Groundbreaking Wireless Charging Performance for Every Application

Phyo Aung Kyaw
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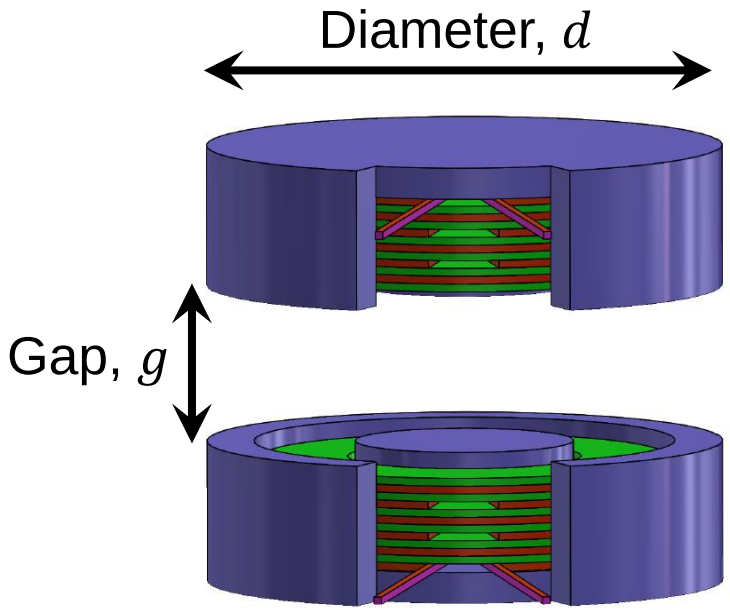
Resonant Link

June 9, 2020

Wireless Power Transfer: The Fundamentals



- Performance depends on
  - k – coupling, determined by size & gap
  - Q – quality factor, determined by loss in coils

$$\eta = \frac{(Qk)^2}{\left(1+\sqrt{1+(Qk)^2}\right)^2}$$

High-performance WPT requires:

high-Q low-loss coils

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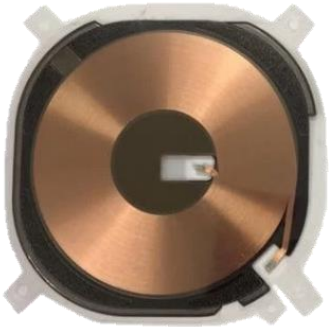
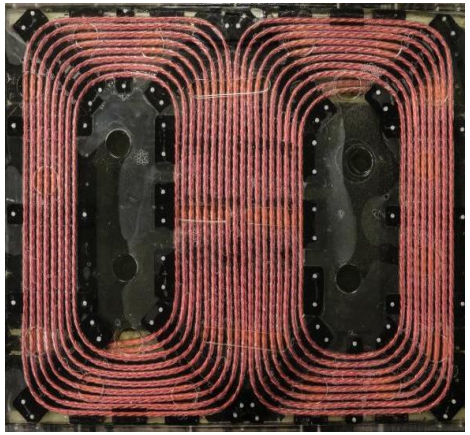
Conventional Wireless Charging Systems

- Coils made with magnet wire or litz wire
  - Skin and proximity effects increase loss.
  - Low-loss litz wire ($\ll \delta$) is expensive.
- Compensation using capacitors
  - Localized heating limits power.
  - High-voltage terminations
- Resulting in:
  - Slow charging speed
  - Large and expensive coils
  - Limited power transfer range





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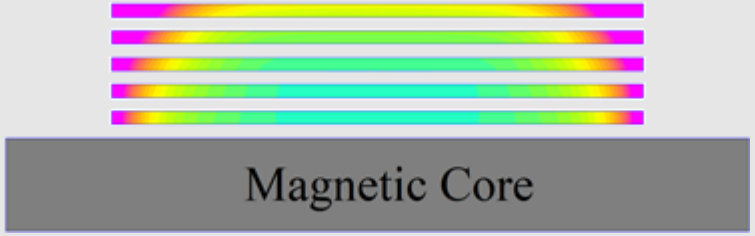
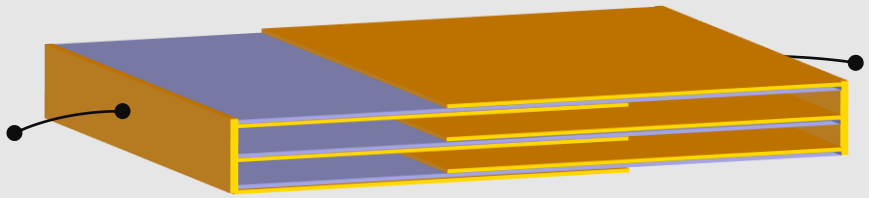
Multilayer Self-Resonant Structures (MSRS)

- Thin metal foils ($\ll \delta$) are readily available.
- Many thin layers in parallel



- Uniform current density using capacitive ballasting



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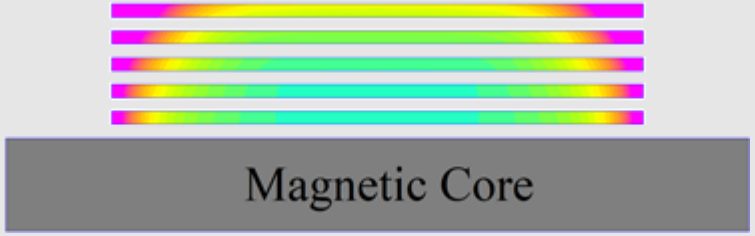

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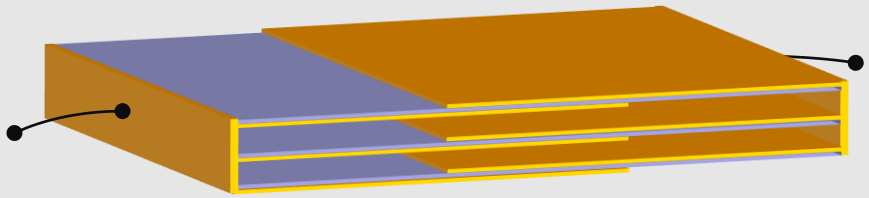

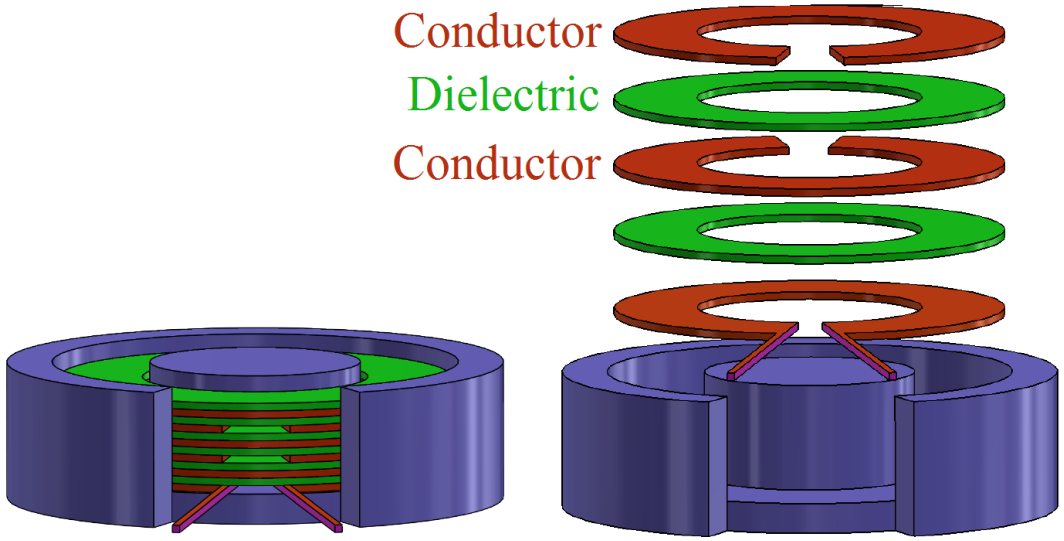

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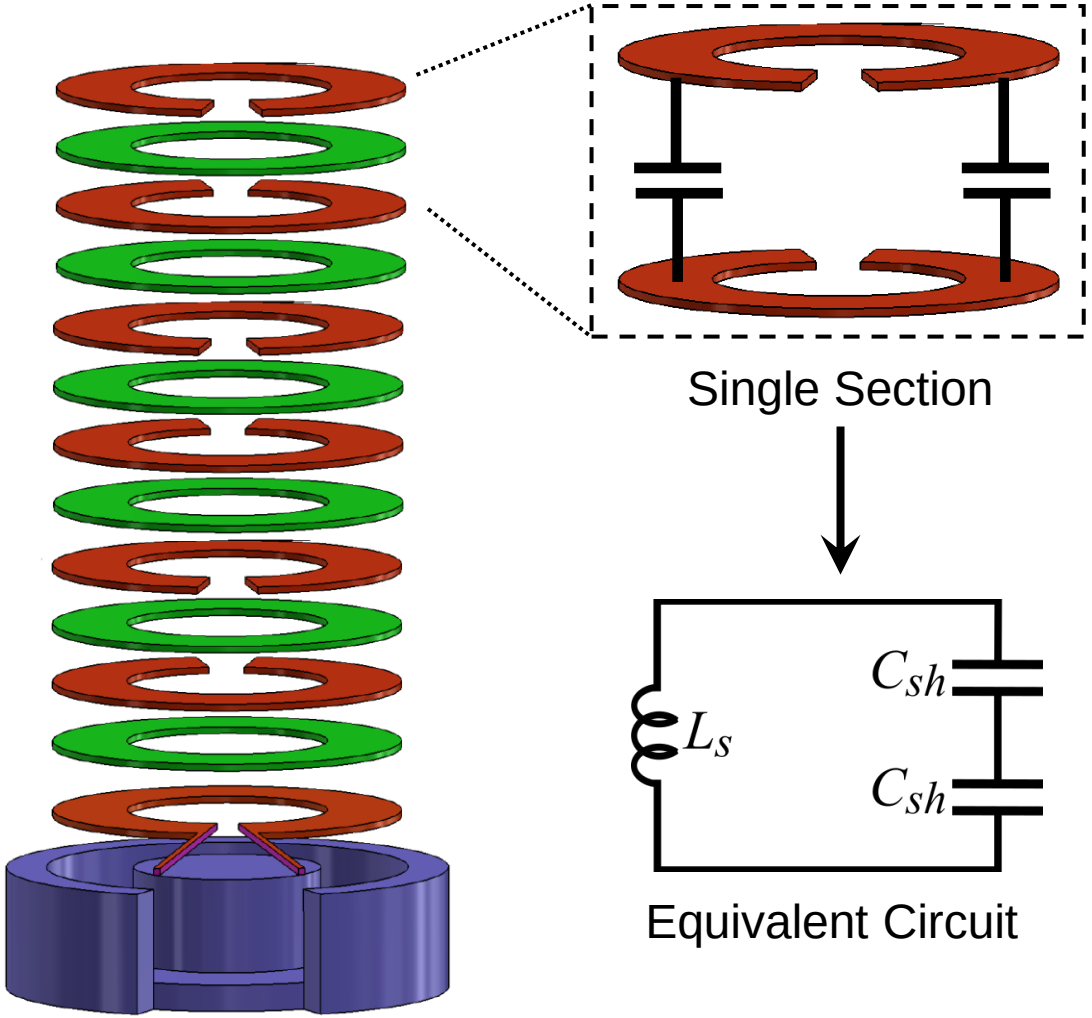
MSRS: Operation Principle



- Current loop → Inductance
- Capacitive connection between adjacent conductor layers

Advantages

- Thin foils ($\ll \delta$)
  - Mitigates proximity effect
- Integrated capacitance
  - No localized heating of capacitors
  - No high-voltage terminations

Patented
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MSRS: High Performance for All Applications

High
Power Density

Low Frequency
High Power

Very Small Size

Qi Compliance

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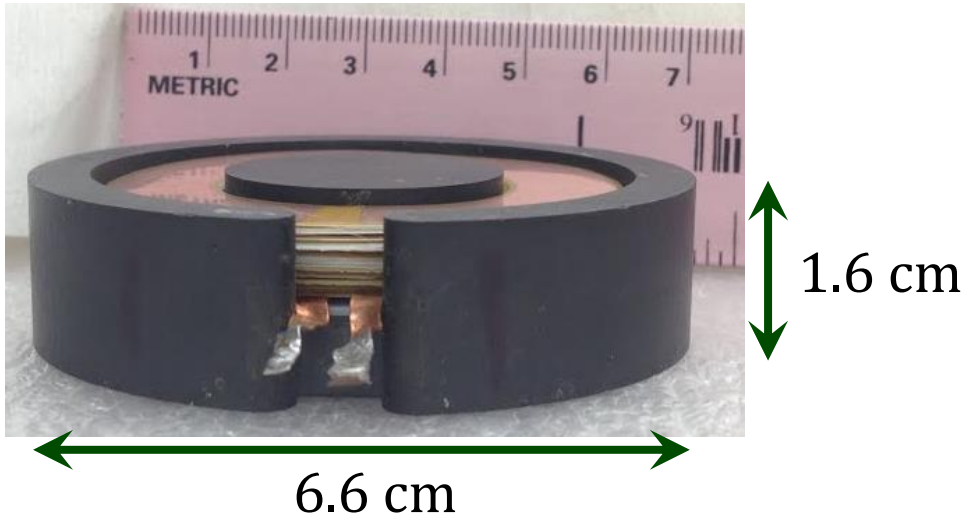
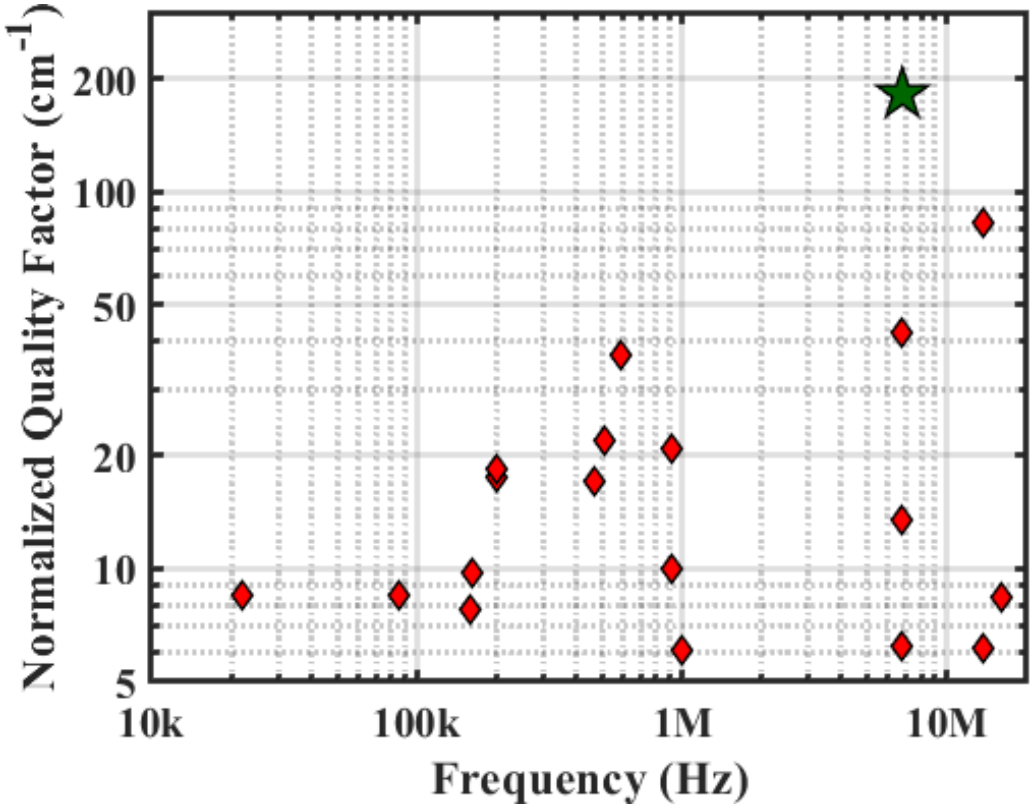
High-Q Resonant Structures





$Q = 1177$ @ 6.78 MHz

- FoM $= Q_d = \frac{Q}{d} = 178$ cm^{-1}
  - 5x larger than Q_d in the literature

Aaron L.F. Stein, Phyo Aung Kyaw, and Charles R. Sullivan. "High-Q self-resonant structure for wireless power transfer." *APEC,* 2017.

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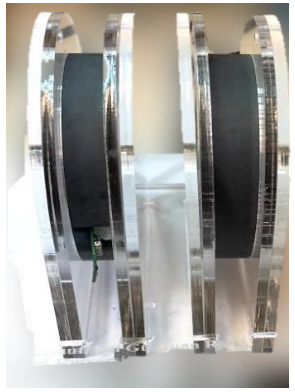
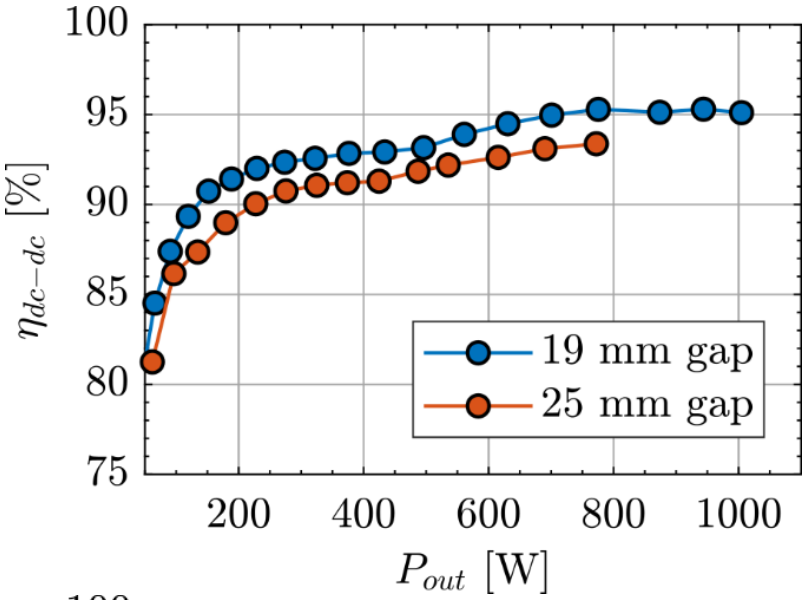
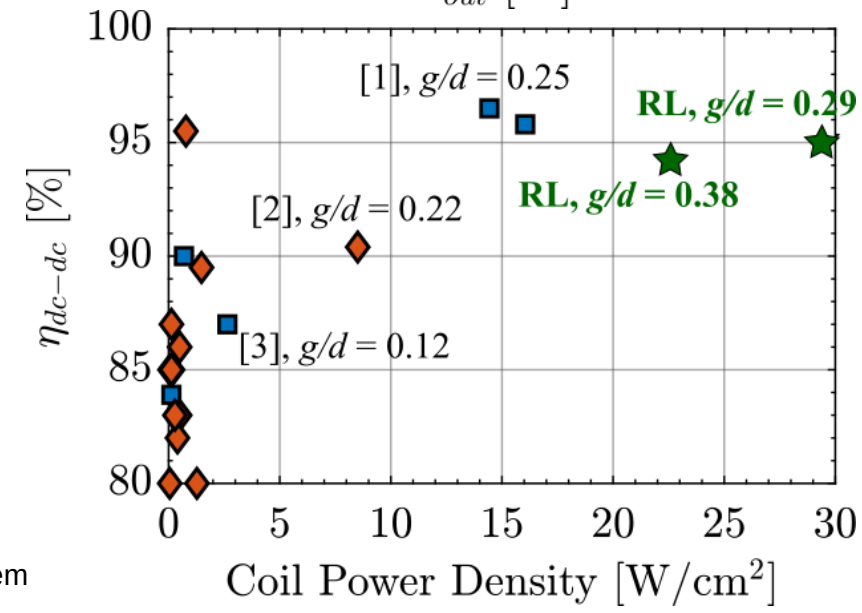
High-Power-Density Wireless Charging System

Inverter MSRS Rectifier



- 6.6 cm coil diameter, 6.78 MHz, 1 kW
- 95%+ dc-dc efficiency
- 2x coil power density at larger gap/size ratio
- *Applications*: mobile robots, drones, light EVs





[1] Roman Bosshard. *Multi-Objective Optimization of Inductive Power Transfer Systems for EV Charging.* PhD Thesis, ETH Zurich, 2015.

[2] Kawin Surakitbovorn, and Juan Rivas-Davilla. “Design of a GaN-Based Wireless Power Transfer System at 13.56 MHz to Replace Conventional Wired Connection in a Vehicle.” *IPEC*, 2018.

[3] https://www.daihen.co.jp/en/d-broad/

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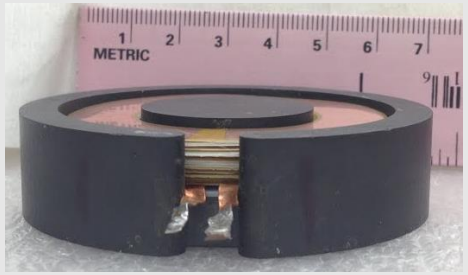
MSRS: High Performance for All Applications

High Power Density

- 6.78 MHz, 1 kW
- 95%+ efficiency



Applications

- Mobile robots, drones
- Light electric vehicles

Low Frequency High Power

Very Small Size

Qi Compliance

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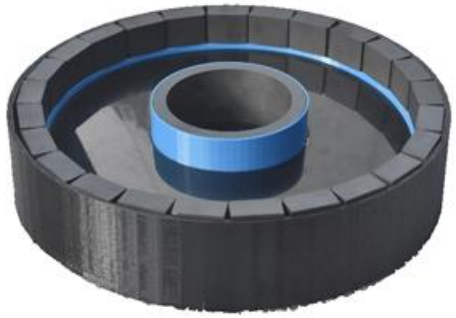
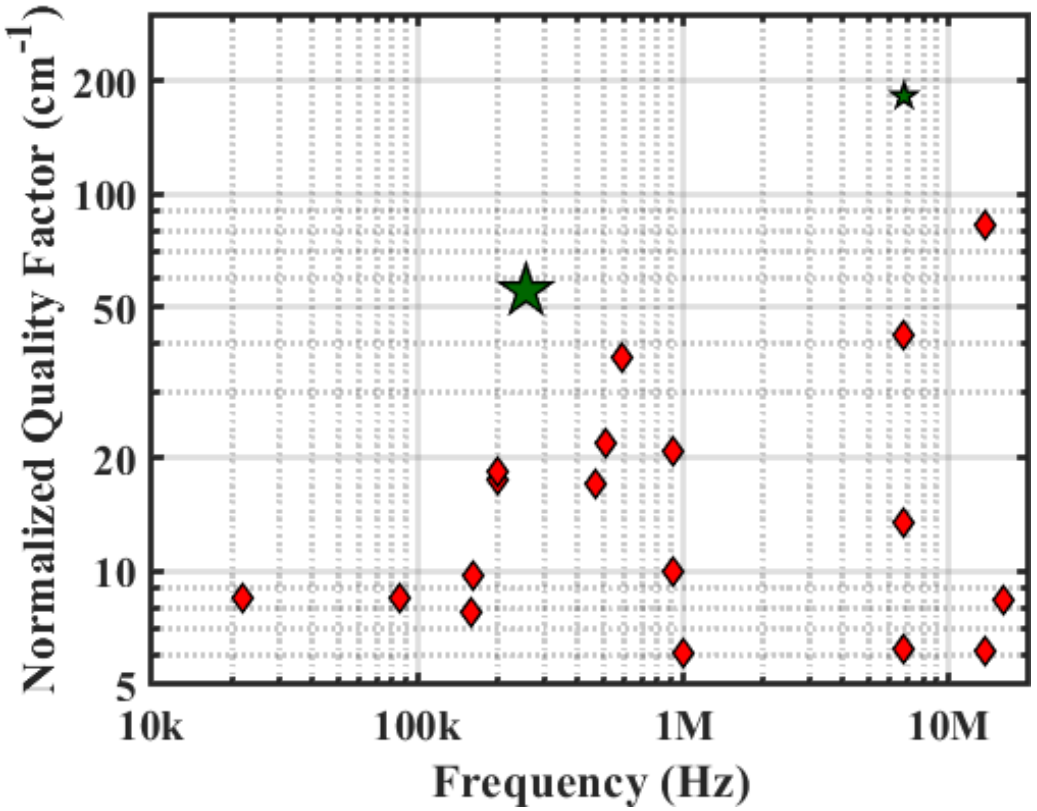
Low-Frequency, High-Power



- 30 cm coil diameter
  - Copper foil separated by PTFE layers
  - Magnetic core: 3C95
- Measured Q = 1660 @ 256 kHz
  - FoM = $Q_d = \frac{Q}{d}$ = 55.33 cm^{-1}
  - 3x higher Q_d than conventional coils



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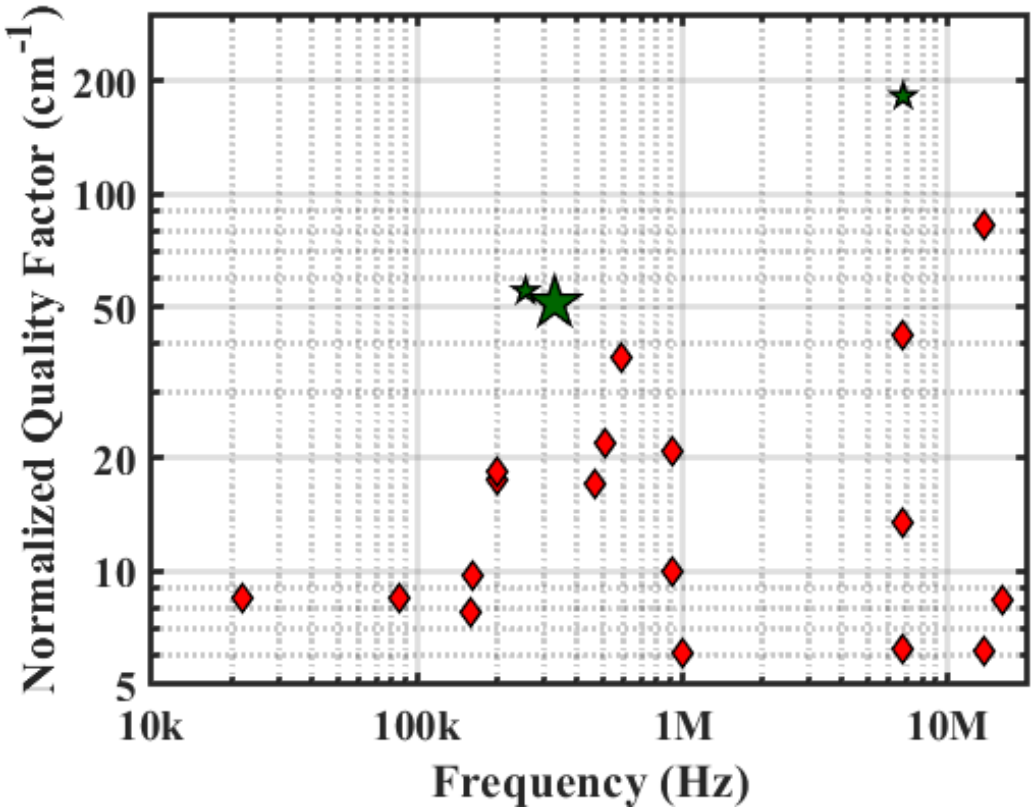
Copper-less Coils

- Aluminum as conductor layers in MSRS
  - 10x cheaper than copper
  - 3.3x lighter than copper
  - 60% higher resistivity than copper
    - Higher conduction loss
    - Lower proximity effect loss
- Measured Q = 1542 @ 330 kHz
  - FoM = $Q_d = \frac{Q}{d}$ = 51.4 cm^{-1}
  - Lighter and much lower cost



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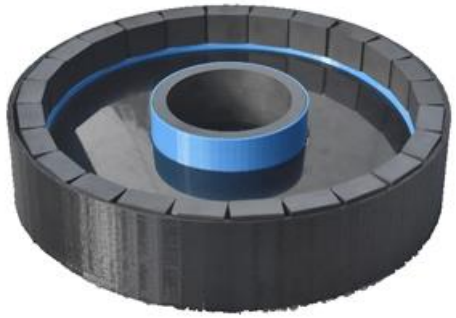
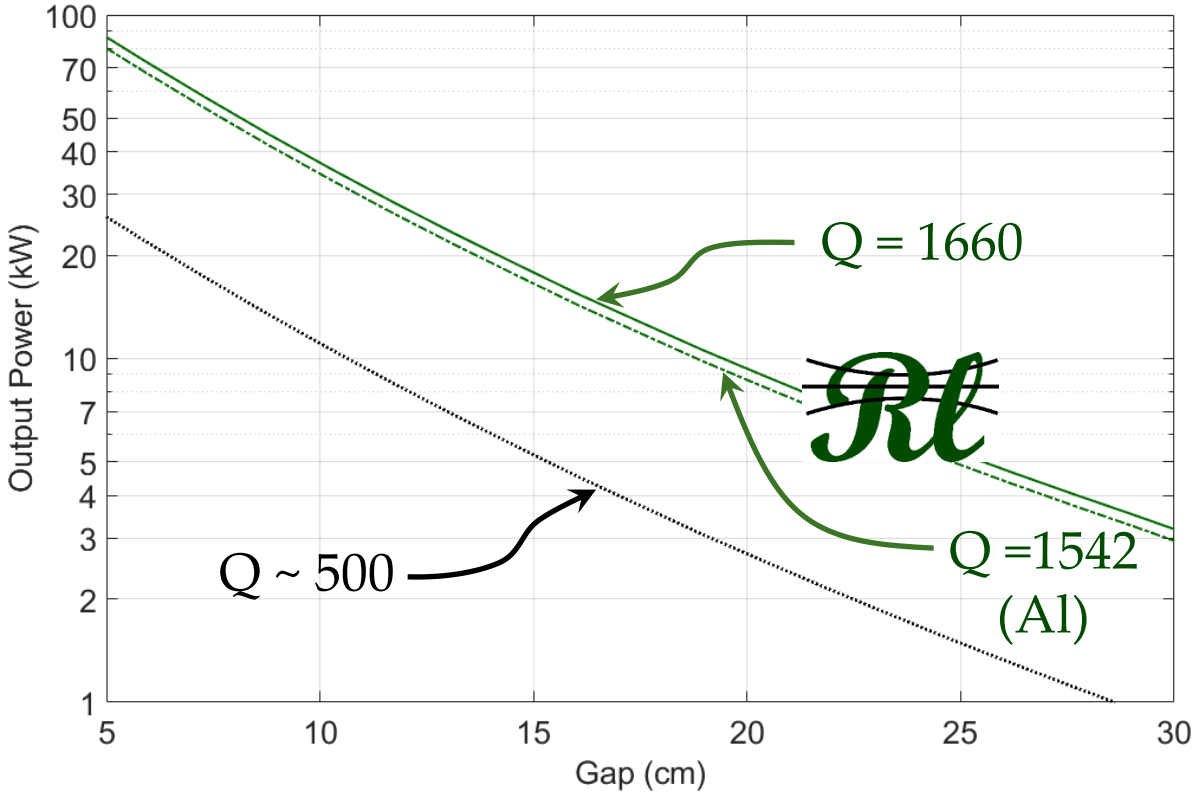
High-Power Wireless Charging



- >3x higher Q than conventional coils $Q \sim 500$
  - >3x higher power capability
- Copper-less MSRS using aluminum foil
  - Similar Q_d as copper-based MSRS
  - Lighter and cheaper
- Gen. 2 coils → SAE J2954 compliance
- *Applications*: EVs, through-wall power



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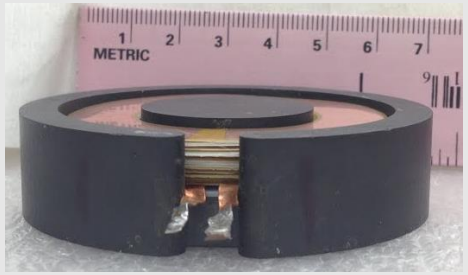
MSRS: High Performance for All Applications

High Power Density

- 6.78 MHz, 1 kW
- 95%+ efficiency

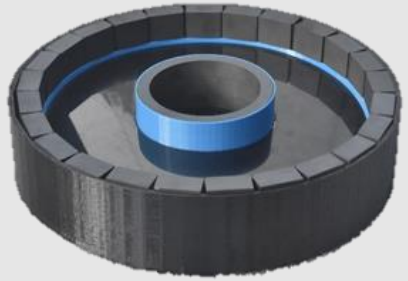


Applications

- Mobile robots, drones
- Light electric vehicles

Low Frequency High Power

- < 400 kHz, > 10 kW
- Copper-less coils



Applications

- Electric Vehicles
- Through-wall power

Very Small Size

Qi Compliance

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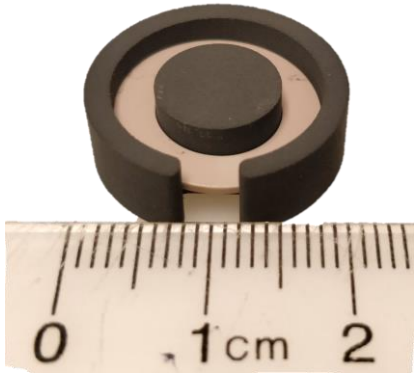
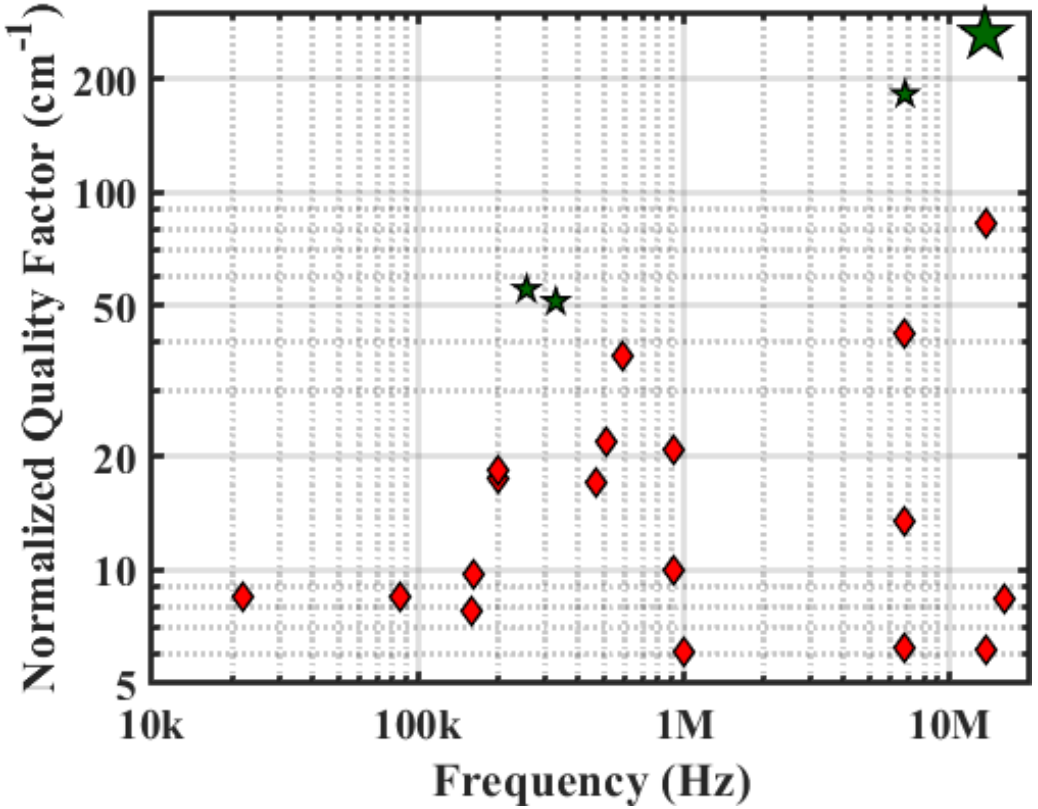
For Size-Constrained Applications



- Fabricated using MLCC process
- 2 cm coil diameter
- Measured Q = 524 @ 13.56 MHz
  - FoM = $Q_d = \frac{Q}{d}$ = 262 cm^{-1}
  - Highest Q_d in the literature
- *Applications*: medical implants, power conversion



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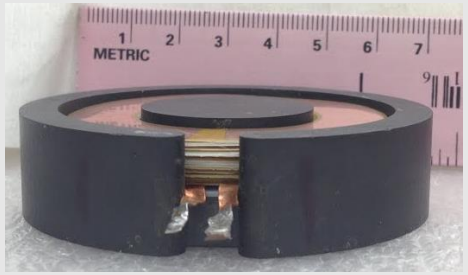

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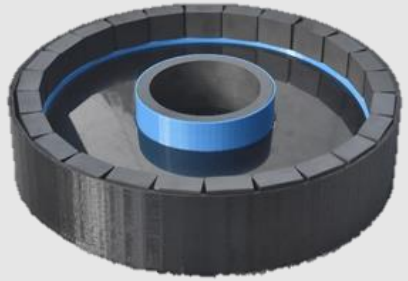
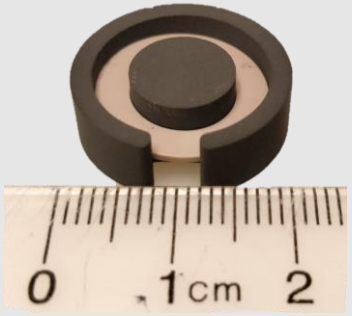


Applications

- Electric Vehicles
- Through-wall power

Very Small Size

- MLCC Process
- Highest-ever Q_d



Applications

- Medical implants
- Power conversion

Qi Compliance

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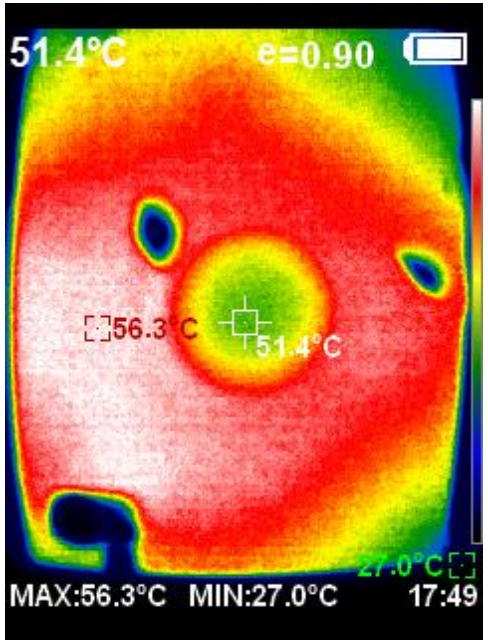
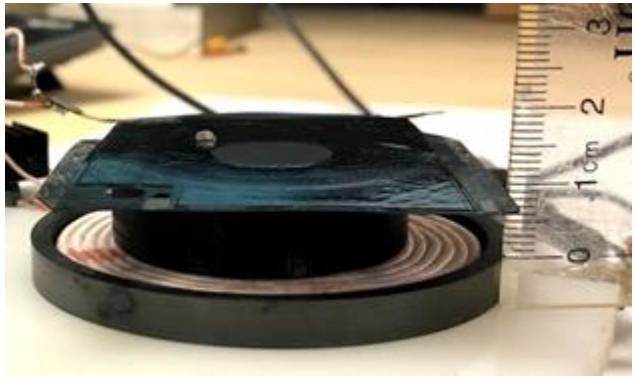
Qi-Compliant Wireless Charging

Head-to-head comparison with coils in commercial phones

~15 W delivered to the device over 1 cm wireless gap

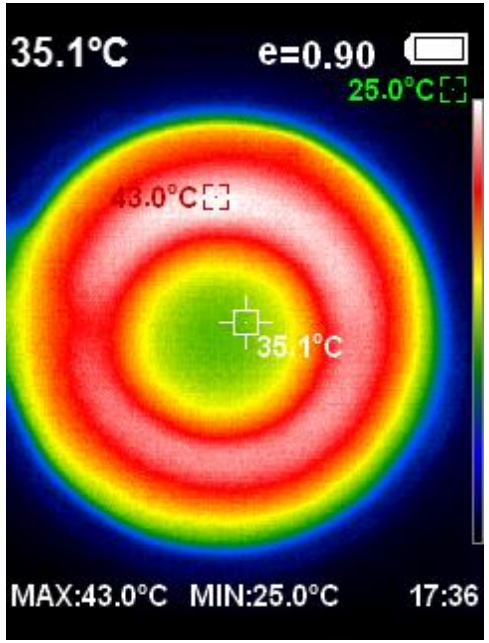
Best Coil in Commercial Phones

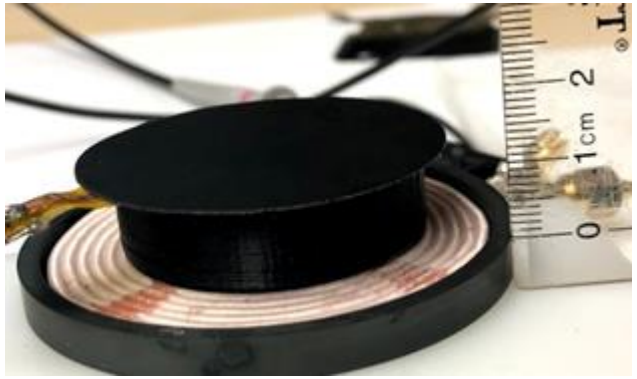




Output Power	15 W
DC-AC Efficiency	82.3 %
Receive Coil Loss	1.83 W

Resonant Link's MSRS (PCB-based)





Output Power	15 W
DC-AC Efficiency	93.6%
Receive Coil Loss	0.72 W

~2.5x lower loss in the receive coil

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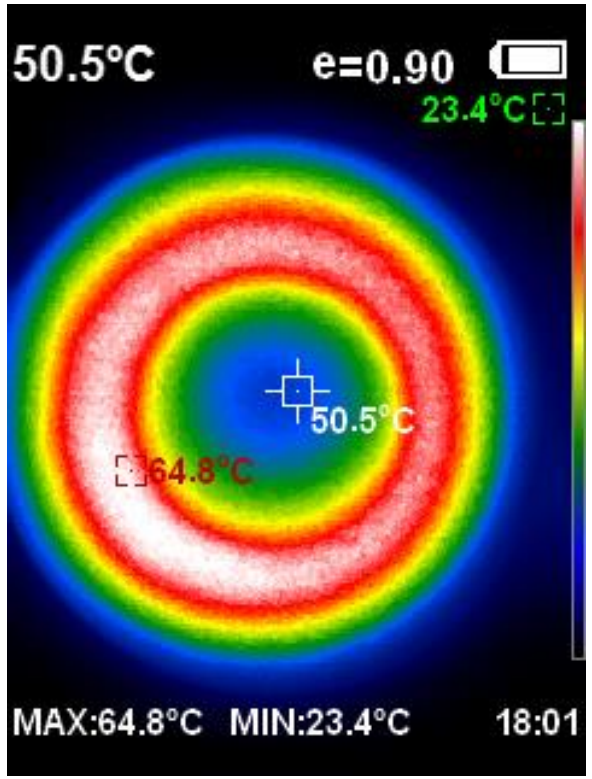
High-Power Consumer Electronic Devices

MSRS enables higher-power charging for tablets and laptops (30-60 W).

Rx Coil: 61 mm diameter, 800 μm thick, 60 W delivered over **2 cm** wireless gap.



Output Power	59.7 W
DC-AC Efficiency	84.2%
Receive Coil Loss	2.44 W

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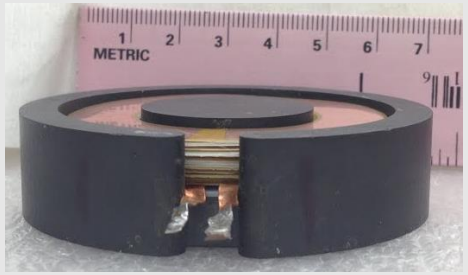
MSRS: High Performance for All Applications

High Power Density



- 6.78 MHz, 1 kW
- 95%+ efficiency

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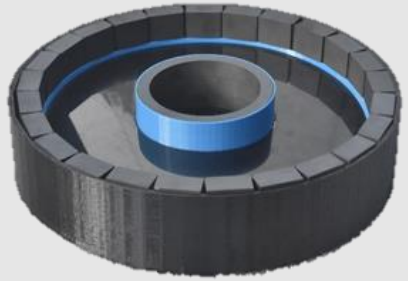
- Light electric vehicles

Low Frequency High Power

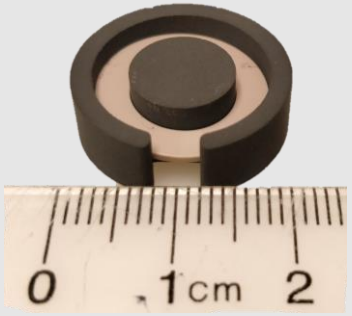


- < 400 kHz, > 10 kW
- Copper-less coils

Applications

- Electric Vehicles
- Through-wall power

Very Small Size



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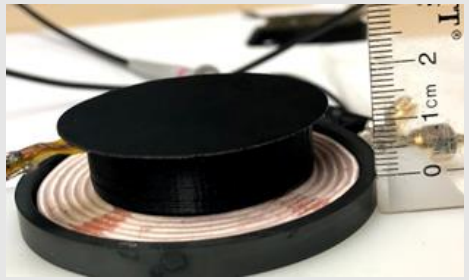
- Highest-ever Q_d

Applications

- Medical implants
- Power conversion

Qi Compliance



- 3x lower loss in Rx
- PCB-based

Applications

- Mobile phones
- Laptops, tablets

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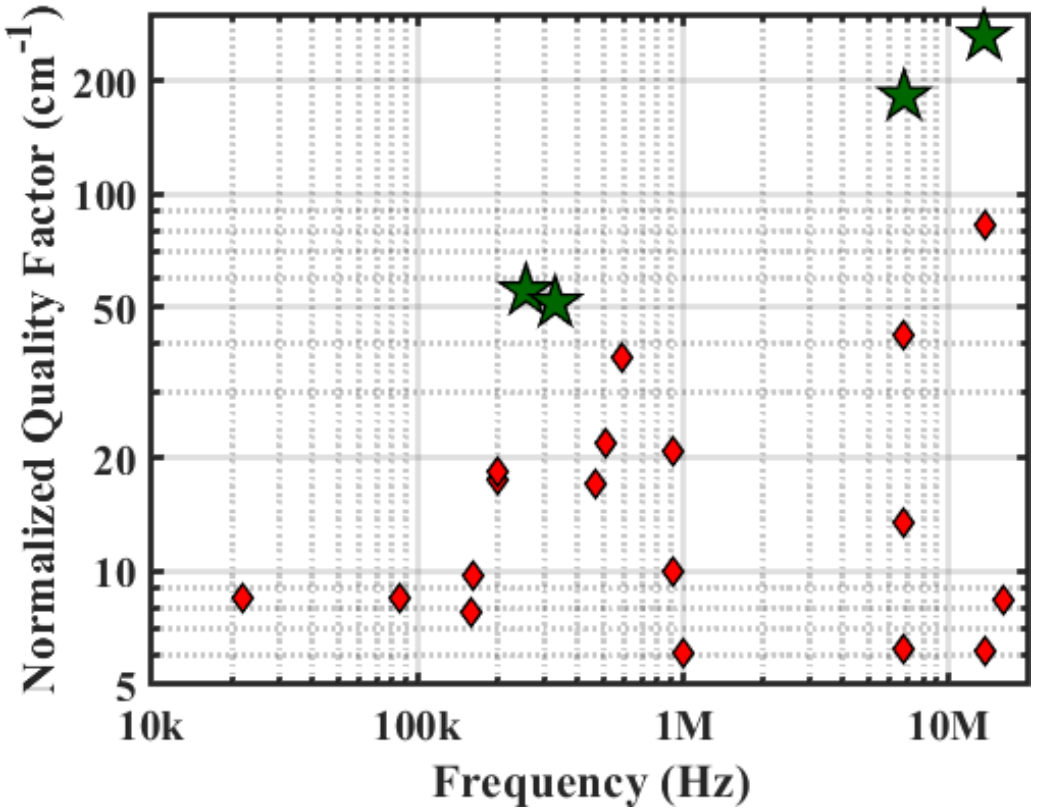
MSRS: High Performance for All Frequencies



Advantages

- Thin foils ($\ll \delta$) mitigates proximity effect
  - Lower loss → Higher quality factor
  - >3x higher Q_d across all frequencies
- Integrated capacitance
  - No localized heating of capacitors
    → Higher power capability
  - No high-voltage terminations
- Mass-manufacturing ready

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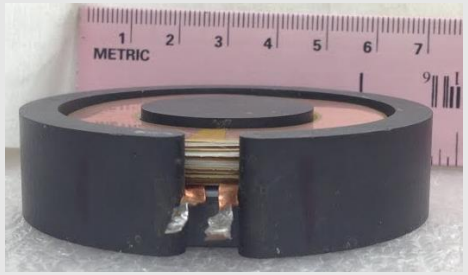
MSRS: High Performance for All Applications

High Power Density



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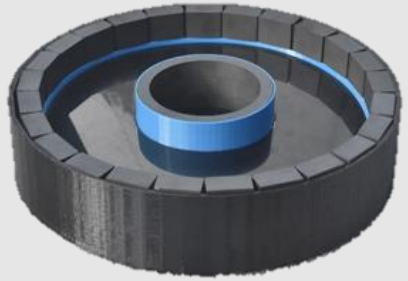
Low Frequency High Power



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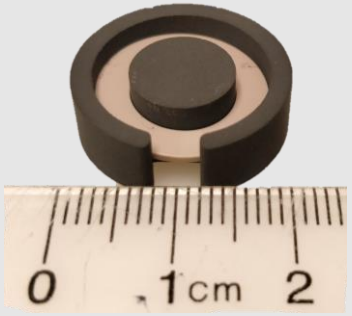

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- Highest-ever Q_d

Applications

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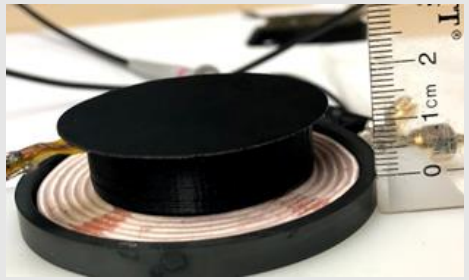
- Power conversion

Qi Compliance



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