

Wireless technology for next-generation implantables

TECHNICAL OVERVIEW



Resonant Link
Medical

| Powering the Future Within™

01 **WPT technology**

02 System components

03 Featured products

04 Summary

Medical device power is challenging

Constraints...

01 EN 45502-1 limits tissue temp rise

02 IEC 6060-1 limits skin safe touch temps

03 FCC Part 15 and 18 limit field strength

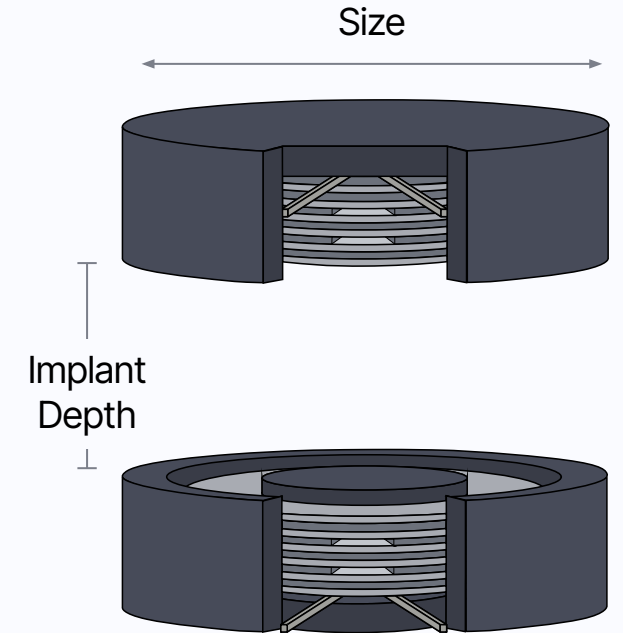
... determine key charging performance metrics:

01 Charge time and frequency

02 Implant size

03 Misalignment tolerance

04 Implant depth



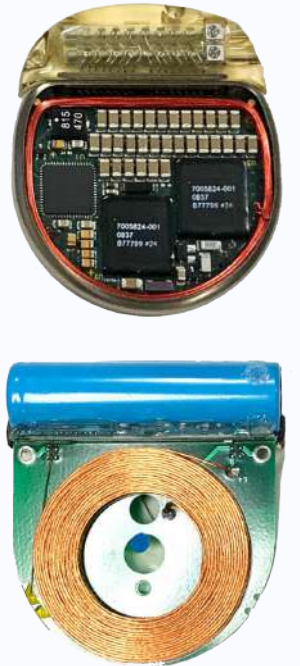
Patients and clinicians are demanding better charging

Drivelines and Primary Cell:

- 👎 High risk of infections and death
- 👎 Unnecessary replacement surgeries every 2-5 years
- 👎 Large, uncomfortable devices from big batteries

Conventional Wireless:

- 👎 Slow, hours-long recharging
- 👎 Charger must be precisely aligned
- 👎 Larger battery to compensate for low efficiency
- 👎 Shallow implant depth limits patient population



Conventional wireless is inefficient because AC distribution minimizes storage NOT loss

Fundamental WPT challenge is handling high AC without excessive loss

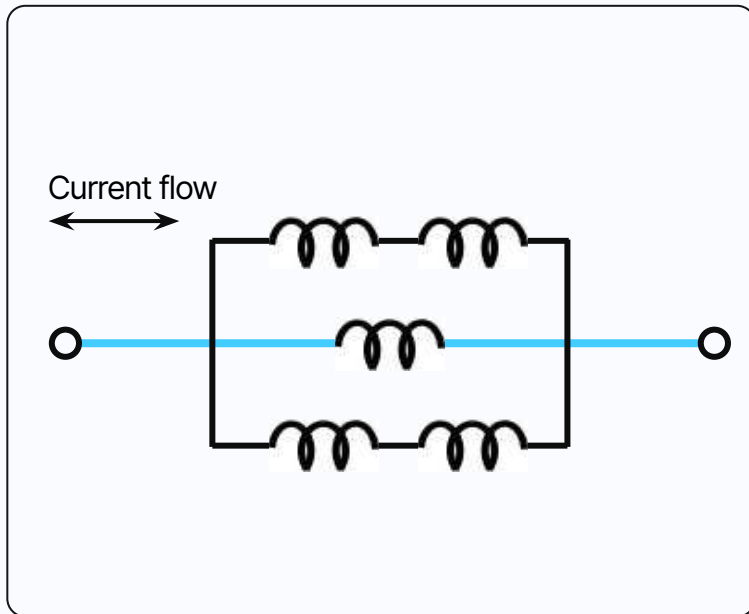
$$P_{\text{loss}} = i^2 R_{\text{ac}} \img alt="flame icon" data-bbox="735 255 775 337"/>$$

Performance Spec	Challenge	RL Differentiation
Implant Depth	<ul style="list-style-type: none">• Increase Tx coil current• Increase inverter current	> 2x
Misalignment Tolerance		> 2x
Implant Size	<ul style="list-style-type: none">• Increase Tx coil current• Increase inverter current• Decrease heat extraction	~1.5x
Recharge Time	<ul style="list-style-type: none">• Increase Rx coil current	5x

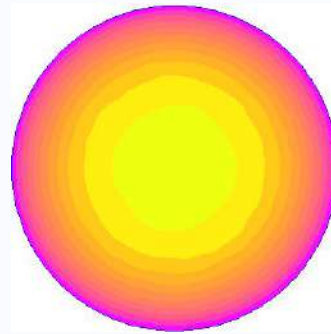
Paradox of AC distribution

The challenge

- 01 Current flows to minimize energy storage
- 02 Minimum energy storage is NOT minimum loss

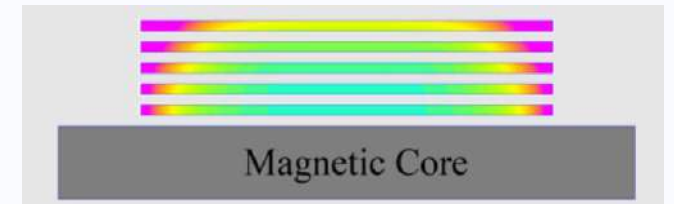


Round wire



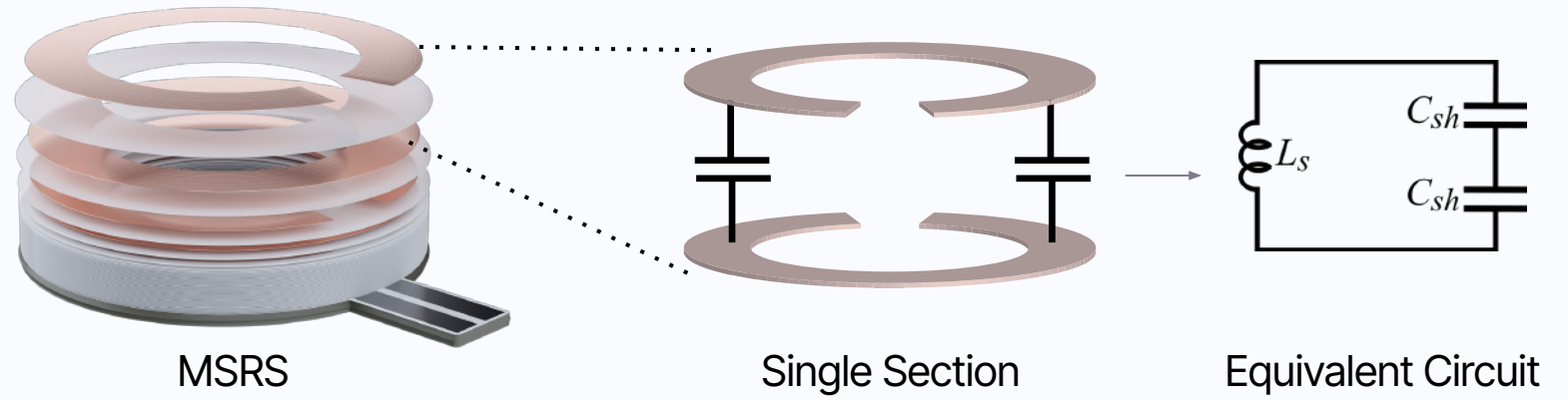
Current crowds on edge

Foil layers



Current crowds away from core and to the edges

MSRS: Operation principle



Integrated L +
C resonator → Compact

01 Current loop → Inductor

02 Displacement current → Capacitor

Main current
Conductor → Thin foils

01 Mitigate skin + proximity effect
Very high Q

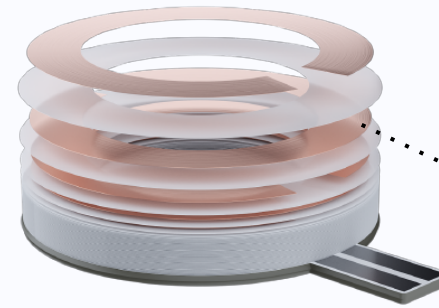
02 Inexpensive

High power
Handling

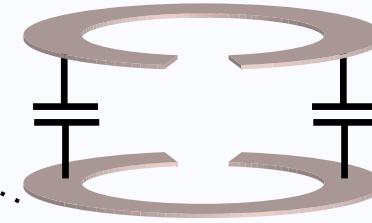
01 No localized heating
of capacitors

02 Terminations are
completely removed

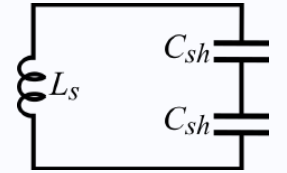
MSRS: Operation principle



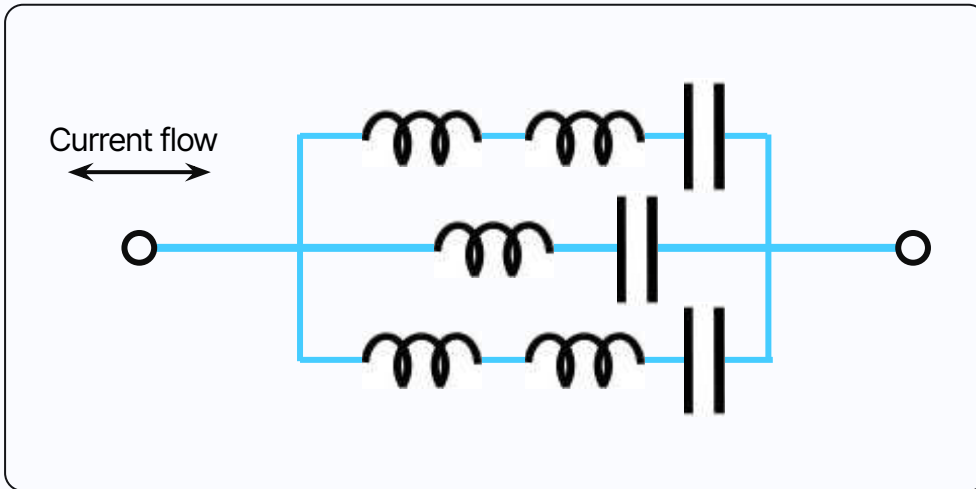
Multi-Layer Self-Resonant
Structure (MSRS)



Single Section



Equivalent Circuit



Breaks AC paradox

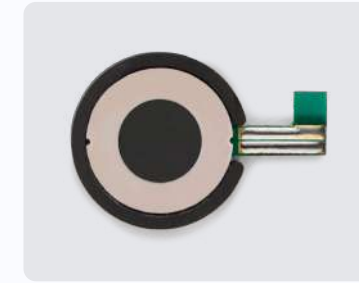
- Ø1 Integrated capacitance determines current distribution
- Ø2 Resonant Link can design current distribution for minimum loss

Conclusion: Up to 10x lower loss in coils

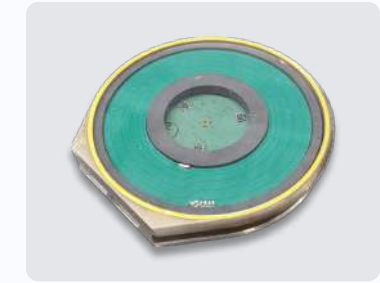
MSRS: Highest efficiency wireless power



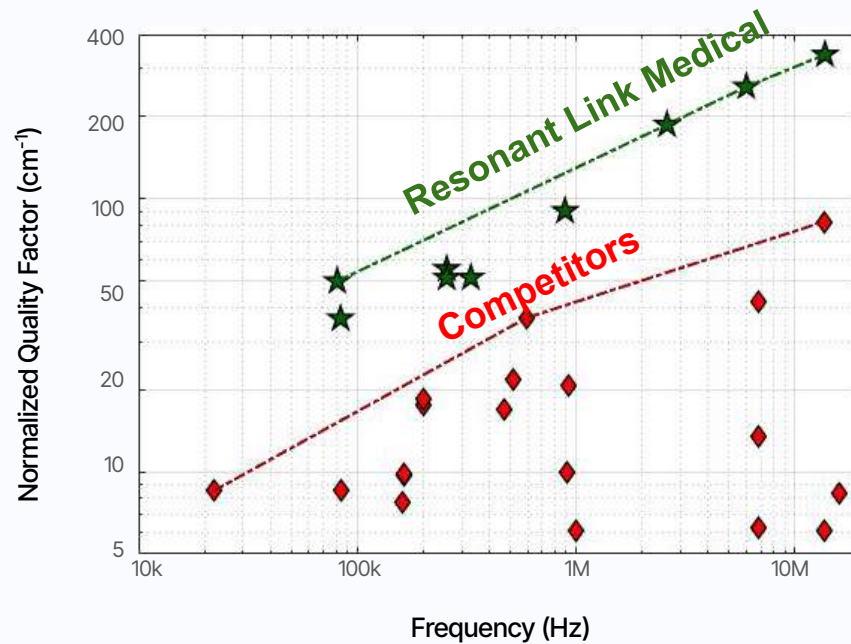
3 mm \varnothing



20 mm \varnothing



60 mm \varnothing



01 5-10x lower loss vs. conventional wireless →
Q of 1,699 @ 6.78 MHz

02 Platform technology breakthrough → highest efficiency
with unprecedented gap, misalignment, and power

03 Built with standard medical device manufacturing
processes and components

Aurion WPT™: The best implantable wireless power

The only technology platform combining patented innovations in coils, power electronics, magnetics, and data transfer for unprecedented performance and a lower-risk path to market.

MSRS™



Highest-performing coils with integrated capacitance for up to 10x lower losses.

Ultra-fast recharge.

LINQ™



Low-loss impedance network for seamless power integration, optimal manufacturability, and the greatest misalignment tolerance and implant depth.

Full power over an unprecedented range.

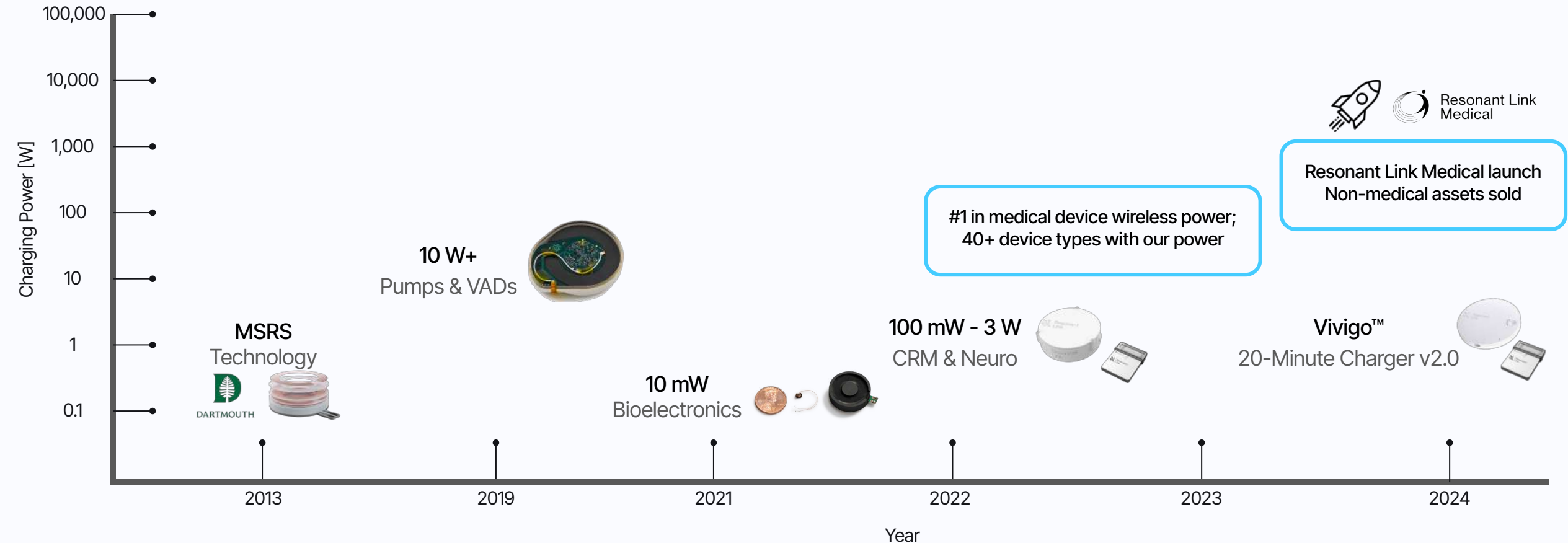
FALCON™



Fast, low-latency power-line-integrated communications and secure, bidirectional data transfer up to 160 kbps.

Reliable, uninterrupted power.

The partner of choice for implantable power, with a proven, expanding line of wireless chargers



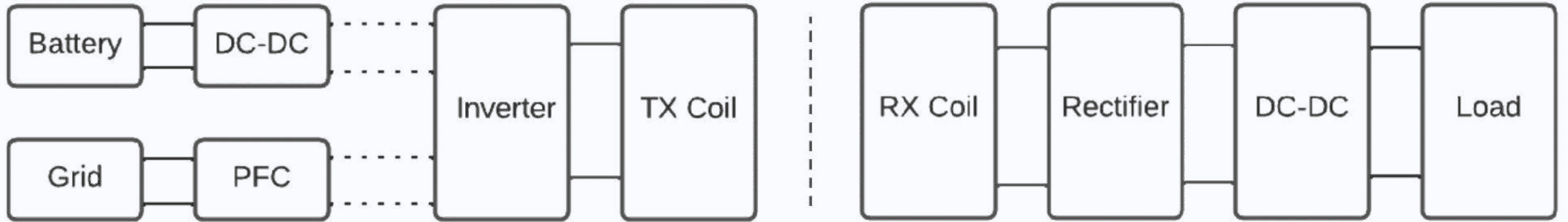
01 WPT technology

02 **System components**

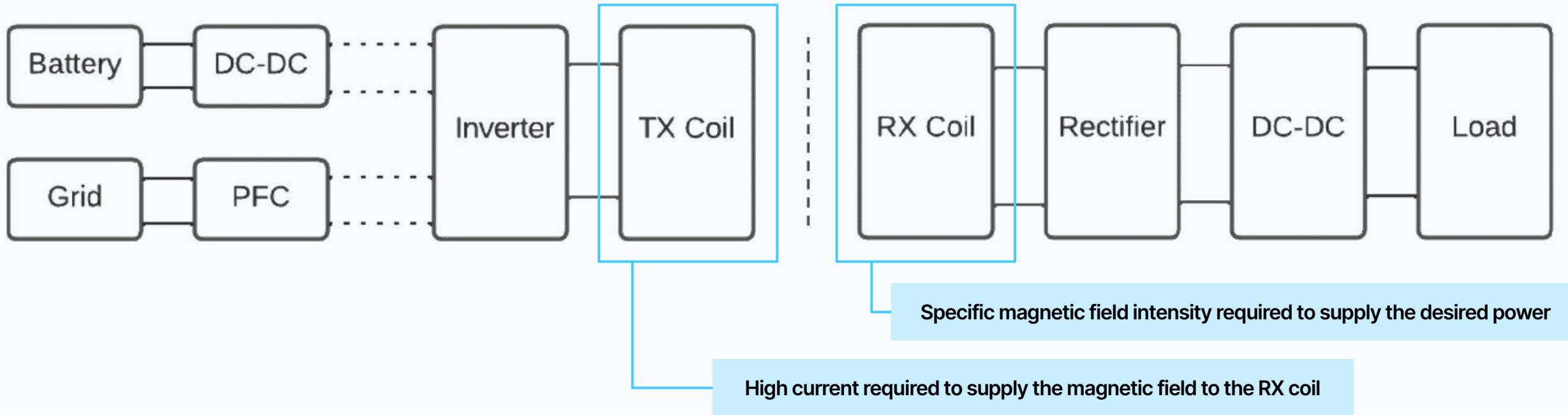
03 Featured products

04 Summary

Wireless power transfer system fundamentals



Wireless power transfer system fundamentals



Conclusion: High-power, long-range WPT requires very large high-frequency AC

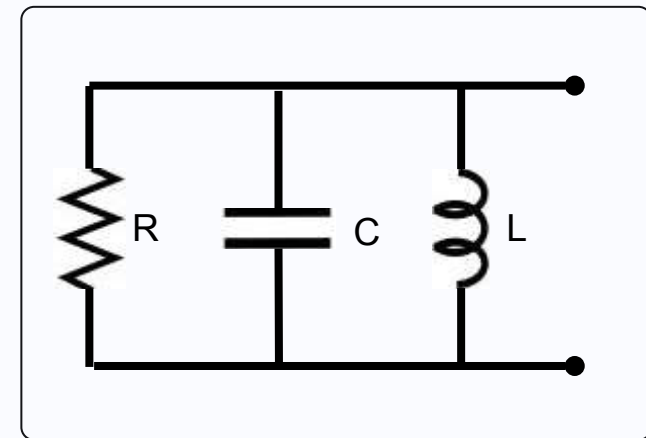
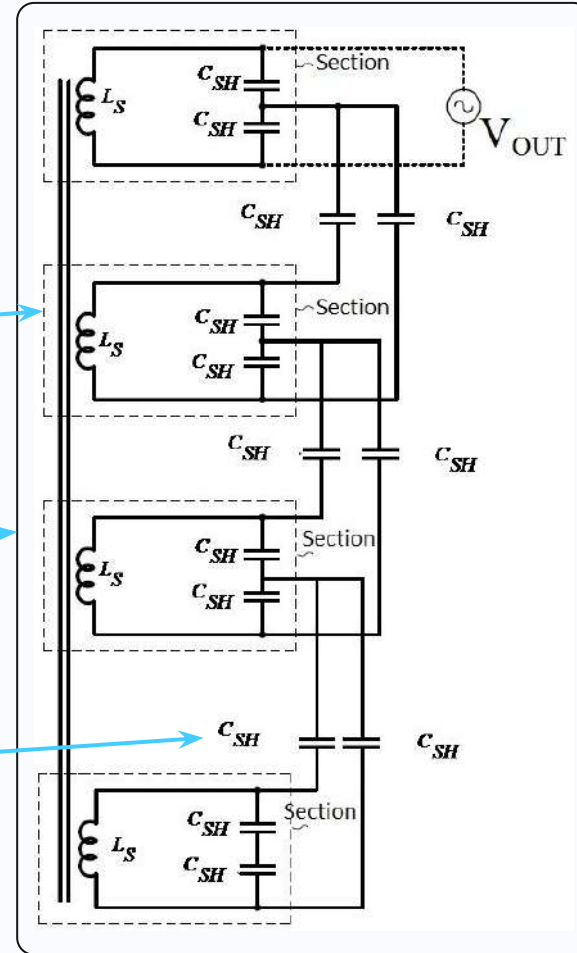
MSRS Circuit model

Pair of C-shaped conductors with excitation terminals

Each pair of C-shaped conductor layers

Magnetic core coupling all conductor layers

Integrated capacitance of the dielectric layers



Effective parallel resonant tank

MSRS Loss model

Loss mechanisms

- 01 Winding loss → 2D FEA + analytical calculation

$$R_{wind} \approx \frac{2\pi\rho}{\ln\left(\frac{r_2}{r_1}\right)t_c M} \left[k_1 F_{cc} + \frac{F_{fw} M^2}{9} \left(\frac{t_c}{\delta}\right)^4 k_2 \right]$$

- 02 Dielectric loss → Material performance metric

$$R_{dielectric} = \frac{D_d}{C_{equiv}\omega}$$

- 03 Magnetic core loss → Linear core loss

Wireless Power Transfer Utilizing a High- Q Self-Resonant Structure

Aaron L.F. Stein, Phyo Aung Kyaw, *Student Member IEEE*, and Charles R. Sullivan, *Fellow, IEEE*

Abstract—The range and efficiency of a wireless power transfer (WPT) system is limited by the quality factor of the resonant coils. Conventional resonant coils are made from solid or litz wire. At MHz frequencies solid wire is not utilized well due to skin effect, and litz wire is very lossy due to proximity effect. We present a multilayer self-resonant structure as a low-cost method for creating high- Q coils. This structure uses thin foil layers that are separated by a dielectric material in order to form an LC resonator, while also forcing equal current sharing between conductors. The self-resonant structure makes it feasible to achieve advantages similar to litz wire, but at multi-MHz frequencies where effective litz wire is not commercially available. These structures are made with foil layers much thinner than a skin depth, which can make handling these thin layers a challenge. To solve this problem, we also present a modified self-resonant structure in which the layered conductors are made with flex-PCB substrates with no vias. The PCB substrates provide a relatively inexpensive way to handle thin conductive layers, and the modified self-resonant structure ensures that the poor dielectric properties of the PCB substrates do not impact the quality factor of the structure. A prototype of the modified self-resonant structure has a quality factor of 1183 at 7.09 MHz, despite only being 6.6 cm in diameter, which is more than 6.5x larger than other coils presented in the literature with a similar diameter. An experimental WPT setup utilizing two self-resonant structures achieves 94% efficiency at a distance of 5.0 cm, which is more than twice the distance as similarly sized conventional coils can achieve while maintaining the same efficiency.

I. INTRODUCTION

Wireless power transfer (WPT) is of great interest for many applications including biomedical, automotive, and consumer hand-held electronics [1]–[4]. In many of these applications, a high-frequency magnetically-coupled resonant system is the most effective method of transmitting wireless power. The efficiency of such a system is limited by the quality factor and coupling factor of the resonant coils that generate the electromagnetic coupling [3], [5], [6]. As the range between the coils increases, the coupling factor decreases; therefore, improving the quality factor of the resonant coils is crucial for increasing the range and efficiency of WPT.

A conventional resonant coil consists of a spiral loop of wire connected to a ceramic or film capacitor. The quality factor of such a coil increases linearly with the diameter of the coil [7], [8]. So we propose a figure of merit Q_d , which is the ratio of the quality factor Q to the diameter d of the coil: $Q_d = \frac{Q}{d}$. Examples in the literature for high frequency coils

around 6.78 MHz report values for Q_d that range from 3 to 28 cm^{-1} [3], [9]–[13].

The Q_d of conventional coils is limited by three main factors. First, below 1 MHz, coils are typically made from litz wire in order to minimize losses due to skin and proximity effects. However, the benefit of using litz wire is limited in the MHz frequency range due to the need to have strand diameters much smaller than the skin depth. Such small strand diameters are either very expensive or not commercially available because they are difficult to manufacture [14]. Second, connections between the litz wire and the capacitors can also be problematic even in the kHz frequency range. Terminating litz wire with a large number of strands is difficult, and the benefit of the litz wire extends only to that point—connections between the capacitors and the litz wire are then solid conductors which are not effectively utilized at high frequencies, and can have eddy-current losses induced by the field of the coil. Finally, although ceramic or film capacitors can use foil or metalized film conductors much thinner than a skin depth, eddy currents can be induced in them depending on their orientation and proximity to the magnetic field produced by the coil. They can also suffer from proximity-effect losses arising from the current flow to them and in them.

In this work, we propose a new multi-layer self-resonant structure, illustrated in Fig. 1, that effectively utilizes thin foil conductors and a low-loss dielectric to create a high- Q resonant coil [15]. This structure consists of alternating layers of C-shape foil conductors and dielectric rings placed in a ferrite core, and forms a parallel resonator in a single component. This integration of capacitance and inductance is similar to the integrated LC and LCT (inductor, capacitor, transformer) passive power components discussed in, for example, [16]–[18]. However, unlike the previous work, multi-layer self-resonant structures use the capacitance not only to implement the necessary capacitance, but also to make the conductors more efficient by equalizing current sharing between them. As a result, they not only provide a parts-count savings through integration, but also provide a dramatic performance benefit. A structure similar to the multi-layer self-resonant structure is reported in [19], but insufficient detail is provided to assess its true capability. In particular, the inductance calculation assumes all the flux is in the magnetic material, resulting in major discrepancy in the calculated versus experimental inductance. No proximity effect losses are considered in the analysis and an appropriate measurement methodology for the Q value is not reported.

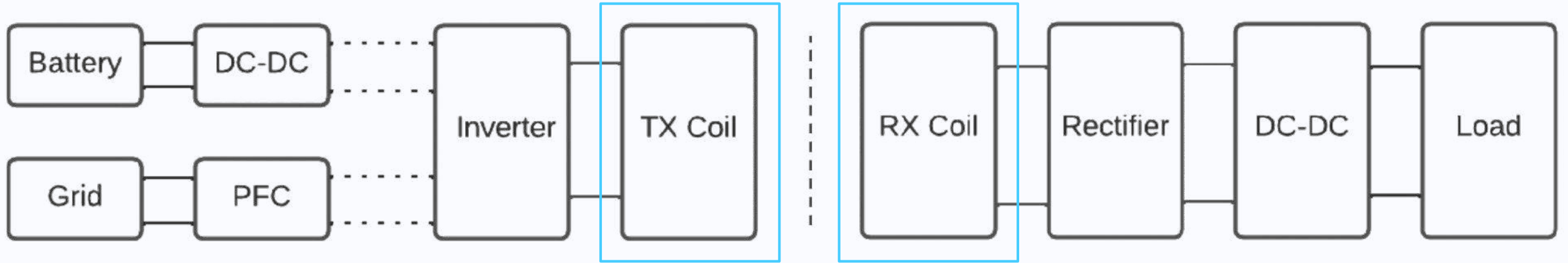
Thin foil layers are vital for the performance of the self-resonant structure, but can make prototyping difficult. To overcome this concern, we also propose a variation of the self-resonant structure that allows fabrication with more con-

⁰This work was supported by the National Science Foundation under Grant Number 1507773.

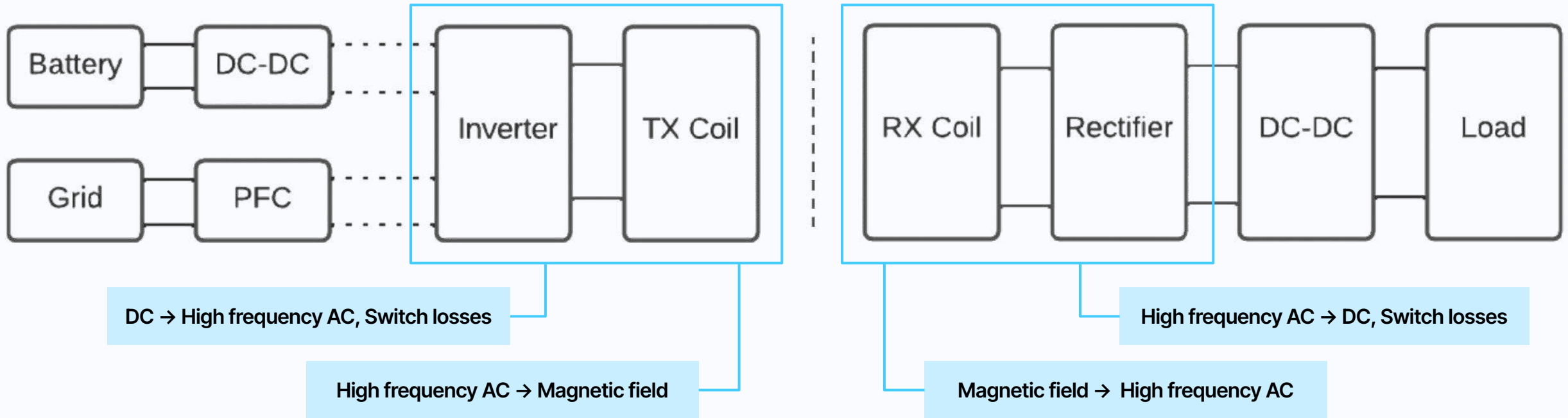
The authors are with the Thayer School of Engineering, Dartmouth College, Hanover, NH 03755 USA (e-mail: Aaron.L.Stein@dartmouth.edu; Phyo.A.Kyaw.th@dartmouth.edu; Charles.R.Sullivan@dartmouth.edu)

Color versions of one or more of the figures in this paper are available online at <http://ieeexplore.ieee.org>.

Wireless power transfer system fundamentals



Wireless power transfer system fundamentals

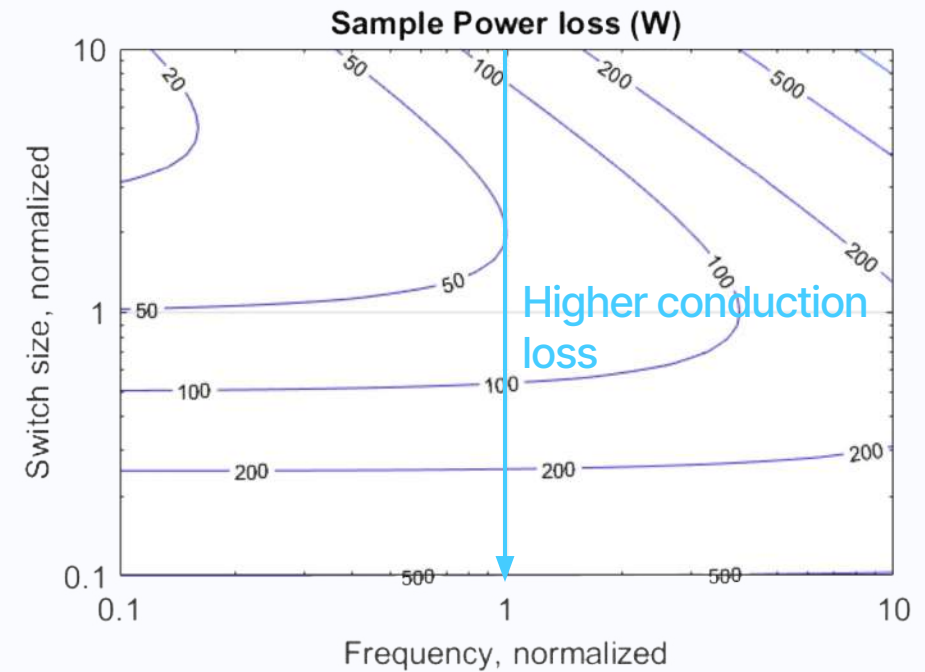
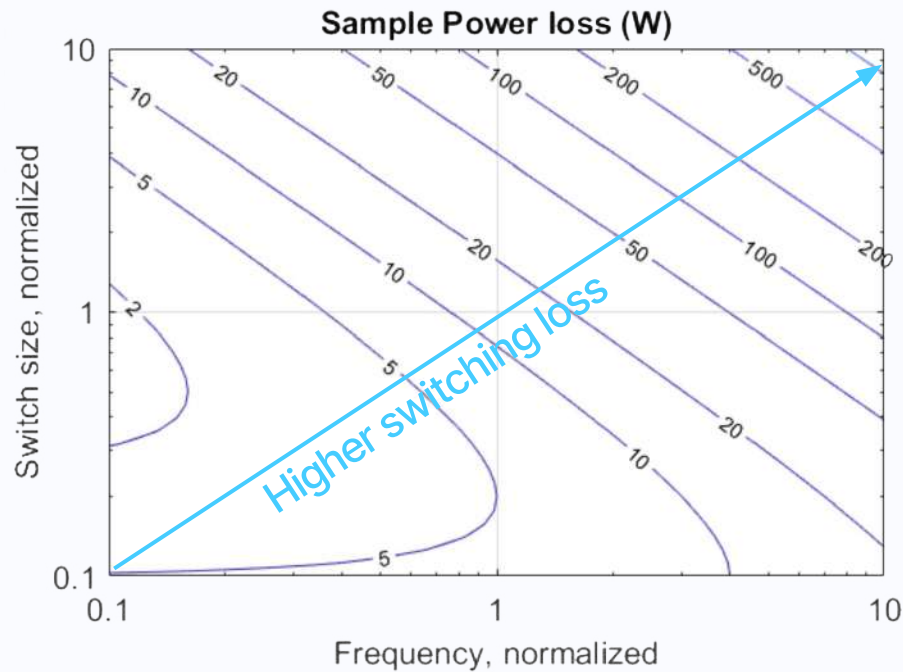


Conclusion: High performance requires optimization across the system

Losses in power electronics

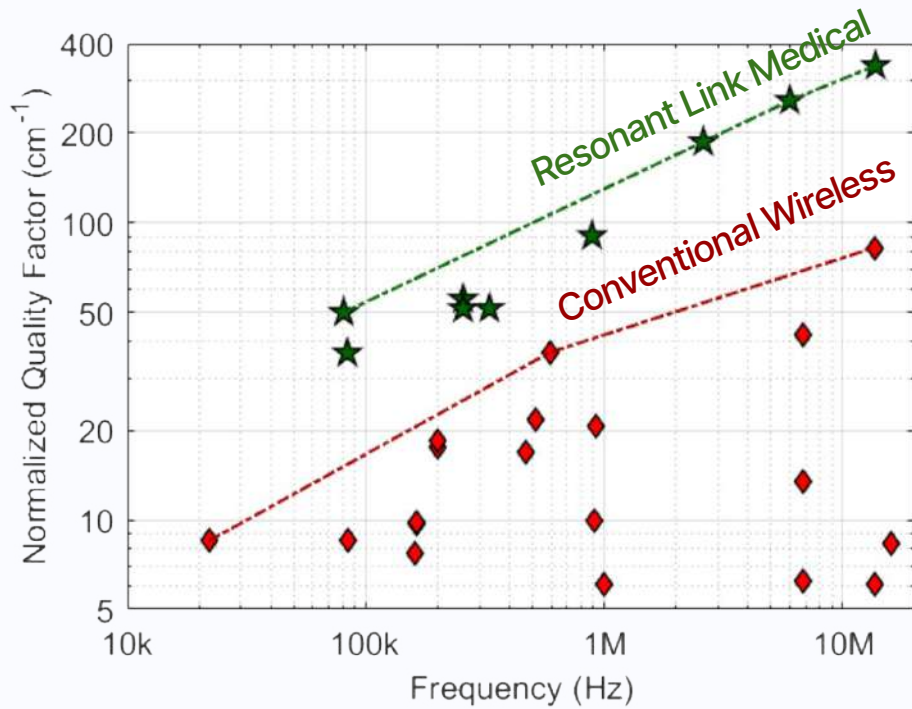
Power switch losses: Switching vs. conduction losses

$$P_{sw} = \frac{1}{2} C_{sw} V^2 f_{sw} + I_{rms}^2 R_{ds,on}$$

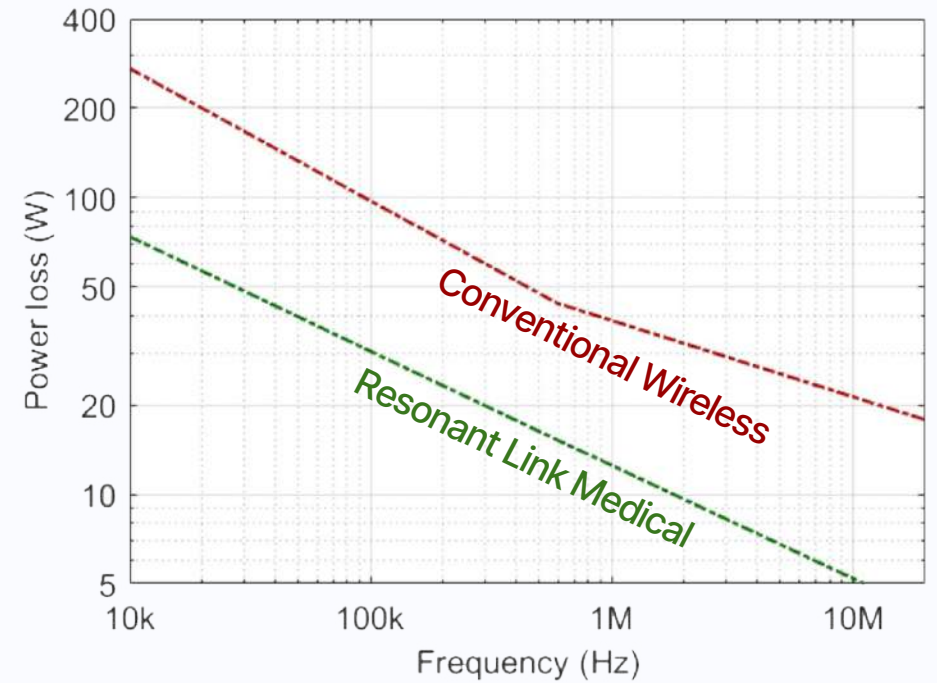


10x higher current

Losses in wireless power coils



For fixed coupling and output power



WPT system total loss

Optimum design

ø1 Frequency

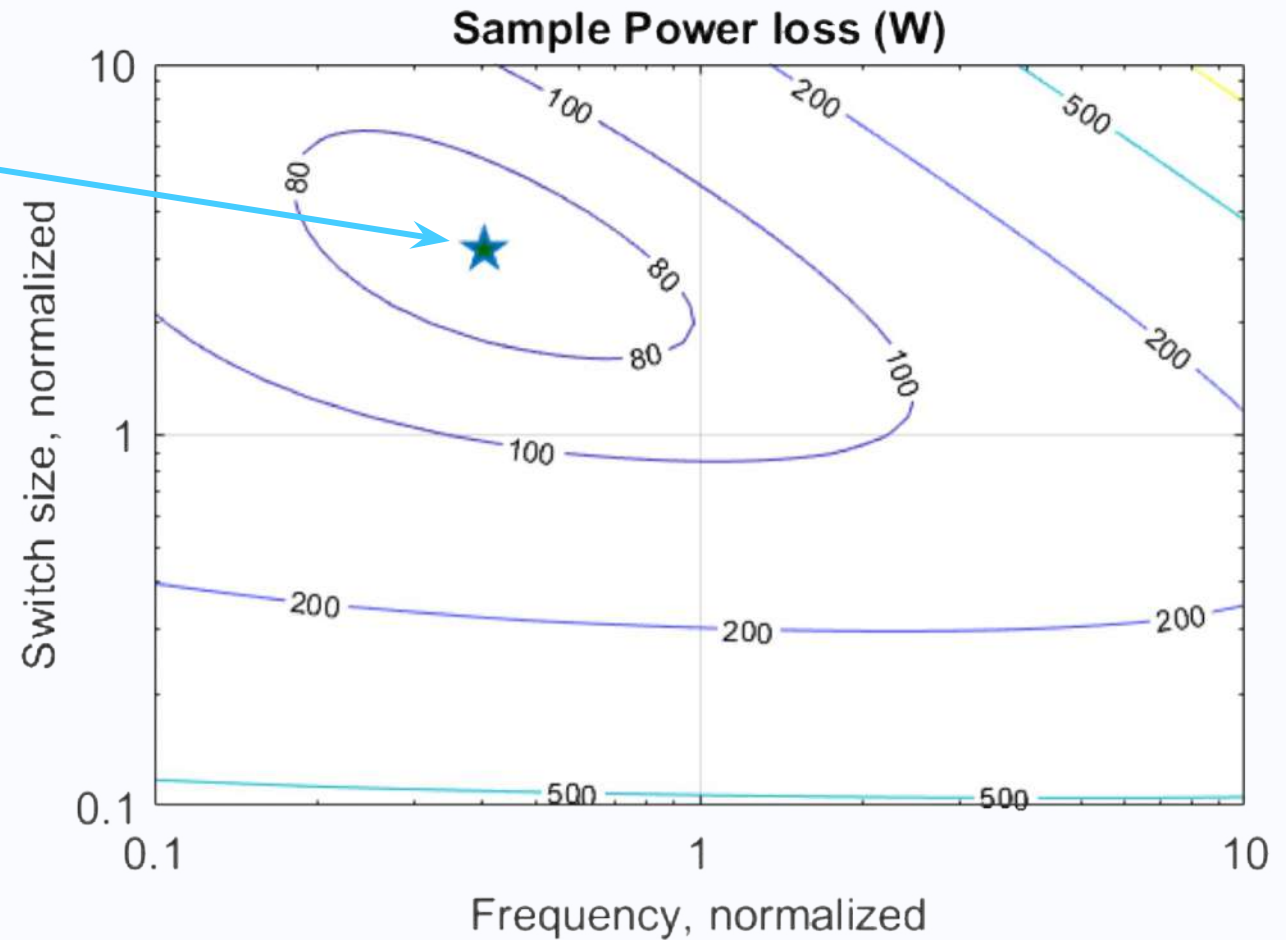
ø2 Switch size

For fixed

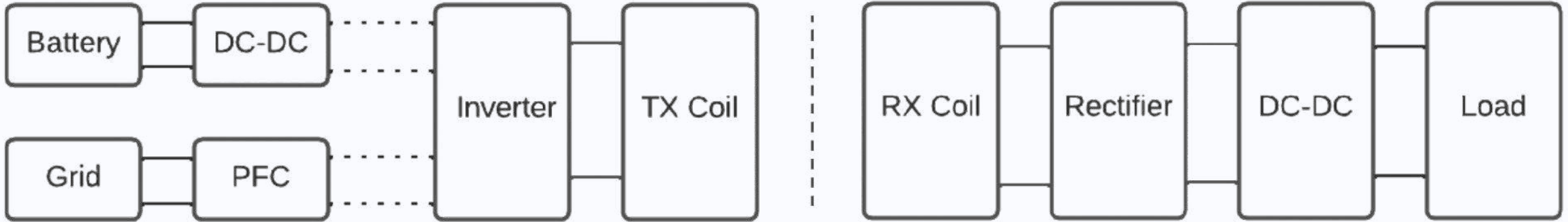
ø1 Current, voltage

ø2 Coil size

ø3 Coupling



Eliminating stages to improve performance



More stages → higher loss, larger volume, higher cost

01 Eliminate stages to improve efficiency and size

02 Optimize remaining stages to perform function of the eliminated stage and to mitigate any adverse impacts

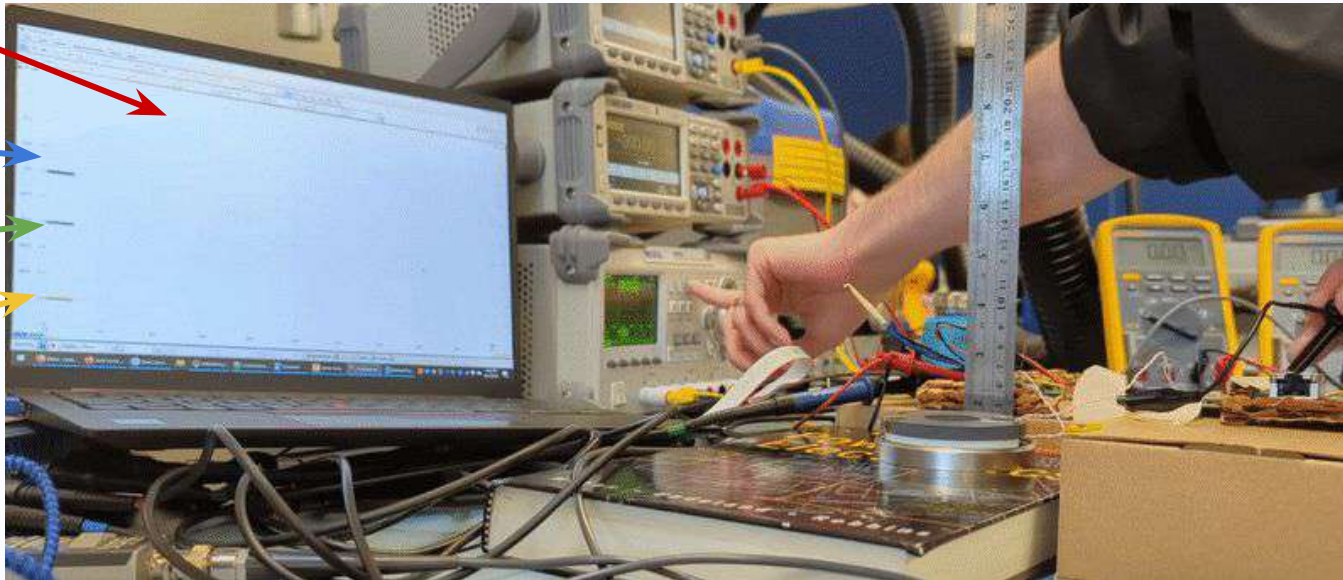
Falcon™: Control via telemetry over wireless power link

Output voltage

Input voltage

Inbound data

Outbound data



Stable output regardless of

- 01 Air gap
- 02 Misalignment
- 03 Movement and vibration

Resonant Link Medical's Aurion WPT™ technology platform is optimized for key performance specs

01 Coil innovations

- a. Low-loss resonant tanks
- b. Integrated impedance matching

02 System innovations

- a. Low-latency telemetry
- b. Co-packaging coils, circuits, and metal packagings
- c. Eliminating stages

03 Fundamental modeling

- a. Power switch modeling and selection
- b. Electromagnetics modeling and simulations
- c. Performance trends vs. optimization parameters



01 WPT technology

02 System components

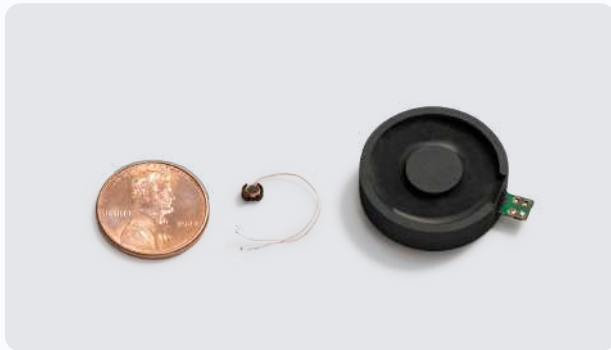
03 **Featured products**

04 Summary

Technology that improves patient compliance, satisfaction, and adoption

Make charging an asset, not a hurdle to your device's success.

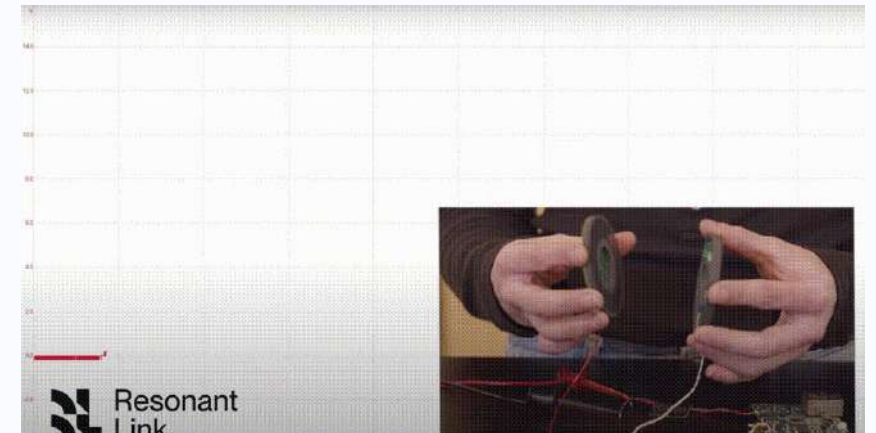
Coils as small as 3 mm



Seamless power delivery








Controls that adapt instantly for uninterrupted communication



Product Platforms accelerate development

Show your device works and get to market sooner with our pre-compliant platforms:

-  Proven performance for implantables
-  Simple GUI for easy use
-  Customized for your implant
-  Fully integrated into your device in months, not years
-  Demonstration systems available today for validation and basic integration



Eterni™

Up to 500 mW of wireless power for tiny implants with or without batteries.



Vivigo™

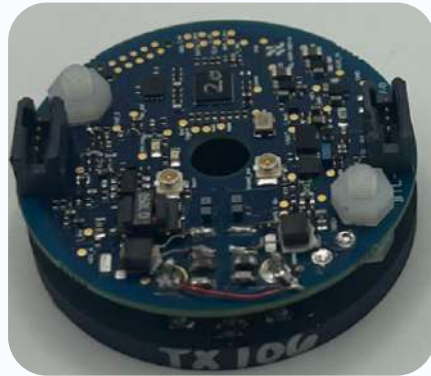
20-minute wireless charging over a large range to improve patient compliance and drive adoption.



Cardessa™

15 W of driveline-free power to enhance patient mobility, therapy adherence, and outcomes.

Eterni™: Miniaturized Power Platform



Specification	Value
Output Power	500 mW rechargeable device (100 mW passive device)
External Hub Size	<20 grams (excluding battery), 40 mm diameter x <14 mm height
Implant Dimensions	10-20 mm diameter 0.5-1 mm thick coils
Max. Implant Depth	25 mm
Max. Misalignment	± 25 mm, up to 20° tilt
Implant PCB Space	35 mm ² , 70 mm ² (inc. MCU)
Operating Frequency	6.78 MHz
Tissue Temperature Rise	1.8°C

Vivigo™: 20-Minute Universal Charger

The fastest and easiest charging



You define:

- IPG coil size, case material
- IPG battery, delivered power

We deliver:

Integrated hardware in 6 months

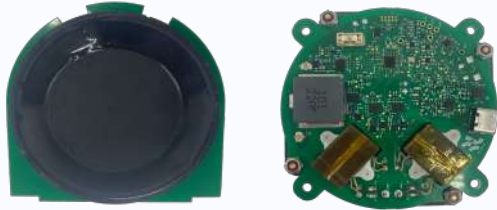
Specification	Value	Differentiation
Max. Output Power	2.5 W, over entire spec'd spatial freedom	5x
Max. Implant Depth	4-6 cm	2x
Misalignment	± 3 cm, up to 30° tilt	2x
Compliance	Pre-certified for IEC 60601, ISO 14708, and FCC Part 15 and 18	
External Hub Size	220 grams 109 mm diameter x 20 mm height	
API	USBC engineering interface Bluetooth API for App development UI includes visual and audio alignment, status feedback, and more	
Implant PCB Space	100-150 mm ²	
Integrated Communication	Bidirectional at 8 kb/s	
MRI Conditional	1.5T, 3T for implant	

Demonstrator systems available soon!

[Datasheet](#) | [Video Demo](#)

Cardessa™: High Power Platform

Fully implanted VADs, TAHs, and drug delivery pumps are now a reality



You define:

- Output voltage, power
- IPG battery, delivered power

We deliver:

Integrated hardware in 6 months

Specification	Value	Differentiation
Output Power	10 W continuous, 15 W for 120 minutes	5x
Input Voltage	12-18 V	
Tissue Temperature	< 3°C at 15 W for 120 minutes < 2°C at 10 W for steady state Compliant with ISO 14708	
External Dimensions	80 mm diameter x 19.2 mm height Coil and power electronics included	1.2x
Implant Dimensions	60 mm diameter x 8 mm height Coil and power electronics included	1.2x
Implant Case	Non-conductive window larger > 60 mm diameter	
Implant Depth	1-3 cm	2x
Misalignment	± 3 cm misalignment , up to 20° tilt	2x
Data Throughput	5 kb/s unidirectional from transmitter to receiver	

Demonstrator systems available

[Datasheet](#)

Proprietary tools for implantable power

Know what works before you build with our modeling and design tools, and our Opportunity Study feasibility analysis.



BioPWR™

Quickly identify wireless power feasibility and constraints

with our verified, in-situ modeling tool that combines bioenergetic, thermal, magnetic, and electrical domains.



BioPRD™

Learn the best way to build your wireless power system

optimize for performance, manufacturability, and supply chain needs with our all-in-one design tool.

Opportunity Study feasibility analysis frames what's possible in a clear, replicable plan

Know before you build

Constrain product decisions with verified modeling of

- Tissue temp, SAR, and efficiency
- EMI (CISPR 11, FCC, IEC)

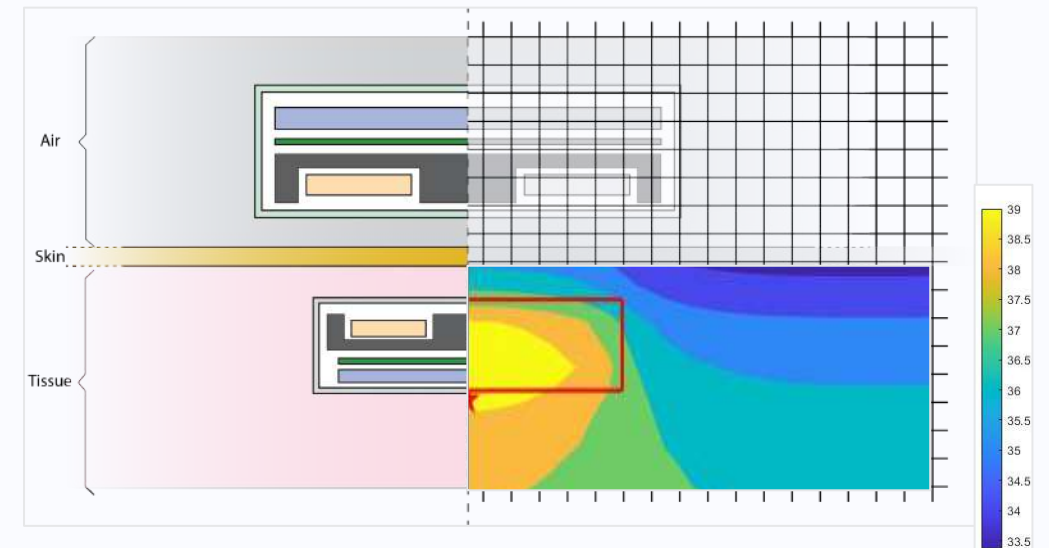
Trade off key product parameters

Enclosure design, size, spatial freedom, power, etc.

Key Deliverables:

- Eliminate infeasible design → best possible specs to guide product decisions
- Power Roadmap → clear EMI-compliant prototype delivery plan
- RLM delivers in one design iteration, everytime

First-of-its-kind BIOPWR™ tool combines bioenergetic, thermal, magnetic, and electrical domains.



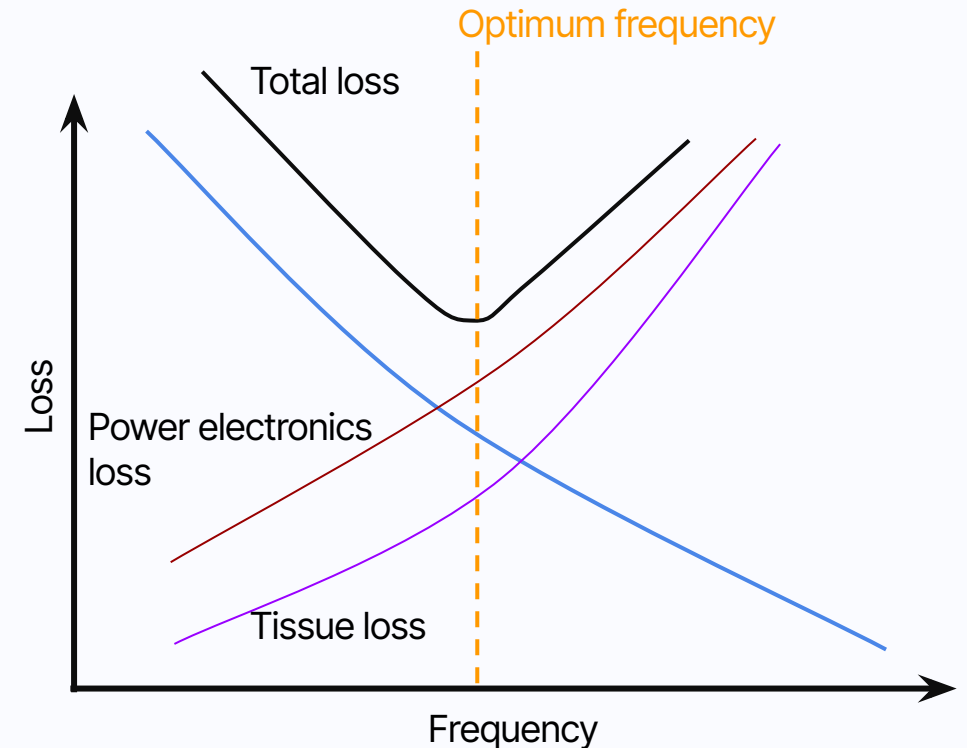
Falcon™: Control via telemetry over wireless power link

Tissue loss induced by WPT electromagnetic field

01 Tissue electrical conductivity → path for eddy current

02 Electrical conductivity depends on tissue type, e.g. muscle is more conductive than fat

02 BioPWR™ and BioPRD™ were built specifically to optimize for implantable power

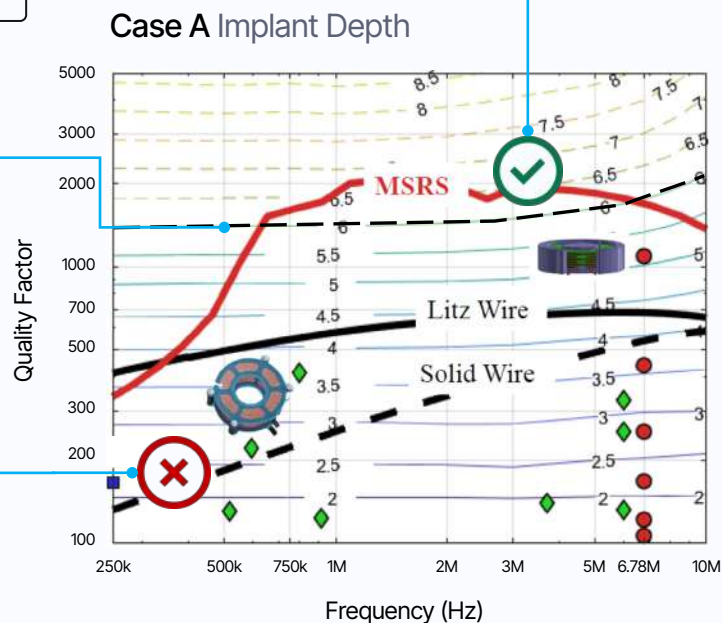


Case study: Failed wireless power program for high-power implantable

Path to <2 °C w/ MSRS

Coupling equiv.
for max gap + mis.

Impossible \$10M+,
2 years, 5x too hot



Started: Infeasible design, tissue temp. 5x too hot

Opportunity study identified

- 01 Excessive loss in coil and enclosure
- 02 Ineffective operating frequency chosen
- 03 Conventional coils could not deliver specs

Program defined: Path to <2 °C

- 01 MSRS coils @ 3.3 MHz with enclosure mods

Key Specifications

Value

Implant depth	1-4 cm
Misalignment	+/- 2.5 cm
Output power	10 W cont.
Tx size	9 cm x 8 mm
Rx size	7 cm x 6 mm

01 WPT technology

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03 Featured products

04 **Summary**

Summary

01 **A platform technology** that enables wireless power for a wide range of applications

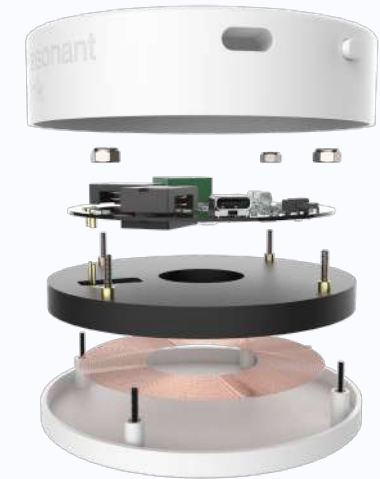
02 System optimization using implantable-specific modeling and design tools unlocks **unparalleled performance**

- a. WPT <> Magnetics <> Thermals in a single solver tool
- b. Eliminating output DC-DC

03 Higher operating frequency provides **significant advantages**, especially for novel devices



▲ 20 mW Medical Device Charger



▲ 10-15 W High Power Platform for Implantable Devices

Let's
change lives,
together



Resonant Link
Medical

| Powering the Future Within™