Measuring Wireless Charging Efficiency In the Real World
Or...

Why a Wireless Charging Spec needs to Support Close & Loosely-Coupled Approaches
Industry-Wide Problem:

There is no Standardized test methodology for specifying power efficiency of a wireless charging system
• Who cares about efficiency?
  • IKEA
  • McDonald’s
  • EPA/China/EU/Gov’t agencies
  • Auto makers
  • Consumers
  • Who doesn’t care?
1. DC out A: Not a valid representation of real-world application
2. DC out B: A good proxy, if the right load range is selected
3. DC out C: The real-world view, also allows complete energy analysis
2 Architectures

Resonant

Inductive

Rezence perimeter coil

Qi planar coil
### Architecture Comparison

<table>
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<tr>
<th>Architecture</th>
<th>Representative Standards</th>
<th>Operating Frequency</th>
<th>Antenna Structure</th>
<th>Benefits¹</th>
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<td>Resonant AKA: Loosely Coupled</td>
<td>• Rezence</td>
<td>• 6.78 MHz</td>
<td>Perimeter</td>
<td>• Extended Z-distance</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Multi-device</td>
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<tr>
<td>Inductive AKA: Closely Coupled</td>
<td>• Qi</td>
<td>• 110 ～ 205 kHz</td>
<td>Planar</td>
<td>• Highly efficient</td>
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<td></td>
<td>• PMA</td>
<td>• 200 ～ 300 kHz</td>
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<td>• Low cost</td>
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</table>

**Question:** Why not use resonant architecture for all applications?  
**Answer:** Efficiency and cost tradeoffs make it inappropriate to do so.

1. There are no Rezence products in the market, so benefits are as per the promotional materials from the A4WP
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Use-Case Examples

Resonant: Under-surface mount

Inductive: Automotive

Inductive: Charging Stand

Inductive: Charging Plate
Efficiency should be calculated as spatial average:

“Total joules into the battery divided by total joules into the transmitter averaged over the charge area/volume for a charge cycle”
Efficiency Measurement

Taken at the optimal spatial position and load power (5W, 4.2V @ 1.2A)
1. Loosely-coupled, high-frequency wireless charger
   – EPC-9112
   – Similar to A4WP/Rezence Class 3
   – 6.78 MHz operation

2. Closely-coupled, low-frequency wireless charger
   – BQ500212
   – Qi spec 1.1.2, Type A11
   – 110 ~ 210 kHz
Model determines load resistance, voltage and current test conditions
Energy required for typical (90%) charge-cycle of a 2100 mA hr. battery
High-Frequency Wireless Charger

Efficiency Experiment

Efficient Power Conversion Evaluation Kit EPC9112
- 6.78 MHz operation
- GaN switches
- ZVS, Class D amplifier
- NuCurrent antenna system compliant to Rezence class-3

GaN Driver
5Vout
VDD
8V – 36V
Gate Drive & Control
7.5V

LDO

Synchronous buck pre-regulator

Zero Voltage Switching Class D Amplifier

R_load

EPC Device Board
(Receiver)
Efficiency vs. position for 10 ohm load
“Open-Loop”
2 Configurations

Resistive Load Configuration

Battery Charging Configuration

EPC Device Board (Receiver)

Synchronous DC-DC Buck Regulator

Battery Charger

0V - >40V

5.0V

0V - 28V
Low-Frequency Wireless Charger Efficiency Experiment

Texas Instruments Evaluation Kit bq500212
- 100 ~200 kHz operation
- CMOS switches
- Würth antenna compliant to Qi A11
Efficiency vs. position for 5 ohm load Full System
Qi is the most efficient system by design.

Efficiency is impacted by:
- Switching frequency
- Antenna design
- Spatial position / Coil-coupling coefficient
- Maximum Power-Point Transfer
Battery Model: 2100 mA hr.

Total energy over 5% to 95% charge cycle: 27 k Joules
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Real-World Efficiency

Total Energy Efficiency

Qi = 59.4%
Rezence = 39.6%

65.7 kJ
η = 39.6%

43.8 kJ
η = 59.4%

27 kJ
η = 100%
Conclusions

• Real-world conditions must be used
• Efficiency should be defined as a spatial average based on real-world use
  – “Total joules into the battery divided by total joules into the transmitter over one charge cycle”
• Qi (low-frequency system) total charge efficiency ~60%
• High-frequency total charge efficiency ~40%
• A wireless charging standard that meets all market needs and use-cases must be dual-mode (resonant & inductive)
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Thank You