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# V072819_02

## RF Exposure Testing Results

## For

## WiTricity Halo™ PV Wireless Power Transfer System

## For

## Golf Carts and Neighborhood Electric Vehicles

| | |
|---|---|
| **Equipment Under Test** | GWL1300 and VWL1300 |
| **Date of Test** | February 09, 2024 |
| **Report Issue Date** | March 08, 2024 |

| **Test Specifications:** | **Applicant:** |
|---|---|
| KDB 680106 D01 Wireless Power Transfer v04 | WiTricity Corporation<br>57 Water Street<br>Watertown, MA 02472<br>U.S.A. |

# 1 Summary of Results

VPI has reviewed the FCC's guidance for testing of Wireless Power Transfer (WPT) systems in KDB 680106 (publication date: October 24, 2023) and its attachment "680106 D01 Wireless Power Transfer v04" (publication date: October 24, 2023). VPI also reviewed WiTricity's EMF Test Procedure (incorporated as an attachment) for the proposed wireless power product and finds the procedure is in accordance with FCC's guidelines. The WiTricity test procedures were followed to collect the data presented.

Pursuant to the FCC's guidance in the aforementioned publications, a reference limit of 90 A/m is established as a baseline for determining the Pass / Fail criteria of each set of tests. All measurements were performed with a calibrated Narda ELT-400 magnetic field meter with a 3-axis field probe using 100 $cm^2$ loops; except where noted, measurements with a 3-axis probe having 3 $cm^2$ loops were also performed.

## 1.1 On-vehicle Testing

### 1.1.1 Vehicle Perimeter and Edge

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 5.63 A/m (7.08 µT) | Passenger Side, Center, Vehicle | PASS |

### 1.1.2 Vehicle Underside

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 25.89 A/m (32.54 µT) | Passenger Side, Center, Vehicle | PASS |

### 1.1.3 Vehicle Floor

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 3.81 A/m (4.79 µT) | Center Floor, Rear | PASS |
| 90 A/m (113.10 µT) | 10.23 A/m (12.86 µT) | Center Floor 3 $cm^2$ probe | PASS |

#### 1.1.4 Vehicle Seats

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 0.22 A/m (0.28 µT) | Front Driver Seat | PASS |

## 1.2 Standby Mode Testing

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 24.49 A/m (30.78 µT) | Center Power Hub | PASS |

## 1.3 Off-vehicle Testing

#### 1.3.1 Four Sides: Maximum Height and Offset / Minimum Coupling

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 50.77 A/m (63.8 µT) | Front | PASS |

#### 1.3.2 Top: Maximum Height and Offset / Minimum Coupling

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 36.61 A/m (46.00 µT) | Diagonal Offset | PASS |
| 90 A/m (113.10 µT) | 70.43 A/m (88.51 µT) | Diagonal Offset 3 $cm^2$ Probe | PASS |

#### 1.3.3 Four Sides: Minimum Height and Offset / Maximum Coupling

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 10.57 A/m (13.28 µT) | Center, Passenger Side | PASS |

#### 1.3.4 Top: Minimum Height and Offset / Maximum Coupling

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 18.30 A/m (23.00 µT) | Offset Across | PASS |

### 1.3.5 Four Sides: Nominal Height / Nominal Coupling

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 13.41 A/m (16.85 µT) | Center, Driver Side | PASS |

### 1.3.6 Top: Nominal Height / Nominal Coupling

| Limit | Max Value | Location | PASS / FAIL |
|---|---|---|---|
| 90 A/m (113.10 µT) | 18.89 A/m (23.74 µT) | Top, Off Receiver | PASS |

# 2 Measurement Equipment and Methods

VPI utilized a calibrated Narda ELT-400 Field Meter for all Electromagnetic Field (EMF) measurements performed. The field meter is capable of reading up to 400 kHz. The frequency of operation of the WPT system under test was verified to be a fixed frequency of 85 kHz, which falls easily within the capabilities of the Narda ELT-400 meter.


Calibrated Narda ELT-400 Meter and Probe Utilized for Testing

## 2.1 Magnetic Field Measurement Units

The Narda ELT-400 gives field strength values in micro-Tesla. Given that all measurements were performed with the open-air probe in open air, the field levels are converted from B Field to H Field using the following formula: $H = \frac{B}{\mu_0}$, where $\mu_0 = 4\pi \times 10^{-7}$.

## 2.2 Operation of Narda ELT-400 Instrument

The field meter contains two different attachable probes. All probes consist of 3 internal loops each orthogonal to each other to measure the total magnitude of the B-Field ($|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$). The larger attachable probe that was used for most of the testing has internal loop areas of 100 cm$^2$ (internal loop radius, $r = \sqrt{\frac{100}{\pi}} \cong 5.64\ cm$). The outer protective shell of the 100 cm$^2$ probe has a diameter of 12.5 cm (radius = 6.25 cm). An alternative smaller probe has its internal loop areas set to 3 cm$^2$ (internal loop radius, $r = \sqrt{\frac{3}{\pi}} \cong 0.977\ cm$). The small probe outer shell diameter is 3.2 cm (radius = 1.6 cm).

The following settings were used on the Narda ELT-400 meter:

- Mode = 320 µT
- Range = High
- Detection = RMS
- Display mode = Both Instantaneous & Max Hold values measured
- Cutoff = 30 Hz

# *3 Data Visualization*

Prior to testing, the setup distances described in WiTricity's test procedure were validated to ensure that the center of the probe was always used as the reference location. Additionally, it was validated that the distance from the probe center any part of the WPT system was always ≤ 20 cm. In many cases, the distance was much less than 20 cm for conservancy.

The raw field data can be found in Section 4, *Appendix of Raw Data Collected*. All measurements were taken by hand using grid markings to help position the probe to a relative accuracy of approximately ± 5mm; however, the grid spacing used for off-vehicle testing was less than the internal radius of the probe's loops. The field levels are visualized to give spatial acuity with finer detail using bilinear interpolation (without affecting the actual localized maximums). In the cases where a different pattern was used, the field levels are visualized as relative spots. In all cases, the color of the heatmaps are set with the local relative maximum for best field gradient visualization.

## *3.1 On-vehicle Testing*

For on-vehicle testing, WiTricity provided a cardboard template that set the position between the wheel-guide and the Power Hub precisely. These were temporarily secured in place for the remainder of the on-vehicle testing.

Multiple attempts were made to maneuver the vehicle into a position with as much misalignment of the vehicle to the wheel guide that still resulted in the vehicle charging. After multiple attempts, the offset between the center of the Receiver and Power Hub were measured as follows:

- Offset in Direction of Travel: 2 cm
- Offset Side-to-Side: 4 cm

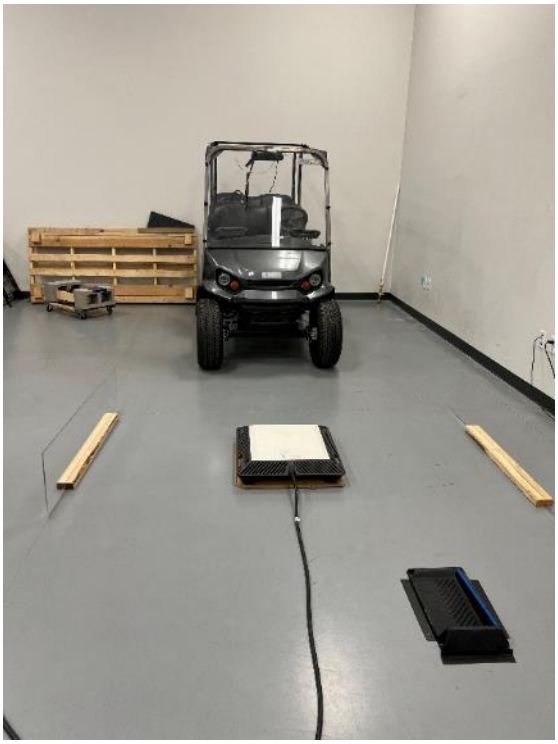
The Receiver Height was also measured as follows:

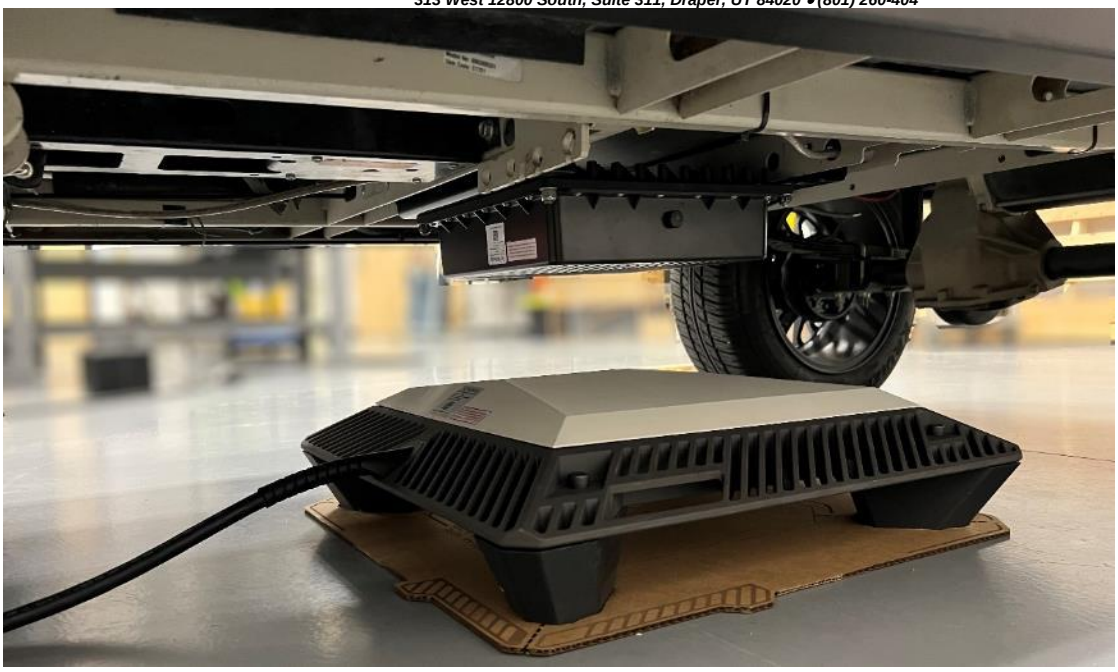
- Ground to Bottom of Receiver: 26 cm

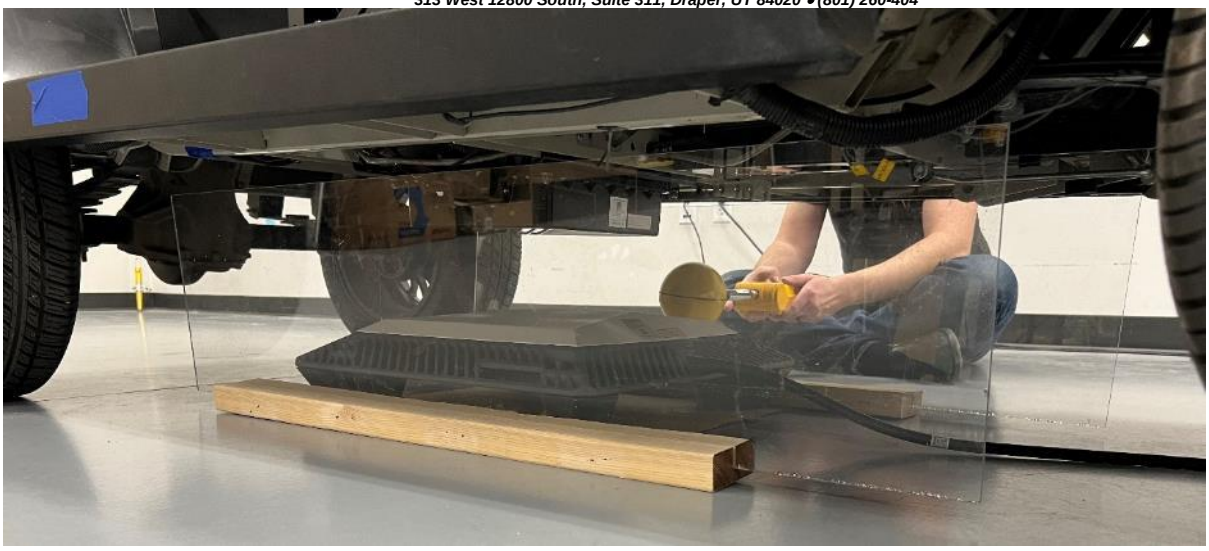
However, the Power Hub was raised with risers 7 cm, thus resulting in a distance of 19 cm between the metal base of the Power Hub and the bottom of the Receiver. From an internal inspection of the Power Hub's coil (which sits at 6 cm above the metal base of the Power Hub), this results in a distance of about 13 cm from the Power Hub Coil to the bottom of the Receiver.

To confirm that all measurements were taken with the WPT system active and charging at maximum power to the battery, the vehicle state-of-charge (SOC) was confirmed to be 45% when testing began and resulted in a final SOC of 65% when all testing was complete.

### 3.1.1 Measurement and Setup Images

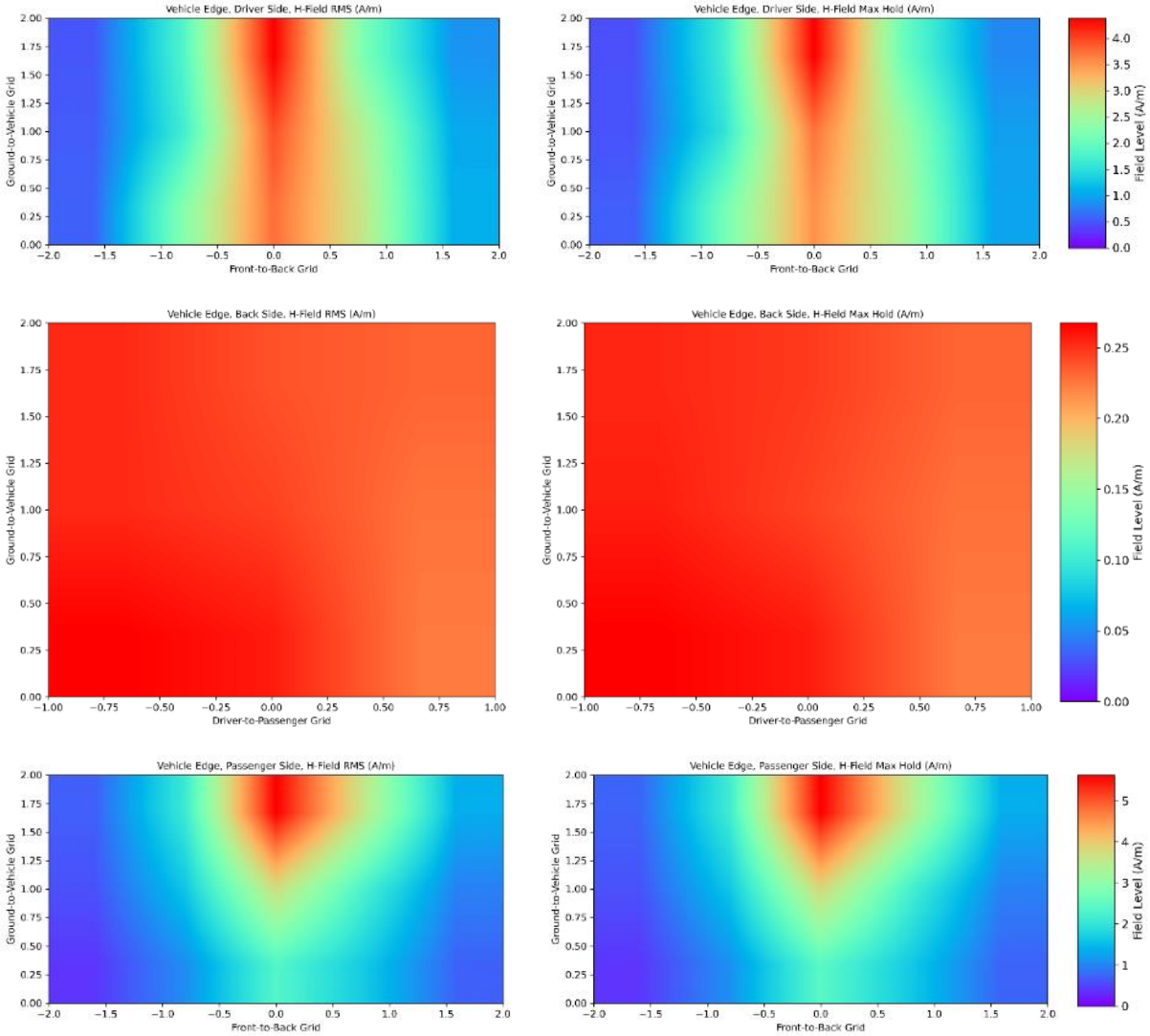


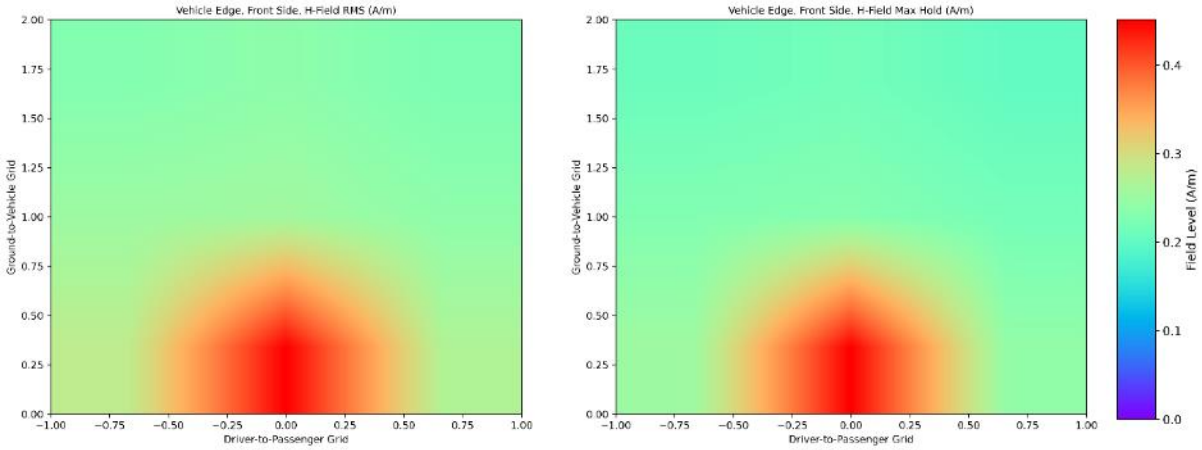




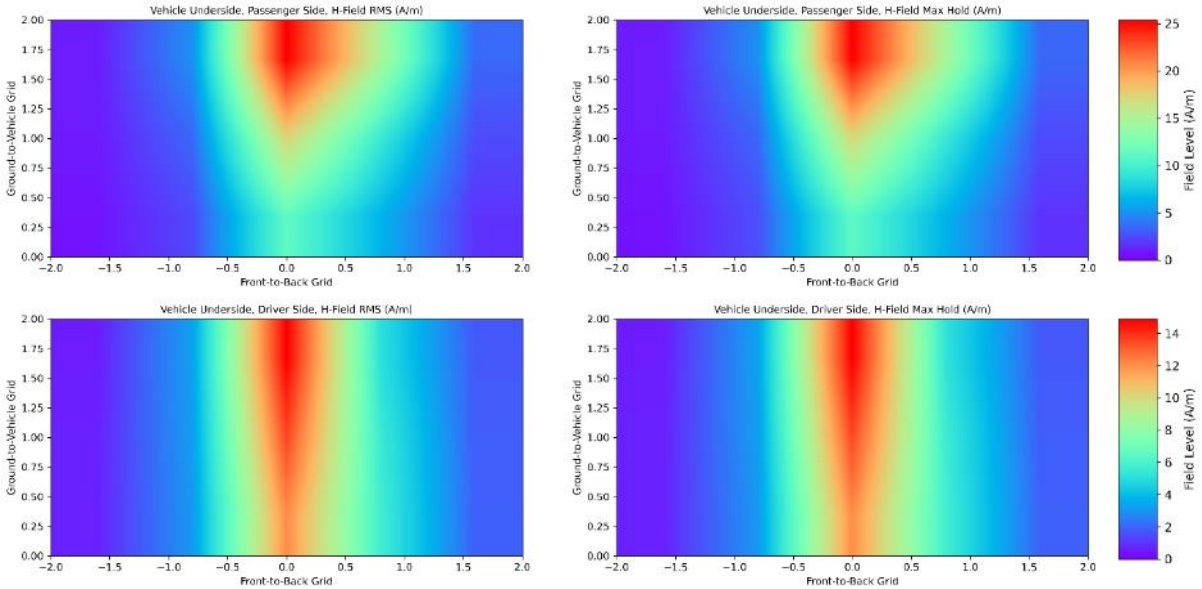
### 3.1.2 Visualization of Field Levels

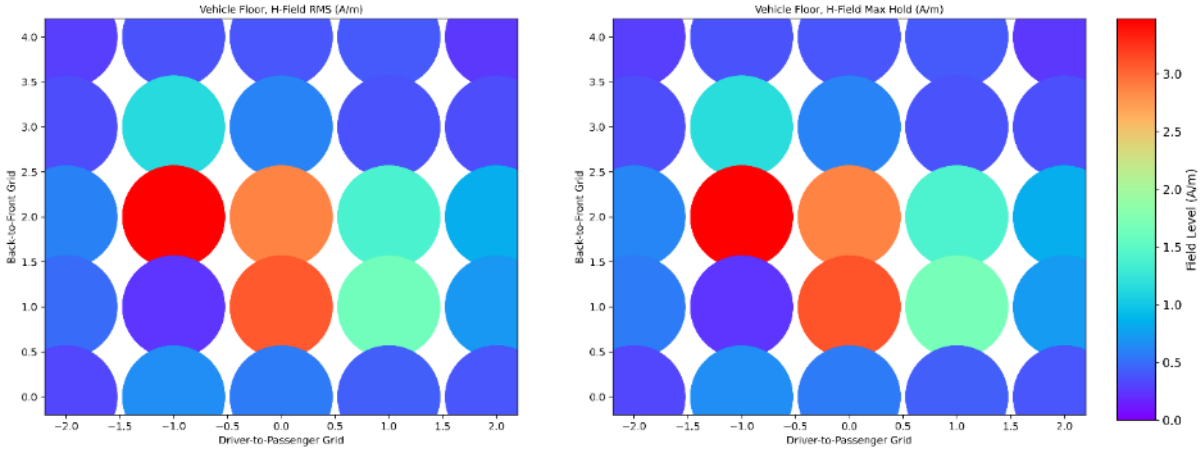
#### 3.1.2.1 Perimeter Edge of Vehicle






### 3.1.2.2 Undersides of Vehicle

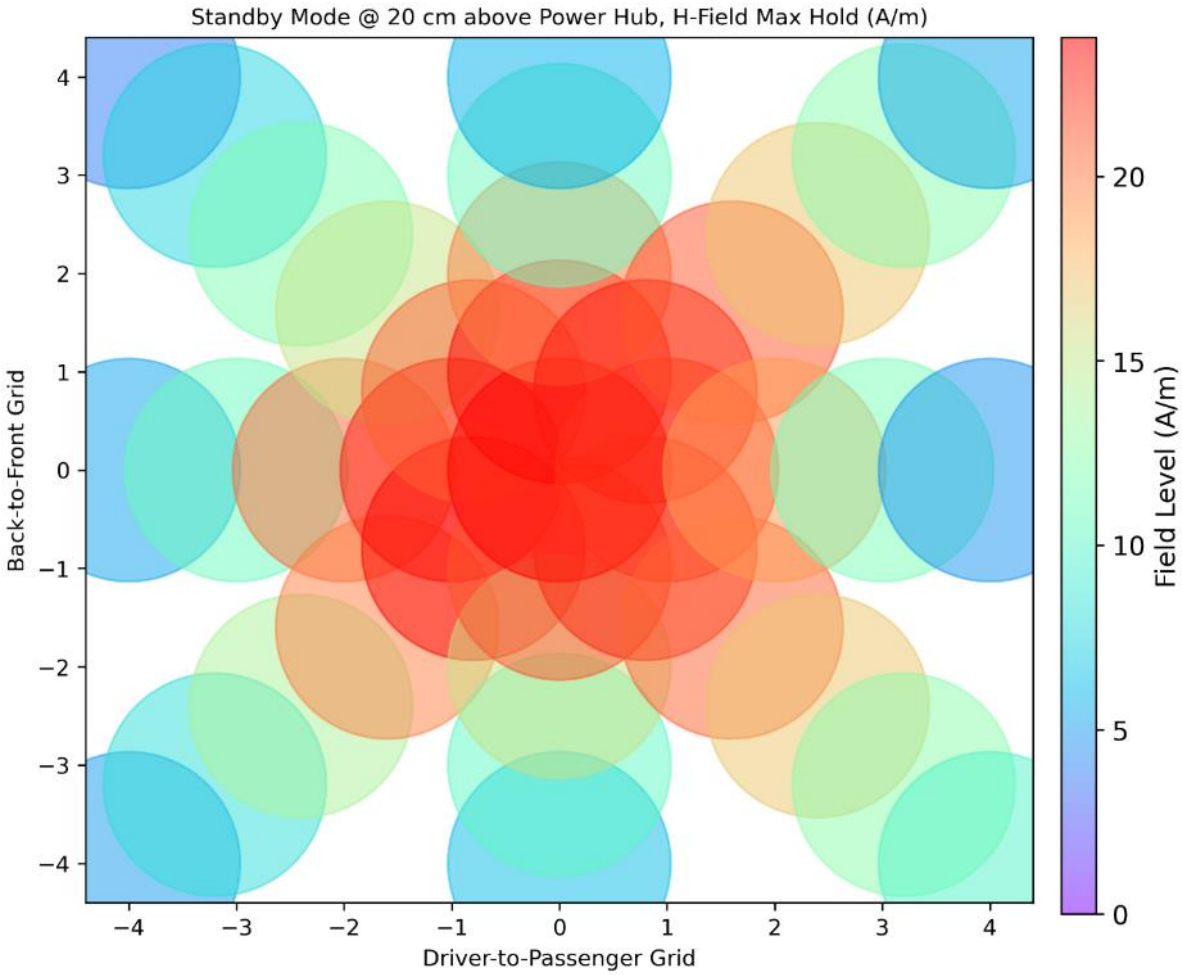


## 3.2 Standby Mode Testing

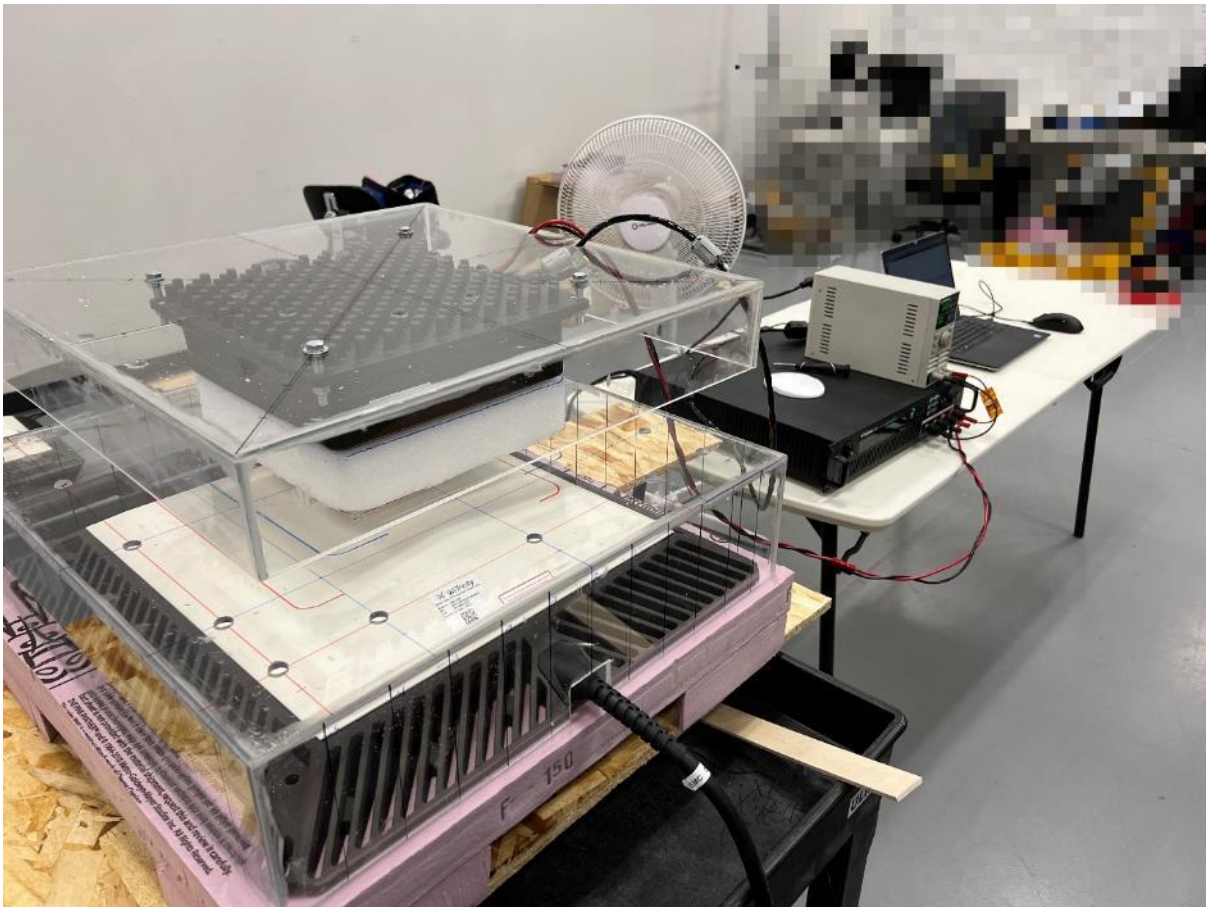
### 3.2.1 Measurement and Setup Images

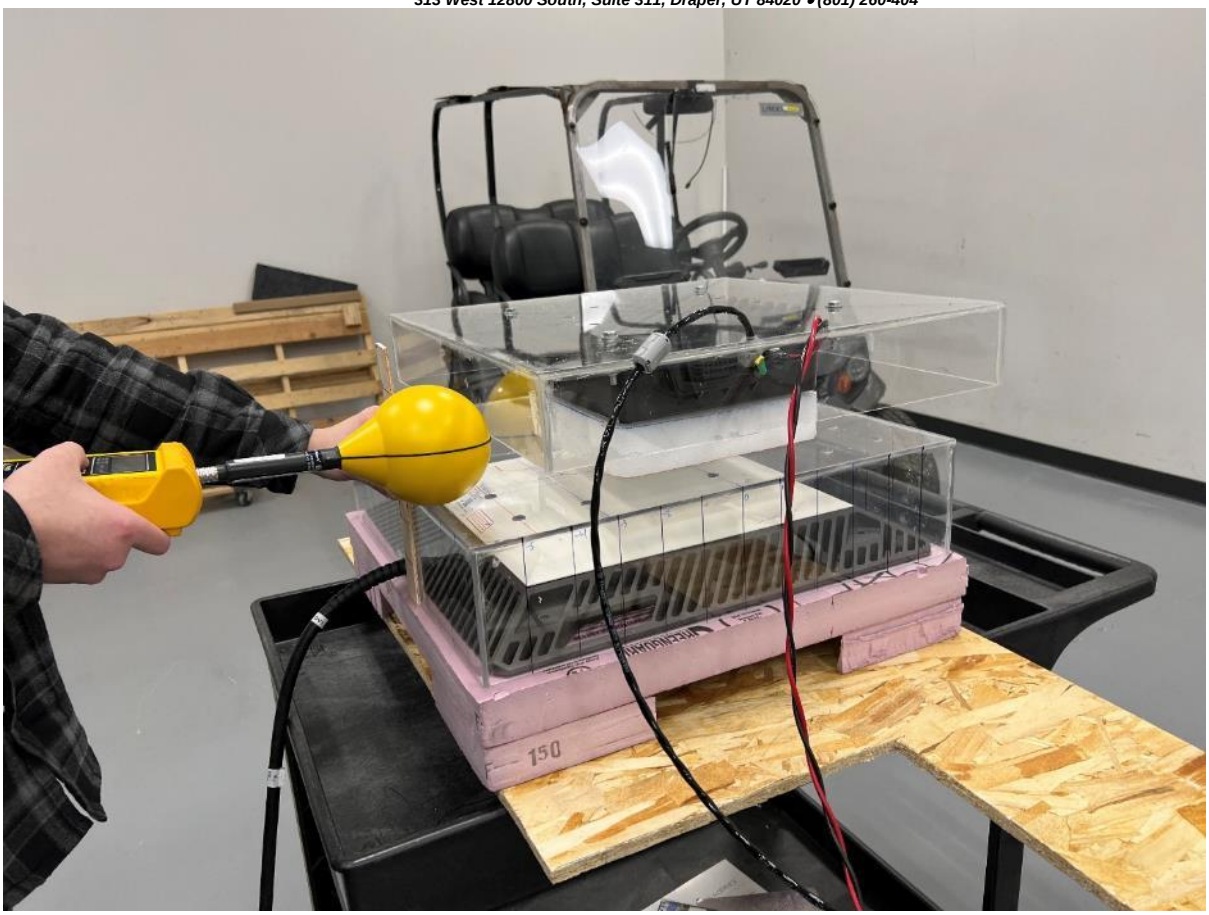
### 3.2.2 Visualization of Field Levels



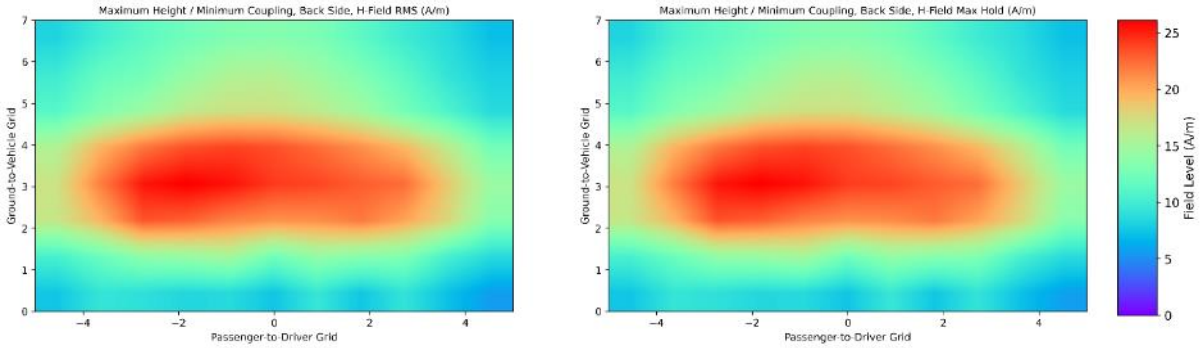
## 3.3 Off-vehicle Testing

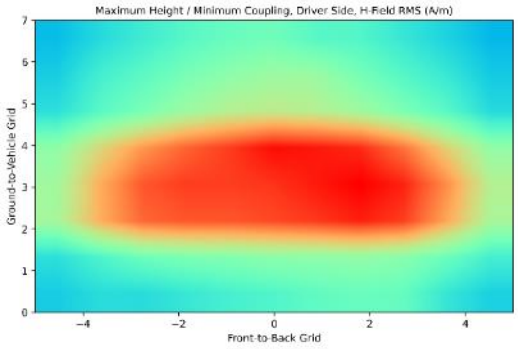
### 3.3.1 Measurement and Setup Images

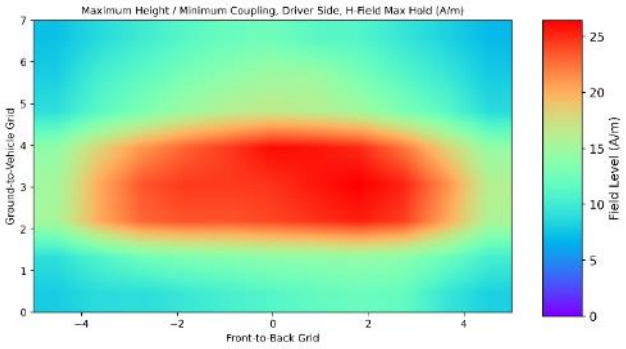


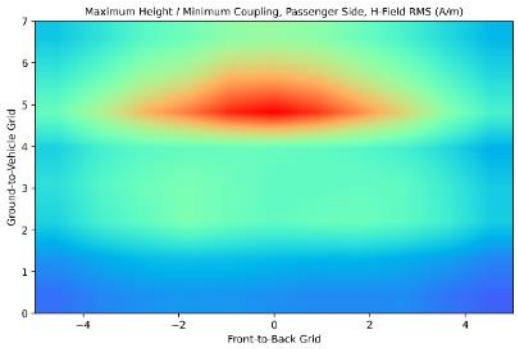

150

### 3.3.2 Visualization of Field Levels




Maximum Height / Minimum Coupling, Driver Side, H-Field RMS (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid


Maximum Height / Minimum Coupling, Driver Side, H-Field Max Hold (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid
Field Level (A/m)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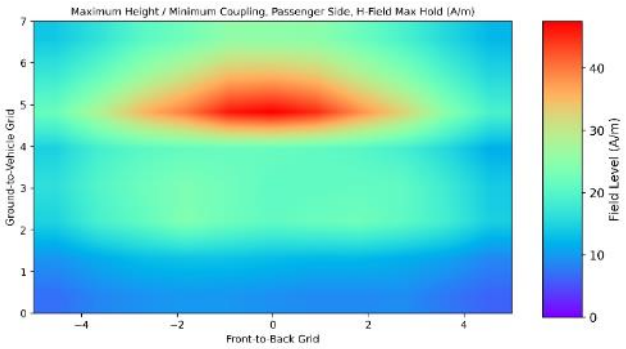
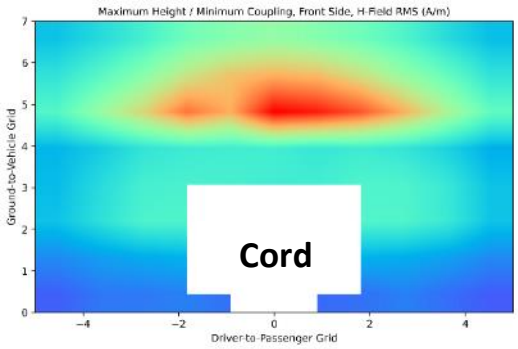
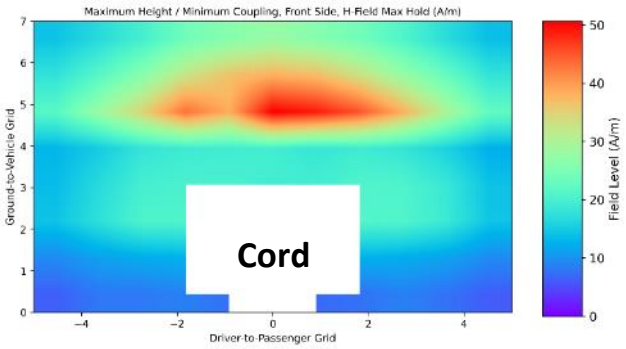
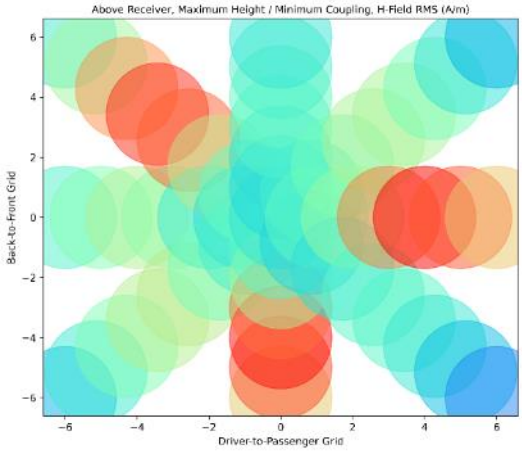
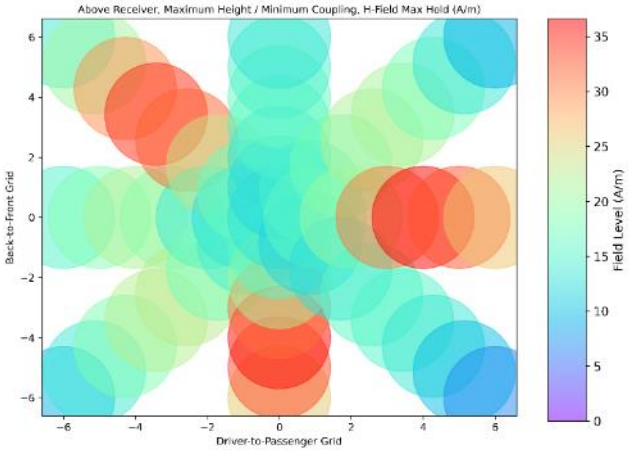
Ground-to-Vehicle Grid
Front-to-Back Grid

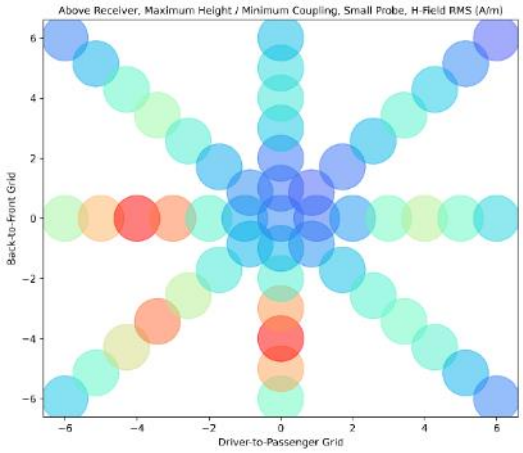

Maximum Height / Minimum Coupling, Passenger Side, H-Field Max Hold (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid
Field Level (A/m)

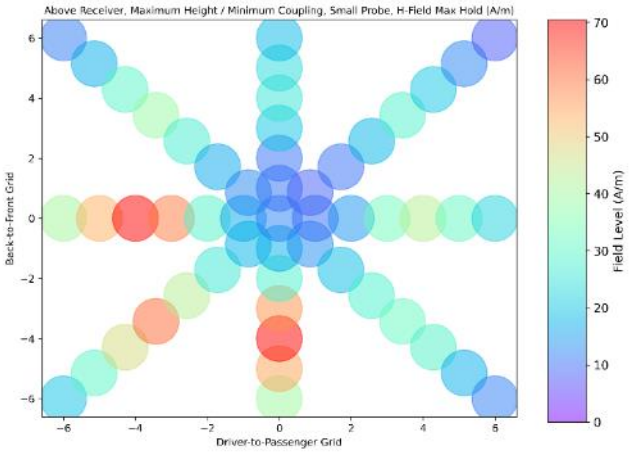

Maximum Height / Minimum Coupling, Front Side, H-Field RMS (A/m)
Ground-to-Vehicle Grid
Cord
Driver-to-Passenger Grid

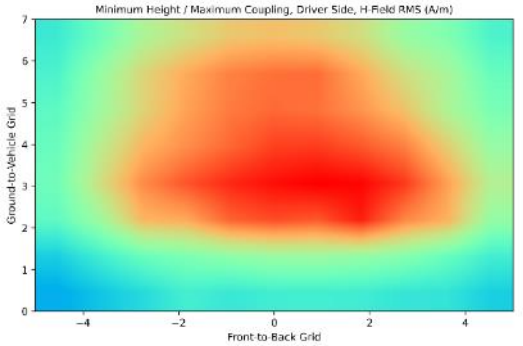

Maximum Height / Minimum Coupling, Front Side, H-Field Max Hold (A/m)
Ground-to-Vehicle Grid
Cord
Driver-to-Passenger Grid
Field Level (A/m)

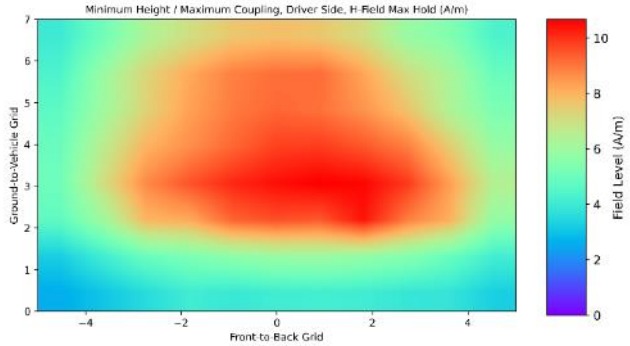

Above Receiver, Maximum Height / Minimum Coupling, H-Field RMS (A/m)
Back-to-Front Grid
Driver-to-Passenger Grid

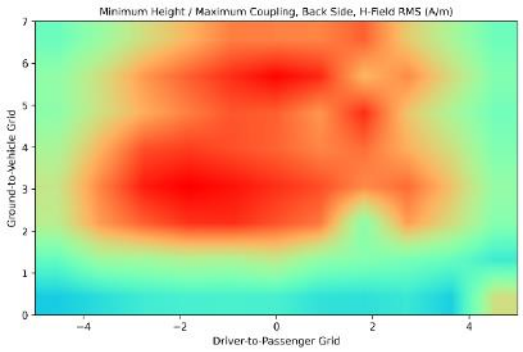

Above Receiver, Maximum Height / Minimum Coupling, H-Field Max Hold (A/m)
Back-to-Front Grid
Driver-to-Passenger Grid
Field Level (A/m)


Above Receiver, Maximum Height / Minimum Coupling, Small Probe, H-Field RMS (A/m)
Back-to-Front Grid
Driver-to-Passenger Grid


Above Receiver, Maximum Height / Minimum Coupling, Small Probe, H-Field Max Hold (A/m)
Back-to-Front Grid
Driver-to-Passenger Grid
Field Level (A/m)


Minimum Height / Maximum Coupling, Driver Side, H-Field RMS (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid


Minimum Height / Maximum Coupling, Driver Side, H-Field Max Hold (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid
Field Level (A/m)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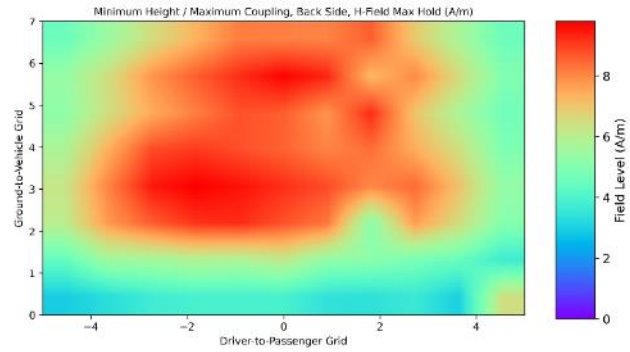
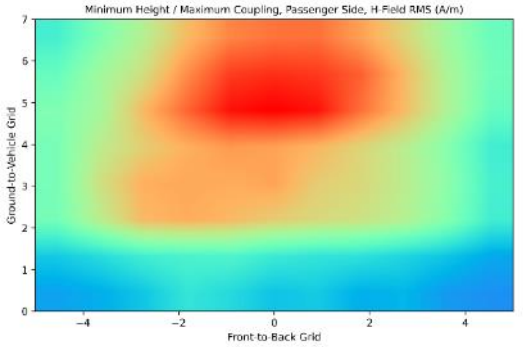
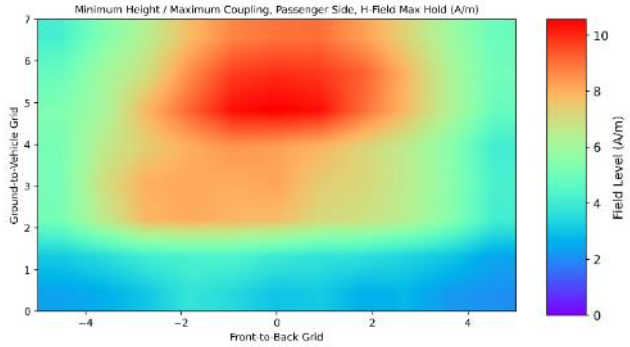
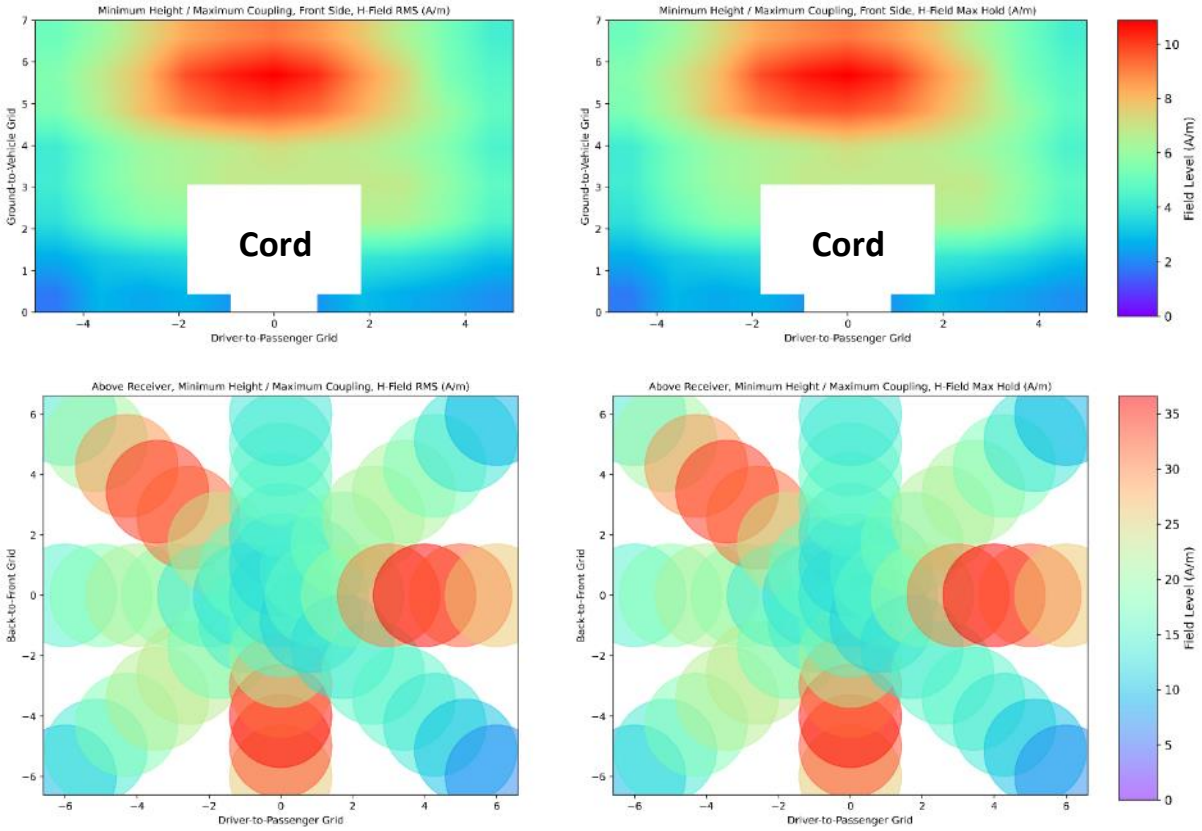
Ground-to-Vehicle Grid
Driver-to-Passenger Grid


Minimum Height / Maximum Coupling, Back Side, H-Field Max Hold (A/m)
Ground-to-Vehicle Grid
Driver-to-Passenger Grid
Field Level (A/m)


Minimum Height / Maximum Coupling, Passenger Side, H-Field RMS (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid


Minimum Height / Maximum Coupling, Passenger Side, H-Field Max Hold (A/m)
Ground-to-Vehicle Grid
Front-to-Back Grid
Field Level (A/m)




# 4 Appendix of Raw Data Collected

## 4.1 On-vehicle Testing

NOTE: Vehicle purposely offset on wheel guide for near-worst-case conditions: Forward 2 cm from center alignment and towards passenger 4 cm from center alignment.
Underside = Plexiglass against the edge of Power Hub

Front — Back

| | Outside Edge | Driver Side | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | -2 | | -1 | | 0 | | 1 | | 2 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| High | Vehicle | 0.62 µT | 0.63 µT | 2.28 µT | 2.29 µT | 5.51 µT | 5.97 µT | 2.73 µT | 2.74 µT | 1.09 µT | 1.09 µT |
| | Midway | 0.65 µT | 0.65 µT | 2.11 µT | 2.10 µT | 4.96 µT | 5.06 µT | 3.34 µT | 3.34 µT | 1.29 µT | 1.30 µT |
| Low | Ground | 0.71 µT | 0.73 µT | 2.84 µT | 2.85 µT | 4.72 µT | 4.80 µT | 3.50 µT | 3.51 µT | 1.34 µT | 1.34 µT |
| | | Sweep Max Hold | | 5.90 µT | | | | | | | |

Driver side — Passenger side

| | Outside Edge | Back Side | | | | | |
|---|---|---|---|---|---|---|---|
| | X | -1 | | 0 | | 1 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| High | Vehicle | 0.32 µT | 0.32 µT | 0.30 µT | 0.31 µT | 0.29 µT | 0.29 µT |
| | Midway | 0.32 µT | 0.32 µT | 0.31 µT | 0.31 µT | 0.29 µT | 0.29 µT |
| Low | Ground | 0.34 µT | 0.34 µT | 0.32 µT | 0.33 µT | 0.28 µT | 0.28 µT |
| | | Sweep Max Hold | | 0.35 µT | | | |

Front — Back

| | Outside Edge | Passenger Side | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | -2 | | -1 | | 0 | | 1 | | 2 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| High | Vehicle | 0.87 µT | 0.91 µT | 2.63 µT | 2.69 µT | 7.07 µT | 7.08 µT | 4.40 µT | 4.40 µT | 1.70 µT | 1.70 µT |
| | Midway | 0.74 µT | 0.75 µT | 2.03 µT | 2.04 µT | 4.67 µT | 4.79 µT | 2.77 µT | 2.77 µT | 1.21 µT | 1.21 µT |
| Low | Ground | 0.49 µT | 0.49 µT | 1.34 µT | 1.37 µT | 2.95 µT | 3.05 µT | 2.05 µT | 2.05 µT | 0.90 µT | 0.91 µT |
| | | Sweep Max Hold | | 6.94 µT | | | | | | | |

Driver side — Passenger side

| | Outside Edge | Front Side | | | | | |
|---|---|---|---|---|---|---|---|
| | X | -1 | | 0 | | 1 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| High | Vehicle | 0.29 µT | 0.29 µT | 0.30 µT | 0.30 µT | 0.28 µT | 0.28 µT |
| | Midway | 0.32 µT | 0.32 µT | 0.32 µT | 0.32 µT | 0.30 µT | 0.30 µT |
| Low | Ground | 0.35 µT | 0.35 µT | 0.57 µT* | 0.63 µT* | 0.34 µT | 0.34 µT |
| | | Sweep Max Hold | | 0.61 µT | | | |

*Note: Bottom measurent in contact with power cord.

| | Underside | Driver Side | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | -2 | | -1 | | 0 | | 1 | | 2 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| High | Vehicle | 0.71 µT | 0.72 µT | 4.11 µT | 4.16 µT | 18.71 µT | 18.76 µT | 6.41 µT | 6.51 µT | 2.16 µT | 2.17 µT |
| | Midway | 0.83 µT | 0.85 µT | 3.97 µT | 4.03 µT | 17.01 µT | 17.05 µT | 6.96 µT | 7.03 µT | 2.27 µT | 2.28 µT |
| Low | Ground | 0.83 µT | 0.84 µT | 3.83 µT | 3.84 µT | 15.19 µT | 15.21 µT | 7.18 µT | 7.18 µT | 2.35 µT | 2.35 µT |
| | | Sweep Max Hold | | 19.30 µT | | | | | | | |

| | Underside | Passenger Side | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | -2 | | -1 | | 0 | | 1 | | 2 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| High | Vehicle | 1.21 µT* | 1.23 µT* | 6.17 µT | 6.27 µT | 31.89 µT | 32.54 µT | 18.84 µT | 18.98 µT | 4.40 µT | 4.41 µT |
| | Midway | 1.11 µT | 1.14 µT | 4.35 µT | 4.36 µT | 21.82 µT | 22.01 µT | 11.85 µT | 11.90 µT | 3.11 µT | 3.12 µT |
| Low | Ground | 0.87 µT | 0.87 µT | 3.03 µT | 3.32 µT | 14.10 µT | 14.27 µT | 8.03 µT | 8.07 µT | 2.11 µT | 2.13 µT |
| | | Sweep Max Hold | | 32.50 µT | | | | | | | |

*Note: Taken with probe up against a vehicle cable

Driver side — Passenger side

| | Passenger Area | Floor | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | -2 | | -1 | | 0 | | 1 | | 2 | |
| | Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| | Front 1 | 0.36 µT | 0.36 µT | 0.47 µT | 0.47 µT | 0.48 µT | 0.48 µT | 0.50 µT | 0.51 µT | 0.32 µT | 0.32 µT |
| | Front 0 | 0.44 µT | 0.44 µT | 1.43 µT | 1.47 µT | 0.75 µT | 0.75 µT | 0.47 µT | 0.47 µT | 0.44 µT | 0.45 µT |
| | Front -1 | 0.75 µT | 0.79 µT | 4.37 µT | 4.37 µT | 3.61 µT | 3.61 µT | 1.74 µT | 1.74 µT | 1.05 µT | 1.05 µT |
| | Back 1 | 0.61 µT | 0.70 µT | 0.29 µT | 0.30 µT | 3.86 µT | 3.91 µT | 2.05 µT | 2.11 µT | 0.90 µT | 0.91 µT |
| | Back -1 | 0.40 µT | 0.40 µT | 0.83 µT | 0.83 µT | 0.71 µT | 0.71 µT | 0.53 µT | 0.53 µT | 0.49 µT | 0.49 µT |
| | | Sweep Max Hold | | | 4.79 µT | (front and back) | | | | | |
| | | Sweep Max Hold, Small Probe | | | 12.86 µT | | | | | | |

Note: Center of Front seat at floor with small probe measured 10.70 µT (where large probe was maximum)
Note: Room ambient with small probe measured at 2.197 µT

| Passenger Area | Seats |
|---|---|
| Z | Sweep Max Hold |
| Front driver seat | 0.28 µT |
| Front passenger seat | 0.27 µT |
| Back seats | 0.25 µT |
| Sweep Max Hold, All Seats | 0.28 µT |

## 4.2 Standby Mode Testing

| No Receiver Present | Top Diagonal | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 |
| | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold |
| Diagonal 1 | 4.93 µT | 9.52 µT | 14.93 µT | 19.23 µT | 26.11 µT | 29.84 µT | 28.25 µT | 25.93 µT | 21.26 µT | 15.68 µT | 12.28 µT |
| Diagonal 2 | 6.41 µT | 10.36 µT | 17.58 µT | 24.81 µT | 29.62 µT | 30.78 µT | 28.84 µT | 26.51 µT | 21.45 µT | 15.61 µT | 6.78 µT |

| No Receiver Present | Top Across | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| X | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 |
| | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold | Max Hold |
| Front to Back | 6.86 µT | 13.69 µT | 25.66 µT | 28.67 µT | 29.42 µT | 27.93 µT | 23.55 µT | 14.47 µT | 6.03 µT |
| Driver to Passenger | 7.44 µT | 13.80 µT | 24.90 µT | 29.49 µT | 29.43 µT | 26.51 µT | 19.47 µT | 13.05 µT | 8.03 µT |

# 4.3 Off-vehicle Testing

## *4.3.1 Maximum Height, Maximum Offset / Minimum Coupling*

| Centered | First Side (Front) | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 17.72 µT | 17.76 µT | 20.95 µT | 21.05 µT | 24.78 µT | 24.81 µT | 30.10 µT | 30.14 µT | 32.91 µT | 33.00 µT | 34.69 µT | 35.05 µT | 32.78 µT | 32.91 µT | 30.17 µT | 30.30 µT | 26.18 µT | 26.25 µT | 21.07 µT | 21.41 µT | 17.18 µT | 17.19 µT |
| 6 | 22.30 µT | 22.38 µT | 27.19 µT | 27.20 µT | 33.18 µT | 33.26 µT | 40.98 µT | 41.06 µT | 46.01 µT | 46.02 µT | 48.04 µT | 48.20 µT | 46.82 µT | 46.85 µT | 41.78 µT | 41.80 µT | 34.98 µT | 35.03 µT | 28.89 µT | 29.03 µT | 22.30 µT | 22.52 µT |
| 5 | 26.68 µT | 27.25 µT | 35.12 µT | 35.20 µT | 43.43 µT | 43.59 µT | 54.00 µT | 54.24 µT | 48.09 µT | 48.20 µT | 63.66 µT | 63.68 µT | 61.42 µT | 61.42 µT | 56.74 µT | 56.80 µT | 48.08 µT | 48.09 µT | 37.54 µT | 37.56 µT | 28.30 µT | 28.35 µT |
| 4 | 16.31 µT | 16.28 µT | 18.73 µT | 18.75 µT | 22.55 µT | 22.73 µT | 23.86 µT | 23.85 µT | 24.18 µT | 24.22 µT | 24.50 µT | 24.50 µT | 23.09 µT | 23.07 µT | 23.92 µT | 23.97 µT | 22.68 µT | 22.75 µT | 19.73 µT | 19.77 µT | 15.51 µT | 15.57 µT |
| 3 | 16.90 µT | 16.92 µT | 21.10 µT | 21.11 µT | 24.82 µT | 24.84 µT | 25.22 µT | 25.25 µT | 25.20 µT | 25.28 µT | 24.33 µT | 24.49 µT | 24.29 µT | 24.31 µT | 26.10 µT | 26.15 µT | 26.00 µT | 26.00 µT | 23.20 µT | 23.23 µT | 17.65 µT | 17.70 µT |
| 2 | 17.75 µT | 17.80 µT | 21.85 µT | 21.93 µT | 25.90 µT | 25.95 µT | 26.07 µT | 26.15 µT | cord | cord | cord | cord | cord | cord | 26.41 µT | 26.45 µT | 26.18 µT | 26.25 µT | 23.45 µT | 23.57 µT | 17.85 µT | 17.98 µT |
| 1 | 11.84 µT | 11.88 µT | 13.75 µT | 14.11 µT | 15.20 µT | 15.25 µT | 15.93 µT | 15.98 µT | cord | cord | cord | cord | cord | cord | 15.85 µT | 15.92 µT | 15.40 µT | 15.42 µT | 14.04 µT | 14.30 µT | 11.75 µT | 11.88 µT |
| Underneath | 7.91 µT | 7.91 µT | 10.01 µT | 10.08 µT | 10.15 µT | 10.18 µT | 10.86 µT | 10.93 µT | 9.34 µT | 9.37 µT | cord | cord | 8.84 µT | 8.84 µT | 9.34 µT | 9.45 µT | 10.85 µT | 10.87 µT | 9.17 µT | 9.56 µT | 7.60 µT | 7.63 µT |
| | Sweep Max Hold | 63.80 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Second Side (Driver) | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 8.91 µT | 9.13 µT | 10.93 µT | 10.93 µT | 12.53 µT | 12.54 µT | 14.15 µT | 14.16 µT | 15.23 µT | 15.23 µT | 15.72 µT | 15.69 µT | 14.17 µT | 14.18 µT | 13.80 µT | 13.80 µT | 12.00 µT | 12.01 µT | 10.35 µT | 10.35 µT | 8.65 µT | 8.70 µT |
| 6 | 9.95 µT | 9.98 µT | 12.92 µT | 12.93 µT | 14.48 µT | 14.50 µT | 16.30 µT | 16.30 µT | 17.63 µT | 17.64 µT | 18.60 µT | 18.66 µT | 18.45 µT | 18.55 µT | 16.10 µT | 16.23 µT | 13.99 µT | 14.02 µT | 12.12 µT | 12.15 µT | 9.71 µT | 9.75 µT |
| 5 | 11.35 µT | 11.38 µT | 14.26 µT | 14.29 µT | 16.45 µT | 16.54 µT | 18.67 µT | 18.70 µT | 20.32 µT | 20.32 µT | 20.94 µT | 20.94 µT | 20.32 µT | 20.32 µT | 18.92 µT | 19.13 µT | 16.58 µT | 16.63 µT | 14.22 µT | 14.27 µT | 10.93 µT | 11.04 µT |
| 4 | 17.75 µT | 17.82 µT | 22.53 µT | 22.67 µT | 26.34 µT | 26.34 µT | 28.96 µT | 28.96 µT | 30.72 µT | 30.74 µT | 32.70 µT | 32.72 µT | 32.20 µT | 32.35 µT | 31.35 µT | 31.38 µT | 28.03 µT | 28.06 µT | 22.89 µT | 22.93 µT | 18.00 µT | 18.00 µT |
| 3 | 18.90 µT | 18.92 µT | 25.20 µT | 25.37 µT | 29.56 µT | 29.56 µT | 30.67 µT | 30.77 µT | 30.60 µT | 30.73 µT | 31.00 µT | 31.02 µT | 32.15 µT | 32.23 µT | 33.25 µT | 33.22 µT | 31.72 µT | 31.72 µT | 26.81 µT | 26.85 µT | 20.13 µT | 20.14 µT |
| 2 | 19.16 µT | 19.19 µT | 25.15 µT | 25.28 µT | 28.79 µT | 28.80 µT | 29.53 µT | 29.68 µT | 29.56 µT | 29.62 µT | 30.13 µT | 30.17 µT | 30.80 µT | 31.06 µT | 31.85 µT | 31.84 µT | 30.54 µT | 30.57 µT | 25.43 µT | 25.50 µT | 19.42 µT | 19.52 µT |
| 1 | 11.36 µT | 11.36 µT | 13.62 µT | 13.69 µT | 15.65 µT | 15.67 µT | 16.50 µT | 16.63 µT | 16.94 µT | 17.06 µT | 17.58 µT | 17.64 µT | 17.70 µT | 17.73 µT | 17.95 µT | 18.10 µT | 17.30 µT | 17.43 µT | 15.50 µT | 15.62 µT | 12.92 µT | 12.93 µT |
| Underneath | 9.88 µT | 9.90 µT | 11.09 µT | 11.13 µT | 11.03 µT | 11.20 µT | 12.08 µT | 12.12 µT | 13.07 µT | 13.10 µT | 13.70 µT | 13.87 µT | 14.74 µT | 14.80 µT | 15.20 µT | 15.25 µT | 14.97 µT | 14.98 µT | 11.90 µT | 11.98 µT | 10.16 µT | 10.19 µT |
| | Sweep Max Hold | 32.23 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Third Side (Back) | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 10.35 µT | 10.37 µT | 12.58 µT | 13.00 µT | 14.32 µT | 14.46 µT | 15.63 µT | 15.65 µT | 16.63 µT | 16.70 µT | 16.86 µT | 16.95 µT | 16.30 µT | 16.31 µT | 14.38 µT | 14.40 µT | 12.34 µT | 12.35 µT | 10.91 µT | 10.95 µT | 8.95 µT | 9.00 µT |
| 6 | 12.28 µT | 12.28 µT | 14.80 µT | 14.82 µT | 15.67 µT | 15.76 µT | 17.85 µT | 17.86 µT | 19.65 µT | 19.66 µT | 19.80 µT | 19.81 µT | 18.37 µT | 18.38 µT | 16.56 µT | 16.57 µT | 14.22 µT | 14.24 µT | 11.60 µT | 11.62 µT | 10.04 µT | 10.05 µT |
| 5 | 13.91 µT | 13.93 µT | 16.61 µT | 16.81 µT | 18.34 µT | 18.45 µT | 20.62 µT | 20.70 µT | 21.45 µT | 21.55 µT | 21.55 µT | 21.60 µT | 20.44 µT | 20.45 µT | 18.71 µT | 18.71 µT | 15.87 µT | 16.00 µT | 13.40 µT | 13.41 µT | 10.82 µT | 10.83 µT |
| 4 | 19.68 µT | 19.65 µT | 24.48 µT | 24.55 µT | 27.65 µT | 27.66 µT | 29.45 µT | 29.48 µT | 30.03 µT | 30.03 µT | 29.45 µT | 29.50 µT | 28.12 µT | 28.12 µT | 26.52 µT | 26.57 µT | 24.33 µT | 24.35 µT | 20.51 µT | 20.53 µT | 15.80 µT | 15.82 µT |
| 3 | 21.27 µT | 21.30 µT | 27.25 µT | 27.36 µT | 31.87 µT | 31.89 µT | 32.83 µT | 32.87 µT | 32.03 µT | 32.04 µT | 30.37 µT | 30.34 µT | 29.93 µT | 30.00 µT | 28.89 µT | 28.98 µT | 28.17 µT | 28.17 µT | 23.28 µT | 23.28 µT | 18.23 µT | 18.24 µT |
| 2 | 20.93 µT | 20.97 µT | 24.40 µT | 24.42 µT | 29.25 µT | 29.37 µT | 28.71 µT | 28.74 µT | 27.15 µT | 27.22 µT | 26.47 µT | 26.50 µT | 26.60 µT | 26.78 µT | 27.60 µT | 27.64 µT | 25.48 µT | 25.50 µT | 22.22 µT | 22.22 µT | 16.96 µT | 17.07 µT |
| 1 | 12.97 µT | 13.02 µT | 15.20 µT | 15.25 µT | 17.50 µT | 17.66 µT | 18.08 µT | 18.10 µT | 18.85 µT | 18.93 µT | 15.60 µT | 15.61 µT | 17.75 µT | 17.78 µT | 17.03 µT | 17.05 µT | 16.57 µT | 16.60 µT | 12.92 µT | 13.03 µT | 10.92 µT | 11.01 µT |
| Underneath | 9.38 µT | 9.38 µT | 11.72 µT | 11.76 µT | 11.25 µT | 11.30 µT | 10.50 µT | 10.58 µT | 10.80 µT | 10.80 µT | 9.36 µT | 9.36 µT | 11.92 µT | 11.96 µT | 9.40 µT | 9.44 µT | 11.64 µT | 11.65 µT | 9.05 µT | 9.06 µT | 7.03 µT | 7.17 µT |
| | Sweep Max Hold | 30.55 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Fourth Side (Passenger) | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 17.25 µT | 17.25 µT | 20.78 µT | 20.81 µT | 25.61 µT | 25.63 µT | 28.36 µT | 28.38 µT | 32.05 µT | 32.16 µT | 33.13 µT | 31.80 µT | 31.60 µT | 31.64 µT | 27.84 µT | 27.89 µT | 23.81 µT | 23.91 µT | 19.40 µT | 19.41 µT | 15.45 µT | 15.47 µT |
| 6 | 21.98 µT | 22.00 µT | 26.92 µT | 26.97 µT | 33.39 µT | 33.44 µT | 37.26 µT | 38.65 µT | 44.04 µT | 44.07 µT | 44.69 µT | 44.69 µT | 42.44 µT | 42.50 µT | 36.76 µT | 36.77 µT | 31.06 µT | 31.10 µT | 24.55 µT | 24.58 µT | 19.19 µT | 19.25 µT |
| 5 | 27.46 µT | 27.51 µT | 35.75 µT | 35.80 µT | 44.32 µT | 44.42 µT | 49.95 µT | 49.99 µT | 56.86 µT | 57.93 µT | 59.73 µT | 59.73 µT | 55.55 µT | 56.45 µT | 48.43 µT | 48.40 µT | 41.25 µT | 41.32 µT | 31.26 µT | 31.30 µT | 23.84 µT | 23.88 µT |
| 4 | 18.25 µT | 18.34 µT | 23.18 µT | 23.25 µT | 25.72 µT | 25.77 µT | 26.93 µT | 26.93 µT | 27.13 µT | 27.16 µT | 27.12 µT | 27.16 µT | 26.40 µT | 26.45 µT | 25.35 µT | 25.41 µT | 23.30 µT | 23.30 µT | 19.35 µT | 19.40 µT | 14.63 µT | 14.65 µT |
| 3 | 20.50 µT | 20.52 µT | 24.82 µT | 24.86 µT | 27.82 µT | 27.85 µT | 29.50 µT | 29.64 µT | 27.95 µT | 28.14 µT | 26.25 µT | 26.25 µT | 26.38 µT | 26.40 µT | 26.76 µT | 26.76 µT | 26.40 µT | 26.45 µT | 22.38 µT | 22.42 µT | 17.50 µT | 17.57 µT |
| 2 | 18.55 µT | 18.57 µT | 23.58 µT | 23.61 µT | 26.45 µT | 26.55 µT | 29.89 µT | 30.20 µT | 27.85 µT | 27.87 µT | 26.43 µT | 26.43 µT | 27.51 µT | 27.52 µT | 27.88 µT | 28.08 µT | 26.13 µT | 26.15 µT | 22.92 µT | 23.00 µT | 17.80 µT | 18.17 µT |
| 1 | 12.10 µT | 12.10 µT | 14.25 µT | 14.30 µT | 16.09 µT | 16.17 µT | 16.74 µT | 16.79 µT | 16.50 µT | 16.68 µT | 15.97 µT | 16.04 µT | 15.47 µT | 15.52 µT | 15.60 µT | 15.60 µT | 14.56 µT | 14.57 µT | 13.23 µT | 13.36 µT | 10.84 µT | 10.93 µT |
| Underneath | 8.70 µT | 8.72 µT | 10.70 µT | 10.75 µT | 11.75 µT | 11.78 µT | 12.30 µT | 12.31 µT | 12.10 µT | 12.15 µT | 11.58 µT | 11.60 µT | 11.03 µT | 11.05 µT | 11.05 µT | 11.06 µT | 11.24 µT | 11.35 µT | 9.26 µT | 9.45 µT | 7.66 µT | 7.81 µT |
| | Sweep Max Hold | 59.43 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Top (Across) | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -6 | | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| Front to Back | 18.72 µT | 18.78 µT | 23.42 µT | 23.44 µT | 27.52 µT | 27.53 µT | 24.47 µT | 24.50 µT | 17.05 µT | 17.06 µT | 15.48 µT | 15.48 µT | 16.34 µT | 16.35 µT | 20.13 µT | 20.11 µT | 25.34 µT | 25.35 µT | 38.30 µT | 38.54 µT | 46.00 µT | 46.00 µT | 40.82 µT | 40.84 µT |
| Driver to Passenger | 16.63 µT | 16.65 µT | 18.55 µT | 18.59 µT | 20.64 µT | 20.68 µT | 19.10 µT | 19.10 µT | 15.76 µT | 15.84 µT | 15.12 µT | 15.14 µT | 16.36 µT | 16.32 µT | 20.08 µT | 20.05 µT | 27.05 µT | 27.06 µT | 39.21 µT | 39.26 µT | 45.13 µT | 45.16 µT | 41.54 µT | 41.56 µT |

| Centered | Top (Diagonal) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -7 | | -6 | | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
| | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| Diagonal 1 | 17.46 µT | 17.53 µT | 26.06 µT | 26.10 µT | 36.94 µT | 37.07 µT | 43.25 µT | 43.29 µT | 40.11 µT | 40.07 µT | 29.25 µT | 29.36 µT | 21.36 µT | 21.42 µT | 16.32 µT | 16.33 µT | 14.40 µT | 14.40 µT | 15.67 µT | 15.66 µT | 19.54 µT | 19.55 µT | 19.23 µT | 19.20 µT | 16.85 µT | 16.85 µT | 12.45 µT | 12.47 µT |
| Diagonal 2 | 11.87 µT | 11.99 µT | 17.05 µT | 17.18 µT | 22.98 µT | 22.98 µT | 27.98 µT | 28.01 µT | 28.50 µT | 28.56 µT | 22.17 µT | 22.20 µT | 17.84 µT | 17.84 µT | 16.10 µT | 16.13 µT | 18.10 µT | 18.14 µT | 21.81 µT | 21.94 µT | 27.26 µT | 27.34 µT | 26.81 µT | 26.81 µT | 22.12 µT | 22.31 µT | 16.35 µT | 16.44 µT |
| | Sweep Max Hold | 46.00 µT | | | | | | | | | | | | | | | | | | | | | | | | | | |

Small Probe

| Centered | Top (Across) | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -6 | | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| Front to Back | 50.82 µT | 50.82 µT | 66.33 µT | 66.40 µT | 88.51 µT | 88.40 µT | 74.01 µT | 74.18 µT | 36.64 µT | 36.55 µT | 20.63 µT | 20.67 µT | 14.68 µT | 14.74 µT | 12.66 µT | 12.70 µT | 17.70 µT | 17.75 µT | 40.97 µT | 41.22 µT | 53.81 µT | 53.88 µT | 39.30 µT | 39.46 µT | 27.83 µT | 27.83 µT |
| Driver to Passenger | 23.40 µT | 23.40 µT | 29.06 µT | 29.05 µT | 31.94 µT | 31.93 µT | 25.17 µT | 25.14 µT | 13.25 µT | 13.25 µT | 13.10 µT | 13.15 µT | 16.04 µT | 16.05 µT | 21.44 µT | 21.45 µT | 34.90 µT | 34.96 µT | 70.80 µT | 70.88 µT | 88.53 µT | 88.49 µT | 68.50 µT | 68.57 µT | 39.91 µT | 50.03 µT |

| Centered | Top (Diagonal) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -7 | | -6 | | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
| | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| Diagonal 1 | 14.46 µT | 14.49 µT | 21.10 µT | 21.11 µT | 37.38 µT | 37.31 µT | 48.96 µT | 48.97 µT | 34.30 µT | 34.32 µT | 20.48 µT | 20.49 µT | 16.02 µT | 16.05 µT | 14.71 µT | 14.72 µT | 16.72 µT | 16.74 µT | 23.81 µT | 23.82 µT | 35.07 µT | 35.07 µT | 39.91 µT | 39.95 µT | 35.87 µT | 35.86 µT | 21.54 µT | 21.56 µT |
| Diagonal 2 | 24.72 µT | 24.72 µT | 37.43 µT | 37.45 µT | 58.82 µT | 58.78 µT | 76.15 µT | 76.10 µT | 53.91 µT | 53.95 µT | 32.46 µT | 32.47 µT | 22.41 µT | 22.42 µT | 14.63 µT | 14.64 µT | 10.93 µT | 10.93 µT | 13.08 µT | 13.05 µT | 22.80 µT | 22.78 µT | 36.08 µT | 36.08 µT | 25.34 µT | 25.31 µT | 15.48 µT | 15.48 µT |

## *4.3.2 Minimum Height / Maximum Coupling*

| Centered | First Side (Front) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 6.38 µT | 6.39 µT | 7.59 µT | 7.60 µT | 9.17 µT | 9.18 µT | 10.53 µT | 10.55 µT | 11.15 µT | 11.15 µT | 11.51 µT | 11.56 µT | 10.88 µT | 10.90 µT | 9.80 µT | 9.87 µT | 8.19 µT | 8.20 µT | 6.63 µT | 6.65 µT | 5.32 µT | 5.35 µT |
| 6 | 6.95 µT | 7.04 µT | 8.57 µT | 8.57 µT | 10.01 µT | 10.01 µT | 12.31 µT | 12.33 µT | 13.13 µT | 13.25 µT | 13.67 µT | 13.70 µT | 12.93 µT | 12.98 µT | 10.99 µT | 11.00 µT | 9.41 µT | 9.42 µT | 6.75 µT | 6.77 µT | 5.76 µT | 5.79 µT |
| 5 | 6.75 µT | 6.79 µT | 8.33 µT | 8.33 µT | 9.98 µT | 10.00 µT | 11.25 µT | 11.25 µT | 12.01 µT | 12.02 µT | 12.12 µT | 12.20 µT | 11.63 µT | 11.66 µT | 10.36 µT | 10.42 µT | 9.10 µT | 9.10 µT | 7.59 µT | 7.60 µT | 6.04 µT | 6.05 µT |
| 4 | 5.13 µT | 5.15 µT | 6.62 µT | 6.63 µT | 7.73 µT | 7.73 µT | 8.17 µT | 8.18 µT | 8.48 µT | 8.48 µT | 9.04 µT | 9.06 µT | 8.62 µT | 8.63 µT | 8.50 µT | 8.52 µT | 7.90 µT | 7.91 µT | 6.94 µT | 6.96 µT | 5.52 µT | 5.53 µT |
| 3 | 5.19 µT | 5.20 µT | 6.69 µT | 6.70 µT | 7.67 µT | 7.67 µT | 8.07 µT | 8.12 µT | 8.64 µT | 8.65 µT | 8.54 µT | 8.54 µT | 8.61 µT | 8.66 µT | 8.63 µT | 8.64 µT | 8.57 µT | 8.59 µT | 7.33 µT | 7.34 µT | 6.03 µT | 6.03 µT |
| 2 | 4.71 µT | 4.72 µT | 6.06 µT | 6.07 µT | 7.00 µT | 7.08 µT | 7.26 µT | 7.26 µT | cord | cord | cord | cord | cord | cord | 8.21 µT | 8.21 µT | 8.07 µT | 8.08 µT | 7.05 µT | 7.07 µT | 5.62 µT | 5.62 µT |
| 1 | 3.32 µT | 3.32 µT | 3.95 µT | 3.96 µT | 4.30 µT | 4.30 µT | 4.50 µT | 4.51 µT | cord | cord | cord | cord | cord | cord | 4.98 µT | 5.02 µT | 4.84 µT | 4.85 µT | 4.38 µT | 4.38 µT | 3.78 µT | 3.79 µT |
| Underneath | 2.18 µT | 2.20 µT | 3.50 µT | 3.52 µT | 3.15 µT | 3.19 µT | 3.47 µT | 3.47 µT | 2.81 µT | 2.86 µT | cord | cord | 2.72 µT | 2.80 µT | 3.67 µT | 3.68 µT | 3.31 µT | 3.33 µT | 3.03 µT | 3.04 µT | 2.65 µT | 2.65 µT |
| | Sweep Max Hold | 13.67 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Second Side (Driver) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 4.97 µT | 4.99 µT | 6.32 µT | 6.35 µT | 7.94 µT | 7.95 µT | 8.82 µT | 8.85 µT | 9.56 µT | 9.57 µT | 9.76 µT | 9.80 µT | 9.54 µT | 9.57 µT | 8.90 µT | 8.92 µT | 7.44 µT | 7.45 µT | 6.82 µT | 6.82 µT | 5.42 µT | 5.44 µT |
| 6 | 5.41 µT | 5.45 µT | 7.37 µT | 7.43 µT | 9.18 µT | 9.18 µT | 10.27 µT | 10.27 µT | 11.13 µT | 11.16 µT | 11.45 µT | 11.47 µT | 11.52 µT | 11.53 µT | 10.31 µT | 10.37 µT | 8.85 µT | 8.92 µT | 7.85 µT | 7.87 µT | 6.14 µT | 6.16 µT |
| 5 | 5.85 µT | 5.87 µT | 7.57 µT | 7.58 µT | 9.22 µT | 9.25 µT | 10.45 µT | 10.46 µT | 11.25 µT | 11.26 µT | 11.58 µT | 11.63 µT | 11.42 µT | 11.44 µT | 10.74 µT | 10.76 µT | 9.70 µT | 9.70 µT | 7.98 µT | 7.99 µT | 6.63 µT | 6.69 µT |
| 4 | 6.15 µT | 6.17 µT | 8.30 µT | 8.31 µT | 10.03 µT | 10.06 µT | 10.87 µT | 10.87 µT | 11.63 µT | 11.64 µT | 12.31 µT | 12.31 µT | 12.39 µT | 12.40 µT | 11.92 µT | 11.93 µT | 11.15 µT | 11.20 µT | 9.39 µT | 9.40 µT | 7.37 µT | 7.39 µT |
| 3 | 6.33 µT | 6.33 µT | 8.81 µT | 8.81 µT | 10.92 µT | 10.93 µT | 11.97 µT | 11.98 µT | 12.72 µT | 12.73 µT | 13.15 µT | 13.16 µT | 13.42 µT | 13.43 µT | 13.31 µT | 13.31 µT | 12.45 µT | 12.45 µT | 10.47 µT | 10.47 µT | 8.12 µT | 8.15 µT |
| 2 | 5.90 µT | 5.93 µT | 7.58 µT | 7.59 µT | 10.00 µT | 10.00 µT | 10.27 µT | 10.27 µT | 11.70 µT | 11.69 µT | 12.11 µT | 12.07 µT | 11.87 µT | 11.88 µT | 12.88 µT | 13.06 µT | 11.00 µT | 11.20 µT | 10.08 µT | 10.09 µT | 7.30 µT | 7.29 µT |
| 1 | 4.05 µT | 4.06 µT | 5.16 µT | 5.15 µT | 6.21 µT | 6.22 µT | 6.73 µT | 6.72 µT | 7.16 µT | 7.16 µT | 7.46 µT | 7.47 µT | 7.51 µT | 7.53 µT | 7.30 µT | 7.31 µT | 6.93 µT | 6.95 µT | 6.16 µT | 6.18 µT | 5.17 µT | 5.18 µT |
| Underneath | 3.20 µT | 3.23 µT | 3.81 µT | 3.81 µT | 4.43 µT | 4.45 µT | 5.21 µT | 5.11 µT | 4.88 µT | 4.90 µT | 5.13 µT | 5.10 µT | 5.16 µT | 5.17 µT | 5.10 µT | 5.10 µT | 4.80 µT | 4.85 µT | 4.75 µT | 4.77 µT | 4.07 µT | 4.08 µT |
| | Sweep Max Hold | 12.87 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Third Side (Back) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 5.68 µT | 5.71 µT | 6.85 µT | 6.87 µT | 8.16 µT | 8.17 µT | 9.20 µT | 9.22 µT | 10.26 µT | 10.28 µT | 10.19 µT | 10.20 µT | 10.13 µT | 10.17 µT | 10.76 µT | 10.78 µT | 8.69 µT | 8.70 µT | 7.23 µT | 7.23 µT | 5.74 µT | 5.74 µT |
| 6 | 6.62 µT | 6.74 µT | 8.13 µT | 8.15 µT | 9.77 µT | 9.80 µT | 10.79 µT | 10.80 µT | 11.58 µT | 11.57 µT | 12.20 µT | 12.23 µT | 11.68 µT | 11.70 µT | 9.08 µT | 9.08 µT | 10.03 µT | 10.04 µT | 8.23 µT | 8.23 µT | 6.26 µT | 6.26 µT |
| 5 | 6.49 µT | 6.55 µT | 8.10 µT | 8.12 µT | 9.36 µT | 9.37 µT | 10.22 µT | 10.22 µT | 10.96 µT | 11.02 µT | 10.78 µT | 10.80 µT | 9.80 µT | 9.82 µT | 11.60 µT | 11.60 µT | 8.82 µT | 8.82 µT | 7.28 µT | 7.28 µT | 5.85 µT | 5.84 µT |
| 4 | 7.24 µT | 7.26 µT | 9.28 µT | 9.29 µT | 11.09 µT | 11.11 µT | 11.36 µT | 11.38 µT | 11.06 µT | 11.06 µT | 10.72 µT | 10.72 µT | 10.13 µT | 10.15 µT | 10.51 µT | 10.52 µT | 9.32 µT | 9.34 µT | 8.13 µT | 8.13 µT | 6.20 µT | 6.19 µT |
| 3 | 7.85 µT | 7.87 µT | 10.16 µT | 10.15 µT | 11.87 µT | 11.89 µT | 12.31 µT | 12.31 µT | 12.00 µT | 12.00 µT | 11.55 µT | 11.56 µT | 11.10 µT | 11.10 µT | 10.04 µT | 10.08 µT | 10.58 µT | 10.60 µT | 8.89 µT | 8.89 µT | 6.69 µT | 6.69 µT |
| 2 | 7.60 µT | 7.62 µT | 9.74 µT | 9.74 µT | 10.79 µT | 10.80 µT | 11.49 µT | 11.50 µT | 11.59 µT | 11.60 µT | 10.99 µT | 10.99 µT | 10.37 µT | 10.37 µT | 6.47 µT | 6.48 µT | 9.66 µT | 9.67 µT | 8.23 µT | 8.22 µT | 6.34 µT | 6.35 µT |
| 1 | 5.54 µT | 5.56 µT | 6.97 µT | 6.98 µT | 7.03 µT | 7.07 µT | 7.39 µT | 7.40 µT | 7.26 µT | 7.27 µT | 7.73 µT | 7.74 µT | 6.62 µT | 6.62 µT | 6.32 µT | 6.47 µT | 6.01 µT | 6.02 µT | 5.63 µT | 5.66 µT | 4.63 µT | 4.64 µT |
| Underneath | 3.68 µT | 3.68 µT | 4.15 µT | 4.15 µT | 4.66 µT | 4.66 µT | 4.85 µT | 4.86 µT | 4.86 µT | 4.87 µT | 4.85 µT | 4.86 µT | 4.30 µT | 4.31 µT | 4.23 µT | 4.24 µT | 4.51 µT | 4.54 µT | 3.76 µT | 3.78 µT | 8.11 µT | 8.11 µT |
| | Sweep Max Hold | 11.87 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Fourth Side (Passenger) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | |
| Z | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| 7 | 5.17 µT | 5.18 µT | 6.67 µT | 6.70 µT | 8.07 µT | 8.10 µT | 9.75 µT | 9.75 µT | 10.92 µT | 10.93 µT | 11.25 µT | 11.27 µT | 11.31 µT | 11.34 µT | 10.36 µT | 10.37 µT | 9.08 µT | 9.08 µT | 7.51 µT | 7.52 µT | 6.13 µT | 6.13 µT |
| 6 | 6.03 µT | 6.04 µT | 7.56 µT | 7.58 µT | 8.75 µT | 8.76 µT | 10.75 µT | 10.76 µT | 12.23 µT | 12.25 µT | 12.45 µT | 12.50 µT | 12.30 µT | 12.31 µT | 11.62 µT | 11.62 µT | 9.85 µT | 9.88 µT | 7.87 µT | 7.89 µT | 6.30 µT | 6.31 µT |
| 5 | 6.67 µT | 6.67 µT | 7.65 µT | 7.66 µT | 9.82 µT | 9.85 µT | 11.51 µT | 11.53 µT | 12.96 µT | 13.00 µT | 13.28 µT | 13.28 µT | 12.94 µT | 13.00 µT | 11.33 µT | 11.35 µT | 9.77 µT | 9.78 µT | 7.94 µT | 7.97 µT | 6.05 µT | 6.09 µT |
| 4 | 6.48 µT | 6.48 µT | 8.25 µT | 8.26 µT | 9.26 µT | 9.27 µT | 10.02 µT | 10.05 µT | 10.50 µT | 10.60 µT | 10.33 µT | 10.34 µT | 9.89 µT | 9.90 µT | 9.08 µT | 9.09 µT | 8.22 µT | 8.22 µT | 6.86 µT | 6.87 µT | 5.07 µT | 5.08 µT |
| 3 | 6.44 µT | 6.44 µT | 8.71 µT | 8.72 µT | 10.05 µT | 10.05 µT | 10.23 µT | 10.23 µT | 10.10 µT | 10.11 µT | 10.30 µT | 10.30 µT | 9.32 µT | 9.32 µT | 8.98 µT | 8.99 µT | 8.25 µT | 8.26 µT | 7.05 µT | 7.05 µT | 5.23 µT | 5.29 µT |
| 2 | 6.38 µT | 6.40 µT | 8.18 µT | 8.25 µT | 9.81 µT | 9.84 µT | 10.10 µT | 10.15 µT | 9.85 µT | 9.88 µT | 9.31 µT | 9.74 µT | 8.95 µT | 8.96 µT | 8.65 µT | 8.67 µT | 8.08 µT | 8.11 µT | 6.84 µT | 6.86 µT | 5.10 µT | 5.13 µT |
| 1 | 3.89 µT | 3.92 µT | 4.43 µT | 4.45 µT | 5.11 µT | 5.12 µT | 5.35 µT | 5.36 µT | 5.45 µT | 5.46 µT | 4.94 µT | 4.97 µT | 4.68 µT | 4.68 µT | 4.58 µT | 4.59 µT | 4.20 µT | 4.20 µT | 3.76 µT | 3.84 µT | 3.09 µT | 3.05 µT |
| Underneath | 2.95 µT | 2.95 µT | 3.22 µT | 3.22 µT | 3.79 µT | 3.80 µT | 4.73 µT | 4.74 µT | 4.34 µT | 4.34 µT | 3.73 µT | 3.73 µT | 3.89 µT | 3.90 µT | 3.23 µT | 3.25 µT | 3.40 µT | 3.40 µT | 2.76 µT | 2.75 µT | 2.58 µT | 2.59 µT |
| | Sweep Max Hold | 13.27 µT | | | | | | | | | | | | | | | | | | | | |

| Centered | Top (Across) | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -6 | | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
| | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| Front to Back | 12.40 µT | 12.49 µT | 15.60 µT | 15.62 µT | 18.96 µT | 18.93 µT | 17.23 µT | 17.28 µT | 11.49 µT | 11.19 µT | 8.76 µT | 8.79 µT | 8.82 µT | 8.53 µT | 10.55 µT | 10.32 µT | 14.06 µT | 14.23 µT | 20.75 µT | 20.78 µT | 22.90 µT | 23.00 µT | 18.33 µT | 18.36 µT | 13.42 µT | 13.42 µT |
| Driver to Passenger | 13.72 µT | 13.75 µT | 17.70 µT | 17.79 µT | 22.18 µT | 22.17 µT | 20.33 µT | 20.37 µT | 13.56 µT | 13.58 µT | 9.88 µT | 9.92 µT | 8.52 µT | 8.53 µT | 8.29 µT | 8.30 µT | 9.50 µT | 9.52 µT | 12.00 µT | 12.02 µT | 13.20 µT | 13.23 µT | 11.99 µT | 12.01 µT | 9.63 µT | 9.64 µT |

| Centered | Top (Diagonal) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | -7 | | -6 | | -5 | | -4 | | -3 | | -2 | | -1 | | 0 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
| | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold | RMS | Max Hold |
| Diagonal 1 | 5.89 µT | 5.89 µT | 8.52 µT | 8.54 µT | 12.06 µT | 12.06 µT | 15.80 µT | 15.81 µT | 16.90 µT | 16.92 µT | 12.30 µT | 12.30 µT | 9.28 µT | 9.30 µT | 8.48 µT | 8.50 µT | 9.13 µT | 9.17 µT | 11.98 µT | 12.02 µT | 15.60 µT | 15.64 µT | 15.44 µT | 15.58 µT | 11.90 µT | 11.93 µT | 7.87 µT | 7.88 µT | 5.37 µT | 5.37 µT |
| Diagonal 2 | 6.39 µT | 6.38 µT | 10.00 µT | 10.00 µT | 14.46 µT | 13.44 µT | 18.63 µT | 18.66 µT | 19.83 µT | 19.77 µT | 14.70 µT | 14.70 µT | 10.43 µT | 10.46 µT | 8.50 µT | 8.54 µT | 8.34 µT | 8.33 µT | 10.14 µT | 10.17 µT | 13.12 µT | 13.13 µT | 12.88 µT | 12.95 µT | 10.22 µT | 10.25 µT | 7.64 µT | 7.67 µT | 5.06 µT | 5.08 µT |
| | Sweep Max Hold | 20.59 µT | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## 4.3.3 *Nominal Height / Nominal Coupling*

| Centered | First Side (Front) |
|---|---|
| Sweep Max Hold | 16.32 µT |

| Centered | Second Side (Driver) |
|---|---|
| Sweep Max Hold | 16.85 µT |

| Centered | Third Side (Back) |
|---|---|
| Sweep Max Hold | 16.26 µT |

| Centered | Fourth Side (Passenger) |
|---|---|
| Sweep Max Hold | 16.50 µT |

| Centered | Top |
|---|---|
| Sweep Max Hold | 23.74 µT |

# 5 Appendix: Witricity Exposure Test Plan

# RF Exposure Testing of WiTricity Halo™ PV Wireless Power System for Golf Carts and Neighborhood Electric Vehicles (NEVs)

***Electromagnetic Field (EMF) Testing of Reference Levels in accordance with FCC's KDB 680106, attachment v04***

Version 1.0

# 1 Contents



# 2 Document Version History

| Version | Date | Editor(s) | Changes |
|---|---|---|---|
| v1.0 | 20-Feb-2024 | Ky Sealy | Original |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

# 3 Applicable documents

| Reference | Document |
|---|---|
| FCC WPT KDB | FCC KDB 680106 - 680106 Wireless Power Transfer (WPT) (fcc.gov) |
| FCC WPT KDB Attachment | FCC KDB 680106 attachment v04 - GetAttachment.html (fcc.gov) |
| IEEE C95.1-2019 | IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz |

# 4 Glossary

| | |
|---|---|
| CFR | Code of Federal Regulations (U.S.) |
| CW | Continuous Wave |
| DRL | Dosimetric Reference Limit |
| EHC | Environmental Health Criteria |
| ELF | Extremely Low Frequency |
| EMC | Electromagnetic Compatibility |
| ERL | Exposure Reference Level |
| FCC | Federal Communications Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISED | Canada's Innovation, Science and Economic Development department |
| KDB | Knowledge Data Base |
| NEV | Neighborhood Electric Vehicle |
| OEM | Original Equipment Manufacturer |
| PTV | Personal Transportation Vehicle |
| PV | Personal Vehicle |
| RF | Radio Frequency |
| WPT | Wireless Power Transfer |

# 5 Introduction

The WiTricity Halo™ PV wireless power system allows golf carts to be charged wirelessly. This includes Neighborhood Electric Vehicles (NEV), Personal Transportation Vehicles (PTV), Industrial vehicles, and golf cart fleets that have been enabled for wireless charging.

The system consists of a Power Hub with optional risers, a riser installation template, a wheel guide installation template, and a wheel guide.

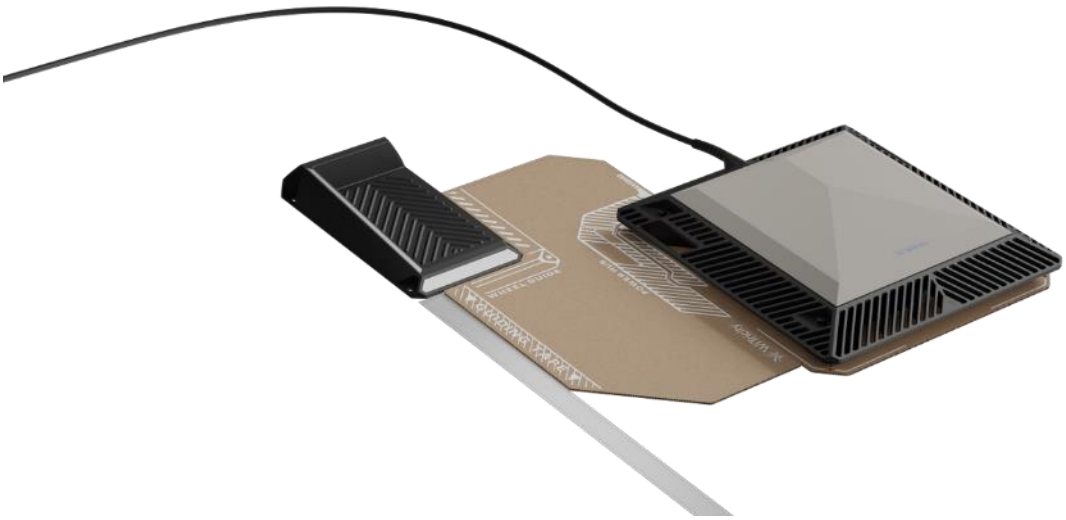


*Figure 1: Power Hub on risers, installation template, wheel guide, and alignment guiding tape*

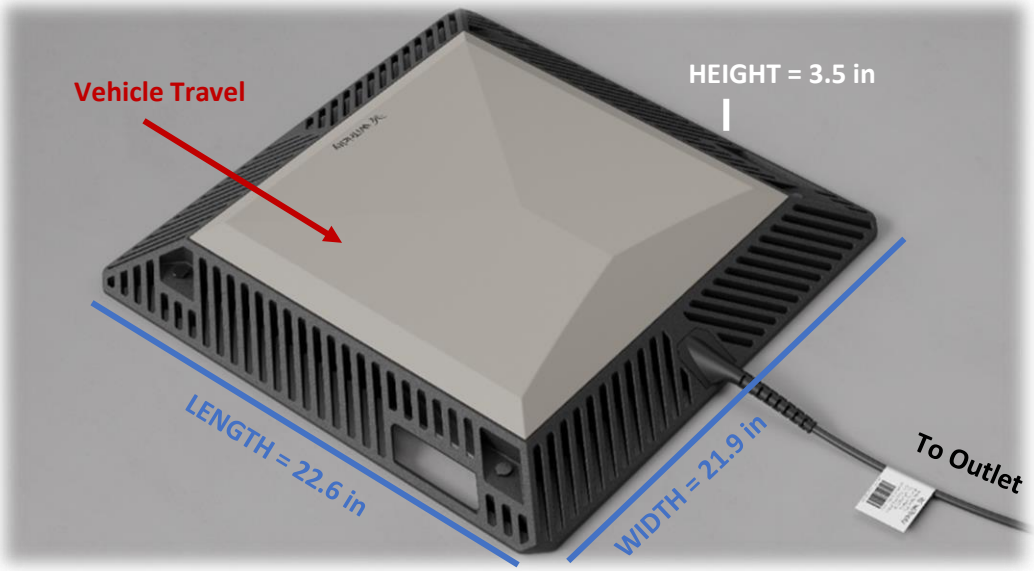



*Figure 2: Power Hub Detailed View*

Wireless power transfer occurs via a near-field magnetic field at a fixed frequency of 85 kHz operating using principles of magnetic resonance wireless power.

Operating instructions and installation details are provided in the WiTricity Halo ™ PV Power Hub User Manual. An excerpt of the specific RF Exposure warnings in the manual are provided below:

- Keep all cardiac implantable electronic devices, including pacemakers, more than roughly 16 inches (40 cm) from all parts of the Power Hub when powered on. Do not lay on or next to the Power Hub at any time. Medical devices such as pacemakers, defibrillators, and other implantable devices may contain sensors that respond to fields in close proximity. Consult with your physician and device manufacturer for more specific guidance.
- Maintain a minimum distance of roughly 8 inches (7.87 in or 20 cm) from the Power Hub at all times when plugged in.
- The Power Hub meets the requirements in IEEE C94.1-2019, Safety Levels for Human Exposure of Electromagnetic Fields when used in accordance with instructions.
- The Power Hub utilizes near-field radio frequencies at 85 kHz for wireless power transfer. The exposure reference level is tested at 7.87 inches (20 cm) or less from the Power Hub.
- Do not crawl under or place any body parts underneath the vehicle during charging.
- Do not attempt to move or adjust the Power Hub or any of its accessories while plugged in.

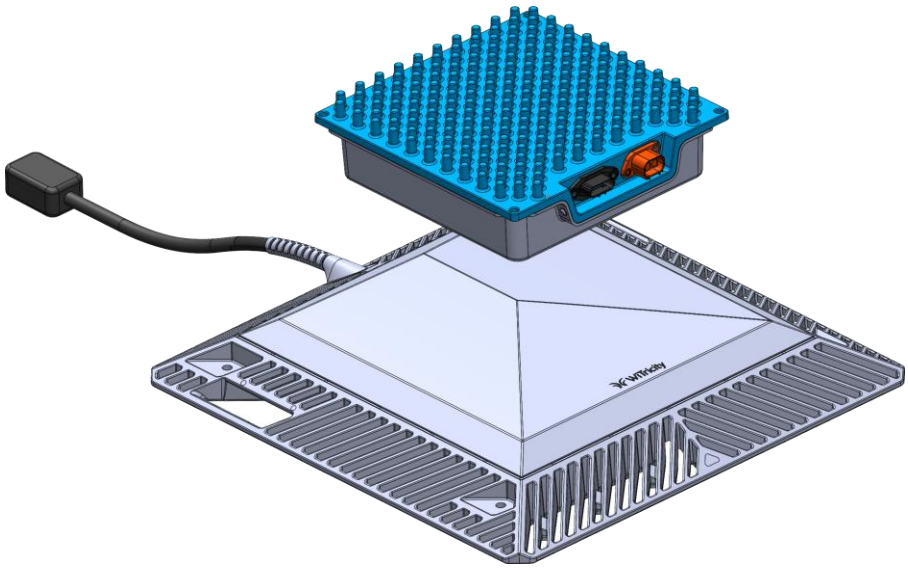


*Figure 3: Example of WiTricity Halo™ PV Receiver over the Power Hub*

*Figure 4: Example depiction of WiTricity Halo™ PV System on Golf Cart*

# 6 Executive Summary

This report discusses the detailed test procedures utilized in evaluating the RF exposure testing of the WiTricity Halo™ PV Wireless Power System for Golf Carts and Neighborhood Electric Vehicles (NEVs). Additionally, it provides information about RF exposure effects to magnetic fields below 100 kHz, discusses the rationale for the distance criteria used for testing, and provides insights into the reference levels used as a basis for exposure evaluation. For additional reference, the report also provides insights into the magnetic design and operation of the wireless power system.

The test procedures, measurement distances, measurement equipment, and reference levels utilized for testing of the WiTricity Halo™ PV Wireless Power System are all consistent with the requirements outlined in the *FCC's Wireless Power Transfer v04 attachment* to *KDB 680106 issued on October 24, 2023* [1].

# 7 Effects of Human Exposure to Magnetic Fields < 100 kHz

In 2007, the World Health Organization, with joint sponsorship by multiple other organizations, created the *Environmental Health Criteria 238* report on *Extremely Low Frequency Fields (EHC 238)* [2] addressing frequencies ranging from 0 Hz to 100 kHz. Regarding the interaction of the body with magnetic fields in this frequency range, it states in Section 1.1.2, "For magnetic fields, the permeability of tissue is the same as that of air, so the field in tissue is the same as the external field. The bodies of humans and animals do not significantly perturb the field. The main interaction of magnetic fields is the Faraday induction of electric fields and associated current densities in the conductive tissues."

*EHC 238 (section 1.1.12)* further indicates in its summary that no causal chronic health effects have been shown but rather, "Only the acute effects have been established…"; where an "acute

effect" (Glossary) is defined as, "Effect of short duration and occurring rapidly…following a single dose or short exposure to a substance or radiation." Regarding these acute effects, EHC 238, in section 12.2.2, establishes that in the extremely low frequency (ELF) range, "…magnetic fields can affect the nervous system of people exposed to them, resulting in … nerve stimulation, at very high exposure levels. …These acute effects on the nervous system form the basis of international guidelines. However, they are unlikely to occur at the low exposure levels in the general environment and most working environments."

IEEE C95.1-2019 [3], in section 1.3.3.2, also provides clearer and more direct language as to the known effects of exposure below 100 kHz: "Below 100 kHz, this standard protects against aversive or painful effects associated with electrostimulation, which has a characteristic response time that is much less than 1 s and exposures are thus assessed in terms of instantaneous fields or currents. … **Electrostimulation that might occur at the upper tier limit has no lasting adverse health effect.**" (bold emphasis added). In IEEE C95.1-2019, the upper tier refers to occupational limits which include a reduction factor of 3 over what 99% of the population would not even perceive. For general public exposure, an additional reduction factor of 3 (total 9 times) is applied for limbs and an additional factor of 9 (total 27 times) is applied for other tissues. The limits in IEEE C95.1-2019 include significant margins for both general public and occupational use cases.

The only known exposure risk for very strong magnetic fields below 100 kHz is electrostimulation (or nerve stimulation), which could result in a nerve tingling sensation when extremely high fields are present. However, standards that address this type of exposure provide extremely large safety margins to ensure this temporary causal effect does not occur whatsoever.

There are two general methodologies for ensuring compliance with RF Exposure standards: The first is a *Fundamental Requirement* and the second is a *Conservative Level Check*. The *Fundamental Requirement* method checks actual magnetic field impact to human tissue by means of tissue mimics (SAR for frequencies above 4 MHz) or by simulation (particularly for electrostimulation conditions < 100 kHz). The *Conservative Level Check* is based on assumptions that uniform whole body exposure occurs at a maximum magnetic field level and is therefore ultra-conservative since this practically never occurs for WPT (i.e., higher fields are very localized). The *Conservative Level Check* is easier to measure because standard free-space field instruments can be used to determine the field levels.

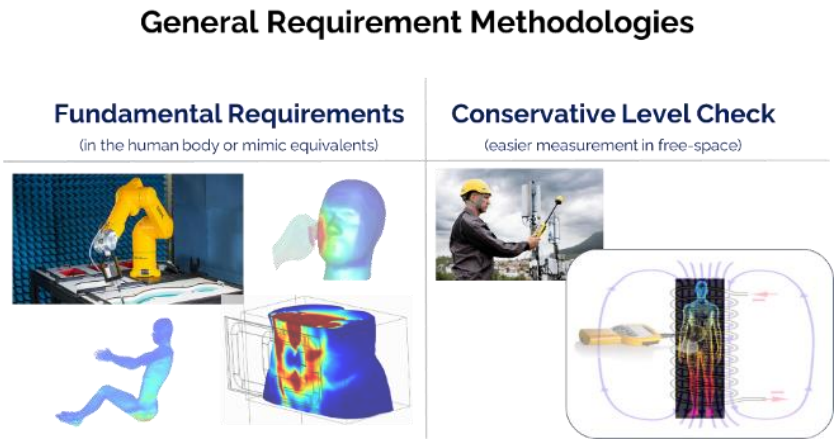



*Figure 5: General RF Exposure Measurement Methods*

Different RF Exposure guideline, standards, and texts refer to these methodologies differently. For example, the IEEE C.95.1-2019 standard refers to the fundamental requirement as a "Dosimetric Reference Limit (DRL)"; whereas it refers to the conservative levels as "Exposure Reference Level (ERL)". However, the FCC's regulations refer to a conservative level as "Maximum Permissible Exposure (MPE)" as discussed in Title 47 CFR §1.1310 [4].

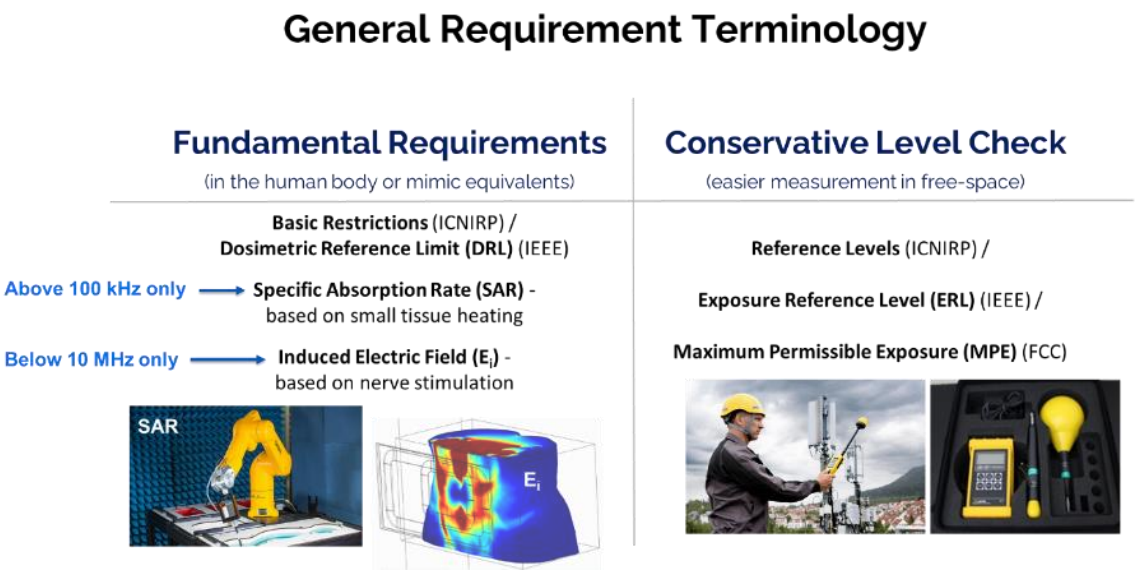



*Figure 6: General RF Exposure Terminology*

When considering the very conservative reference levels (based on whole-body uniform exposure), such as the ERLs in IEEE C95.1-2019, section 4.2.2.1 indicates, "Note that the ERLs … protect against adverse reactions associated with electrostimulation. … lack of compliance with [ERLs] does not necessarily indicate lack of compliance with the DRLs" [3].

The test procedures outlined in this document are intended to show conservative compliance with the reference levels indicated in the FCC KDB 680106 and IEEE's C95.1-2019 ERLs.

# 8 Background on Related RF Exposure Requirements

The U.S. Title 47 Code of Federal Regulations (CFR) provides related requirements for human RF exposure outlined in Parts §1.1307(b) [5], §1.1310 [4], §2.1091 [6], and §2.1093 [7] and these are also referenced by Part §18.313 [8]. However, within the CFR, there are no specific limit criteria provided for frequencies below 100 kHz and the MPE listings only cover from 300 kHz to 6 GHz. Despite this, it is clear the RF exposure should be considered in order to mitigate the temporary effects of nerve stimulation potential below 100 kHz (albeit they are non-chronic and sensational effects only). IEEE C95.1-2019 [3] provides appropriate details for this frequency range including DRLs and ERLs as previously discussed. Using Table 2 and Table 3 to calculate the conservative ERLs in IEEE C95.1, it is possible to determine the appropriate reference level at a frequency of 85 kHz (the WiTricity Halo™ Power Hub WPT Operating Frequency) as follows:

| IEEE C95.1-2019 ERLs, 3.35 kHz to 5 MHz | | |
|---|---|---|
| **Type and Body Part** | **B-Field** | **H-Field** |
| Unrestricted Head / Torso | 205 µT | 163 A/m |
| Unrestricted Limbs | 1.13 mT | 900 A/m |
| Restricted Head / Torso | 615 µT | 490 A/m |
| Restricted Limbs | 1.13 mT | 900 A/m |

*Table 1: IEEE C95.1-2019 Conservative ERLs from 3.35 kHz to 5 MHz*

It should be noted that these field magnitude values are provided for both the B-Field and H-Field. In free-space (e.g., open air) conditions, which is how these are measured, these values are related through the free-space magnetic permeability constant, $\mu_0$, where $\mu_0 = 4\pi \times 10^{-7}$ and $B = \mu_0 H$ for these conditions.

The unrestricted levels consider the general public who may be entirely unaware of an emission source or potential exposure in an open area. The restricted levels consider areas that are not in the general public environment. For example, it could be considered that the space underneath the vehicle is a restricted environment; whereas the space in and around the vehicle would be considered an unrestricted environment.

Interestingly, ISED Canada issued an updated *Supplementary Procedure for Assessing Compliance of Equipment Operating from 3 kHz to 10 MHz with RSS-102*, *SPR-002*, *Issue 2*, in October of 2022 [9] that considered wireless power transfer in this range of frequencies. In SPR-002, Issue 2, ISED provides their own set of conservative reference levels by which exposure can be evaluated as shown below:

| Canda's SPR-002, Issue 2, Reference Levels 3 kHz to 10 MHz (RMS) | | | |
|---|---|---|---|
| **Body Part** | **B-Field (translated from H-Field)** | **H-Field** | **Relaxation Factor** |
| Head / Torso | 113 µT | 90 A/m | 1.0 |
| Leg | 170 µT | 135 A/m | 1.5 |
| Arm | 283 µT | 225 A/m | 2.5 |
| Hand/foot | 565 µT | 450 A/m | 5.0 |

*Table 2: Canda's SPR-002, Issue 2, H-Field Reference Level Relaxation for Local Exposure*

While the U.S. Code of Federal Regulations doesn't provide MPE / reference level value below 300 kHz, it does distinguish between three different types of devices for radiation exposure evaluation; namely "fixed devices", "mobile devices", and "portable devices". The table below is derived in concept from the text found in 47 CFR §2.1091 [6], and §2.1093 [7]:

| U.S. CFR, Title 47 §2.1091(b) and §2.1093(b) RF Exposure Device Types | | |
|---|---|---|
| **Device Type** | **Description** | **Evaluation Distance** |
| Portable | Device not fixed and generally used in such a way that the RF source is within 20 cm of the user's body. | 0 cm |
| Mobile | Device is not fixed and generally used in such a way that the RF source has a separation of at least 20 cm from the user's body or nearby persons. | 20 cm |

| | | |
|---|---|---|
| Fixed | Physically secured device not easily moved while transmitting. | Application Dependent |
| Other | Per §2.1091(b), other cases such as modular or desktop that are not easily classified. | Application Dependent |

*Table 3: U.S. CFR Title 47, §2.1091(b) and §2.1093(b) RF Exposure Device Types*

Furthermore, the FCC has provided guidance in their attachment v04 to KDB 680106 [1] to indicate that a value of **90 A/m** is appropriate for assessment of any device operating below 100 kHz. Based on the aforementioned standards and reports, it is clear this value is extremely conservative and also incorporates consideration only for full body exposure (i.e., including head and torso) without separating restrictions or expectations that may be present and could allow relaxation for arms, legs, hands, and feet.

For the WiTricity Halo™ PV Wireless Power System, the Power Hub meets both the Fixed Device and Mobile Device definition per the CFR requirements; however, for purposes of additional conservancy, the device is tested as a **Mobile Device** using the 20 cm or less evaluation distance requirements even though the application would typically yield greater distances between a user and the system during operation.

## 8.1 FCC KDB 680106 RF Exposure Test Guidelines

For the purposes of compliance to the U.S. CFR and per the FCC's guidance in the v04 attachment to KDB 680106 [1], this section focuses on listing specific requirements indicated in Section 3, "RF Exposure Requirements" of the KDB. A bulleted summary list of these requirements (that relate to the WiTricity Halo™ PV WPT System is provided below:

- WPT devices must comply with RF exposure requirements for all design configurations in which they can operate. At a minimum, they must be evaluated for the worst-case scenario (typically maximum output power).
- RF exposure compliance for equipment authorization must follow guidance of KDB 447498 [10] [11].
    - Refers back to KDB 680106 for RF Exposure Limits below 100 kHz and related requirements.
    - Transmitters operating in consumer products must comply with general population exposure limits as applicable.
    - Device operating instructions and installation requirements must be consistent with chosen test configurations presented for compliance purposes.
    - User instructions for installation, OEM integration, or assembly by a third-party must be sufficiently clear and consistent for the target audience. The manufacturer is responsible for ensuring installers and integrators have a clear understanding of the compliance requirements.
    - For mobile devices operating in mostly stationary configurations and when a sufficiently large separation distance is inherent in the installation conditions, a simplified procedure may be used for assessing compliance following approval obtained via KDB.

- Any device operating at frequencies below 100 kHz is considered compliant when the external (unperturbed) temporal peak field strengths do not exceed the following reference levels: 83 V/m for the electric field strength (E) and **90 A/m** for the magnetic field strength (H).
    - HOWEVER, for "low-frequency" loop/coil emitting structures that lead to dominant H-field near-field emissions (E/H ratio less than 1/10 of the 377-ohm free space wave impedance, typically frequencies less than 1 MHz), **only H-field measurements are sufficient for demonstrating MPE limit compliance**. (Where E-Field refers to the electric field strength and H-field refers to the magnetic field strength).
- Field measurements should be made from all sides of the transmitter, along the principal axes defined with respect to the orientation of the transmitting element (e.g., coil). Symmetry considerations may be used to reduce the amount of testing.
- If the probe sensing element is more than 5 mm from the probe outer surface AND the positions are not reachable then estimated modeling is needed to determine the positions that are not reachable.
    - (Note: For the WiTricity Halo™ WPT System Test Procedures all positions are reachable, and in some cases a smaller field probe is used to show compliance at even smaller distances than 20 cm.)
- Manufacturers shall use the KDB Inquiry process to obtain FCC concurrence for the WPT device testing under "Equipment Compliance Review "(ECR) and "Wireless Power Transfer". Information on the WPT operating frequency, conducted power for the radiating structure, mobile vs portable demonstrated scenarios of operation, including RF exposure compliance information, and maximum distance from the WPT transmitter to which a load can be charged.

# 9 Test Plan Details for RF Exposure Compliance with FCC KDB 680106

## 9.1 Test Equipment for Measuring Magnetic Field

A Narda ELT-400 Field Probe [12] that is designed specifically for the purpose of exposure level testing is used to evaluate the magnetic field present at a given location. The field probe consists of a meter that provides B-Field readings up to 400 kHz and two options for detachable probes. The primary probe used for the majority of measurements consists of 3 internal loops each orthogonal to each other and each having an area of 100 cm$^2$ (internal loop radius, $r = \sqrt{\frac{100}{\pi}} \cong 5.64\ cm$). The outer protective shell of the 100 cm$^2$ probe has a diameter of 12.5 cm (radius = 6.25 cm). An alternative smaller probe has its internal loop areas set to 3 cm$^2$ (internal loop radius, $r = \sqrt{\frac{3}{\pi}} \cong 0.977\ cm$). The small probe outer shell diameter is 3.2 cm (radius = 1.6 cm).

The meter value (when set in the appropriate mode) provides the magnitude of the B-Field computed across all three orthogonal axes, $|B| = \sqrt{B_x^2 + B_y^2 + B_z^2}$ in micro-Tesla.

For purposes of testing the WiTricity Halo™ PV WPT System, the larger probe is primarily used to capture the most area on each side of the WPT system with a reasonable number of points (being spaced less than the internal probe radius). However, in several instances, the smaller probe is also used to determine field levels much closer to the source. The bounding boxes around the WPT system are adjusted by ~6.25 cm less to account for the large shell of the probe and ensuring that all measurements occur based on the center of the probe.

The settings used on the Narda ELT-400 for testing the WiTricity Halo™ PV WPT system are as follows:

- Mode = 320 µT
- Range = High
- Detection = RMS
- Display mode = Both Instantaneous & Max Hold values measured
- Cutoff = 30 Hz

These settings account for the dynamic range of the fields expected (to ensure no overload), maximize resolution, and are consistent with KDB 680106 [1] and IEC C95.1-2019 [3] requirements when considering that the magnetic field emission is a continuous wave (CW) sinusoidal emission.

The value on the meter read-out can be translated to the equivalent H-Field with the following formula $H = \frac{B}{\mu_0}$, where $\mu_0 = 4\pi \times 10^{-7}$, considering that the field measurements occur in open air (i.e., $\mu_r \cong 1$) . Pursuant to the guidance in KDB 680106, a measurement of only the magnetic-field is sufficient on the basis that the transducer is a near-field magnetic source operating at a low-frequency (i.e., 85 kHz), and therefore, the magnetic field component is by far dominant in the region of measurement.

## 9.2 Test Procedure for On-Vehicle Operation

### 9.2.1 Receiver Installation on Vehicle

The WiTricity Halo™ PV Receiver is mounted to the underside of the vehicle and always centered from side-to-side. Each vehicle is customized specifically with an appropriate mounting bracket and mechanical, electrical, communication interfacing, thermal, EMC, and RF exposure considerations are accounted for by coordinating between the vehicle OEM and WiTricity's engineering staff. For RF exposure considerations (and for thermal reasons), the Receiver is mounted with sufficient space between the floorboard (e.g., ≥ ~5 cm) and the heatsink of the Receiver. Some OEM floorboards have a thin aluminum plate or foil that further reduces field levels on the vehicle floor, and others utilize materials that do not perturb the magnetic field whatsoever. For each vehicle, a specialized cardboard template is provided to set the location of the wheel-guide relative to the Power Hub and thus the amount of positional variation seen by the WPT system is minimized.

For testing purposes, a vehicle was chosen that has undergone appropriate engineering evaluation and modification to support the WiTricity Halo™ PV WPT System. The floorboard of this particular vehicle is non-metallic and impervious to the magnetic fields and therefore demonstrates a worst-case field exposure condition into the vehicle.

On the vehicle used for testing, the Receiver is mounted such that there is ~ 5 cm space between the Receiver's heatsink and the bottom side of the floorboard. The bottom of the Receiver resides at a distance of 26 cm from the ground when the vehicle is unloaded (~25 cm loaded); however, the Power Hub is raised by 7 cm. This means that the effective operational distance between the base of the Power Hub and the bottom of the Receiver is ~18 cm loaded to 19 cm unloaded (resulting in internal coil-to-coil spacing of ~12-13 cm). For conservative testing, worst-case unloaded conditions are used.


*Figure 7: Receiver mounted on real vehicle with actual mounting hardware and Power Hub with 7 cm risers*

When determining the mounting bracket design for a given vehicle, in general, the height between the Power Hub base and the bottom of the Receiver is typically designed to sit at a distance of 18 – 19 cm unloaded for best all-around user experience. This also means that operation above 19 cm generally does not occur even though the units are tested for RF exposure up to 20 cm between the Power Hub base and Receiver bottom.

### 9.2.2 Test Procedure

In preparation for testing, the vehicle is prepared with the WiTricity Halo™ PV Receiver as it is designed for installation. The Power Hub has the vehicle-specific risers attached to it and a cardboard template is laid out to set the fixed relative position between the wheel guide and the Power Hub as indicated in the WiTricity Halo™ PV Power Hub user manual. The wheel guide and Power Hub are fixed into position for testing (though not semi-permanently as would be done in an end-application). Once the setup is ready for testing, the following are the test procedures for determining the magnetic field levels present for RF exposure evaluation:

1. The vehicle is driven into position with multiple attempts to purposefully misalign the Power Hub and Receiver into a near worst-case scenario (that would typically be unlikely) by driving the vehicle in odd conditions onto the wheel guide. The position used for

testing will be determined by the worst-case alignment offset position that still results in power transfer while the vehicle wheel is touching the wheel guide.

*Figure 8: Vehicle positioning off edge of wheel guide for purposeful misalignment*

2. A plexiglass stand is placed underneath the sides of the vehicle ~6.25 cm from the edge of the vehicle used as a reference for the 100 $cm^2$ Narda ELT-400 probe (i.e., large probe).
3. The qualified laboratory technician performs the following measurements and records them starting on the driver side of the vehicle:
    a. 5 measurements equally spaced from front-to-back, each at 3 different heights: ground, mid-way, vehicle underbody (resulting in 15 measurements on one side). Each measurement taken both with instantaneous values and maximum hold values. For purposes of recording the 0 location (front-to-back) is set at the center of the Receiver.
    b. The technician places the instrument in max-hold condition and slowly sweeps the entire side of the vehicle to find the maximum field value against the plexiglass and records this value.

*Figure 9: On-vehicle test with grid and plexiglass set so probe is centered at vehicle edge*

4. The technician then performs a similar sweep on the back side of the vehicle but using only 3 horizontal locations with the 3 vertical heights of the probe (resulting in 9 points of measurement). The instantaneous value and max-hold values are recorded for each point. A final slow-moving max-hold sweep across the entire vehicle rear is recorded. (Note: that plexiglass is not used for the back and front, but instead the technician places the probe reaching well underneath the vehicle in these conditions.)
5. The passenger side is also measured in the same way as the driver side of the vehicle.
6. The front side is also measured in the same way as the back side of the vehicle.

7. The plexiglass is moved all the way under the vehicle until it is touching the edge of the Power Hub. Both the passenger sides and the driver sides are measured in the same way but with the technician laying or sitting to reach the probe well under the vehicle and against the plexiglass (i.e., center of the large probe ~6.25 cm from the edge of the Power Hub).

*Figure 10: On-vehicle test with grid and plexiglass against the Power Hub*

8. The technician maps out a reasonable 5 x 5 grid across the inside floor of the vehicle and performs the same instantaneous and max-hold measurements. The technician also slowly moves the large probe across the entire floor in max-hold mode to obtain and record the very highest measurement and location.
9. The technician performs a slow sweep across the front driver seat, the front passenger seat, and across the entire back seat in max-hold mode to obtain and record the largest field on the seats.
10. The technician swaps to the smaller field probe (3 $cm^2$) and performs a slow max-hold sweep across the entire floor inside the vehicle to obtain and record the very highest field level directly against the floor.

## 9.3 Test Procedure for Standby Operation

In Standby operation, a vehicle nor a Receiver is present. In this condition, the Power Hub emits a very low CW field at short durations and low duty cycle. However, for purposes of correct measurement, the CW duration is increased in firmware to be greater than 1 second and a field light indicator placed on the Power Hub to show the technician when the field is present.

To prepare for this test, the large field probe is used, and a foam extension added to the field probe with a length of ~14 cm (~13.75 cm) so that the probe center resides 20 cm from the surface of the Power Hub.

*Figure 11: Field Probe Setup for Standby Measurements*

The technician performs the following test procedures:

1. 11 max-hold measurements are made and recorded from one corner of the Power Hub plastic to the other corner (with a spacing less than the radius of the field probe.
2. The same 11 measurements and recordings are made in the opposite diagonal.
3. 9 measurements and recordings are made front-to-back (spacing also less than the radius of the field probe).
4. 9 more measurements and recordings are made side-to-side.

All measurements cross through the center of the Power Hub (center of the coil).

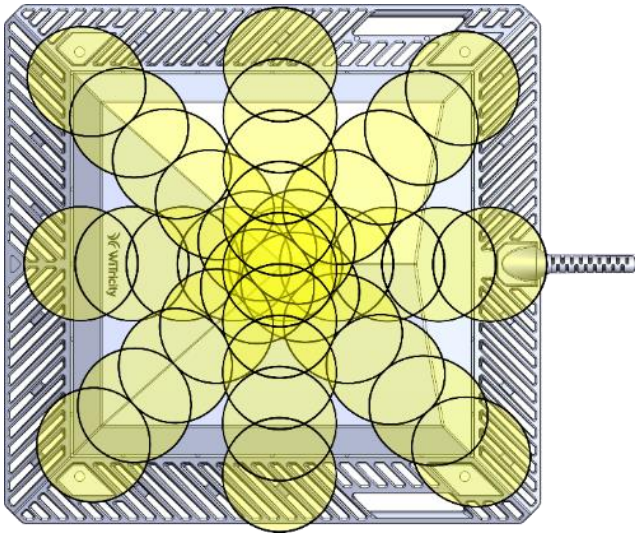


*Figure 12: To-Scale Representation of Probe Locations for Standby Measurements*

## 9.4 Test Procedure for Off-Vehicle Operation

The off-vehicle test with WPT operation is the most comprehensive and conservative set of tests to show compliance with FCC's KDB 680106 [1]. In this case, the WPT system is placed on a 100 cm foam stand-off (to ensure no impact on the magnetic field) and a plexiglass box is placed

directly on top of the Power Hub with the outer dimensions being 58.7 cm x 56.7 cm x 14 cm. The dimensions of the box are chosen to correspond with a tight fit around the Power Hub on all four sides, and then the height is chosen to set the minimum distance for power transfer. In all cases, the inner coil of the Power Hub is ≤ 13.75 cm from the plexiglass box. When the Narda ELT-400 100 $cm^2$ probe is placed directly up against the plexiglass box, it ensures that the center of the probe is ≤ 20 cm from the Power Hub internal coil and ≤ 6.25 cm from any part of the Power Hub.

A Plexiglass cover is also mounted directly on to the WPT Receiver, with the Receiver centered in the cover laterally and the heatsink of the Receiver being pressed directly against the plexiglass. The dimensions of the plexiglass box are 54.5 cm x 54.5 cm. The height of the plexiglass sides for the Receiver are inconsequential and set to merely prevent the probe from encroaching the area between; however, the Receiver's plexiglass sides are set so that the Receiver bottom is unencumbered and able to be set directly against the Power Hub's plexiglass box without interfering.

The Receiver's plexiglass therefore is ≤ 13.75 cm from any part of the Receiver's internal coil and thus ≤ 20 cm to the center of the Narda ELT-400 100 $cm^2$ probe during measurement. Of course, when the probe is placed on the top of the Receiver's cover, the probe edge is directly against the Receiver's heatsink and ~6.25 cm to the center of the large probe or ~1.6 cm to the center of the small probe.

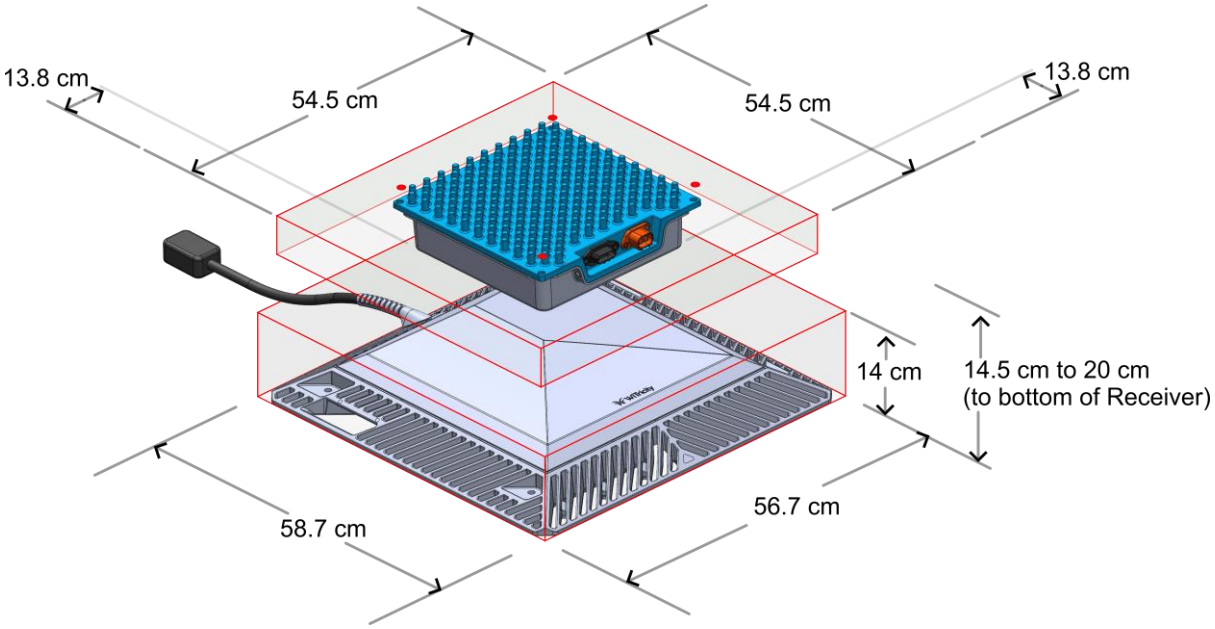



*Figure 13: Off-Vehicle Setup with Plexiglass for Measurement Grid Reference*

The Receiver's height and lateral position can be varied by using foam spacers and markings on the Power Hub's plexiglass that are pre-measured for quick setup. Three different conditions are measured to show the range of field levels that could be expected as follows (see Figure 19 and Section 10.1):

1. Lowest coupling condition with Receiver set at the maximum height and offset.
    a. Bottom of Receiver at 20 cm (Z height) from base of Power Hub heatsink.
    b. Center of Receiver offset by 5 cm in X and 5 cm in Y.

2. Highest coupling condition with Receiver set at the minimum height and centered on the Power Hub.
    a. Bottom of Receiver at 14 cm – 14.5 cm (Z height) from base of Power Hub heatsink.
    b. Center of Receiver and Center of Power Hub perfectly aligned.
3. A nominal coupling condition with the Receiver set at nominal height and centered on the Power Hub.
    a. Bottom of Receiver at 17 cm (Z height) from base of Power Hub heatsink.
    b. Center of Receiver and Center of Power Hub perfectly aligned.
    c. (Note: For this condition, the full grid of measurements is not taken on all sides but rather a slow max-hold sweep to obtain the largest value for each side.)

It can be validated that the worst-case condition for RF exposure is the lowest coupling condition where the Receiver is mounted at a height of 20 cm from the base of the Power Hub and offset by 5 cm in both X & Y. All measurements are performed with the maximum output current and power output capability of the system into an electronic load (to avoid changing load conditions of a battery) – being pre-verified as the worst-case condition by WiTricity.

For a measurement grid, the number of vertical and lateral measurements of each of the four sides is chosen to ensure that the grid spacing is less than the internal loop radius of the Narda ELT-400 100 $cm^2$ probe. This results in 12 measurements being performed laterally and 7 measurements vertically for each lateral position. The number of measurements and grid setup is chosen to ensure the center-most location of the setup is always a measurement. The setup condition details and measurement locations on all four sides are shown below.

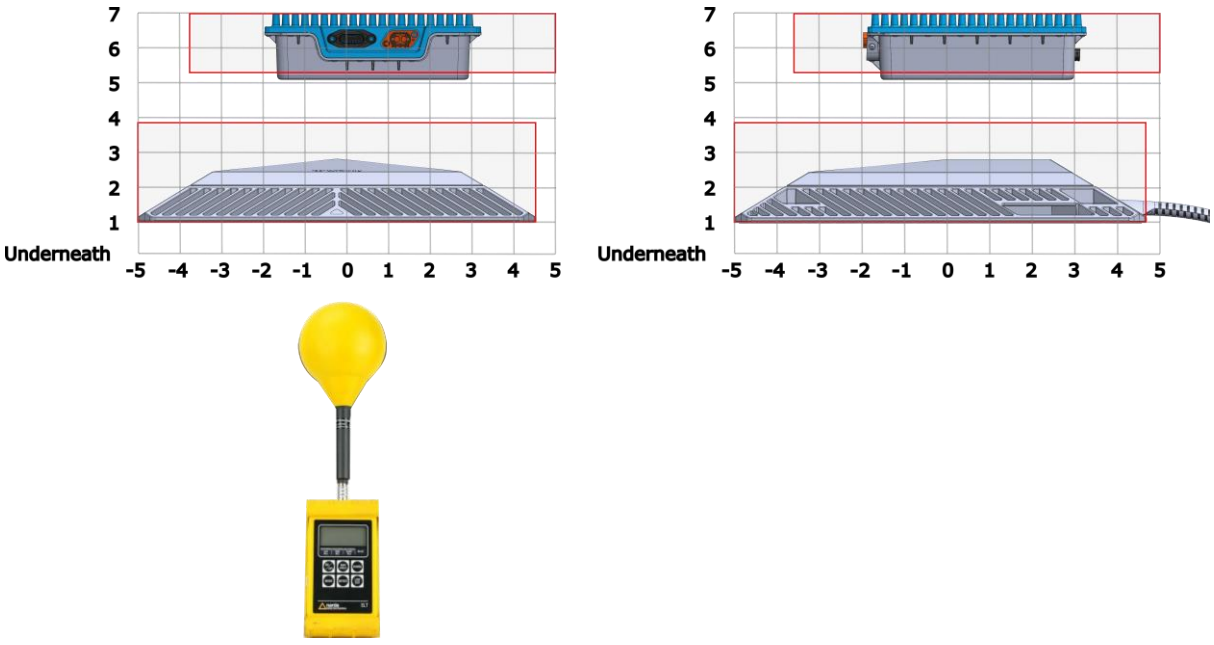



*Figure 14: Two sides shown with grid locations setup for lowest-coupling position. Everything is shown to scale.*

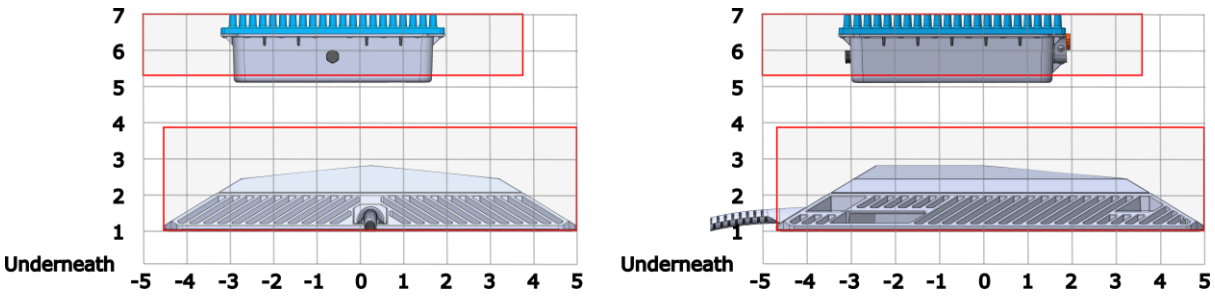



*Figure 15: Remaining two sides of the lowest-coupling position shown with grid locations for probe measurements.*

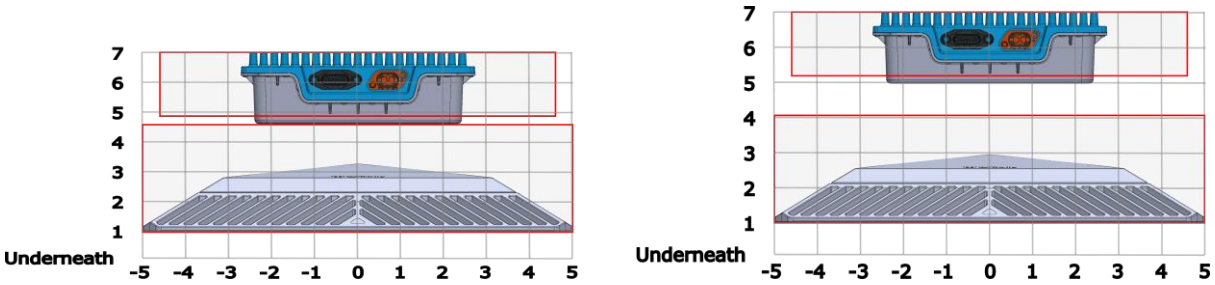



*Figure 16: Maximum-coupling (lowest height) - Left; and Nominal-coupling (17 cm height) - Right: One Side of Each*

For thorough coverage of the top of the WPT system, 15 measurements are made across each diagonal and 13 measurements are made front-to-back and side-to-side – all crossing the center.

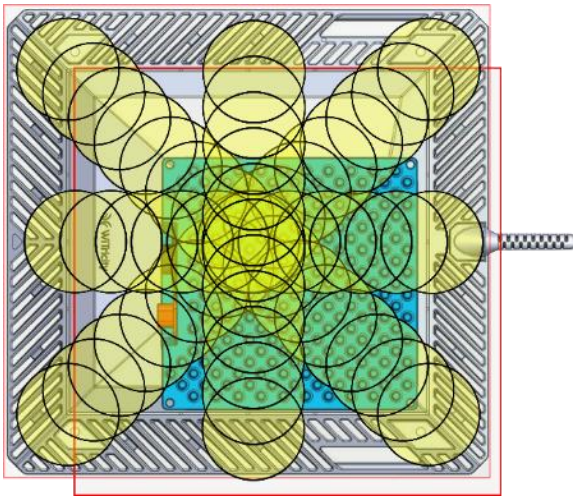


*Figure 17: Top-side Measurement Locations of Lowest-coupling Conditions with the ELT-400 100 cm² Probe Represented by Yellow Circles (to scale)*

The Test Procedure for the off-vehicle measurements (once fully setup and powered) is as follows:

Lowest Coupling / Maximum Height / Maximum Offset Condition:

1. Using the large probe, measurements are taken and recorded on the front side (cord side) with each measurement taken including the instantaneous and maximum-hold values at each position.
2. A slow sweep of the large probe across the entire front face is made in a max-hold mode and the value recorded.

3. Steps 1 and 2 are repeated for the driver side, back side, and passenger side of the off-vehicle system. In all cases, the probe is pressed directly against the plexiglass.
4. The large probe is positioned directly against the top side of the plexiglass (touching the Receiver heatsink) and the probe measurements are taken across each diagonal and across the WPT system center-to-center from front-to-back and side-to-side. All instantaneous and max-hold values are recorded for each position.
5. The large probe is swept across the entire top side slowly and the overall max-hold value is recorded.
6. Steps 4-6 are repeated on the top side with the small 3 $cm^2$ Narda ELT-400 probe and values recorded (to obtain measurements as close to the Receiver's heatsink as possible).

Highest Coupling / Minimum Height / Centered Condition:

- Steps 1-6 are repeated for the highest-coupling condition.

Nominal Coupling / 17 cm Height (from Power Hub heatsink base to Receiver bottom) / Centered Condition:

1. A slow sweep is made with the large probe across the front side of the WPT system with a maximum-hold and the value recorded.
2. Step 1 is repeated on the driver side, back side, passenger side, and top-side while being sure to cover every grid position in the max-hold condition and the value recorded.

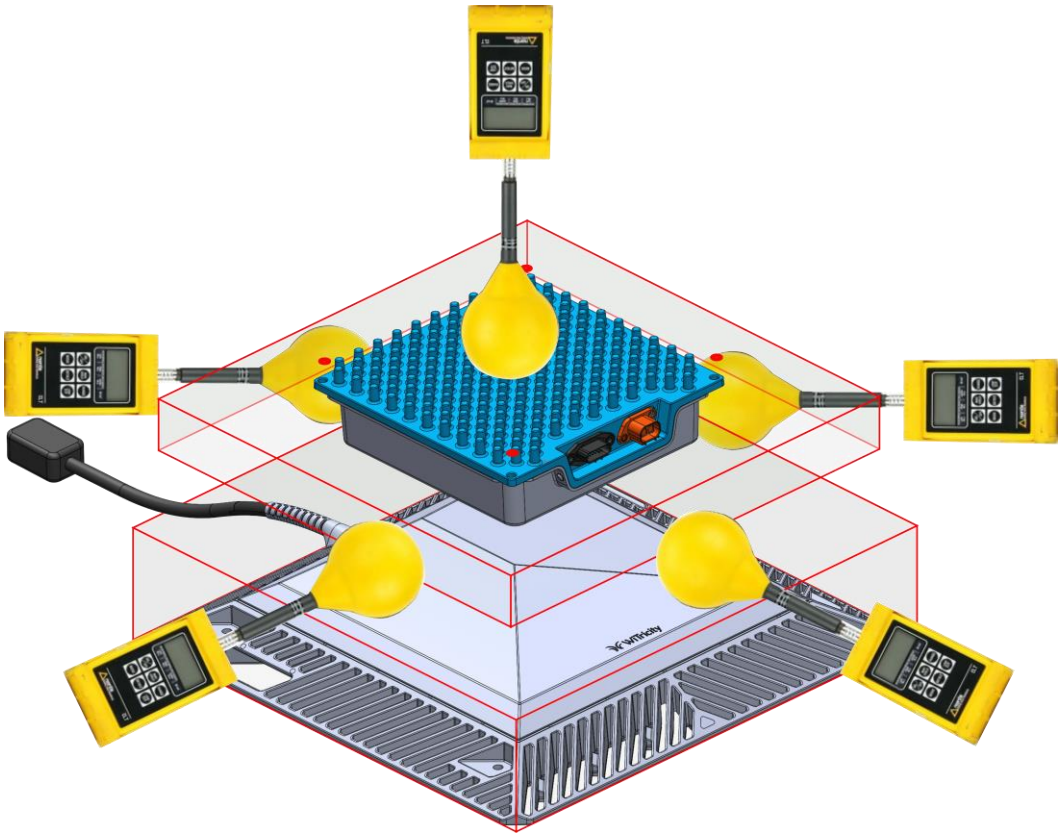


*Figure 18: WiTricity Halo™ PV WPT System Measurement of 5 Sides with Probes Shown to Scale.*

# 10 ANNEX – Supplemental System Information

## 10.1 WiTricity Halo™ PV WPT General System Operation

The WiTricity Halo™ PV wireless power system draws its power from a standard 120 VAC, 15+ A rated standard circuit and can provide up to 900 W output at the Receiver. The Receiver can be configured to operate between 36 V and 90 V to cover a variety of batteries (specific voltage range limited in configuration for a specific vehicle). The maximum current output allowed is 20 Amps under all conditions. For 900 W output, this means that the highest current and highest output power level occurs simultaneously when the output voltage is at 45 V (i.e., 45 V x 20 A = 900 W). Below 45 V, the output is limited by the 20 A current rating, and above 45 V, the output is limited by the 900 W output rating.

The Receiver coil current level (and hence localized field produced by the Receiver) is only dependent on the power output level because the internal voltage produced by the Receiver coil is held fixed (via out-of-band control communications) and the output conditioning (e.g., bucked voltage or boosted current) is produced by a localized high-efficiency DC-DC converter internal to the Receiver. This condition is true for all cases except for the lowest coupling condition, where the internal voltage produced by the Receiver coil decreases by no more than ~30% before power output must be reduced. The Power Hub Coil current is set by obtaining feedback from the Receiver but is limited by a maximum allowable value that restricts the maximum magnetic field produced by the Power Hub in any condition (maximized at a minimum coupling position).

The range of operation that is possible for power transfer is defined in 3D space with the origin being at the center of the Power Hub coil in the X and Y axes (geometric center of the Power Hub) and the zero point for the Z-axis being at the base of the Power Hub heatsink (without risers). In this case, the allowable Z-offset from the base of the Power hub to the bottom of the Receiver is from 150 mm to 200 mm. The allowable Z-offset in the X and Y axes can simultaneously be +/- 50 mm (noting that both the Power Hub Coil and the Receiver Coil are symmetric in X and Y). For testing purposes, the highest coupling condition has been tested down to 140 mm or 145 mm in the Z-axis (i.e., X,Y,Z = 0 mm, 0 mm, 140 mm – 145 mm) when possible; however, under these conditions, the system become severely limited in its operation. The lowest coupling position thus occurs at the largest height and offset of X,Y,Z = 50 mm, 50 mm, 200 mm and is shown to produce maximum exposure fields under this condition (with all other conditions being less).

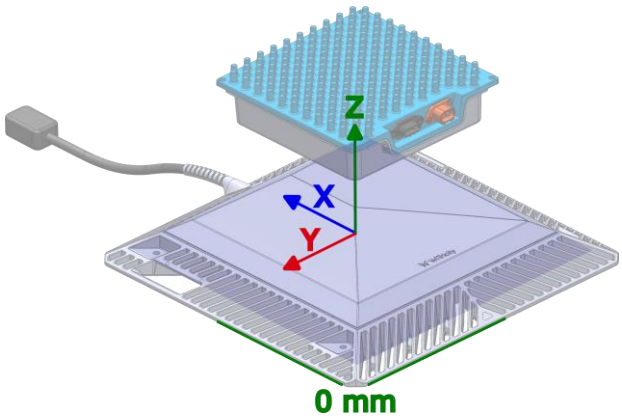



*Figure 19: Relative Coordinate System*

The Power Hub provides the localized magnetic field for transferring power to the vehicle's Receiver using a fixed frequency operating at 85 kHz in an unmodulated continuous wave (CW) sinusoid. The details of the magnetic transducers (i.e., Power Hub coil and Receiver coil) can be found in Annex 10.2. All transitions for changes to the magnetic field are overdamped and limited by the Power Hub and Receiver coil current limitations that are restricted both by firmware and hardware limitations.

When there is no Receiver directly coupled to the Power Hub (within the positional requirements above), the Power Hub is in a Standby mode. In Standby, a very low field is emitted from the Power Hub in short durations at a very low duty cycle. The field levels in Standby are well below exposure requirements at 20 cm even though interaction with the device at this distance is unlikely.

All communications between the Power Hub and the Receiver are performed over out-of-band communications using the 2.4 GHz band with transceivers operating in a proprietary mode compliant with FCC's Title 47, Part 15c requirements. The Receiver and its 2.4 GHz radio are powered only by the Power Hub (i.e., no vehicle auxiliary power to maintain the Receiver) therefore, the Power Hub will only increase its current beyond the Standby conditions when a Receiver is directly over the Power Hub and within WPT operating range.

When the WiTricity Halo™ PV Wireless Power Receiver is installed on the vehicle, it is always installed in the center left-to-right / driver-to-passenger sides. The position of the Receiver on each vehicle may differ front-to-back, but it will always be installed in a condition that ensures more than 20 cm of the vehicle is around the Power Hub (and usually substantially more). From an operational point of view, standard vehicle tires are around 8 inches (20 cm) in width, and the tires must be able to completely clear the Power Hub (with margin) for it to be a viable product on that vehicle; this implies that from the outermost edges of the Power Hub to the edge of the vehicle will always be greater than 8 inches (20 cm).

### 10.1.1 Summary of information requested in KDB 680106 for the WPT System

- **WPT Operating Frequency:** 85 kHz (fixed frequency)
- **Conducted Power for Each Radiating Structure:** The operation of the WPT system is in the near-field therefore, technically the field level is proportional only to Power Hub's coil current and independent of the power level. However, for purposes of operation, the field level is only ever at maximum condition when the maximum distance and offset of operation are applied and maximum power output is required. The **maximum power output is 900 W from the Receiver**. However, when considering localized losses in the Receiver (e.g., rectification, DC-DC conversion, quiescent power, etc.), and also losses in both the Power Hub and Receiver coils, the amount of power provided from the local inverter inside the Power Hub to the Power Hub coil can reach up to ~1000 W.
- **Mobile or Portable Scenarios of Operation and RF Compliance Information:** The WiTricity Power Hub™ WPT System can be considered either a fixed device or a mobile device given the distance in which the user interacts with the system are greater than 20 cm from the WPT coils. For purposes of conservative testing, the WPT system is considered a **Mobile Device**. There are two primary operating conditions namely Standby and WPT Operation. In Standby, a very low field is emitted from the Power Hub in short durations at a very low duty cycle. Exposure requirements for Standby conditions are easily met at 20 cm (irrespective of the duration and duty cycle –

considering only the continuous maximum field level). The Power Hub is typically bolted or affixed with semi-permanent adhesive to a concrete or asphalt floor where the vehicle will be parked regularly. For WPT Operation, a corresponding WiTricity Halo™ PV Receiver must be present and mounted to the underside of a vehicle in accordance with the manufacturer's instructions (i.e., centered left-to-right on the vehicle and well beneath the vehicle underbody). During WPT Operation, the area near the Power Hub is always restricted by the vehicle itself. Instructions are provided in the WiTricity Halo™ PV User Manual further confirm that a separation distance of 20 cm is to be maintained.

- **Maximum Distance from the WPT transmitter at which, by design a load can be charged (including slow-charging operations):** The maximum distance between the internal coil of the Power Hub to the internal coil of the Receiver is 14 cm and a maximum offset at that distance for which power can be delivered is ±5 cm in both lateral and horizontal directions. The specifications for the WiTricity Halo™ PV WPT system use a different datum however for simplicity. In the specifications, the datum is located at the base of the Power Hub (see pictorial representation) but still centered laterally with respect to the coil and the entire Power Hub. Since the internal Power Hub coil surface sits at 6 cm, the maximum WPT height is represented as being 20 cm, which is the distance from the ground to the Receiver when the Power Hub sits flush on the ground. It should be noted that the Receiver is only powered by the Power Hub (no auxiliary or back-up power) and therefore, the Power Hub will not exceed its Standby conditions unless a Receiver is directly coupled (i.e., vehicle covering the Power Hub) and communicating through an out-of-band 2.4 GHz radio certified under FCC Part 15c.

## 10.2 WiTricity Halo PV WPT Magnetic Field Transducer Details

### 10.2.1 WiTricity Halo PV Power Hub Coil

The top of the Power Hub coil sits at ~6 cm from the metal heatsink base of the Power Hub. It is covered by a strong plastic cover that does not affect the magnetic field in any way. Basic information about the Power Hub coil can be seen in Figure 20 and Figure 21 below.

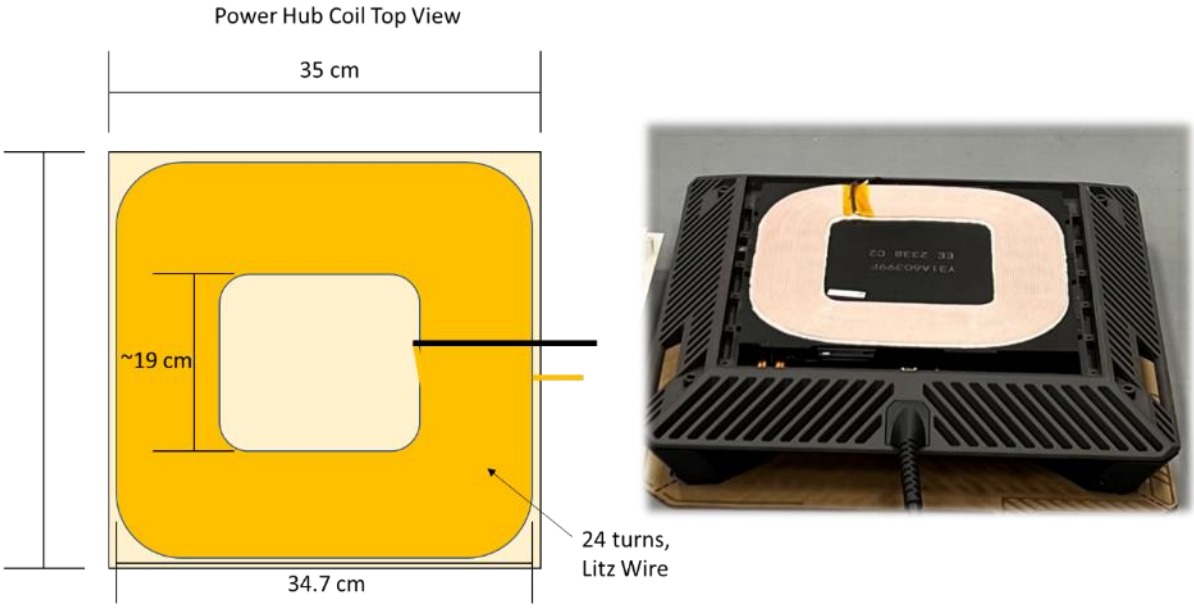



*Figure 20: Power Hub Internal Coil Top View*

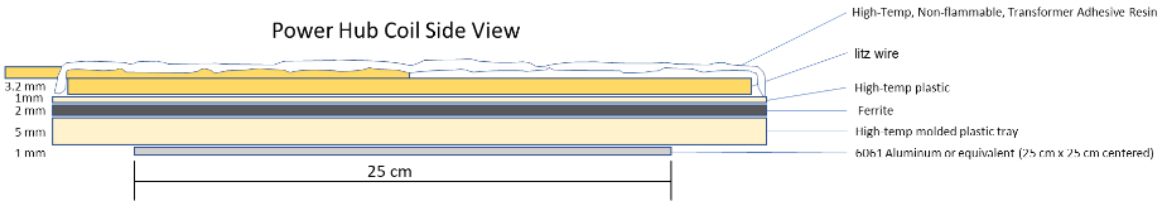



*Figure 21: Power Hub Internal Coil Side View / Stack-up*

As can be seen from the information provided, the Power Hub presents a dominant near-field magnetic field at 85 kHz; and therefore, pursuant to the guidance in the attachment to KDB 680106, only the magnetic field component needs to be measured.

### 10.2.2 WiTricity Halo PV Receiver Coil

The Receiver coil is facing so that the litz wire is pressed directly inside the Receiver's plastic enclosure and this is potted with a non-magnetic material. Basic information about the Receiver coil can be seen in Figure 22 and Figure 23 below.

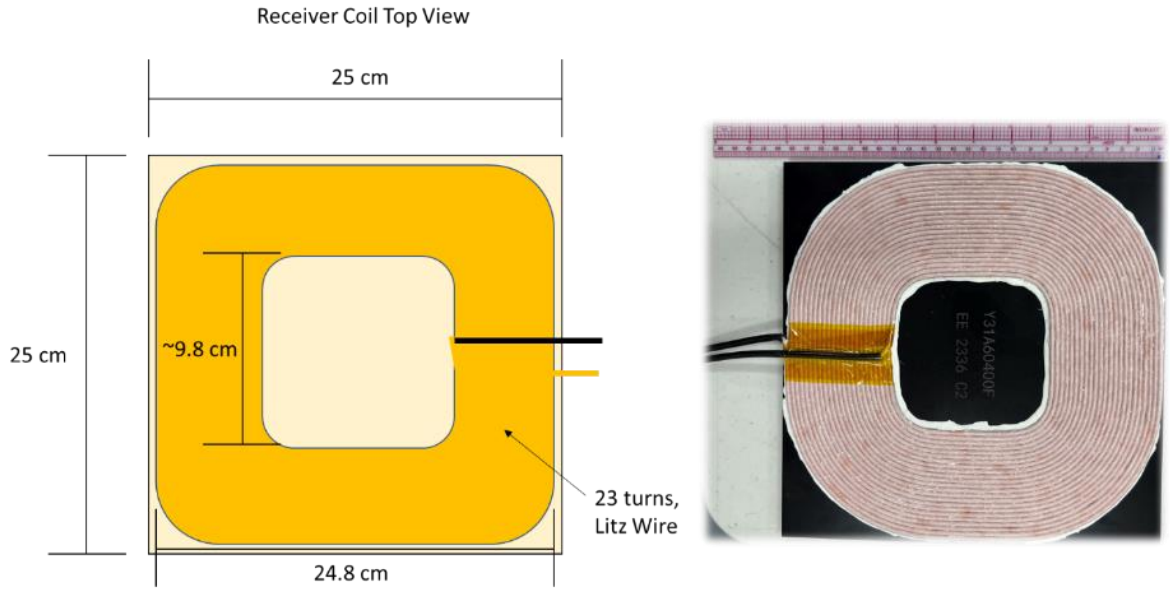



*Figure 22: Receiver Internal Coil Top View*

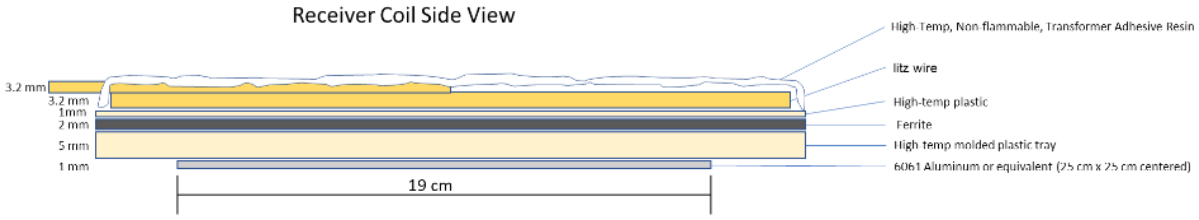



*Figure 23: Receiver Internal Coil Side View / Stack-up*

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