



# EV Wireless Charging

The Next Generation of High Efficiency Charging

# Electric Vehicles are BEAUTIFUL



... but charging cords are ugly and vulnerable!

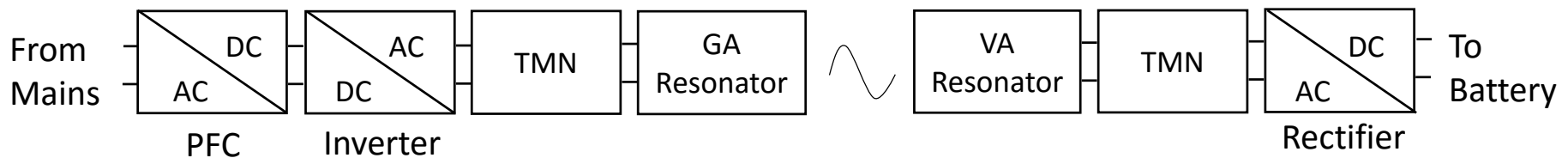


Plug In ?

# What is WiTricity?

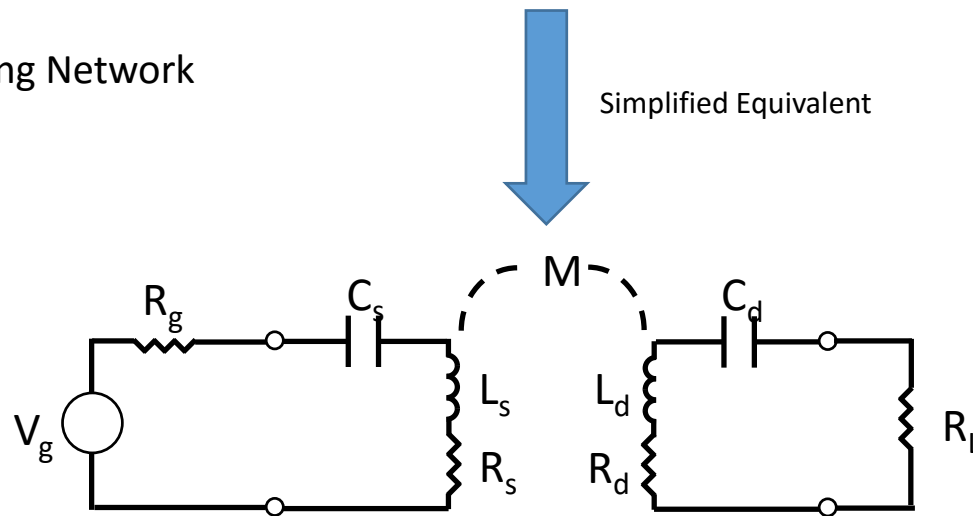
- WiTricity is wireless electricity
  - Enabled through Highly Resonant Wireless Power Transfer (HRWPT)

EV Wireless Charger Block Diagram

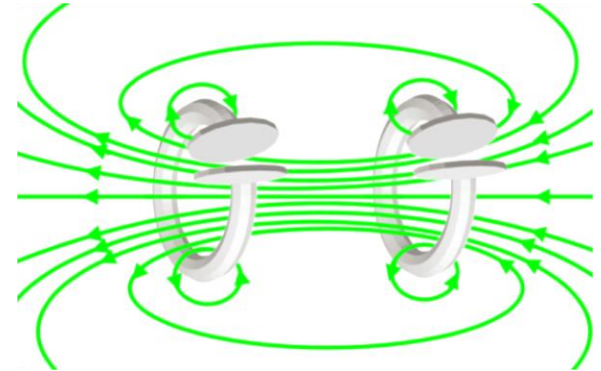
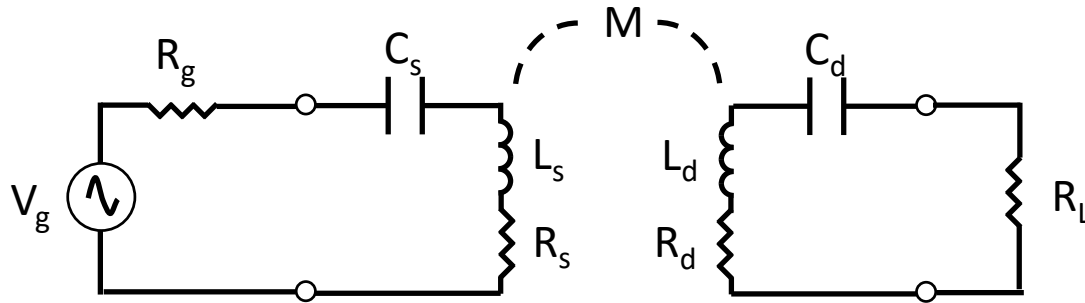


- TMN – Tunable Matching Network
- GA – Ground Assembly
- VA – Vehicle Assembly

Simplified Equivalent



# HRWPT Coupled Mode Theory



Coupling Coefficient:

$$k = \frac{M}{\sqrt{L_s L_d}}$$

Perturbed Quality Factors:

$$Q_s = \frac{\omega L_s}{R_s}$$

$$Q_d = \frac{\omega L_d}{R_d}$$

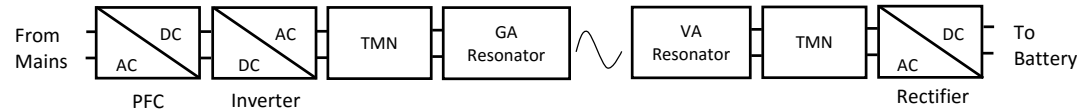
Optimal coil-to-coil efficiency is:

$$\eta_{opt} = \frac{U^2}{(1 + \sqrt{1 + U^2})^2}$$

Where  $U = \frac{\omega M}{\sqrt{R_s R_d}} = k \sqrt{Q_s Q_d}$

\* A Tunable Matching Network (TMN) is used to transform actual load impedance to operate at optimal efficiency across coupling and load variations

# EV Wireless Charging: A New Generation



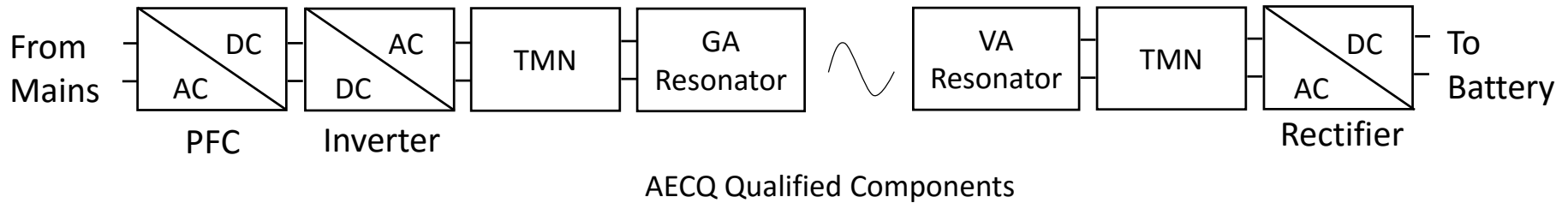
## Key Features and Benefits

- Compliant to SAE J2954 (in draft)
- Up to WPT3 (11.1 kW input) power level direct to battery
- Compatible with existing WPT1 (3.7 kW input) & WPT2 (7.7kW input) systems
- Standards compatible circular resonator design
- Single Phase 240V AC wall input, 85kHz RF operating frequency
- FOD processing supporting all modes (charging, no car present, car present but not charging)
- Additional design allowances for higher power (liquid cooling, amp size, etc.)

## Key Performance Indicators (KPIs)

- **92%-94% end-end efficiency**
- **WPT1, WPT2, WPT3, & Scalable (3.7 kW to 11.1 kW input power and scalable upward)**
- **Full power @ high efficiency over entire X,Y,Z range**
  - **9-25 cm Z range**
  - **± 15 cm lateral, ± 7.5 cm fore-aft**
- **SAE J2954 Z1-Z3 (10 cm - 25 cm) & WPT1-3 Interoperable**
- **Capable of “in ground” source install with no change in performance metrics**

# Features of Electronic System Blocks



## PFC

- High AC-DC Efficiency > 98%
- Power Factor > 0.995 @ Full Load

## Inverter

- High Power Density / High Efficiency Integrated into GA Resonator
- COTS Standard TO-247 Switches

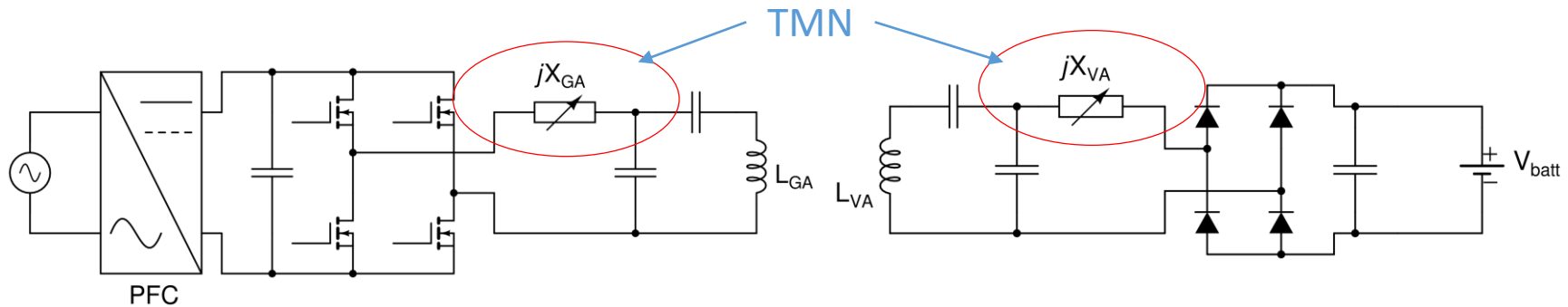
## TMN

- Improves System Efficiency, Range, and Robustness
- Fast settling times < 100 ms

## Rectifier

- High Efficiency Si Rectifier
- Designed for Low di/dT Stress and High Reliability

# Design Topology & TMN Benefits



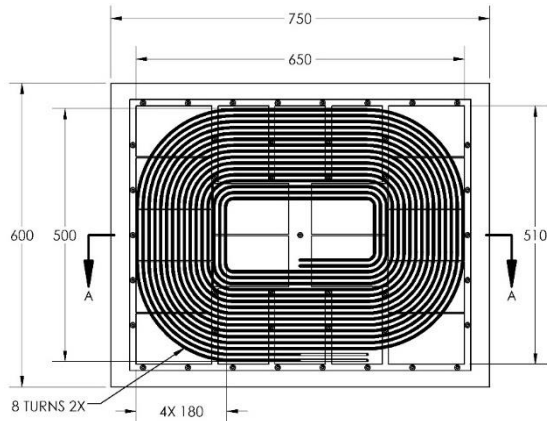
## VA Benefits:

- Coil-to-coil efficiency can be maximized at each XYZ offset
- Limit on power dissipated in device coil can be accommodated
- Complete interoperability between coil classes (Z1 - Z3, WPT1 - WPT3)
- Benefits of post-rectifier DC-DC converter, but with higher efficiency, lower component count, and lower cost
- Allows for use of standard 5% tolerance matching components

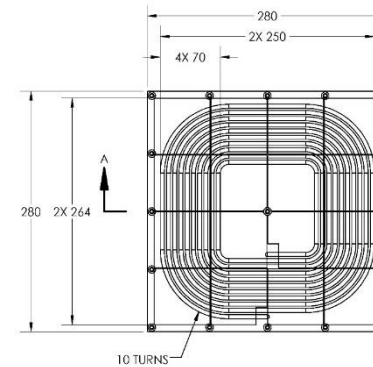
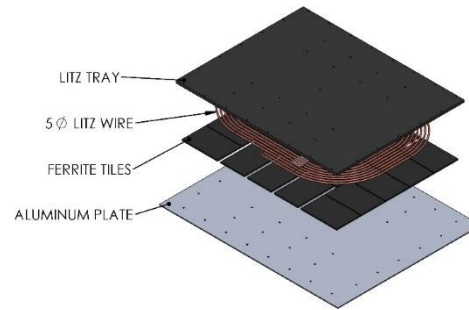
## GA Benefits:

- Enables inverter & PFC to operate at high efficiency, minimum  $A_{RMS}$
- Improved handling of GA resonator detuning
- Allows power throttling down to 100's of Watts
- Allows for use of standard 5% tolerance matching components

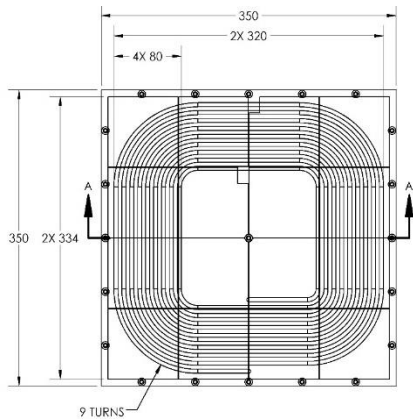
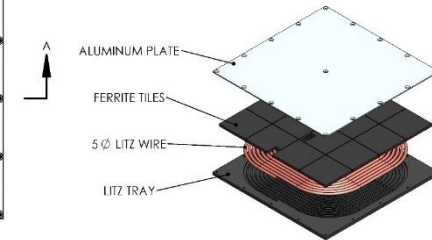
# WPT2 GA and VA Resonators



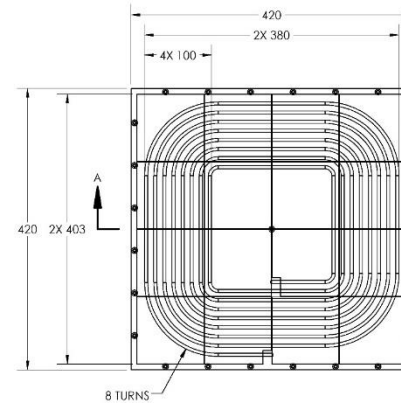
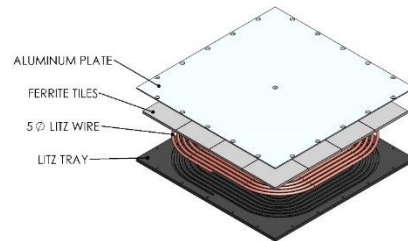
GA Resonator: 600 mm X 750 mm



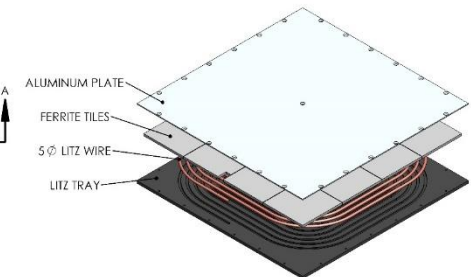
WPT2 / Z1 VA Resonator: 280 mm X 280 mm



WPT2 / Z2 VA Resonator: 350 mm X 350 mm



WPT2 / Z3 VA Resonator: 420 mm X 420 mm

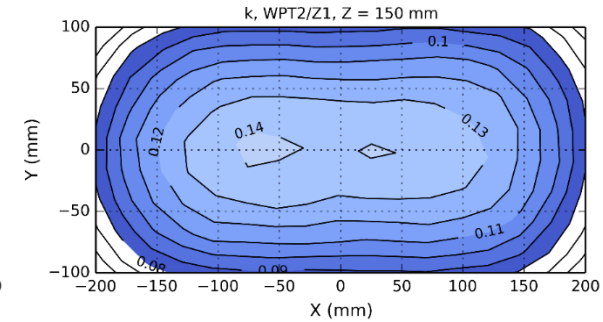
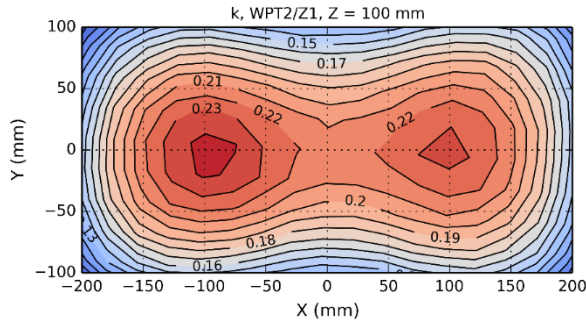




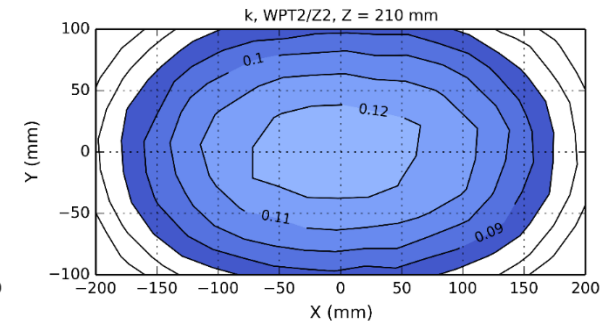
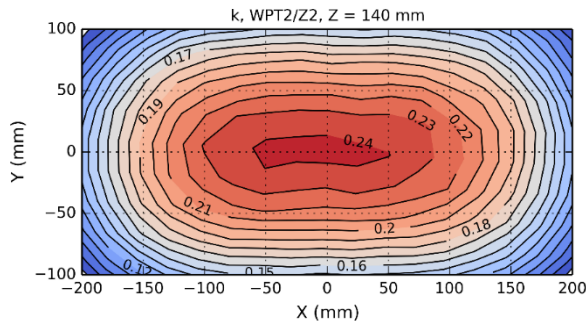
WPT2 → 7.7 kW Input

# Magnetic Performance (Measured Parameters)

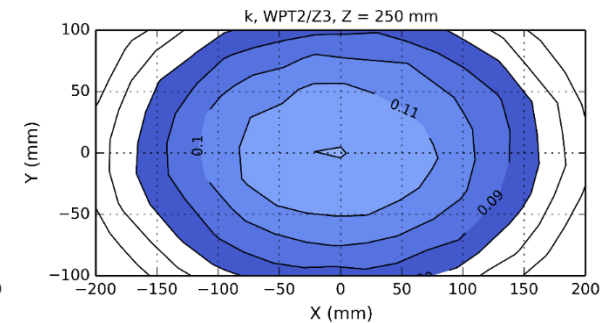
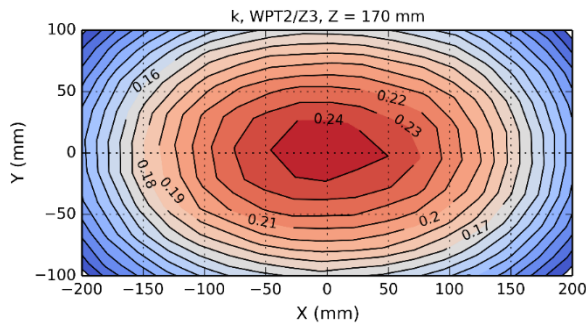
Z1: 100 mm - 150 mm



Z2: 140 mm - 210 mm



Z3: 170 mm - 250 mm



97.1% - 98.2% Coupling Efficiency

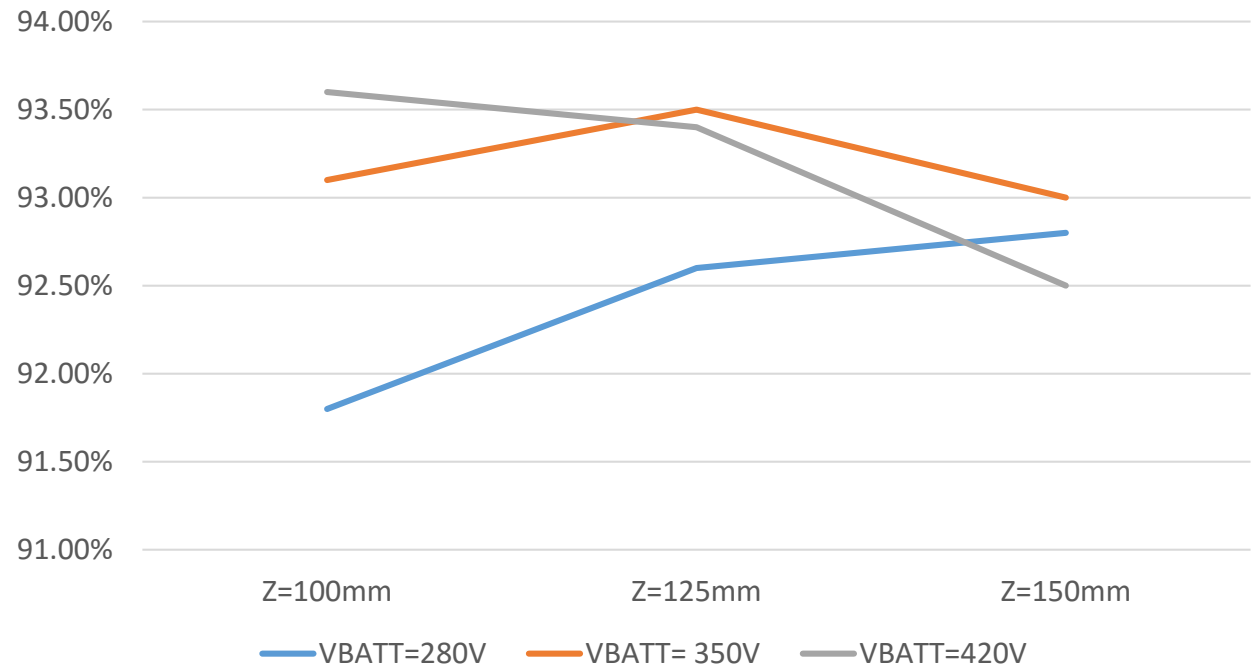
97.0% - 98.7% Coupling Efficiency

96.9% - 98.8% Coupling Efficiency

# Measured WPT2 / Z1 Efficiency

Z (mm)	X (mm)	Y (mm)	V <sub>batt</sub> (V)	Efficiency (%)
100	0	0	280	91.0
			350	92.6
			420	93.4
100	100	0	280	91.8
			350	93.0
			420	93.6
100	0	75	280	91.1
			350	92.7
			420	93.3
100	100	75	280	91.7
			350	93.1
			420	93.5
125	0	0	280	92.4
			350	93.5
			420	93.4
125	100	0	280	92.6
			350	93.5
			420	93.2
125	0	75	280	92.5
			350	92.9
			420	92.6
125	100	75	280	92.6
			350	93.1
			420	92.6
150	0	0	280	92.8
			350	93.0
			420	92.5
150	100	0	280	92.6
			350	92.7
			420	92.0
150	0	75	280	91.7
			350	91.9
			420	92.3
150	100	75	280	91.8
			350	91.8
			420	91.0

Max End-to-End Efficiency Over Battery Voltage and Position



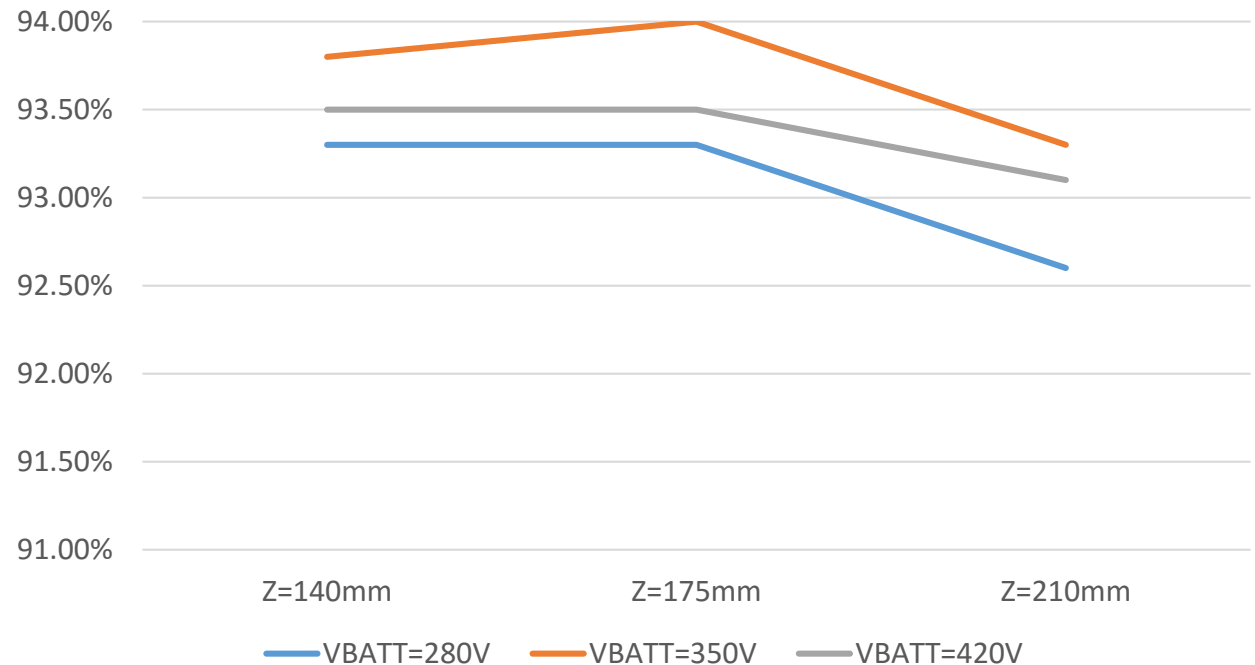
**\*91.0% – 93.6%** Efficiency Over All Z1 Ranges and Battery Voltages

\*Includes all auxiliary power required for operation / communication

# Measured WPT2 / Z2 Efficiency

Z (mm)	X (mm)	Y (mm)	V <sub>batt</sub> (V)	Efficiency (%)
140	0	0	280	93.0
			350	93.7
			420	93.1
140	100	0	280	93.3
			350	93.7
			420	93.0
140	0	75	280	93.1
			350	93.8
			420	93.5
140	100	75	280	92.9
			350	93.8
			420	93.4
175	0	0	280	93.3
			350	94.0
			420	93.5
175	100	0	280	93.0
			350	93.7
			420	93.4
175	0	75	280	92.9
			350	93.7
			420	93.4
175	100	75	280	92.5
			350	93.3
			420	93.2
210	0	0	280	92.6
			350	93.4
			420	93.1
210	100	0	280	92.2
			350	93.0
			420	92.5
210	0	75	280	91.9
			350	93.3
			420	92.4
210	100	75	280	91.2
			350	92.0
			420	91.5

Max End-to-End Efficiency Over Battery Voltage and Position



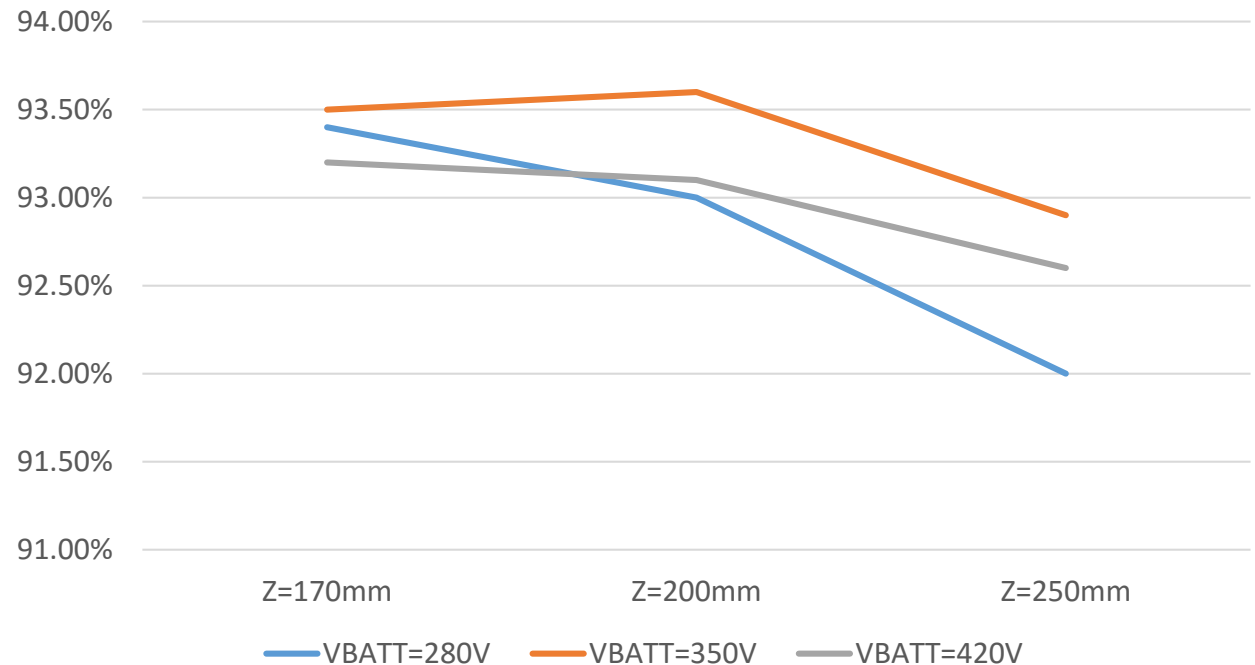
**\*91.2% – 94.0%** Efficiency Over All Z2 Ranges and Battery Voltages

\*Includes all auxiliary power required for operation / communication

# Measured WPT2 / Z3 Efficiency

Z (mm)	X (mm)	Y (mm)	V <sub>batt</sub> (V)	Efficiency (%)
170	0	0	280	93.4
			350	93.4
			420	92.9
170	100	0	280	93.0
			350	93.4
			420	92.9
170	0	75	280	92.9
			350	93.5
			420	93.2
170	100	75	280	92.8
			350	93.4
			420	93.1
200	0	0	280	93.0
			350	93.6
			420	93.1
200	100	0	280	92.8
			350	93.6
			420	93.1
200	0	75	280	92.8
			350	93.4
			420	93.1
200	100	75	280	92.4
			350	93.2
			420	92.9
250	0	0	280	92.0
			350	92.9
			420	92.6
250	100	0	280	91.5
			350	92.1
			420	91.7
250	0	75	280	91.4
			350	92.1
			420	92.0
250	100	75	280	91.4
			350	91.7
			420	91.1

Max End-to-End Efficiency Over Battery Voltage and Position



**\*91.1% – 93.6%** Efficiency Over All Z3 Ranges and Battery Voltages

\*Includes all auxiliary power required for operation / communication

# Questions?

- ✓ Fundamental IP for Wireless Power over Distance
- ✓ Over 350 Patents and Patent applications worldwide
- ✓ 137 Patents Issued as of May 2016

## Published Patents in **Key Countries**

