A View From the Other Side of the Chasm
Solving the Technological Challenges

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Wireless Power: A View From The Other Side of the Chasm

- 200 Million wireless power ICs sold in 2016. *(source: I.H.S)*
- integrated into >25 smartphone
- >20 smartwatches
- >200 Wireless charging pads & 150 smartphone cases
- >70 automotive models as a feature
- Apple joins WPC Qi (Feb 2017)…
- Asian Cellphone players moving rapidly
Content

- Magnetic Induction: Background & Basics
- WPC Qi System Implementations
- Key Considerations for Transmitter Design
- Key Considerations for Receiver Design
- Practical Implementations
Wireless Power Delivery Methods

- Electromagnetic Induction
- Magnetic Induction
- Direct Induction

Magnetic field radiates outward, not shielded

- Magnetic Resonance
- Resonant Transformer
- Resonant Inductive Coupling

 Adds cost and complexity. EMI and efficiency concerns

Practical only for very specialized applications. Many issues!!
Magnetic Induction Wireless Power

How it works
Flux must be captured, ferrite directs furthest flux lines

• We need to capture the flux with the Rx coil inner diameter.
  - Too much flux isn’t always better. Typical Flux density in free space.
The Basic Air Core Transformer Idea

• Coupling coefficient ‘k’ impacts mutual inductance $M$
  - $k$ influenced by turns ratio, ferrite area/thickness, and the space between the coils ($k = 0.5 – 0.8$ ideally)

\[ V_1 = L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} = (j\omega L_1)I_1 + (j\omega M)I_2 \]

\[ V_2 = M \frac{dI_1}{dt} + L_2 \frac{dI_2}{dt} = (j\omega M)I_1 + (j\omega L_2)I_2 \]
Coil Coupling Possibilities

- Not all flux generated by Tx coil is coupled into Rx coil, due to loosely coupled Tx and Rx. e.g. air gap, misalignment
- Flux not coupled into Rx coil can be described using leakage flux

![Diagram showing flux lines and coupling factors](image)

Measured (points) and Calculated (lines) coupling factors for two planar coils with 30 mm diameter
Optimizations and Trade-offs

- Coupling between coils
- Distance (z) between coils
- Ratio of diameters (D2 / D) of the two coils
- Physical orientation
- Quality factor
- Ratio of inductance to resistance

![Diagram showing power efficiency with distance and efficiency axes.](image-url)
How to Get the Most Benefits from an MI Wireless Power System

• Rx coil must be close enough to Tx coil
• Rx coil size should be larger or at least the similar size of Tx coil size
• Use of alignment tool (visual, mechanical, or magnetic force) to best align Rx coil over Tx coil
• Use of Litz wire to minimize coil AC resistance
• Design proper coil gain to maintain optimal operation condition
Coil Gain Design

Good Coil Gain Design

Improper Coil Gain Design
The WPC Qi Advantage

• “Best of both worlds” solution using partially resonant magnetic induction
  - Loosely coupled air-core transformer
  - Useable air-gap working distance of about 3mm – 8mm (depending on transmitter type)
Simplified Designs Using Qi Systems

- Qi certified Transmitter designs are fully worked out, including detailed specification of all operational parameters and the physical coil design.

- Receiver reference designs are similarly worked out, but in a way that enables the designer to choose/modify/make a Receiver coil that perfectly fits the design.

- Because Qi is a robust interoperability standard, IC makers have invested to make single-chip solutions that completely eliminate most of the design work.
WPC Transmitter Basic Topology

- Primary coil ($L_p$) + serial resonance capacitor ($C_p$)
- DC-to-AC Inverter: e.g. half bridge (shown below) or full-bridge
- Power level is controlled by changing transmitter operating frequency, operating duty cycle, and/or bridge supply voltage.
- Power is controlled by the Receiver which is the master of the transmitter
- Multiple coil solutions function the same as single-coil with the “best” coil selected by the transmitter before beginning interoperation with the Receiver
WPC Receiver Basic Topology

- Secondary coil ($L_s$)
- Serial resonance capacitor ($C_s$) for efficient power transfer
- Parallel resonance capacitor ($C_d$) for required alternative method to detect presence of a Receiver device by making 1MHz resonance
- AC-to-DC Rectifier: full bridge (diode, or switched) + capacitor
- Output switch for disconnecting the load

![Diagram of Power Pickup Unit]
WPC Communication (Modulation)

- Receiver modulates load by method of Amplitude Shift Keying (ASK)
  - Switch on/off modulation resistor ($R_m$), or
  - Switch on/off modulation capacitor ($C_m$)
- Transmitter demodulates Receiver information by
  - Sensing primary coil current ($I_p$) and/or
  - Sensing primary coil voltage ($V_p$)
- Transmitter modulates the frequency of the coil power signal to send information to Receiver
  - Receiver measures Tx coil drive frequency to demodulate Transmitter information

Note: Demodulated amplitude ranges from about 800mVpp to 10mVpp
WPC Communication: ASK Modulation

- Bit encoding scheme is defined by WPC
  - Each packet includes preamble, header, message, checksum
  - Each byte includes start bit (0), 8-bit data, parity, and stop. And rate of bit is 2kHz.
- This communication can be seen from Vrect (Rx), VSNS (Tx), ISNS (Tx) and input current (lin)
- ASK communication might be corrupted due to coupling, permanent magnet or repeating transient load.

```
Logic “0” and “1”
```

```
One Byte
```

```
Start b_0 b_1 b_2 b_3 b_4 b_5 b_6 b_7 Parity Stop
```
Tx Specification & Decision Drivers

- Decide target Rx Category: Wearable, Phone, Laptop, Automobile, Space Shuttle
- Decide main input voltage (5V systems are common):
  - Consider Rx Output Power (5W out → 5Vin; 10W out → 9Vin; 15W out; 12Vin)
  - Consult Specification for appropriate Tx and Resonance capacitance.
- Decide maximum power level to be delivered:
  - Select suitable DC power supply for Tx unit (voltage accuracy & current rating).
- Choose the pre-defined Qi Transmitter type that best matches the application
  - Choose from an IC vendor a chip solution that best meets the requirements for cost, efficiency, EMC emissions, component count, etc.
  - Follow closely the IC vendor guidelines for system implementation
- Application Area: Smaller Products will need smaller solutions and more integration.
- Active Area: Surface area available for charging.
Tx Power Control Methods

- **Frequency Control:**
  - Tx varies the operating frequency in order to adjust power, under IDT IC control.

- **Duty Cycle Control**
  - IDT Tx IC varies the Duty Cycle in order to adjust power (applies to system once frequency is fixed).

- **Voltage Control (Buck fed system)**
  - Tx varies the VBRG voltage in order to adjust power.
  - External BUCK with output voltage under IC control.

**LC Power (W) vs. Frequency (Hz), VBRIDGE (V), DUTY Cycle (%)**

Typical Power Available Characteristics
Tx Power Loss Mechanisms

- **Skin Effect**
  - Use wide copper planes for routing power paths and SWx nodes

- **Friendly Metal Absorption**
  - Eddy Current induced by the magnetic field

- **Switching Losses**
  - Series Gate resistance, Gate Driver output resistance

- **Tx Coil Ferrite Magnetic Hysteresis**

- **Current Sense Resistor value vs. accuracy.**
  - Influences: Tolerance (%), Tempco (ppm/°C), Power Rating (W), Package Size
  - Must use Kelvin sense connections
Tx Layout Guidance and Tips

- Full Bridge FETs bypass capacitors from HS FET drain to LS FET source loop area & layer transitions minimized.
- Wide routing for power path (VIN, Vbridge, GND).
- Full Bridge PGND solidly and directly connected to: Power Supply return, TX IC GND Pins, and all bypass capacitor GNDs.
- Sensitive Circuits near Tx IC / away from Bridge and LC tank.
- Tx IC - input bypass capacitor placed first and closest to IC, routed on component side.
- LDO bypass capacitors direct GND connect to E-PAD.
- Current Sense resistor ‘kelvin’ connections to ISNS_H and ISNS_L
  - Separate ISNS_H trace from Power trace to VIN pin.
- Main POWER GND current path not flowing under DEMOD filter GND connections
- IDT offers Layout Guide Application Notes for each Transmitter Type
Rx Considerations

**Zero Current Switching**

In the diagram, the zero current switching (ZCS) is indicated at the SW node. This is crucial for minimizing switching losses and improving efficiency in the rectifier circuit.

**Full Synchronous Bridge Rectifier**

- Rectifier bridge is controlled to be ON/OFF based on the current crossing on AC1 and AC2.
- Both top and bottom MOSFETs are switched OFF during current zero crossing to guarantee ZCS.

**Vrect Headroom vs Iout**

The graph shows the relationship between the rectifier voltage headroom and the output current (Iout). It indicates:

- **Light load**: Vrect headroom vs Iout decreasing curve. Under no load conditions, Vrect target is high to mitigate the high step load response while does not dissipate too much power.
- **Heavy load**: Vrect headroom is set very low to minimize the power loss on LDO.

**Coil Current**

The coil current waveform is shown in the diagram, indicating the alternating current through the inductor (L1).

**ASK Modulation**

This mainly changes the resonant tank gain slightly.
Rx Power Loss Mechanisms

- Rx coil has both copper wire loss (ACR) and ferrite loss (eddy current loss and hysteresis loss).
- Better coil wire: lower ACR with multi-strand to reduce the skin effect and proximity effect when height allows. PCB coils can be designed to reduce proximity loss.
- MOSFET switching and driver loss (includes Coss loss and gate driver loss) is very small due to ZCS
- MOSFET and LDO conduction loss is limited to the die size and cost.
Rx Layout Guidelines and Tips
(IDT P9221 as example)

• Route the power connections wide and on the same side of the PCB as the P9221 (≥ 100mils).
• Use the layer under the P9221 side of the board as a solid ground plane.

• Connect all GND pins to the ground plane(s) using via-in-pads. Add a thermal tab for the J-row GND pins.
• Avoid unnecessary layer transitions of the AC power connections (LC node and the VRECT, AC1, AC2, and GND pins).
• Connect as much copper as possible to every pin of the P9221, including pins that do not carry high current.
• Use minimal trace-to-trace separation for all traces and planes connected to and within 10mm of the P9221-R.
• Use low ESR resonance capacitors (Cs/Cd) to decrease losses in the LC and AC1 current path.
Practical Implementations

*Enabling more vendors to release their products quicker to the market*

1-3W Solution

- Smart Watch Wearables
- Health Monitors
- Fitness Trackers
- Portable Medical
- Headphones and Earphone
- Toys and Accessories

5W Solution

- Transmitter Infrastructure for Home, Office, Furniture
- After Market Automotive
- PC Peripherals
- Portable Medical
- Wireless Speakers

15W Solution

- Transmitter Infrastructure for Home, Office, Furniture
- Fast Charge Cellular
- Tablets
- PC Peripherals
15W Reference Kit

Features

- Complete Wireless Power Solution for 15W Applications
- WPC-1.2.3 compliant
- Transmitter MP-A2 Coil configuration
  - VIN=12V
- Low BOM cost and count
- Up to 87% DC to DC efficiency
  - P9242-R: VIN=12V
  - P9221-R: VOUT=12V & I_{OUT}=1.25A
- Optional LED & audio indicator
  - Indicating power transfer
- Easy break-away coil for user customization
- Supported by extensive library of digital resources to ease design-in effort

Efficiency vs. Output Load Current
Tx: P9242-R, VIN=12V; Rx: P9221-R, VOUT=12V, Gap=3mm; Rx coil: Amotech; Tx Coil: Sunlord

Efficiency [%] vs. OUTPUT CURRENT [A]

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

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Key Takeaways

• Wireless Power: on ‘the other side of the chasm’ and ready to enter mainstream adoption

• System designers converging around the WPC Qi specification

• Turnkey, reference designs 1-15W enable fast & easy copy/paste to evaluate and implement wireless power in a number of applications
Thank You

Analog Mixed Signal Product Leadership in Growth Markets