Introduction to Freescale Wireless Charging

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Agenda

This session introduces wireless charging, market applications, and Freescale's activities

- What is wireless charging?
- The market
- Freescale activities
- How Qi works

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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:

Characteristic	Inductive	Resonance	Capacitive
Efficiency	Comparable to traditional	Comparable to traditional	Comparable to traditional
Power Scalability	Highly	Slightly	Constrained by charge surface area
Operating frequency	< 500kHz	kHz – MHz range	Varies
Thermal Footprint	Dependent on efficiencies	Dependent on efficiencies	None
Multiple Devices	One to One relationship	Yes	One to One relationship
Z - Spatial Freedom	< 1cm	< 4cm	< 1cm
Cost Points	Micro & coils	Complex Rx	Electrodes, amplifiers, transformers

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Market View

WIRELESS POWER CONSORTIUM Qi

- Verizon
- 136 Members
- Complete supply chain
- Power scalability to 120W
- Resonance (via Power by Proxie & Fulton)
- Distances scalable up to 4cm
- Operating frequency 105 – 205kHz
- Currently supported by global telecom operators (Verizon, Orange, Docomo)
- Freescale contributing member

pma power matters alliance

- AT&T
- Inductive Charging
- Resonance (via Witricity)
- Incompatible with Qi
- Distance up to several cm
- Operating frequency 300 – 350kHz
- Freescale member

Alliance for Wireless Power

- Qualcomm & Samsung
- Intel member
- Magnetic Resonance @ 6.78MHz
- Distance of a few cm

WIRELESS POWER CONSORTIUM

NOKIA Connecting People

NTT docomo

verizon

Nokia Lumia 920, 820

Motorola DROID ™ 4

Motorola DROID ™ Bionic

HTC Rezound™

HTC ThunderBolt™

HTC Incredible 2™

htc quietly brilliant

Pantech Breakout

ρANTECH

MOTOROLA

Motorola DROID™ 3

Sharp STYLE SH-05D

Sharp AQUOS™ SH-02D

Samsung DROID ™ CHARGE

SAMSUNG

Verizon (LG) charge pad

LG Lucid™

LG

LG Revolution™

Panasonic

Eluga™ V P-06D

Sharp AQUOS™ f-SH13C

freescale™

Image © Nokia
Image courtesy WPC

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…deployment of wireless charging infrastructure

Image courtesy WPC

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WPC Qi Technology Roadmap

- Current specification includes up to 5W
  - Enable mobile phone market
  - Additional features such as foreign object detection
  - Full flexibility on the device side
  - Wide range of transmitter types available
- 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
  - Est. spec delivery Q4'13
- Medium power: 30-120 Watt
  - Enables charging of tablets and notebook computers
- High power: up to 2000 Watt
  - Enables wireless kitchen appliances

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Freescale Wireless Charging Solutions

Broad Flexibility - Configure and customize through easy-to-use API providing maximum flexibility

Accelerate Time-to-Market – Market-ready reference designs and productized software components

Compliant & Beyond – Leading contributor to the Qi standard, as well as providing multi-protocol support

Freescale Wireless Charging Market Segments

Automotive

Radios

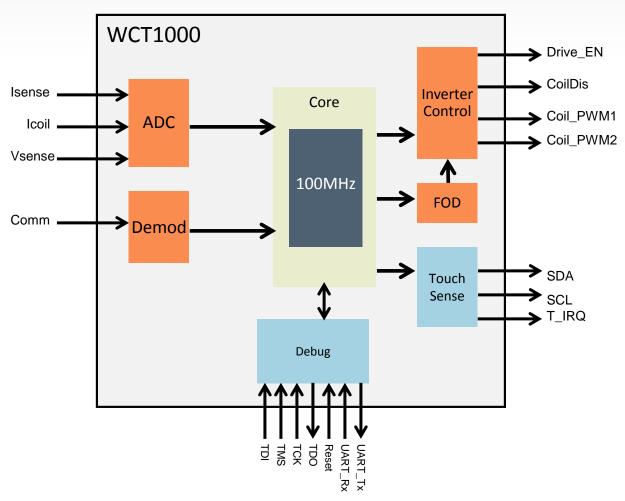Medical

Consumer

Industrial

Power Tools

WCT1000 – Single Coil Transmitter

Hardware

- 100MHz core
- Support half or full-bridge power stage
- Run-time calibration capable
- Low Run power (< 30mA PID loop current)
- Ultra-low Stby power capable
- 32QFN

Software

- Configurable firmware library
  - Core charging functions
  - Foreign objection detection
  - Digital demodulation
- I2C for Touch Sense Interface
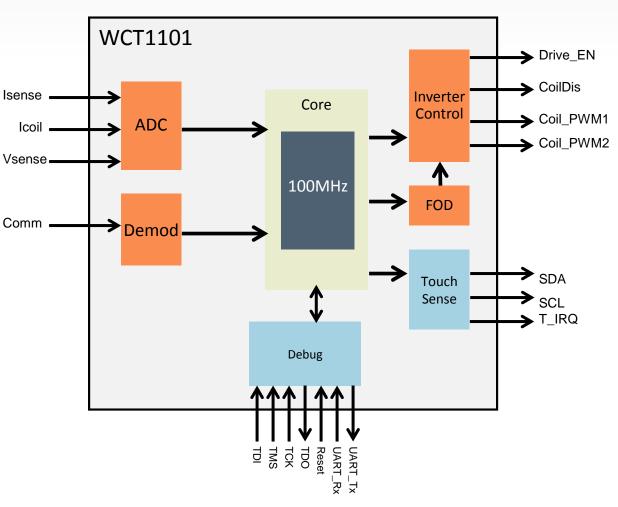
5W Transmitter – Premium Option

Hardware

- 100MHz core
- Support half or full-bridge control
- Run-time calibration capable
- Low Run-power (< 30mA PID loop current)
- Flash & RAM available for customization
- Support single or multi-coil systems
- 20+ Additional IOs for add-on functions
- 64LQFP

Software

- Configurable firmware library
  - Core charging functions
  - Foreign objection detection
  - Digital demodulation
- Additional program memory and IOs for custom application code
- I2C for Touch Sense Interface

WCT1101

Isense → ADC
Icoil → ADC
Vsense → ADC

Comm → Demod

Core
100MHz

Inverter Control → Drive_EN
→ CoilDis
→ Coil_PWM1
→ Coil_PWM2

FOD

Touch Sense → SDA
→ SCL
→ T_IRQ

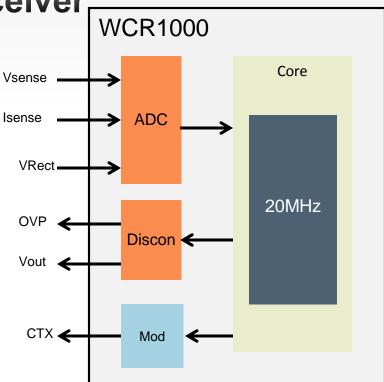Debug

TDI, TMS, TCK, TDO, Reset, UART_Rx, UART_Tx

Wireless Charging Receiver

Hardware

- Support s full 1A output @ 5V
- Programmable interface
- Modulation Control
- System safety monitoring
- Output disconnect control
- 4 x 4 QFN24

Software

- Configurable firmware library
  - Qi communications protocol
  - Battery charging algorithms (NiMH, LiION)
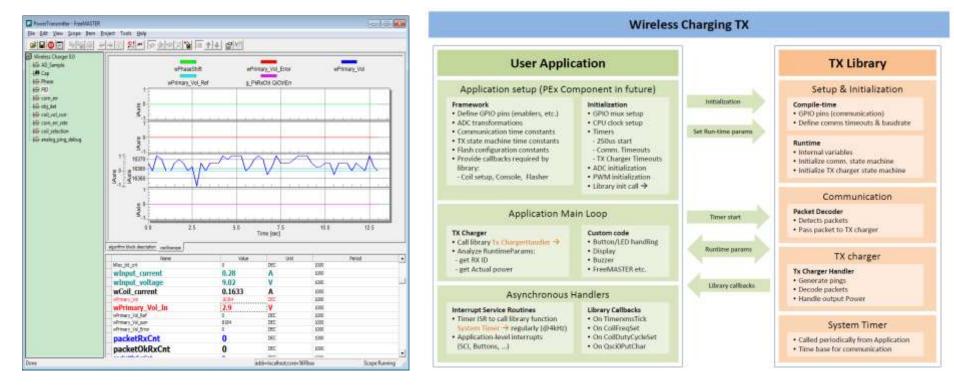 - Foreign Object Detection (FOD) support

WCR1000

Vsense → ADC

Isense → ADC

VRect → ADC

ADC → Core

Core 20MHz

OVP ← Discon

Vout ← Discon

Discon ← 20MHz

CTX ← Mod

Mod ← Core

Freescale Wireless Charging Firmware Library

- Modify parameters on-the-fly using analysis tool (e.g. FSL's Freemaster)
- Tune the system to optimize performance
- Add additional application code (via Freescale API)
- Create true differentiation by customizing your wireless charging product

Freescale Proof-of-Concepts

Medium-power Industrial

- Charges 4x 11.2V / 4.8Ah battery packs simultaneously
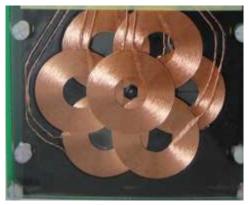- 80% transfer efficiency
- 56F8257 / QB8 MCU

Medium-power consumer

- Provide 25W of power transfer
- 80% transfer efficiency
- Implements basic foreign-object detection
- 56F8257 / QB8 MCU

Low-power consumer

- 5W solution
- 7-coil array for free position
- 56F8006

5W consumer Rx

- True 5W power delivery
- Qi-1.1
- Discreet solution offers better thermal mgt

Low-cost Consumer Transmitter

5Watt Single-Coil Charger

- Rev. 2 alpha sampling now
- General board availability December '13
- Kit includes schematic, BOM & design files
- Includes configurable library file for system tuning
- Premium version silicon & library available for application layer programming
- Internal digital demodulation for major BOM cost reduction
- **Supports most standard single-coils designed for 5 Watt applications**

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

Automotive Qi Transmitter Block Diagram
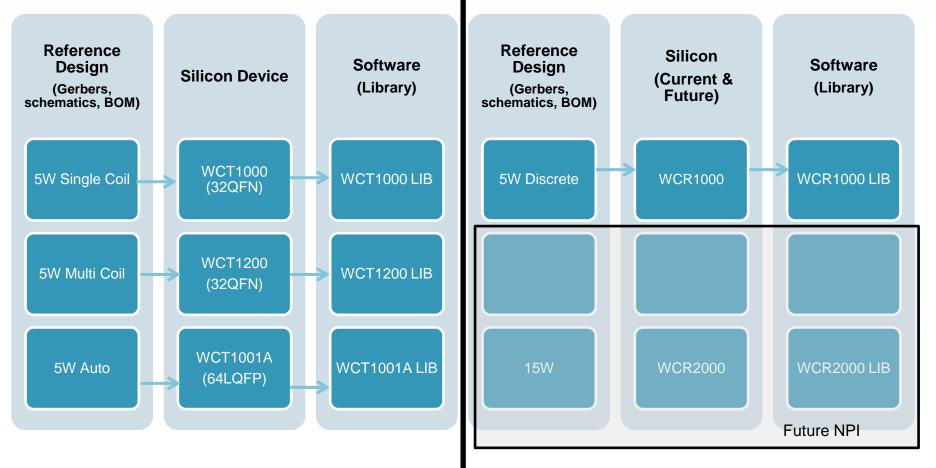
Feature Rich Automotive Reference Design

- WPC A13 Automotive Charger
  - Rev. 2 alpha sampling August'13
  - General board availability December '13
  - Kit includes schematic, BOM & design files
  - Includes configurable library file for system tuning & application layer programming

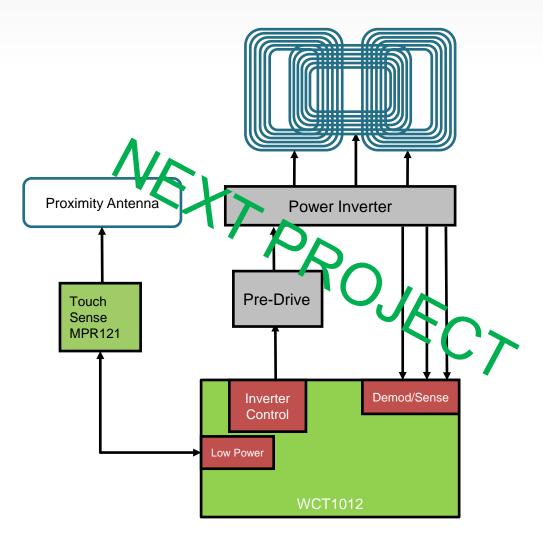| Features	Benefits
Greater than 5 Watts output power	Deliver full 5W to receiver
> 60% transfer efficiency	Lower thermal footprint
Supports FOD per WPC 1.1 spec	Detect foreign objects to maximize user experience
Low operational & Stby power using touch sense interface	Achieve ultra-low power consumption during operation
Integrated CAN bus support	Lower BOM cost
Fixed frequency operation	Avoid key FOB frequency interference
Meet CISPR 25 requirements	Improved EMI protection to meet auto standards
NFC capable (using premium version device)	Implement NFC use case & show coexistence with Qi
Dual-Mode Capable	Support both Qi & Powermat protocols
AECQ-100 Level 2 qualified	Automotive qualified

What You Get!

Freescale Transmitter Solutions

Reference Design (Gerbers, schematics, BOM)	Silicon Device	Software (Library)
5W Single Coil	WCT1000 (32QFN)	WCT1000 LIB
5W Multi Coil	WCT1200 (32QFN)	WCT1200 LIB
5W Auto	WCT1001A (64LQFP)	WCT1001A LIB

Freescale Receiver Solutions

Reference Design (Gerbers, schematics, BOM)	Silicon (Current & Future)	Software (Library)
5W Discrete	WCR1000	WCR1000 LIB
15W	WCR2000	WCR2000 LIB

Future NPI

freescale™

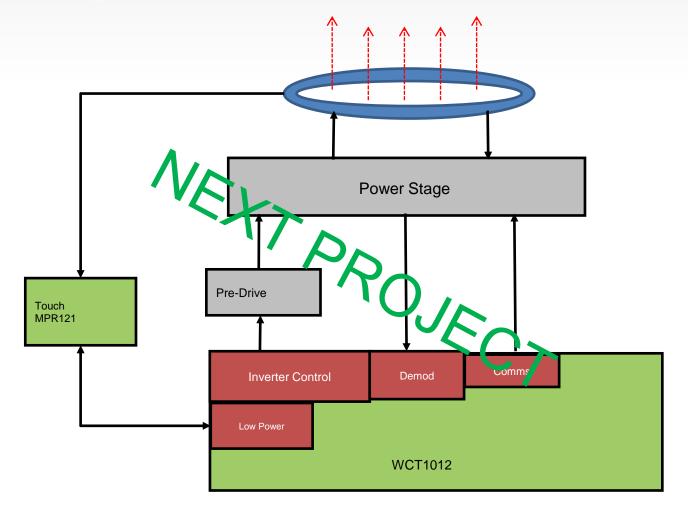# 5W Multi-coil transmitter for Consumer

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5W Multi-coil Transmitter for Consumer

- 5 Watt multi-coil to support aftermarket mobile phones
- Support both PCB & wired magnetics
- Generalized to support variety of multi-coil configurations
- Maximum flexibility via programmable solution
- Real-time debug and tuning capability
- Dual-mode support
- Internal digital demodulation for decreased BOM
- Premium configuration to add value-added differentiation
- Availability ~ Dec '13

15W Single-coil Transmitter for Consumer

NEXT PROJECT

- Power Stage
- Pre-Drive
- Touch MPR121
- Inverter Control
- Demod
- Comms
- Low Power
- WCT1012

15W Single-coil Transmitter for Consumer

- 15 Watt single-coil transmitter solution

- Targets high-end smartphone & tablet applications

- Reduce battery charge time & increased battery capacities

- Maximum flexibility via programmable solution

- Real-time debug and tuning capability

- Internal digital demodulation for decreased BOM

- Premium configuration to add value-added differentiation

- Availability ~ Q1 '14

freescale ™

Freescale Value Proposition

Broad Flexibility

- Generalized solutions to support a wide range of magnetics options
- Configurable hardware for added features
- 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
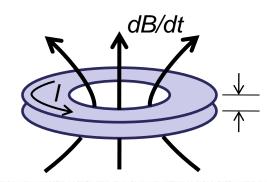- Wireless charging expertise

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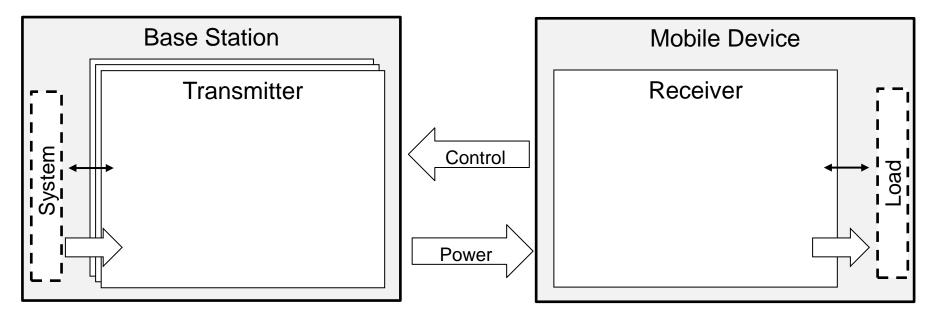- The market
- Freescale activities
- How Qi works

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)
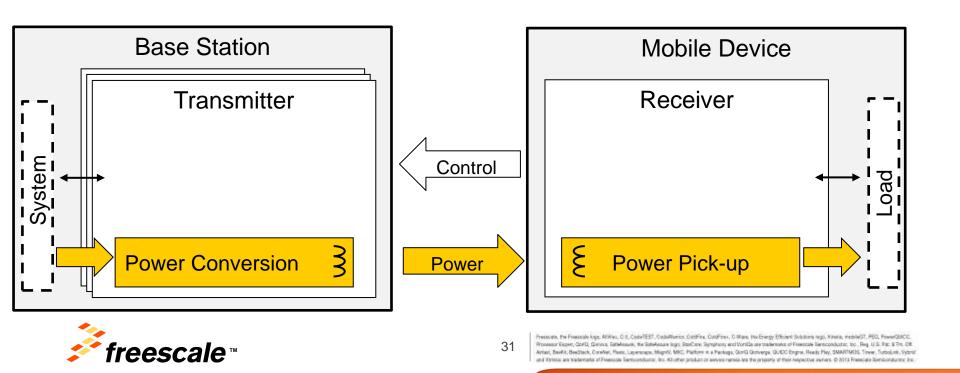
System Overview (Top View)

- 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)
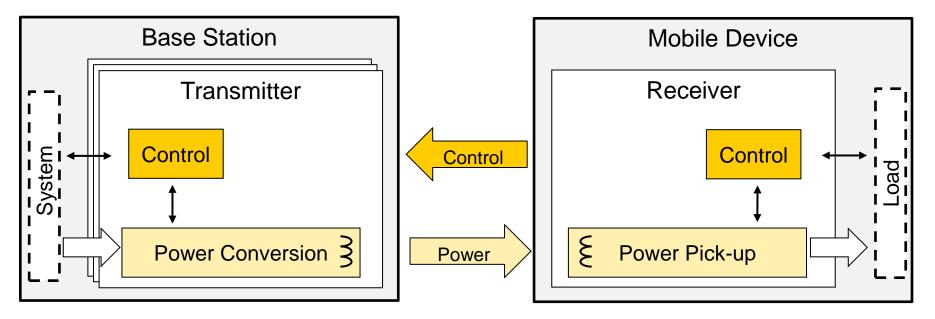 - Receiver provides control information to transmitter

System Overview (Power Conversion)

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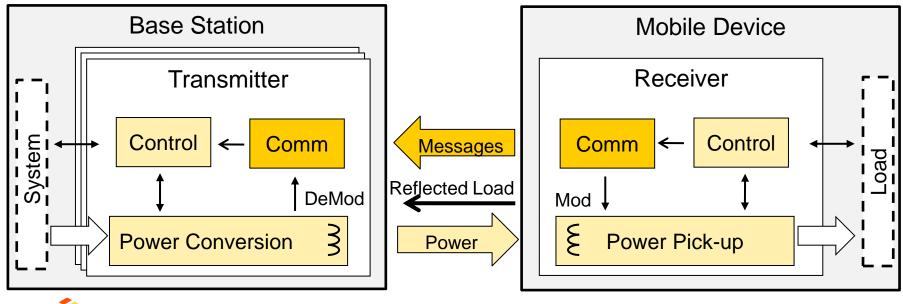
System Overview (Control)

- 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)
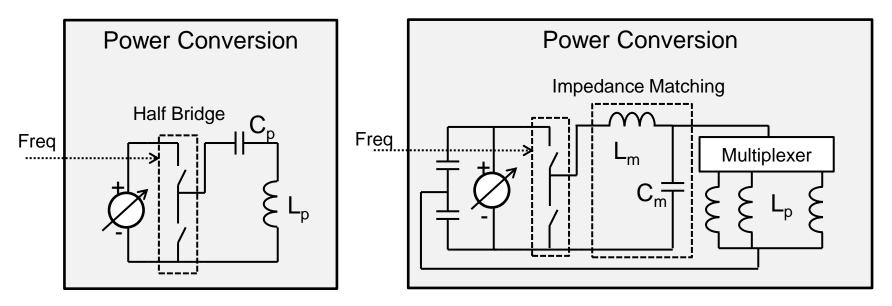
System Overview (Communication)

- 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
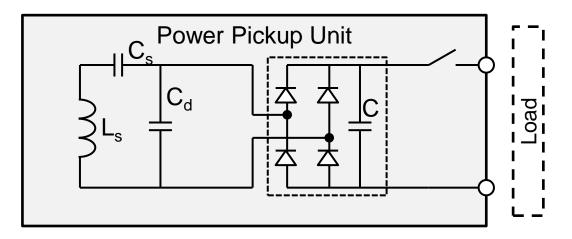- Coil array implementation
- Controlled by e.g. frequency or voltage
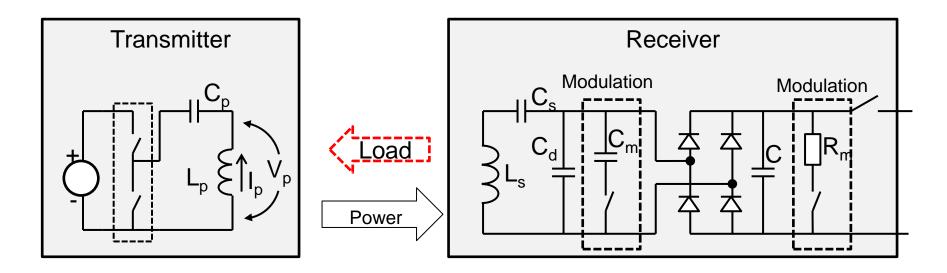
Power Pick Up (Receiver)

- 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
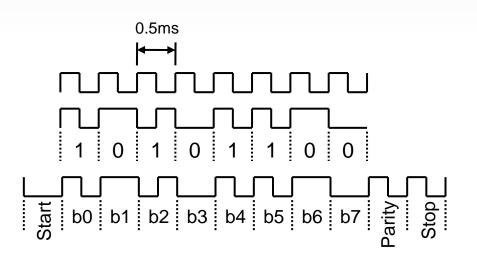- Output switch for (dis-)connecting the load

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)

Communication (Data-Format)

- Speed: 2 Kbit/s

- Bit-encoding: bi-phase

- Byte encoding:
  Start-bit, 8bit 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)

1	0	1	0	1	1	0	0

0.5ms

Start | b0 | b1 | b2 | b3 | b4 | b5 | b6 | b7 | Parity | Stop

Preamble	Header	Message	Checksum

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

Adapted

Power Transfer Control

Transmitter

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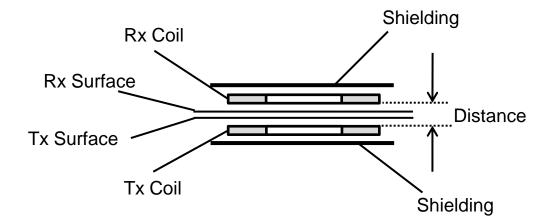 - Desired control point
  - Actual control point

Receiver

- Calculate control error
  = difference between
  - Desired control point
  - Actual control point
- Communicate control error message
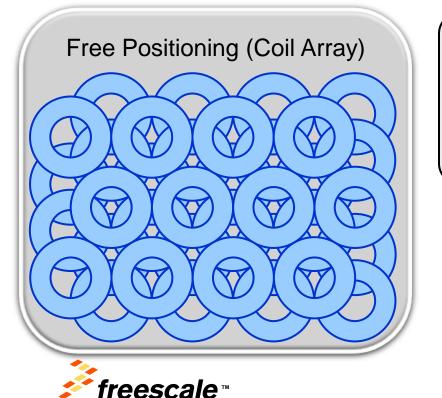
Coupling between Coils

- 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)
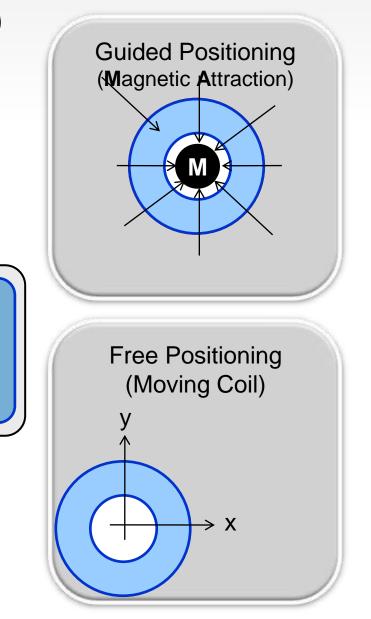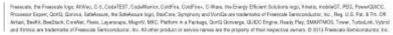   - Aligning the coils (next page)

Coil Alignment (Design Freedom)

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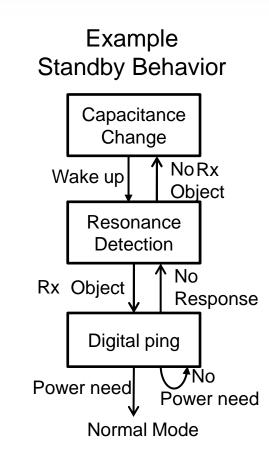- Free positioning with selective activation of coils in coil array

Guided Positioning (**M**agnetic **A**ttraction)

Free Positioning (Coil Array)
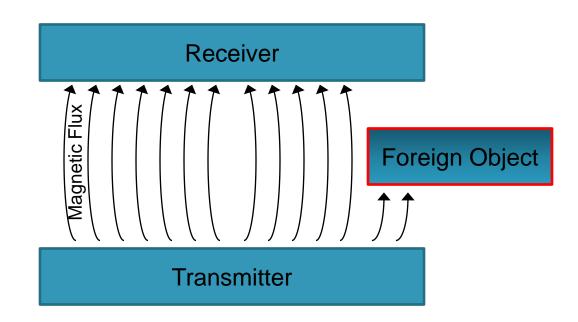
Free Positioning (Moving Coil)

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

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:

$$P_{loss} = P_{transmitted} - P_{received}$$

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

$$P_{transmitted} = P_{in} - P_{txlosses}$$

- 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 --- 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)