FTF FREESCALE TECHNOLOGY FORUM 2014

Freescale **Wireless Charging** Solutions

FTF-CON-F0020

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freescale™

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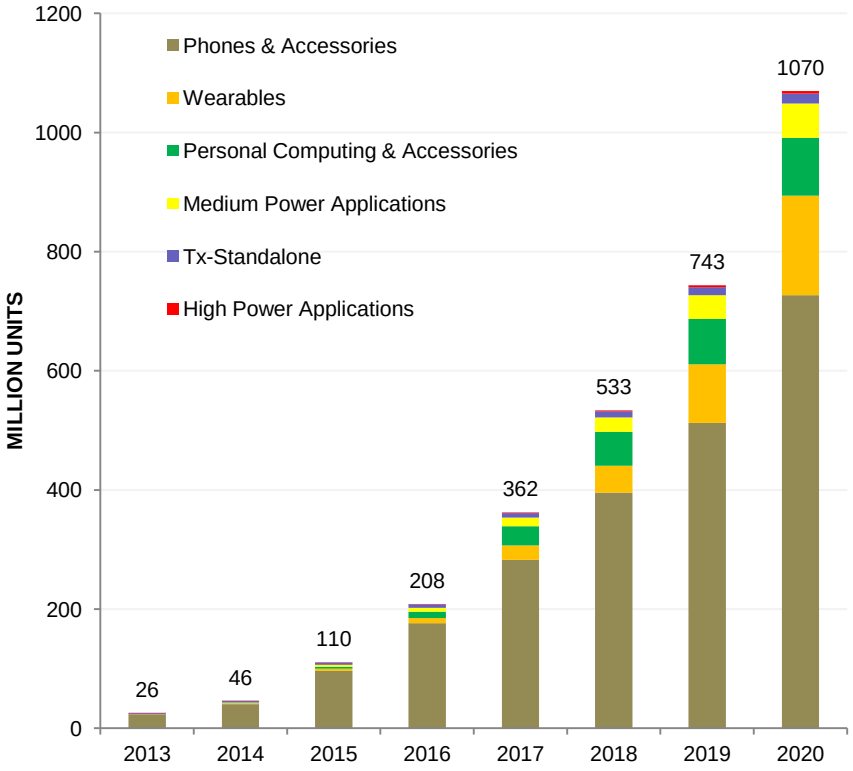
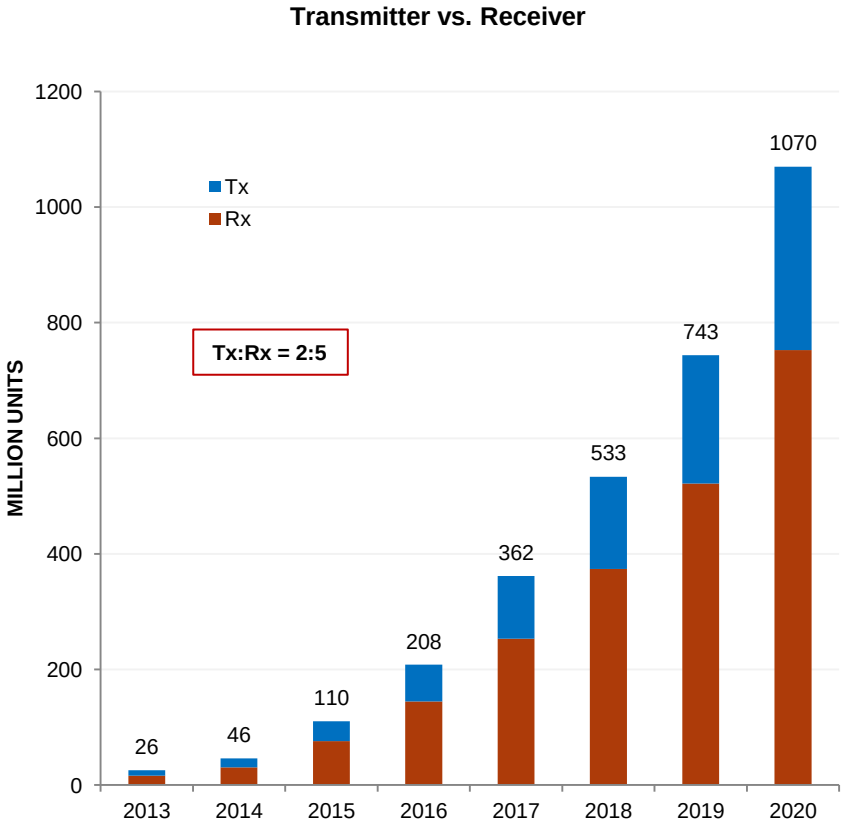
Agenda

- Market
- Freescale solutions
- How wireless charging works
- Difference between inductive and resonance

Wireless Charging TAM



Smartphones
Wearables
Medium Power - Tablets
Tx-Standalone – Automotive in-car



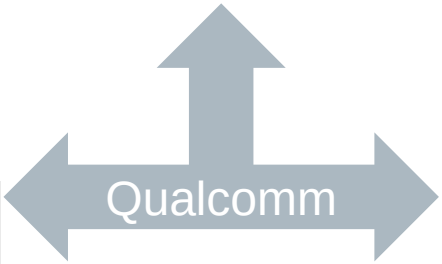
Rx higher volume, but cheaper price vs. Tx.
Perception– Provider with Tx & Rx has a complete solution.

***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**



Alliance for Wireless Power

- Qualcomm, Samsung, Intel
- Resonance @ 6.78MHz
- Distance of a few cm

pma power matters alliance

- AT&T
- Inductive Charging
- Resonance
- Distance up to several cm
- Operating frequency 300 – 350kHz
- **Freescale member**

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

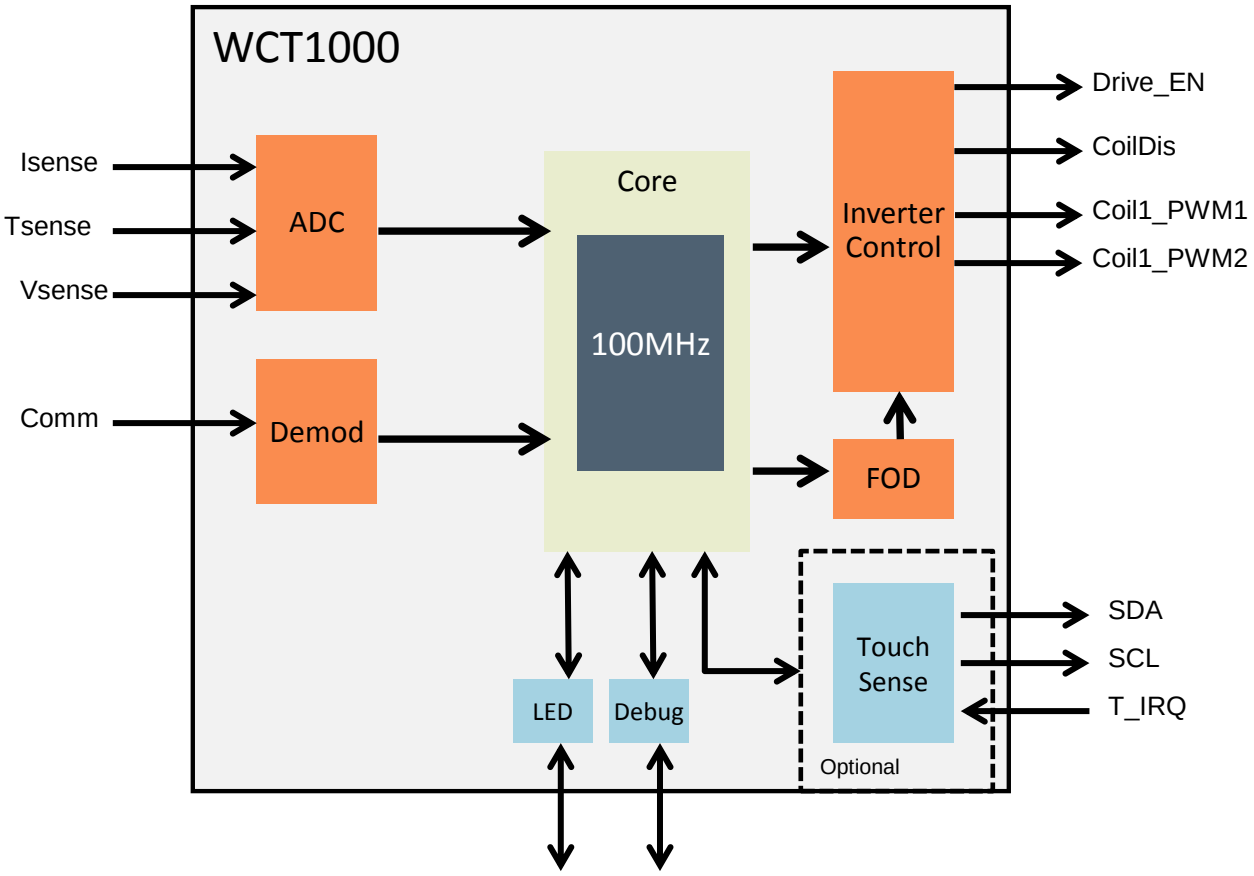
WCT1000 – Single Coil Transmitter

Hardware

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

Software

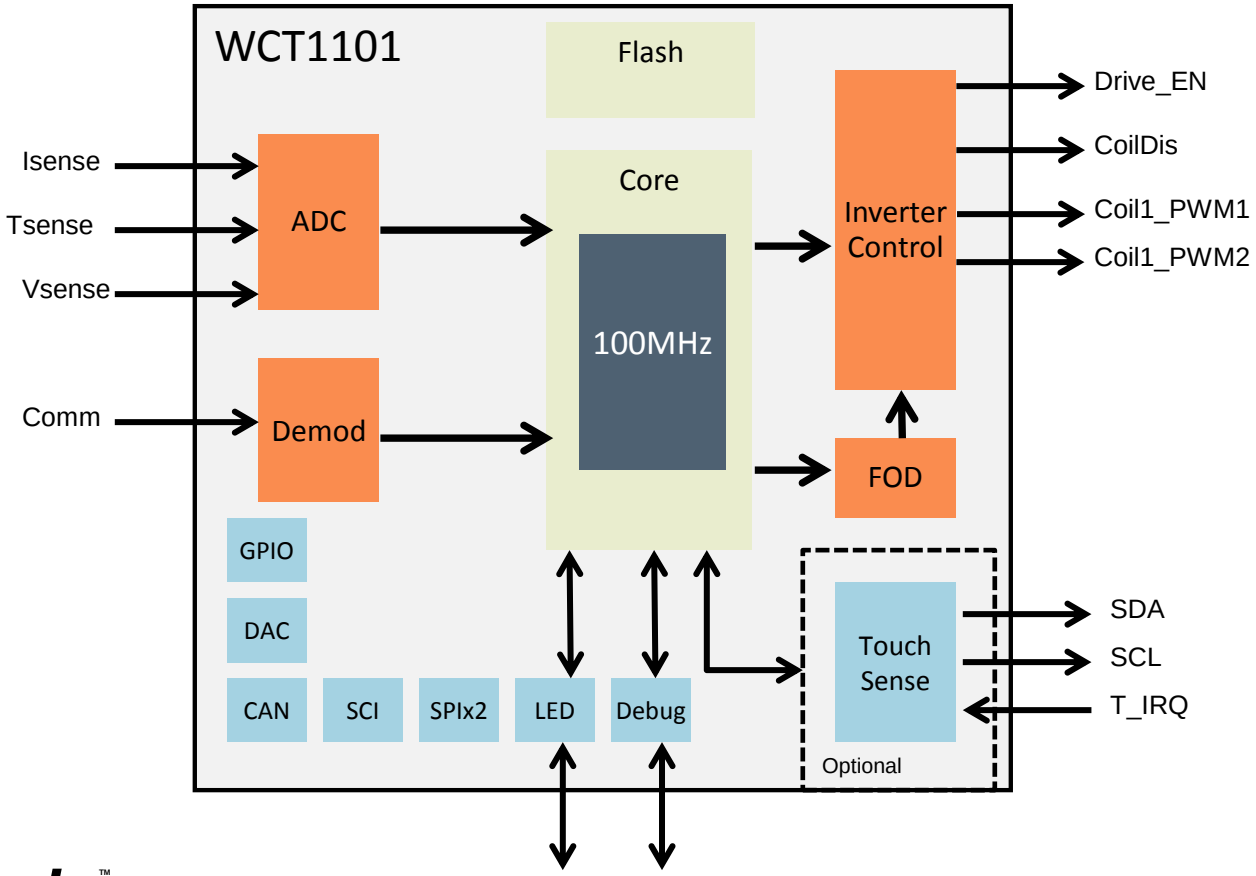
- Closed loop PID algorithm
- Foreign Object Detection
- Digital demodulation
- I2C for Touch Sense Interface (low power)



WCT1101 – Single-coil Premium

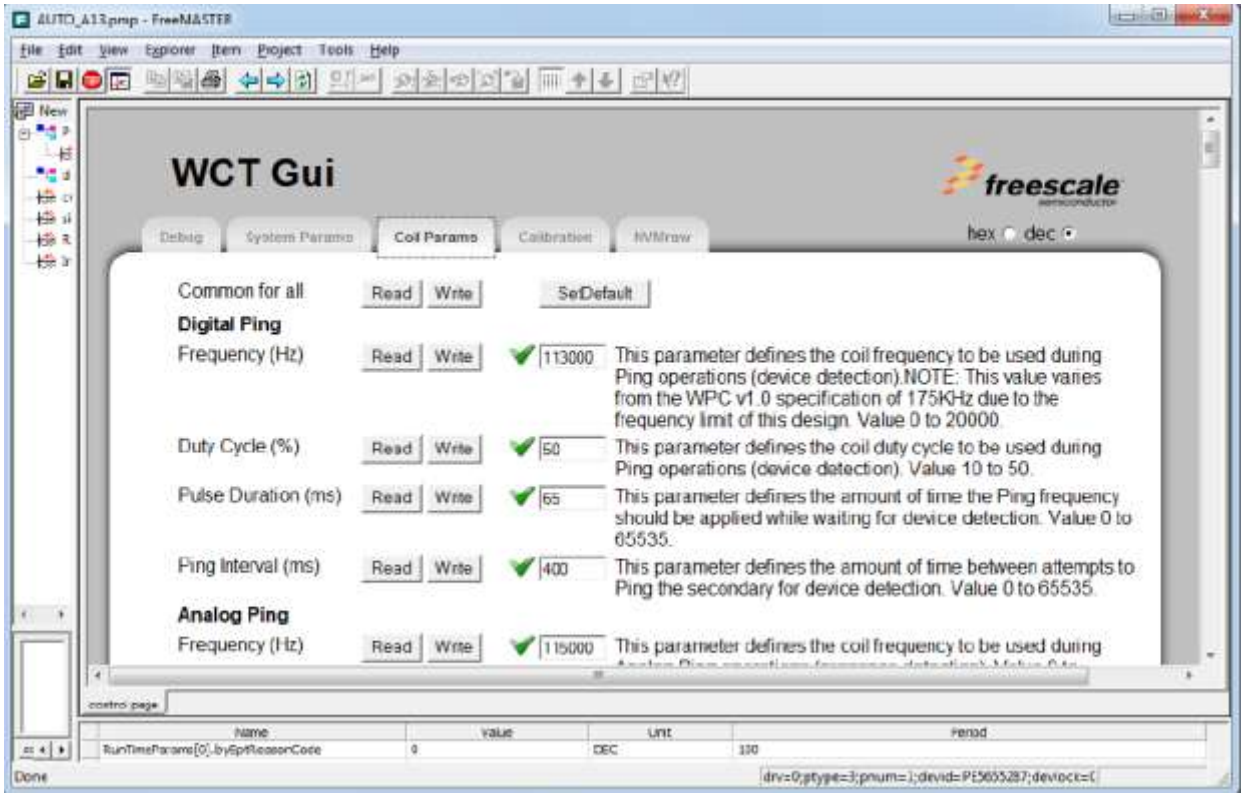
WCT1101 - Premium

- 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

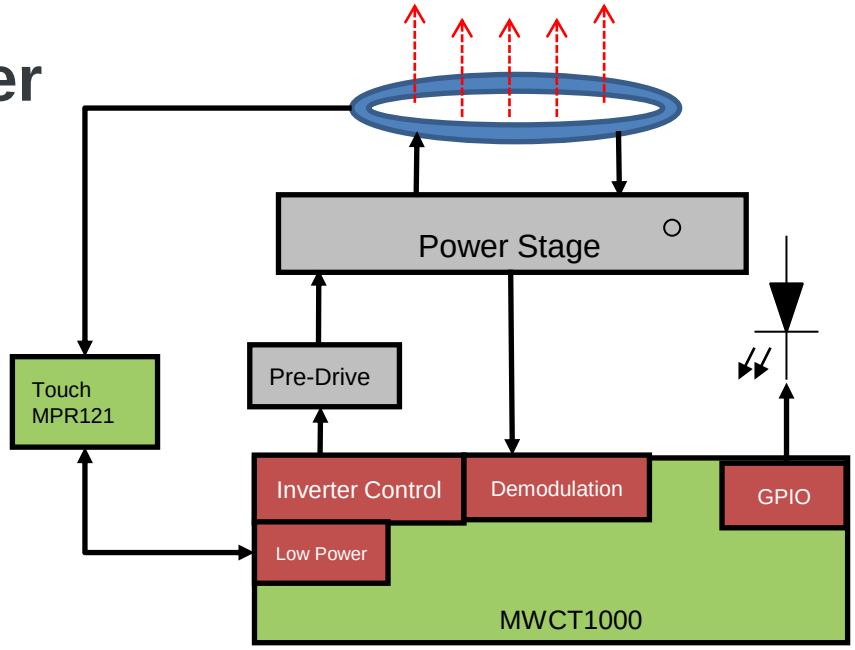
- Provide 25W of power transfer
- 80% transfer efficiency
- Implements basic foreign-object detection

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**

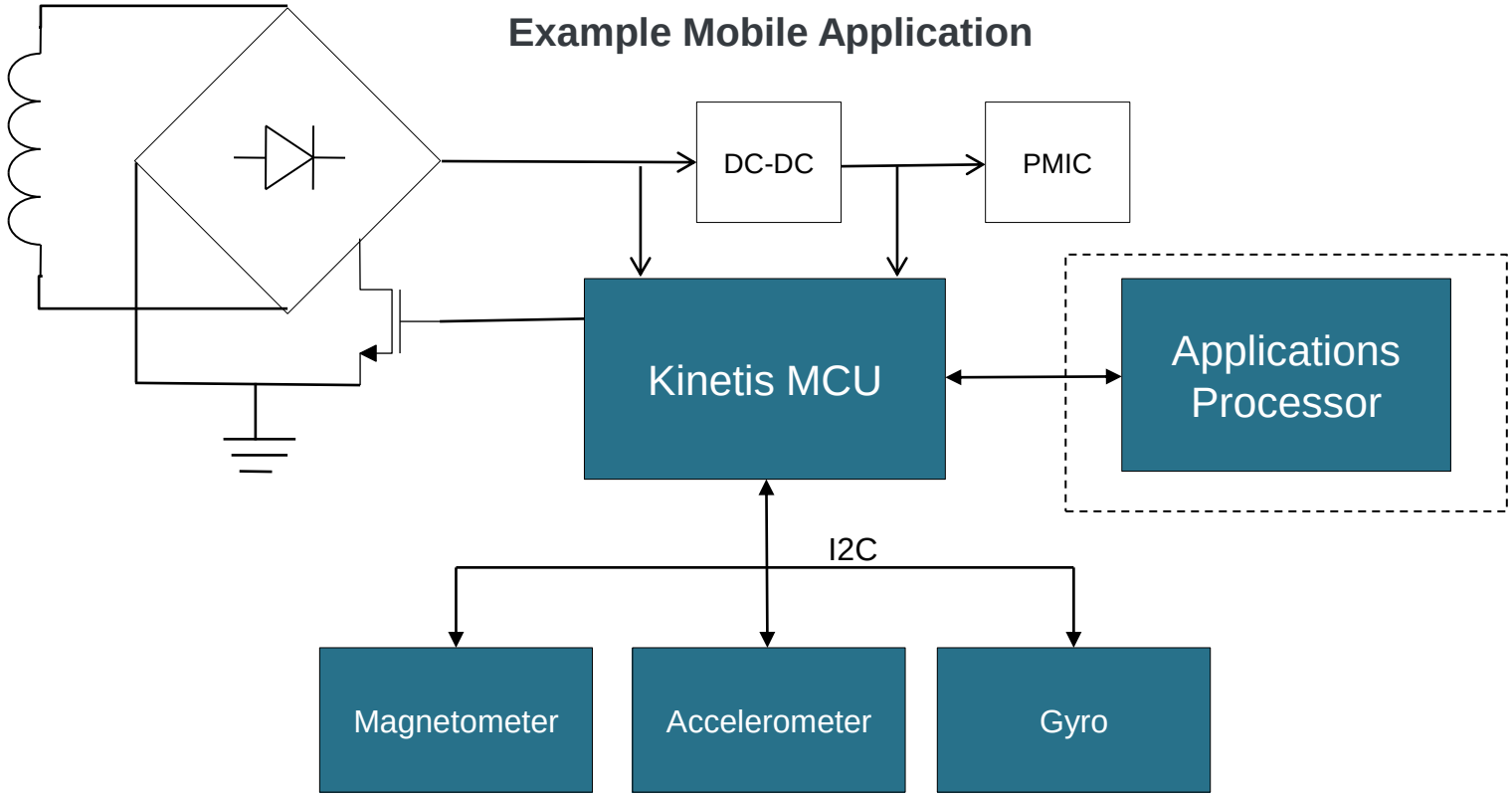


Features	Benefits
Greater than 5W output power	Deliver full 5W to receiver
Up to 77% transfer efficiency	Lower thermal footprint
Supports FOD per WPC 1.1 spec	Detect foreign objects to maximize user experience
Wide input voltage tolerance (4.25 – 5.6V)	Operates under flexible input supply voltages
MCU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

Freescale Embedded Receiver

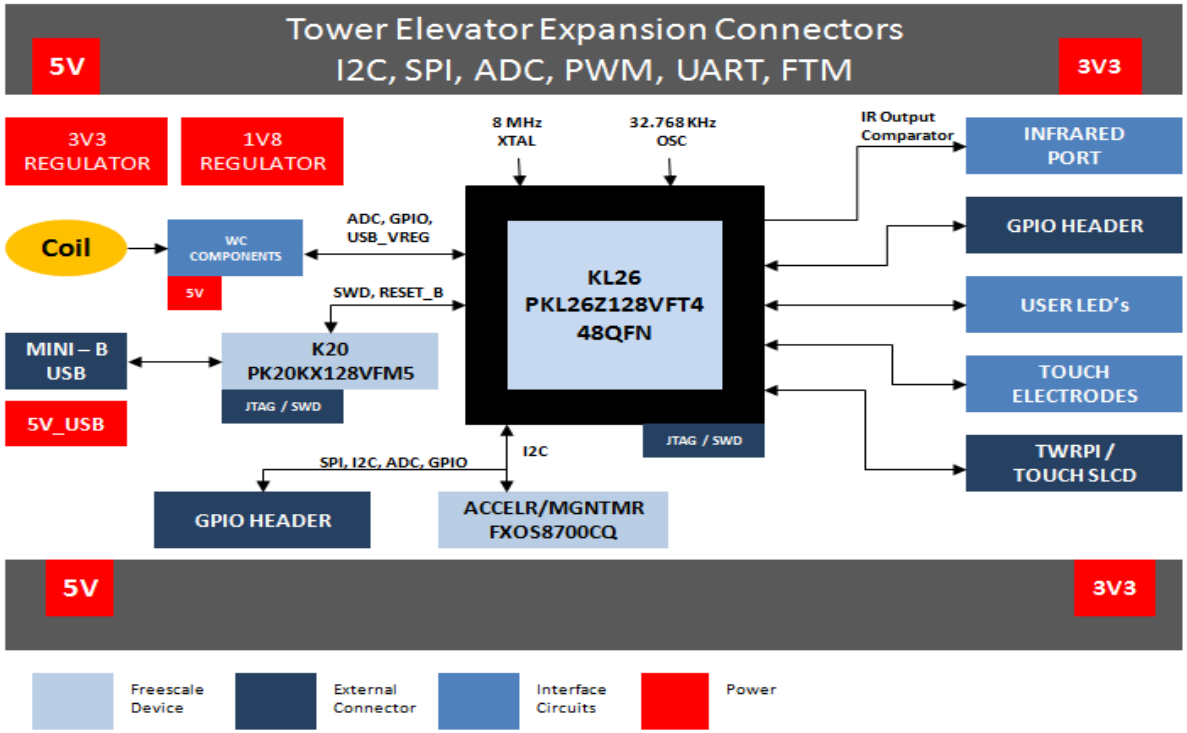
5W Embedded Receiver Concept

- 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



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

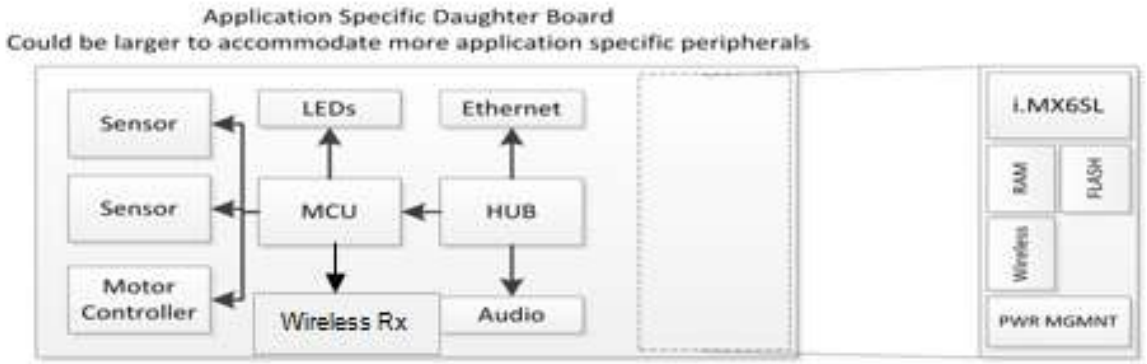
Vertical	Categories
Fitness & Wellness	Sports and Heart Rate Monitors Pedometers, Activity Monitors Smart Sport Glasses Smart Clothing Sleep Monitors Emotional Measurements
Healthcare & Medical	CGM (Continuous Glucose Monitoring) ECG Monitoring Pulse Oximetry Blood Pressure Monitors Drug Delivery (Insulin 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

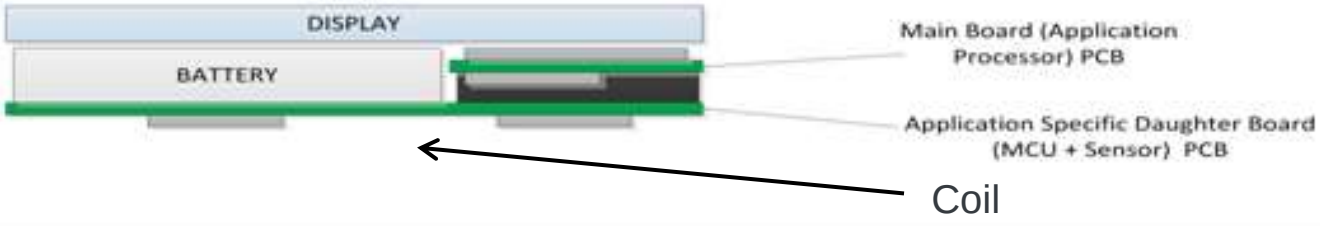
5W Wearables Reference Design

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”)

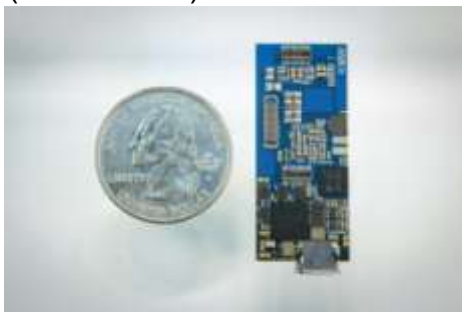




WaRP
Wearable Reference Platform

WaRPboard.org

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



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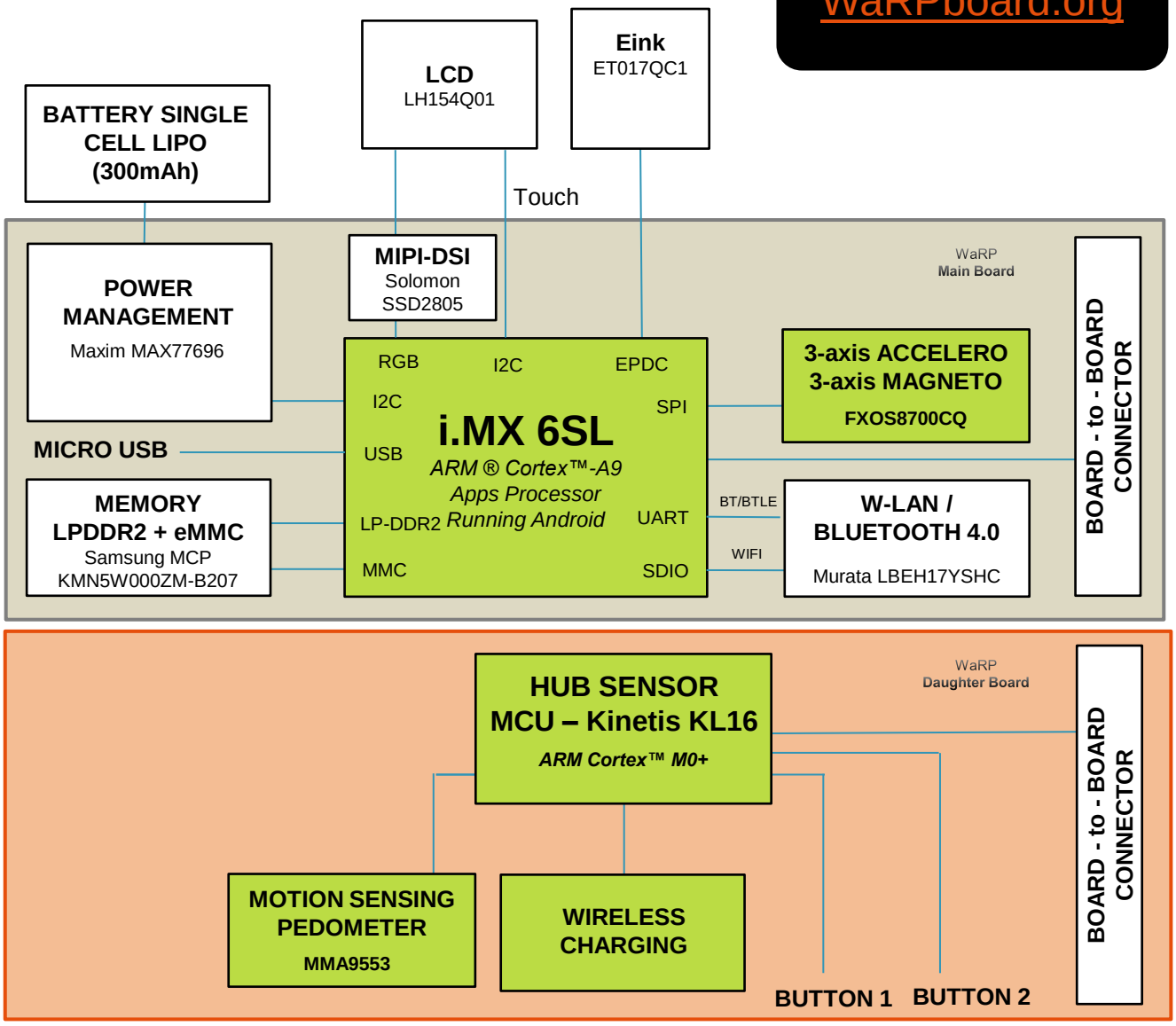
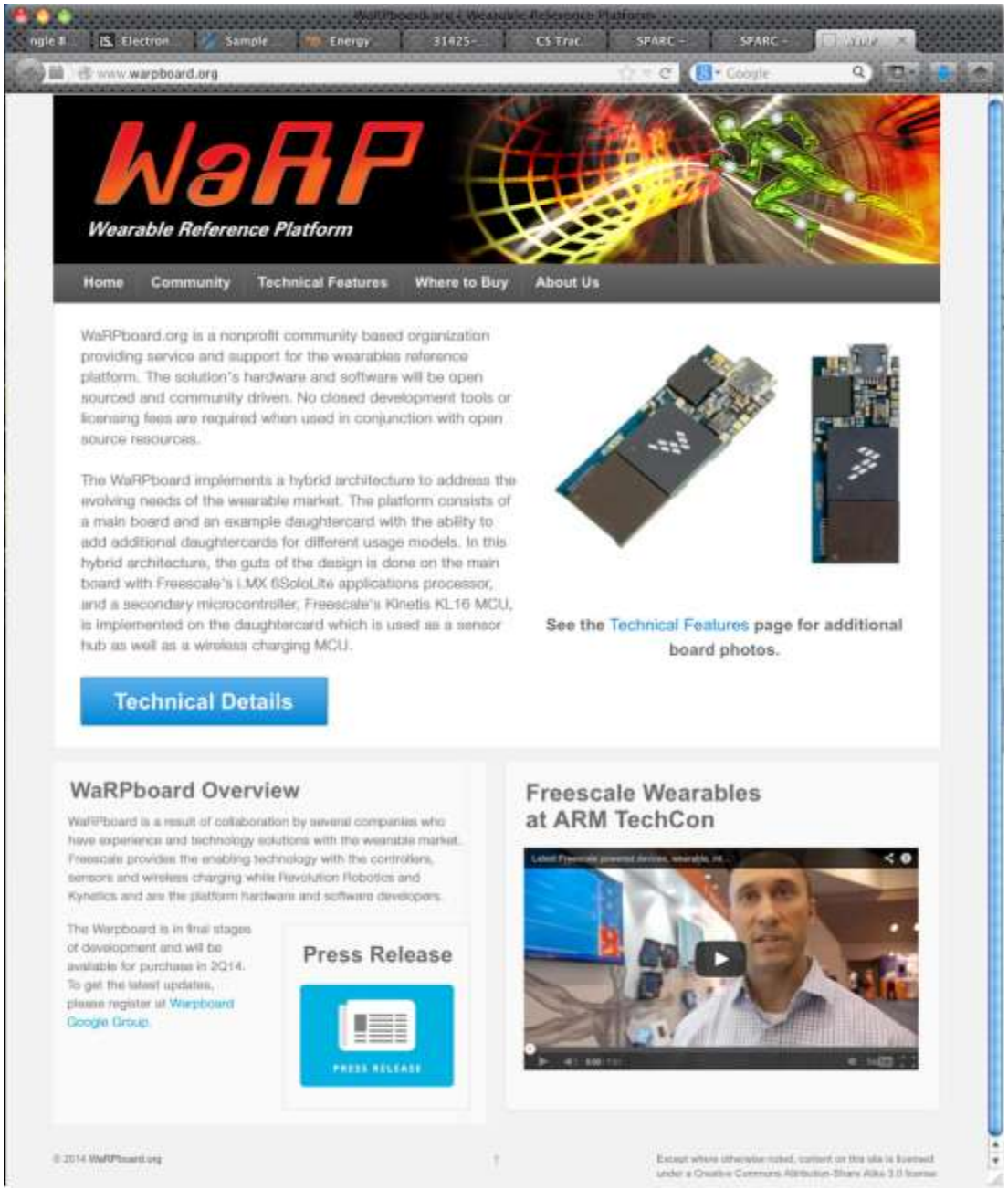


WaRPboard.org

- 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



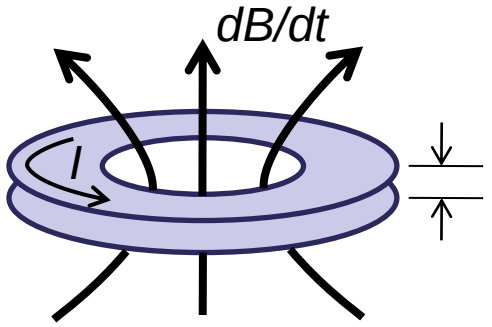
How Closely-coupled Inductive Charging Works

How It Works

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

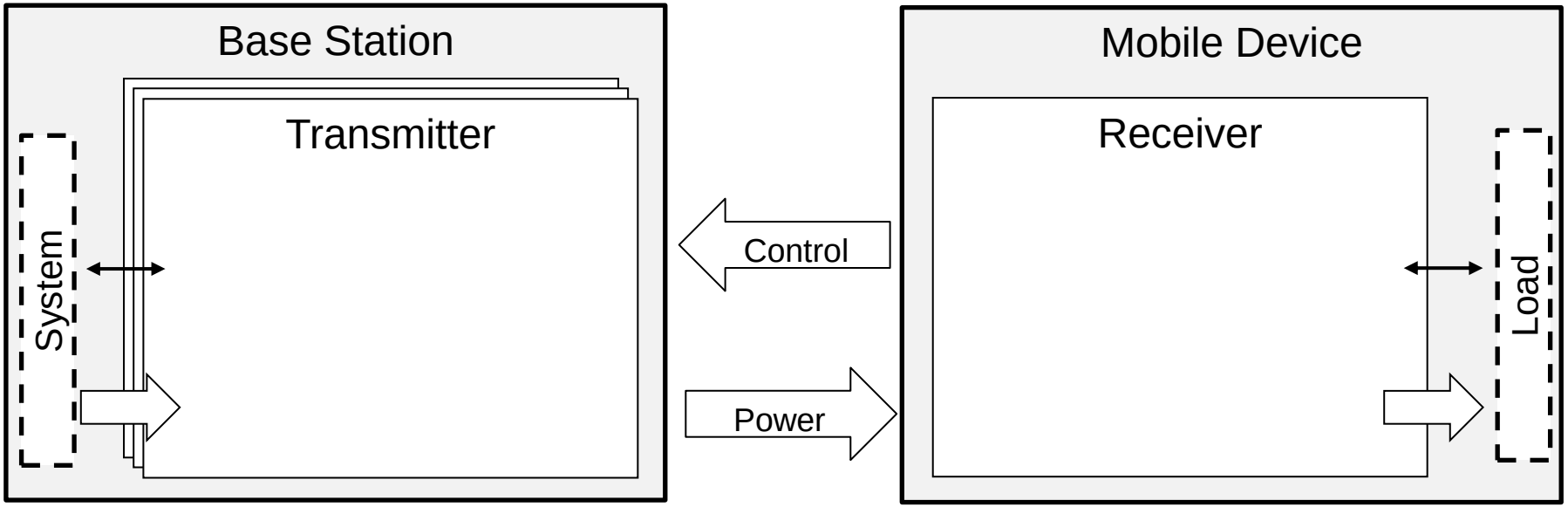
- Scalable power delivery
  - Currently at 5W and moving beyond

- Power transfer via magnetic induction
  - Loosely coupled transformer
  - At short distance (few mm)



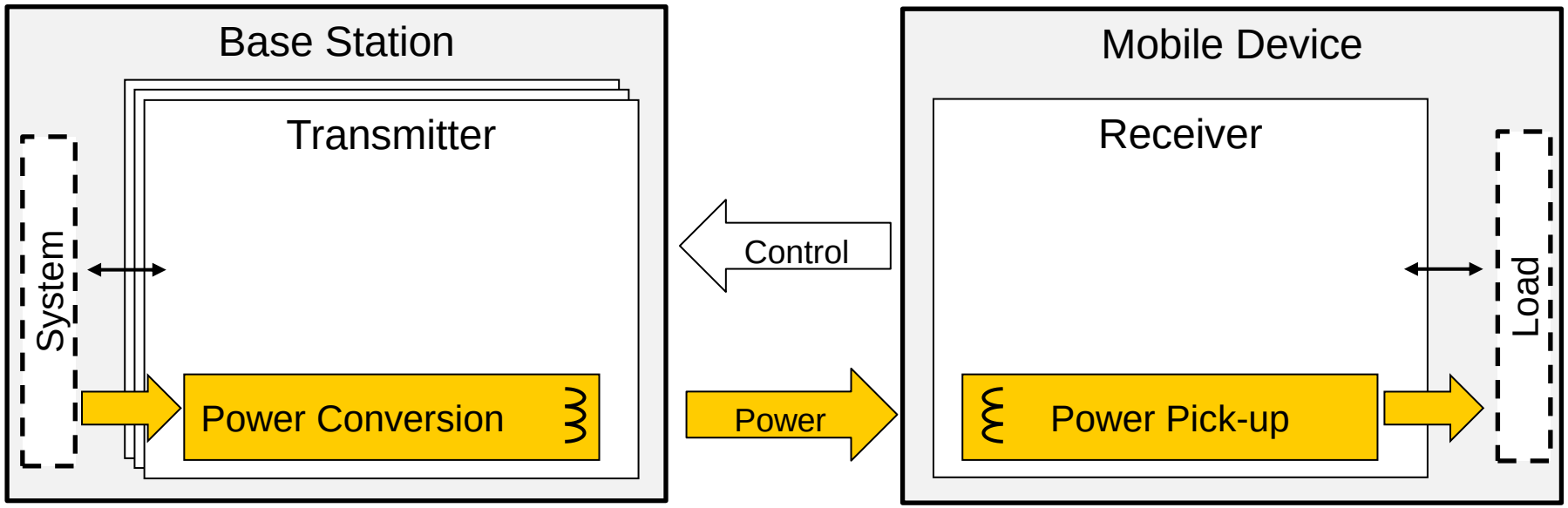
System Overview (Top View)

- 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



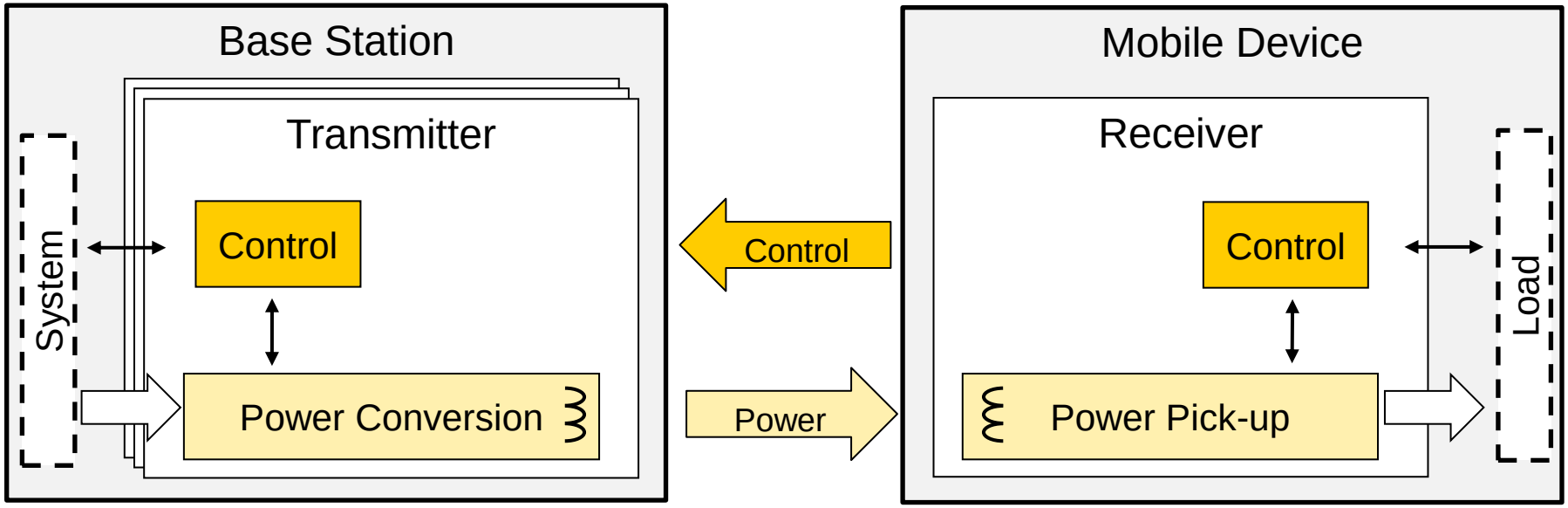
System Overview (Power Conversion)

- Power Conversion Unit converts electrical power to wireless power signal
- Power Pickup Unit converts wireless power signal to electrical power



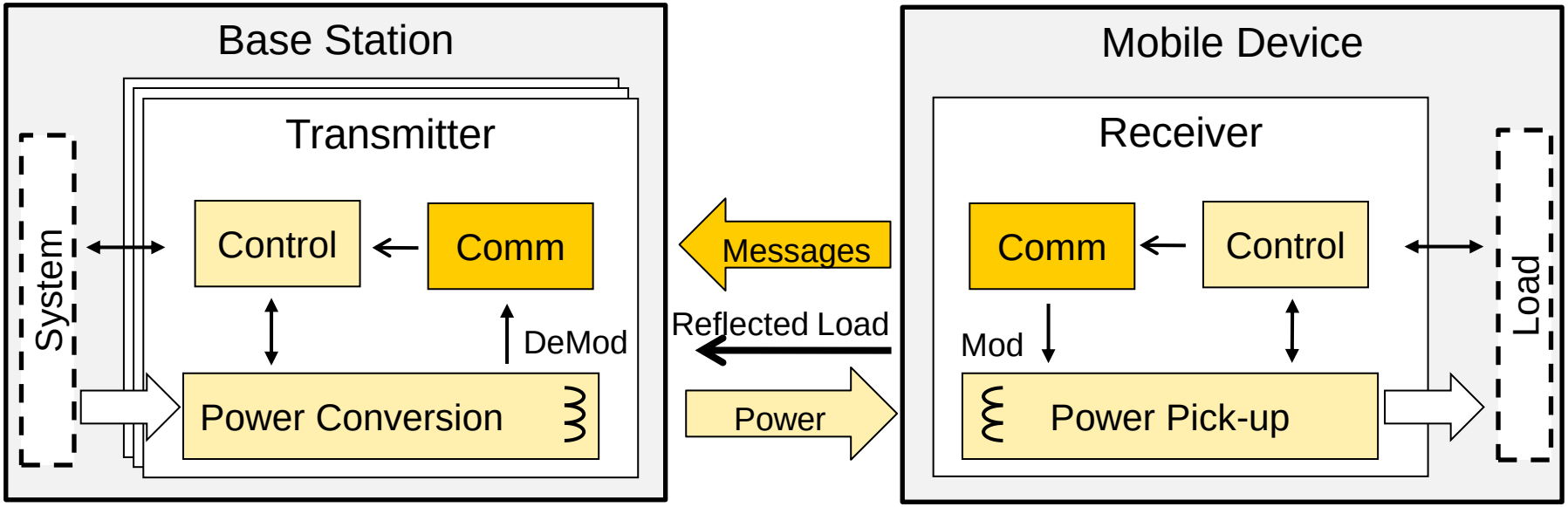
System Overview (Control)

- 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)



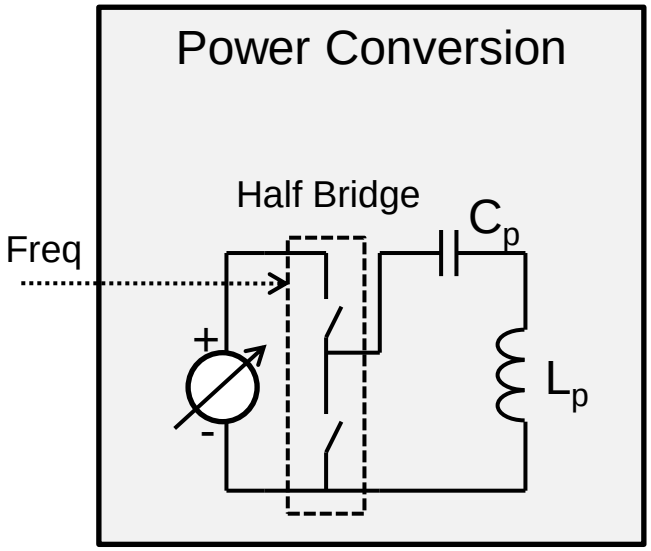
System Overview (Communication)

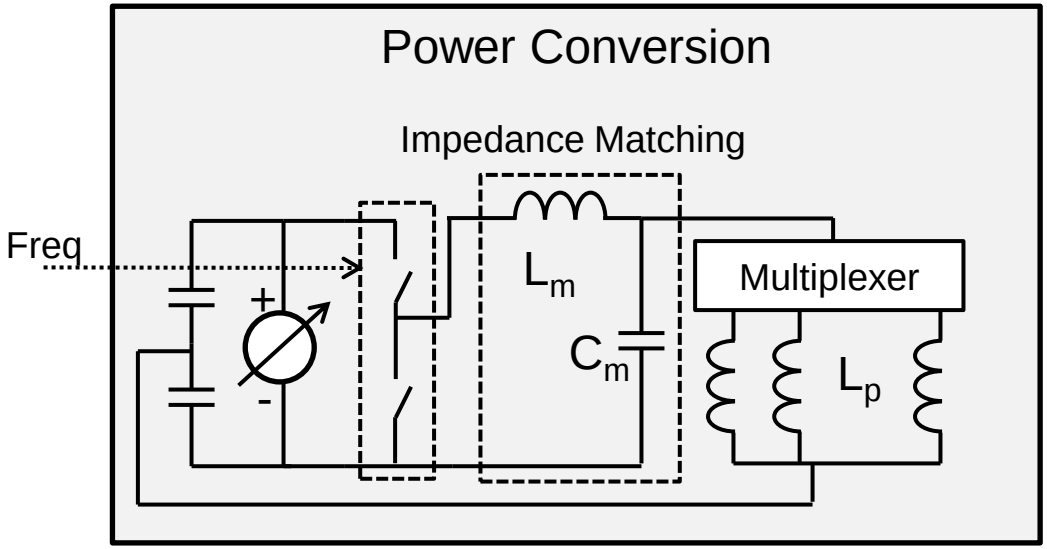
- Receiver sends messages
  - To provide control information to the transmitter
  - By load modulation on the power signal
- Transmitter receives messages
  - To receive control information from the receiver
  - By de-modulation of the reflected load



Power Conversion (Transmitter)

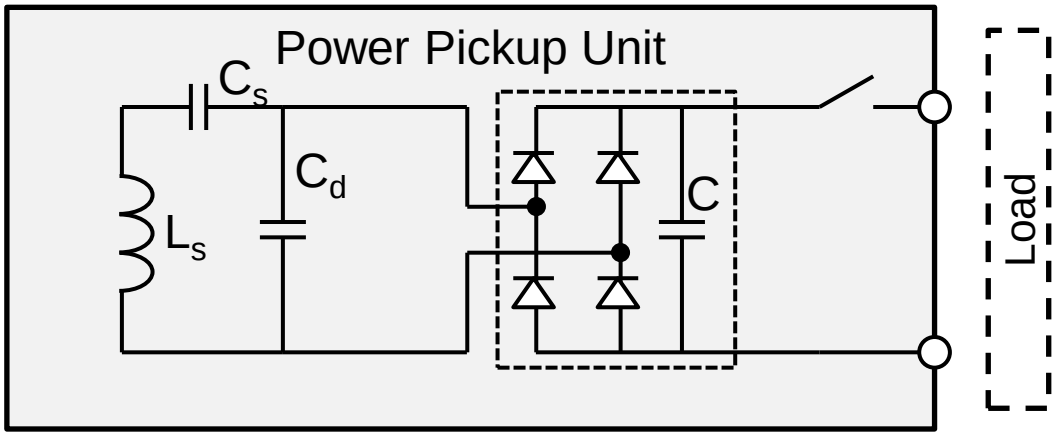
- Primary coil (L_p) + serial resonance capacitor (C_p)
- Inverter: e.g. half bridge
- Coil array implementation
- Controlled by e.g. frequency or voltage





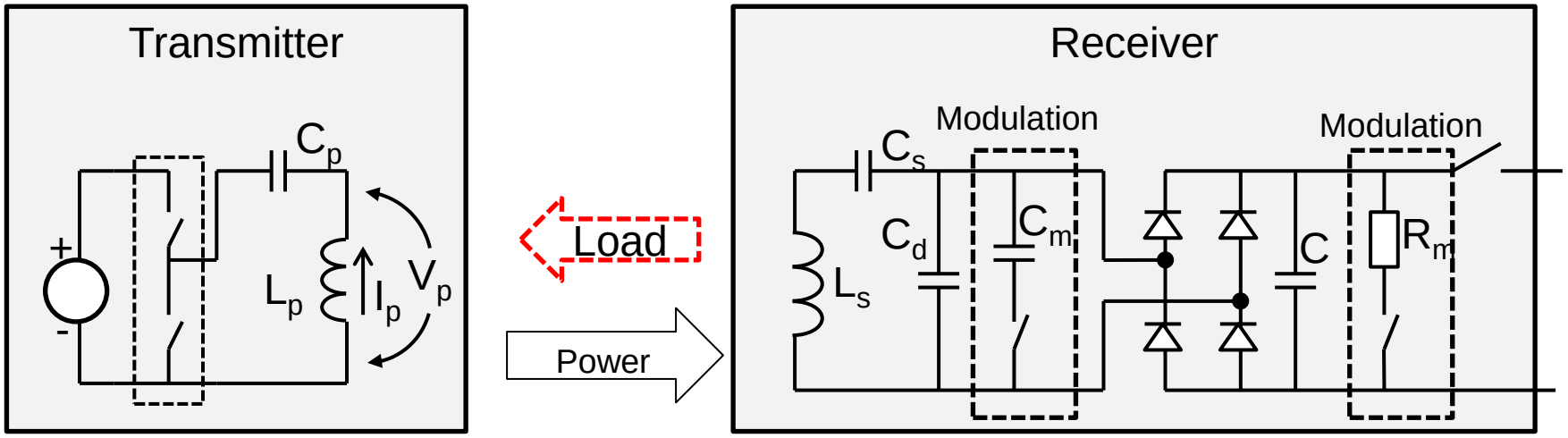
Power Pick Up (Receiver)

- 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



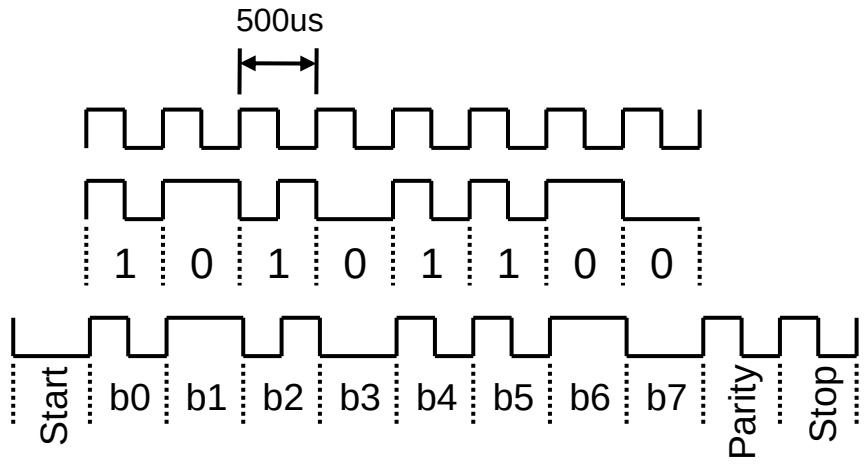
Communication (Modulation)

- 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)

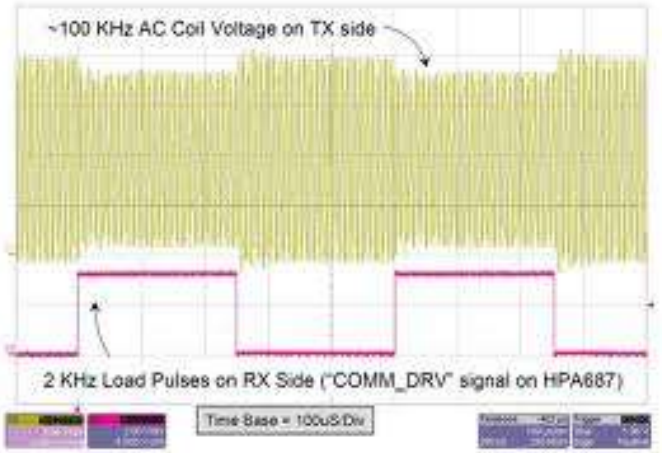


Communication (Data-Format)

- 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)

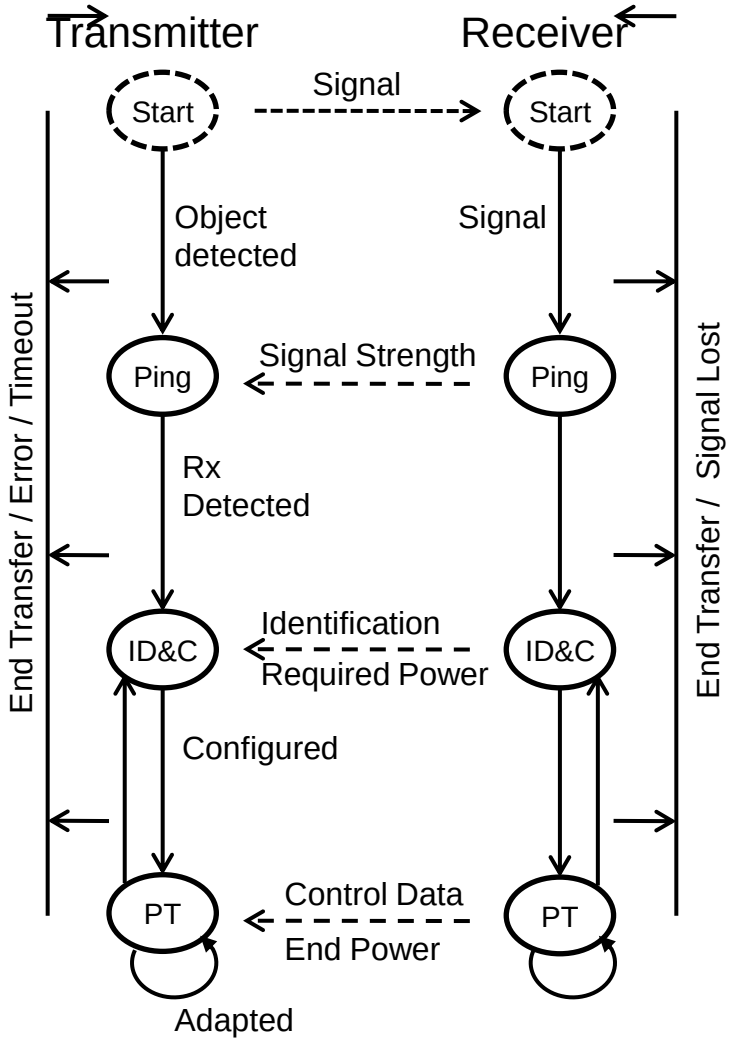


Preamble	Header	Message	Checksum



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



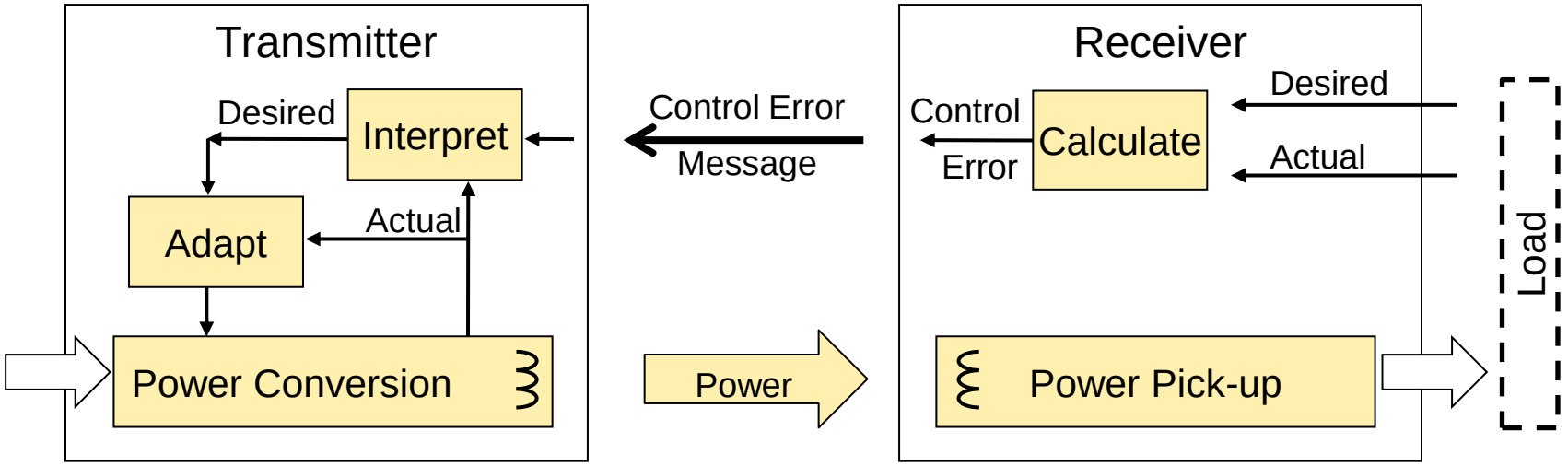
Power Transfer Control

Transmitter

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

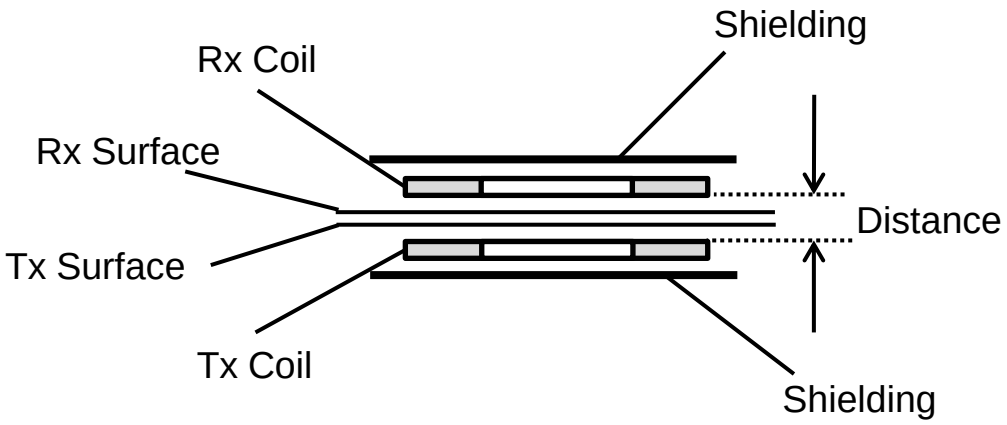
Receiver

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



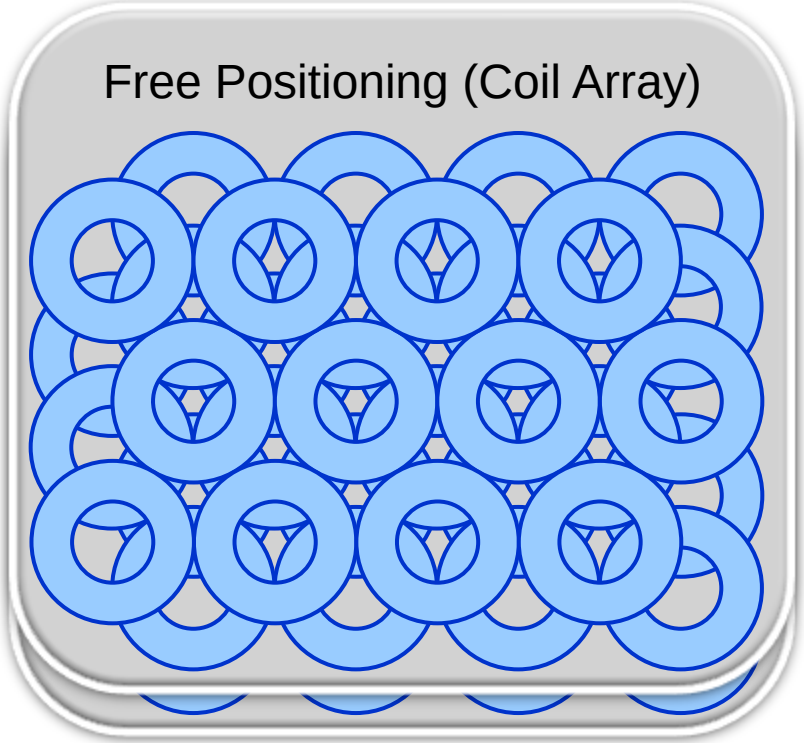
Coupling Between Coils

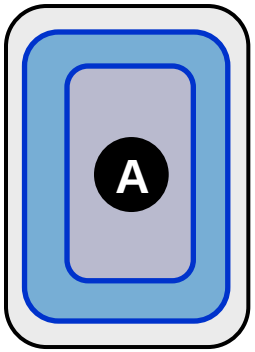
- Good coupling between coils is achieved by
  - Choosing appropriate dimensions of coils (matching size)
  - Keeping the distance between coils small (flat interface surface)
  - Adding magnetic permeable material (shielding)
  - Aligning the coils (next page)

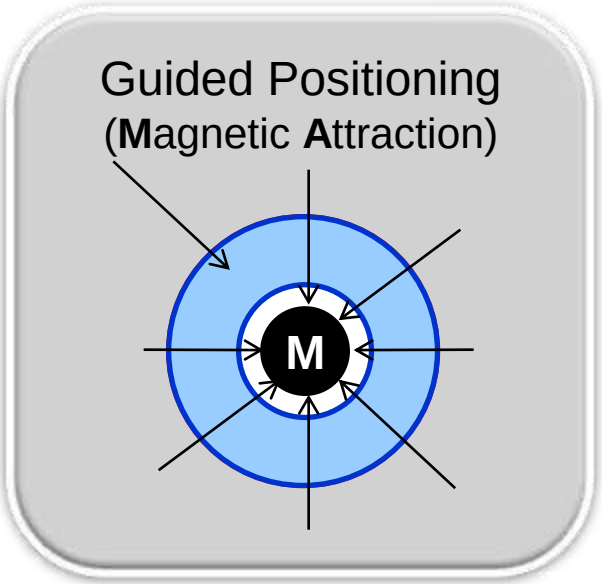


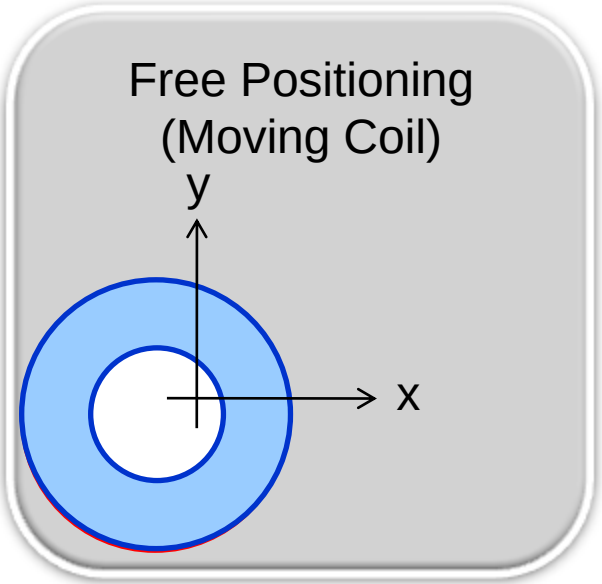
Coil Alignment (Design Freedom)

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





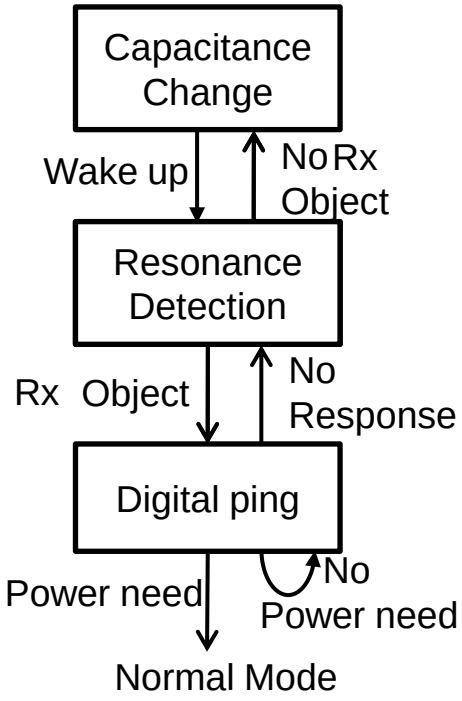




Standby Power

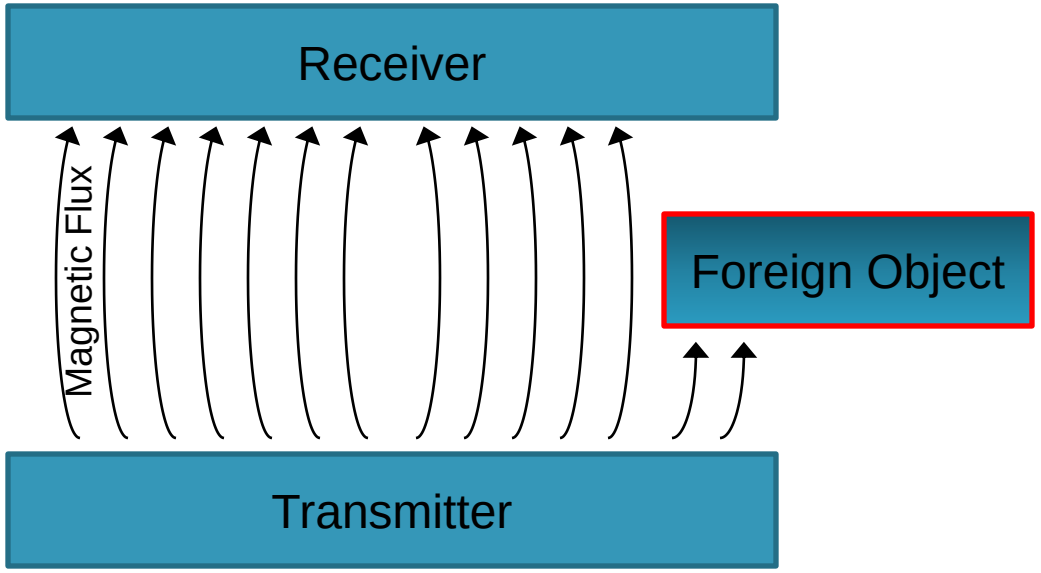
- Transmitter can enter standby power mode when
  - No device is present or
  - present devices need no power (battery charged)
- Transmitter can apply various methods to react on a receiver
  - Capacitance change
    - To detect the placement of a potential receiver
    - E.g. 0.1 mW
  - Resonance detection , 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



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:

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

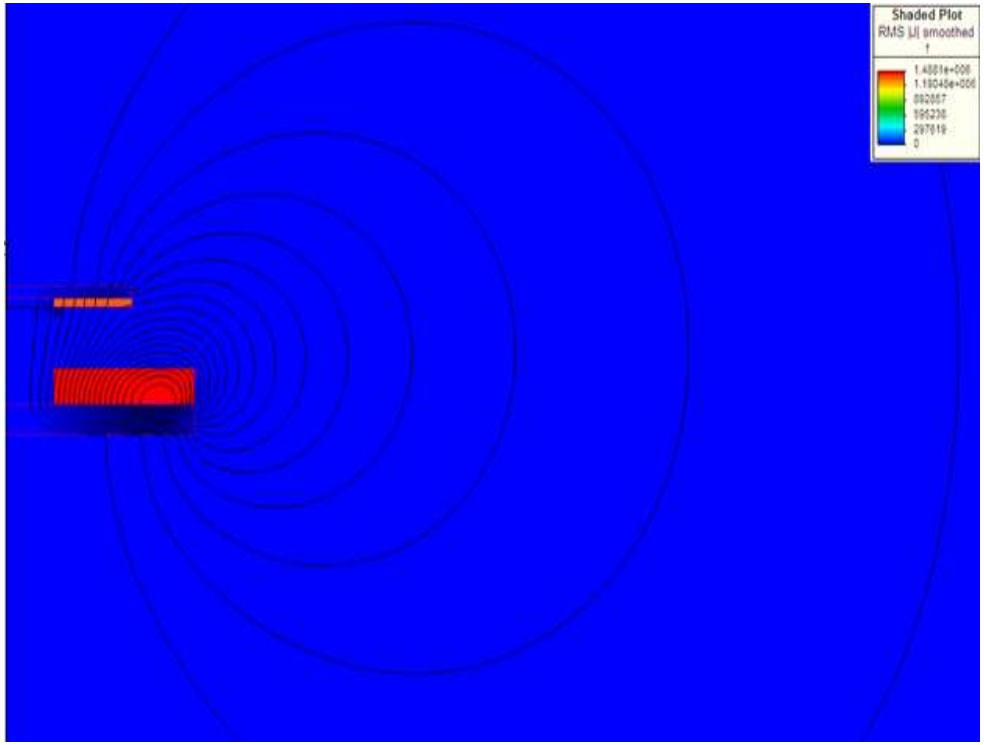
- And the received power can be calculated as follows:

$$P_{received} = P_{load_{meas}} + P_{rxlosses}$$

- 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

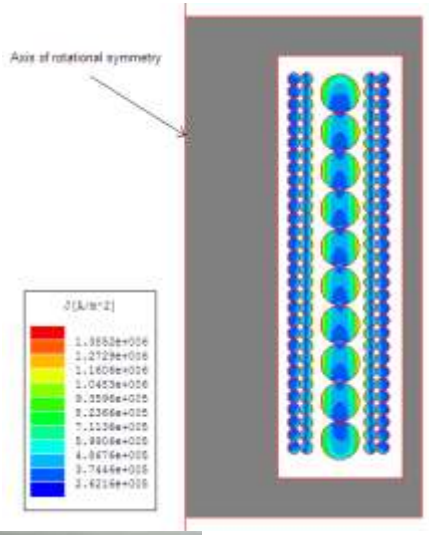


Power Loss Considerations

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

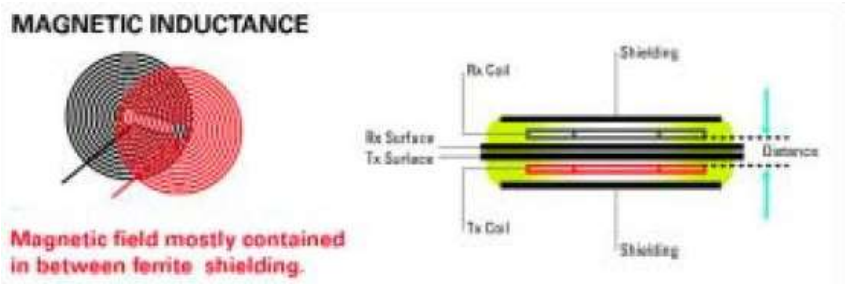
- AC resistance increases with frequency
  - Proximity effect (current crowding from multiple turns, core material)
  - Skin effect (current crowding from internal magnetic fields)

- 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)



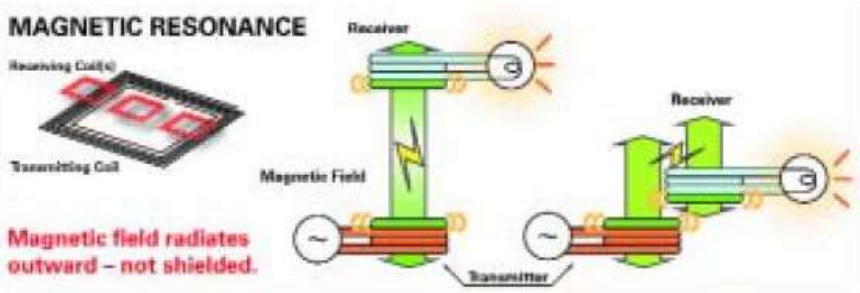
Magnetic Induction Technology

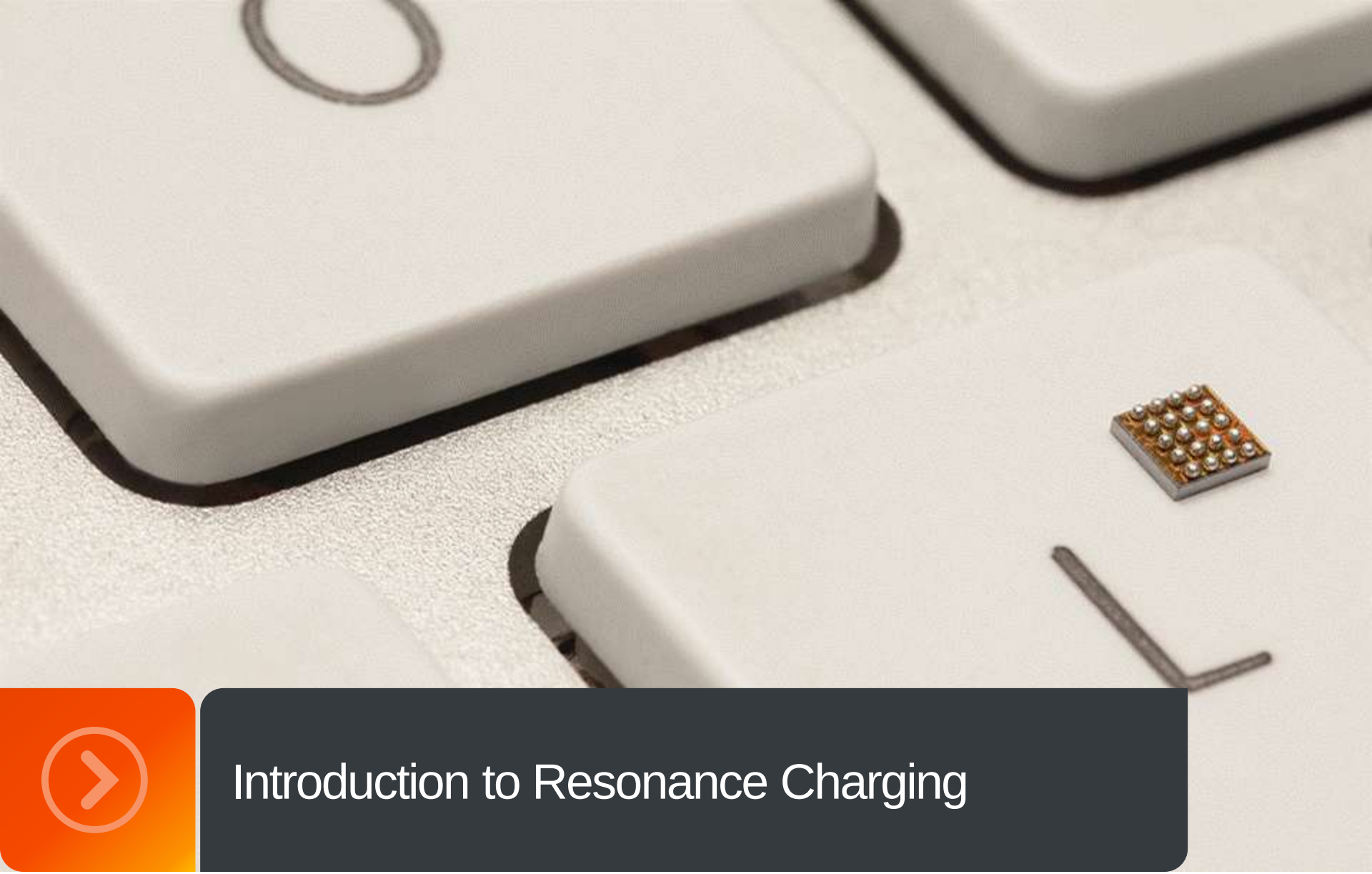
- Transmitter coil that creates a magnetic field; receiver coil picks up the magnetic field and generates electric current
  - Advantages: simple, efficient, safe, power scalable, matured
  - Key technology challenges: shield, coil alignment, and good coupling
  - Disadvantages: limited x/y/z space, 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.)



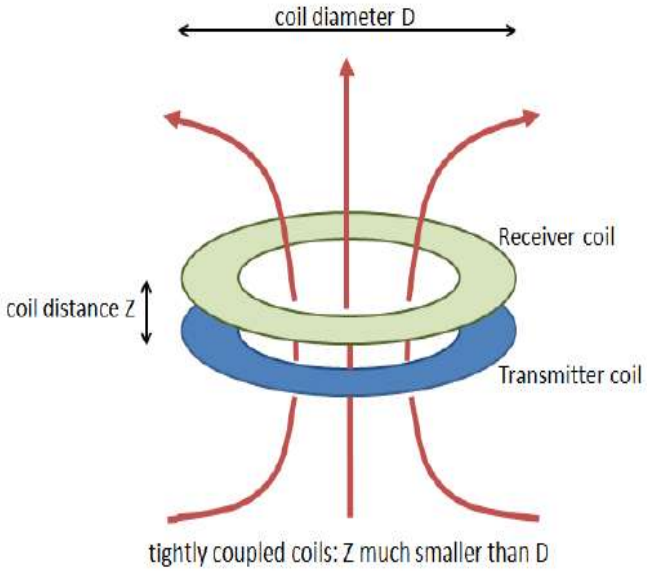


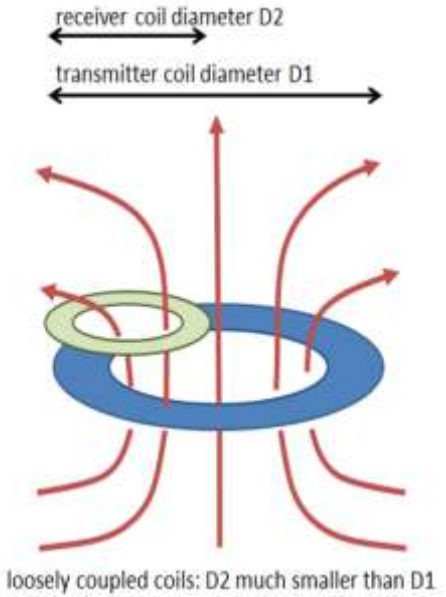
Introduction to Resonance Charging

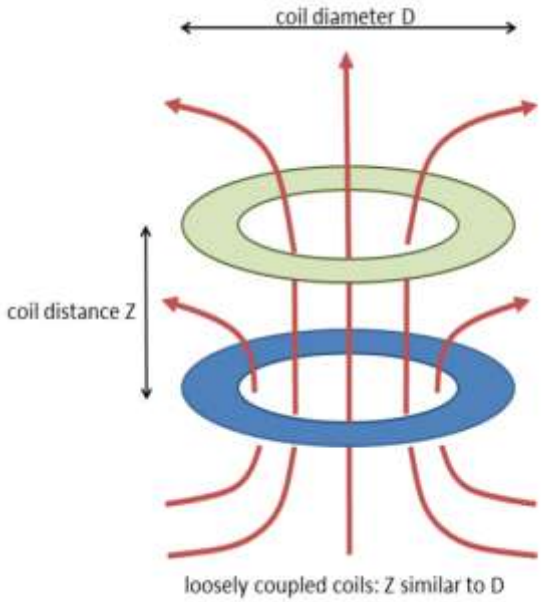
Some Definitions

- 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

Coupling Factor





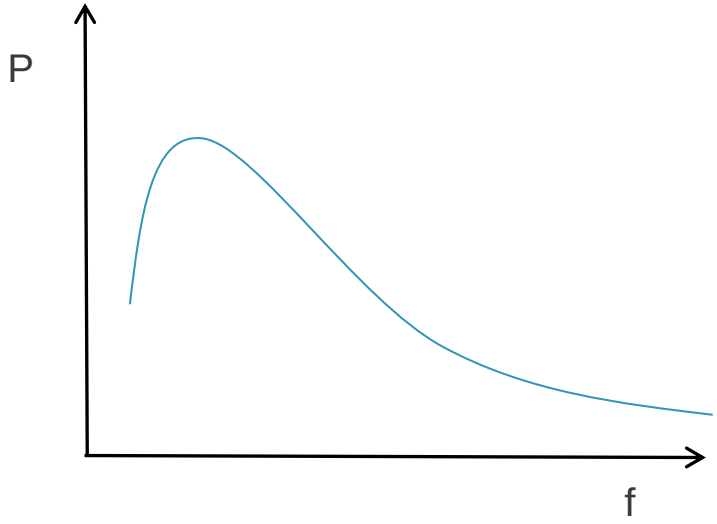


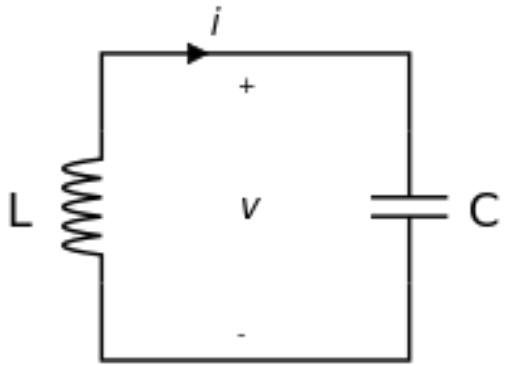
Operating Behavior

- 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

$$\omega_0 = \frac{1}{\sqrt{LC}}$$ → Resonant frequency

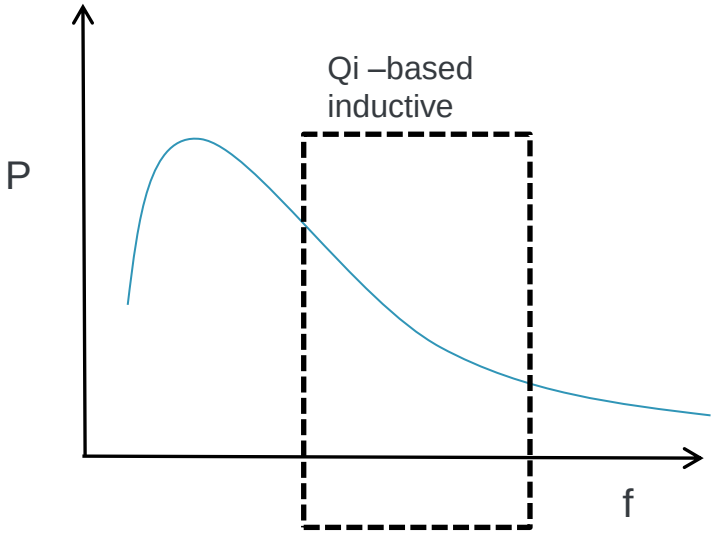
$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$ → Quality factor - determines how resonant the system behaves

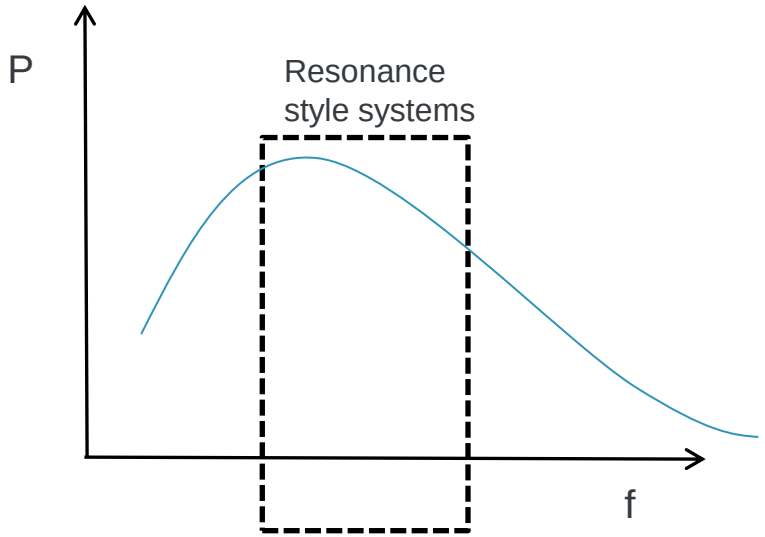




Operating Behavior

- 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

Architecture	Efficiency	X,Y Freedom	Z Freedom	EMI	Multi-device charge
Inductive, single-coil	+	-	-	+	-
Inductive, multi-coil	+	+	-	+	+
Single-coil, resonant	-	+	+	-	+
Multi-coil, resonant	-	+	+	+	+

More Information

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

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

- Randy Ryder
  - randy.ryder@freescale.com

www.Freescale.com

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