Freescale Wireless Charging Solutions

FTF-CON-F0020

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A P R . 2 0 1 4
Agenda

• Market
• Freescale solutions
• How wireless charging works
• Difference between inductive and resonance
Wireless Charging TAM

Transmitter vs. Receiver

Rx higher volume, but cheaper price vs. Tx. 
Perception – Provider with Tx & Rx has a complete solution.

Source: IMS, Gartner, Wireless Power Consortium, Powermat, A4WP
Market View

**Wireless Power Consortium**
- Verizon
- 136 Members
- Complete supply chain
- Power scalability to 120W
- Resonance
- Distances scalable up to 4cm
- Operating frequency 105 – 205kHz
- **Freescale member**

**PMA (Power Matters Alliance)**
- AT&T
- Inductive Charging
- Resonance
- Distance up to several cm
- Operating frequency 300 – 350kHz
- **Freescale member**

**Alliance for Wireless Power**
- Qualcomm, Samsung, Intel
- Resonance @ 6.78MHz
- Distance of a few cm

**MOU**
Receiver Group Based on Applications

- **Applications (<2.5W)**
  - As small as possible
  - High integration with Analog and Charging

- **Applications (5W)**
  - Must have good thermal performance
  - Less thickness
  - w or w/o charging controller for different application

- **Applications (10 - 15W)**
  - Must have good thermal performance
  - Less thickness
  - w or w/o charging controller for different application
  - 5W compatible

- **Higher Power Applications (>15W)**
  - 3 cells to 5 cells with output voltage: 12.6v to 21v
  - Good thermal performance
  - Accept additional charging controller for battery pack
  - Not covered by Qi specs yet
Latest Qi-enabled Products Available Today
WPC Qi Update

• Current specification includes up to 5W
  - Enable mobile phone market
  - Additional features such as foreign object detection
  - Wide range of transmitter types available
• Extension of 5W specification to include resonance now under draft
  - Targeting a draft specification release in 2014
• Extending the Qi low power specification to 15 Watts
  - Enables fast phone charging
  - Align with increased power requirements of smart phones
  - Enable wireless charging for new class of devices
  - Draft specification under review; public release expected in 2014
• Medium power: 30-120 Watt
  - Enables charging of tablets and notebook computers
PMA Update

- Tx specification released for review
  - PMA-3 (5W single-coil available for product development)
  - Single-coil Litz implementation
  - Magnetic alignment requirement
  - Frequency of operation 205kHz – 300kHz
  - Input voltage requirement of 18V
  - FOD requirement
- Multi-coil designs in proposal stage
- Compliance requirements not finalized yet
- No clear synergy to develop dual-mode system and meet all requirements
- Resonance working group established (adopt A4WP?)
Freescale Wireless Charging Solutions

Broad Flexibility
Industry’s first programmable solution, offering customers the utmost design flexibility

Accelerate Time-to-Market
Production-ready designs with market specific focus

Unequivocal Performance
Unparalleled performance delivering an optimized HW and SW platform
Freescale Value

**Hardware**
- Transmit controller ICs with high performance core and peripherals
- Power efficient control loop processing
- Digital demodulation and foreign object detection
- UART, SPI, I2C interfaces for external communication
- Ability to use additional memory and I/Os to add more features

**Software**
- Firmware library to perform wireless power core functions
- Programmable interface to adjust core function parameters
- Customize feature set and behavior
- Ability to add additional features outside of wireless core function

**Reference Designs**
- Production-ready reference designs for key markets
- Ready designs with minimal configuration and necessary tuning
- WCTGUI easy-to-use real-time tuning and debug tool
WCT1000 – Single Coil Transmitter

Hardware
• 100 MHz core
• Support any 5W single coil type
• Run-time calibration capable
• Low-power (< 30mA PID loop current)
• 32QFN

Software
• Closed loop PID algorithm
• Foreign Object Detection
• Digital demodulation
• I2C for Touch Sense Interface (low power)
WCT1101 – Single-coil Premium

WCT1101 - Premium
• Program memory available to build and customize application
• Additional IOs to expand platform capabilities (e.g. multi-channel charger, NFC, Communications capabilities, etc.)
• 64LQFP
Software Development Tool – WCT GUI

- **Configuration**: System parameters, coil parameters and FOD parameters
- **Calibration**: Analog signal sensing coefficients, FOD algorithm coefficients
- **Debugging**: System real-time status and variables
Reference Platforms
Early Activities

Medium-power industrial

• Charges 4x 11.2V / 4.8Ah battery packs simultaneously
• 80% transfer efficiency

Medium-power consumer

• Provide 25W of power transfer
• 80% transfer efficiency
• Implements basic foreign-object detection

Low-power consumer

• 5W solution
• 7-coil array for free position
Low-cost Consumer Transmitter

- 5Watt Single-Coil Charger
  - General board availability now
  - Compliant to Qi 1.1.2 specification
  - Kit includes schematic, BOM & design files
  - Includes configurable library file
  - Internal digital demodulation for major BOM cost reduction
  - **WCT1101 available for premium option**
  - Supports most standard single-coils designed for 5 Watt applications

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 5W output power</td>
<td>Deliver full 5W to receiver</td>
</tr>
<tr>
<td>Up to 77% transfer efficiency</td>
<td>Lower thermal footprint</td>
</tr>
<tr>
<td>Supports FOD per WPC 1.1 spec</td>
<td>Detect foreign objects to maximize user experience</td>
</tr>
<tr>
<td>Wide input voltage tolerance (4.25 – 5.6V)</td>
<td>Operates under flexible input supply voltages</td>
</tr>
<tr>
<td>MCU run power &lt; 30mA / Stby @ &lt; 5mA</td>
<td>Achieve ultra-low power consumption during operation</td>
</tr>
<tr>
<td>LED for alignment options</td>
<td>Low-cost alignment indicators for users</td>
</tr>
<tr>
<td>e-BOM cost est. &lt; $5.00</td>
<td>Highly competitive price-to-value solution</td>
</tr>
</tbody>
</table>
5W Embedded Receiver Concept

- Target applications: smart watches, mobile medical devices, fitness monitors, mobile phones, etc.
- Wireless charging with minimal cost adder
- Remove the need for a separate wireless charging ASIC
- Can be implemented wherever a Freescale MCU exists
- Lowest system BOM cost compared to existing implementations

Example Mobile Application

- DC-DC
- PMIC
- Kinetis MCU
- Applications Processor
- Magnetometer
- Accelerometer
- Gyro
5W Kinetis Wireless Charging Tower Board

- Freescale Tower development board using KL26 MCU
  - Sensor support for accelerometer and magnetometer
  - Wireless charging receiver control
- Early samples available ~ 4/14
- Sensor Fusion software
- Wireless charging receiver library
- Can be used as standalone receiver or integrated with additional features
5W Kinetis Wireless Charging

• Key Features
  - Est. BOM cost savings to implement FSL wireless charging receiver ~ 20 – 30% compared to competitor solutions
    ▪ Additional components necessary include low-cost rectifier and buck controller, including necessary passives
    ▪ Estimated system BOM cost to implement receiver function < $0.80 (w/out MCU and coil)
  - Only 4 – 6kB of flash needed; ~1k SRAM
  - Requires only 5 - I/Os!!
  - Use ANY Freescale Kinetis MCU

• Benefits of discrete topology
  - More control over system parameters by discreet component selection
  - Manage thermal footprint by spreading heat generators
  - Use of a general purpose MCU provides more freedom and flexibility
  - Embed additional system features and reduce overall cost
  - Flexible system platform; scale up / down in power; embed additional features
Freescale Wearable Reference Platform
# Wearable Market: Segmentation

<table>
<thead>
<tr>
<th>Vertical</th>
<th>Categories</th>
</tr>
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</table>
| **Fitness & Wellness** | Sports and Heart Rate Monitors  
Pedometers, Activity Monitors  
Smart Sport Glasses  
Smart Clothing  
Sleep Monitors  
Emotional Measurements |
| **Healthcare & Medical** | CGM (Continuous Glucose Monitoring)  
ECG Monitoring  
Pulse Oximetry  
Blood Pressure Monitors  
Drug Delivery (Insulin Pumps)  
Wearable Patches (ECG, HRM, SpO2) |
| **Infotainment**   | Smart Watches  
Augmented Reality Headsets  
Smart Glasses  
Wearable Imaging Devices |
| **Industrial & Military** | Hand-worn Terminals  
Augmented Reality Headsets  
Smart Clothing |
5W Wearables Reference Design

Features
- Kinetis MCU to drive sensors and wireless charging receiver and i.MX 6 series processor
- Reference platform providing fully featured hardware platform to develop differentiated product
- Target applications: smart watches, fitness gear, medical devices, etc.
- Wireless charging receiver functionality via Kinetis MCU to provide charging Li-Ion coin cell
- Launched at CES 2014

Daughter Board PCB size:
42 mm x 42 mm
(1.65” x 1.65”)

Coil
Main Board PCB size: 38 mm x 16 mm (1.49” x 0.55”)

Daughter Board PCB size: 42 mm x 42 mm (1.65” x 1.65”)

**Overview of Components:****

- **Main Board:***
  - **i.MX 6SL**
    - ARM® Cortex™-A9
    - Apps Processor
    - Running Android
  - **3-axis ACCELEROMETER**
    - FXOS8700CQ
  - **3-axis MAGNETOMETER**
  - **SPI**
  - **USB**
  - **WIFI**
  - **BT/BTLE**
  - **LPDDR2 + eMMC**
    - Samsung MCP
    - KMN5W000ZM-B207
  - **MEMORY MANAGEMENT**
    - Maxim MAX77696
  - **POWER MANAGEMENT**
  - **BATTERY SINGLE CELL LIPO**
    - LH154Q01
  - **Touchscreen Interface**
  - **MIPI-DSI**
    - Solomon SSD2805
  - **RGB**
  - **I2C**
  - **EPDC**
  - **USB**
  - **MMC**
  - **W-LAN / BLUETOOTH 4.0**
    - Murata LBEH17YSHC
  - **BOARD - to - BOARD CONNECTOR**
  - **MICRO USB**

- **Daughter Board:***
  - **HUB SENSOR MCU – Kinetis KL16**
    - ARM Cortex™ M0+
  - **WIRELESS CHARGING**
  - **MOTION SENSING PEDOMETER**
    - MMA9553
  - **BUTTON 1**
  - **BUTTON 2**
  - **BOARD - to - BOARD CONNECTOR**

**Hardware List:**

- **Display:**
  - **LCD**
  - **Eink ET017QC1**
- **Memory:**
  - **LPDDR2 + eMMC**
  - **Power:**
    - **BATTERY SINGLE CELL LIPO** (300mAh)
  - **Micro USB**
  - **Memory:**
    - **LPDDR2 + eMMC**
      - Samsung MCP
      - KMN5W000ZM-B207
  - **Processing:**
    - **i.MX 6SL**
      - ARM® Cortex™-A9
      - Apps Processor
      - Running Android
  - **Connectivity:**
    - **3-axis ACCELERO**
      - FXOS8700CQ
    - **3-axis MAGNETO**
    - **SPI**
    - **USB**
    - **WIFI**
    - **BT/BTLE**
    - **LPDDR2 + eMMC**
    - **BOARD - to - BOARD CONNECTOR**
    - **MICRO USB**

**Software:**

- **Operating System:**
  - Running Android

**Additional Components:**

- **Flash Memory:**
  - **SDIO**
  - **MMC**
  - **POWER MANAGEMENT**
    - Maxim MAX77696
  - **Motion Sensing:**
    - **MMA9553**
  - **Button:**
    - **BUTTONDOWN**
    - **BUTTONUP**
  - **Wireless Charging**

**Design & Manufacturing:**

- **Design by NXP**
  - **WaRP board.org**
  - **Freescale**
  - **External Use**
• Available Now
  - Website
  - Block Diagram
  - WaRPboard Google Group
• Planned availability
  - Design files (open source)
  - Android 4.3 BSP (open source)
• Timeline
  - Announced Jan 2014
  - Demonstration at FTF
  - Pre-orders/Shipping 2Q14
• Ordering
  - WaRPboard.org
  - Distributors/eTailers
• For more details, contact:
  - Sujata Neidig or Robert Thompson
How Closely-coupled Inductive Charging Works
How It Works

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

• Scalable power delivery
  – Currently at 5W and moving beyond

• 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 ($V_p$)
Communication (Data-Format)

- Speed: 2 kbps
- 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 and 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 and 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
  \[ \text{control error} = \text{difference between} \]
  - Desired control point
  - Actual control point
- Communicate control error message

![Diagram of Power Transfer Control](image)
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
  - No Rx Object
- Resonance Detection
  - Rx Object
  - No Response
- Digital ping
  - Power need
  - No Power need
  - 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:

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

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

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

• And the received power can be calculated as follows:

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

• Characterization of “expected” system losses make foreign objects easily identifiable --- NOT!!
Magnetics Introduction

• Air Core Transformer
  - TX – Create Local Magnetic Flux
  - RX – Convert Coupled Flux into Current

• Shielding Materials Keep flux out of other subsystems
  - Batteries
  - Housing
  - PCB Planes, etc
Power Loss Considerations

• Switching losses
  - WPC operates ~100kHz – 210kHz
    ▪ Regulated as Unintentional Radiator
  - Higher Frequencies (6.78MHz, 13.56MHz) increase losses in inverter stage

• AC resistance increases with frequency
  - Proximity effect (current crowding from multiple turns, core material)
  - Skin effect (current crowding from internal magnetic fields)

• PCB coils useful in RX coil
  - Balance ohmic losses vs. current needed
    ▪ Good choice >~400mA
  - High gauge FPWB, PCB needed
    ▪ Wire coils may be more cost effective for high current (>~400mA)
Magnetic Induction Technology

- Transmitter coil that creates a magnetic field; receiver coil picks up the magnetic field and generates electric current
  - Advantages: simple, efficient, safe, power scalable, matured
  - Key technology challenges: shield, coil alignment, and good coupling
  - Disadvantages: limited x/y/z space, difficult for multiple devices operation together
Magnetic Resonance Technology

• Both transmitter and receiver coils operate at approximately same natural frequencies
  - Advantages: spatial free, multiple devices support, efficient
  - Key technology challenges: power scalable, environment safety, receiver design
  - Disadvantages: open magnetic field radiation, additional communication link (Bluetooth, Zigbee etc.)
Introduction to Resonance Charging
Some Definitions

- **Coupling Factor** – The amount of EM flux being received by the receiver from the transmitter
  - Tightly coupled systems have higher performance, i.e. efficiency, low losses
  - Loosely coupled systems compromise on efficiency and EMI in order to gain more spatial freedom
Operating Behavior

- Resonant frequency is determined by the selection of L & C
- How resonant the system behaves is determined by several factors
- Resonant systems, both Tx and Rx operate at same resonant frequency

\[ \omega_0 = \frac{1}{\sqrt{LC}} \quad \rightarrow \quad \text{Resonant frequency} \]

\[ Q = \frac{1}{R} \sqrt{\frac{L}{C}} \quad \rightarrow \quad \text{Quality factor - determines how resonant the system behaves} \]
Operating Behavior

• Qi-based systems have two resonant circuits
  - 100kHz +/- 5% to enhance power transfer
  - 1MHz +/- 10% as a device detection method
• Qi-based systems operate to the right of the resonance point
Resonance vs. Inductive?

- Not a simple answer – it depends
- Depending on use case will determine which method is better fit
- Whether it is WPC, PMA, A4WP, all are constrained by the same principles of physics

<table>
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<tr>
<th>Architecture</th>
<th>Efficiency</th>
<th>X,Y Freedom</th>
<th>Z Freedom</th>
<th>EMI</th>
<th>Multi-device charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive, single-coil</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
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More Information

- Freescale wireless charging solutions:  
  - www.freescale.com/wirelesscharging

- Freescale 5W single-coil wireless charging reference design:  
  - www.freescale.com/5w1coiltx

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