCR1000
WCR11xx
Integrated ASK/PSK Rectification

MC56F8257
WCT5010
WCT5000
Qi

MC56F8247
WCT3010
WCT3000
Qi

MC56F8247
WCT3000A
Auto

WCT1010
WCT1000
Qi

WCT31xx
FET Drivers

WCT5000
Qi

WCT31xx
FET Drivers

WCT3000
Qi

WCT5000
Qi

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WCR1000 Wireless Power Receiver

 Silicon
- RS08KB 8 bit MCU core
- Operation frequency @ 25Mhz
- Up to 12KB Program FLASH with Security
- Clock sources
  - External Crystal/Resonator Oscillator
  - 32 Khz Tunable Internal Relaxation Oscillator
- One Lower Power Timer
- 1 x 8 channel 12-bit ADC
- Three Analog Comparators with 6bit Vref
- One Serial Communications Interface (SCI)

 Software
- Qi communications protocol
- Battery charging algorithms (NiMH, LiION)
- Foreign Object Detection (FOD)
**WCT3000 Wireless Charging Transmitter**

**SILICON**

- 56800E V3 Core @ 50MHz/100MHz from cache memory
- 32kB Flash
- 6 channel PWM (512ps resolution)
- 2 x 3 channel ADC (800ns conversion rate)
- 4 channel DMA controller
- 32 LQFP

**Software**

- Closed loop PID algorithm
- Foreign Object Detection
- Digital demodulation (ASK/PSK)
- LED control
- CAN driver
- UART driver
- Support dual-mode solutions
Freescale WCT solution benefits

• Flexibility
  - Flash based → extra code can be added by customer
  - Support any type of power control (frequency, phase, rail,…)
  - Family of part to expand product portfolio on one architecture

• Low Power
  - High performance DSP instruction set cut down power (28mA PID loop operating current)

• Reliability
  - Low power operation minimizes temperature increase

• Quality
  - Auto grade AEC-Q100 level 2 quality
Software Model

**Custom**
- Full flexibility
- Proprietary System
- Potentially non-Qi
- Custom technical specifications

**Semi-custom**
- Additional programmability
- More hardware flexibility (PWMs, ADCs)

**Standard**
- ASSP
- Tx Qi-based Solutions
- Rx Qi-based Solutions
For More Information

• Freescale Solutions
  - Freescale DSC Home Page
    ▪ www.freescale.com/dsc

  - Wireless Charger Home Page
    ▪ www.freescale.com/wirelesscharging