# Intel® Model: 13110NGW

# FCC ID: PD913110NG

# IC:1000M-13110NG

Intel® Model 13110NGW Embedded Inside an HTC Virtual Reality (VR), Model 2Q4L100

WiGig Subsystem with RFEM 3

***4 April 2018***

Simulations and Measurements Comparisons and Compliance Descriptions Report ***Revision 1.3***

# Contents



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# List of Abbreviations

**Table 1 – Abbreviations**

| Abbreviation | Definition |
|---|---|
| Ant | Antenna |
| Az | Azimuth |
| BB | Base Band |
| BF | Beam Forming |
| BT | Bluetooth |
| BW | Bandwidth |
| CPU | Central Processing Unit |

| Abbreviation | Definition |
|---|---|
| El | Elevation |
| EM | Electro-Magnetic |
| GHz | Gigahertz |
| IF | Intermediate Frequency |
| MAC | Media Access Control |
| M.2 | M2: Formerly known as Next Generation Form Factor (NGFF); used as specification for connectors of the expansion cards mounted on computer |
| mm-Wave | Millimeter Wave |
| PC | Personal Computer |
| PCIe | Peripheral Component Interconnect Express; a PCI Special Interest Group standard |
| R&D | Research and Development |
| RF | Radio Frequency |
| RFEM 3 | Third-generation Radio Front End Module |
| RFIC | Radio Frequency Integrated Circuit |
| RX | Receive |
| SKU | Stock Keeping Unit, specific product model version |
| SoC | System-on-Chip |
| TDM | Time Division Multiplexing |
| TPC | Transmit Power Control |
| T/R SW | Transmit/Receive Switch |
| TX | Transmit |
| WiGig | Wireless Gigabit Alliance – the alliance that promoted the 60GHz into 802.11ad standard. |

## Terms and Definitions

- **Sub-array:** A predefined group of radiating elements that are excited simultaneously with same amplitude and possibly different phases. There are three Sub-arrays, and each one of them includes between 10 to 12 of the 24 elements of RFEM 3. The Sub-arrays are also called Sub-Arrays.

# 1 Document Scope

## 1.1 Introduction

This document is submitted to support the compliance with the FCC rule located in Title 47 of the Code of Federal Regulations (CFR), parts §2.1093 and §15.255(g), of Intel 13110NGW WiGig module (FCC ID: PD913110NG, IC: 1000M-13110NG), including two separate active antenna arrays, embedded inside the HTC VR HMDA model 2Q4L100.

Per the location of the active RFEM 3 antenna arrays (RFEM 3-A and RFEM 3-B) in the Intel 13110NGW module embedded inside the VR HMDA model 2Q4L100, the distance between the RFEM 3 arrays to the head or body of an end user, at the closest contact point, may be in the near field.

The determination of the near-field average power density is performed using EM simulations and a near field measurements. EM simulations that include the RFEM 3 arrays model embedded inside the VR HMDA model 2Q4L100 is used to determine subsets of the worst case configuration and the correspondent near field power density.

Due to the range of variations and uncertainty introduced by measurement and simulation, both results are applied to supplement each other, to establish conservative compliance information at the evaluation surfaces.

The simulation method and the simulation results are described in the document [3]. The near field measurement system details are described in the document [2] and the comparison between simulation and measurement are shown in this document.

## 1.2 Associated documents

This 'Simulations and Measurements Comparisons and Compliance Descriptions Report' and documents called reference [2] and [3] are not confidential; relevant details and explanations that qualify for confidentiality are included separately in the operational description document called reference [1].

[1] 180215-VR HTC VIVE - Theory of Operation Report

[2] 180215-VR HTC VIVE - Near Field Measurement Report

[3] 180215-VR HTC VIVE - MPE Simulation Report

# 2 Near-Field Measurements Supporting the RF Exposure Power Density Simulations

## 2.1 Introduction

This section presents the near-field power density measurement performed using the worst-case antenna phases found by simulation. This near-field measurement supports the simulation presented in [2]. Indeed, because the distance between the evaluation planes to the device edge is greater than 2 mm with avoiding measurement issues, the comparison between simulation and measurement is performed in the evaluation plane.

A near-field RF exposure system from SPEAG is used to perform these measurements.

## 2.2 Probe characteristics

The probe consist of two dipoles (0.8 mm length) optimally arranged with different angles (γ1 and γ2) to obtain pseudo-vector information, printed on glass substrate protected by high density foam that allows low perturbation of the measured field.

Three or more measurements are taken for different probe rotational angles, deriving the amplitude and polarization information.

The probe's characteristics are illustrated in Table 2.

**Table 2 – Near-field probe characteristics**

| | |
|---|---|
| **Frequency Range** | **750 MHz – 110 GHz** [1] |
| **Length** | 320 mm |
| **Probe tip external diameter** | 8 mm |
| **Probe's two dipoles length** | 0.9mm – Diode loaded |
| **Probe's substrate** | Quartz 0.9 x 20 x 0.18mm ($\varepsilon r$=3.8) |
| **Distance between diode sensors and probe's tip** | 1.5 mm |
| **Axial Isotropy** | ±0.6 dB |
| **Maximum operating E-field** | 3000 V/m |
| **Lower E-field detection threshold** | 5 V/m @ 60 GHz |
| **Minimum Mechanical separation between probe tip and a Surface** | 0.5mm |
| **Calibration reference point** | Diode Sensor |

More details about the measurement system are found in reference [2].

[1] *The probe calibration range is 750 MHz – 90 GHz*

## 2.3 Total field and power flux density reconstruction

Computation of the power density in general requires knowledge of the electric (E-) and magnetic (H-) field amplitudes and phases in the plane of incidence. Reconstruction of these quantities from pseudo-vector E-field measurements is feasible, as they are constrained by Maxwell's equations.

The reconstruction algorithm developed by the system manufacturer, together with the ability of the probe to measure extremely close to the source without perturbing the field, permits reconstruction of the E- and H-fields as well as of the power density on measurement planes located as near as 2 mm away (0.5 mm from probe tip) in the frequency band of 60 GHz.

The average of the reconstructed power density is evaluated over a circular area in each measurement plane. The area of the circle is defined by the user; the default is 1 $cm^2$.

## 2.4 Measurement configurations

The near field measurement is performed on the six following worst case selected from the 72 calculated worst cases (3 channels x 3 sub-arrays x 2 first worst-cases x 4 evaluation planes) showed in reference [3]. The test configurations are summarized in Table 3.

**Table 3 – Test configurations**

| Measured Worst-Case | Simulated Worst-Case | Evaluation Plane [2] | Sub-Array | Channel | Worst-Case | Sim. Phase config.[3] | Meas. Phase Config. |
|---|---|---|---|---|---|---|---|
| Case 1# | Worst Case #1 | EpB | 3 | 1 | 1 | Ph2 #7 | Ph-c #1 |
| Case 2# | Worst Case #2 | EpB | 3 | 2 | 1 | Ph2 #8 | Ph-c #2 |
| Case 3# | Worst Case #5 | EpA | 2 | 3 | 1 | Ph1 #6 | Ph-c #3 |
| Case 4# | Worst Case #1 | EpA1 | 1 | 1 | 1 | Ph3 #1 | Ph-c #4 |
| Case 5# | Worst Case #3 | EpB1 | 1 | 1 | 1 | Ph4 #1 | Ph-c #5 |
| Case 6# | Worst Case #4 | EpB1 | 1 | 2 | 1 | Ph4 #2 | Ph-c #6 |

The phase' configurations of the six measured worst cases listed in the table above are shown in Table 4.

[2] *See Table 12 in [3] for EpA and EpB evaluation planes and Table 21 in [3] for EpA1 and EpB1 evaluation planes.*
[3] *Phase's configuration listed in [3]*

### Table 4 – Phase' configurations of the measured worst cases

| Meas. Phase Config. | Ph-c #1 | Ph-c #2 | Ph-c #3 | Ph-c #4 | Ph-c #5 | Ph-c #6 |
|---|---|---|---|---|---|---|
| Sim. Phase Config. | **Ph2 #7** | **Ph2 #8** | **Ph1 #6** | **Ph3 #1** | **Ph4 #1** | **Ph4 #2** |
| Ant. Index | | | | | | |
| 1 | 270 | 270 | - | - | - | - |
| 2 | 0 | 270 | - | - | - | - |
| 3 | 180 | 180 | - | - | - | - |
| 4 | - | - | 180 | - | - | - |
| 5 | - | - | 90 | 180 | 0 | 0 |
| 6 | - | - | 180 | 180 | 0 | 0 |
| 7 | - | - | - | 90 | 270 | 180 |
| 8 | - | - | - | 180 | 0 | 270 |
| 9 | - | - | 0 | - | - | - |
| 10 | - | - | 270 | - | - | - |
| 11 | - | - | 270 | - | - | - |
| 12 | - | - | 0 | - | - | - |
| 13 | 180 | 90 | 0 | - | - | - |
| 14 | 90 | 90 | 90 | - | - | - |
| 15 | 0 | 270 | 90 | - | - | - |
| 16 | 180 | 180 | 0 | - | - | - |
| 17 | - | - | - | 270 | 180 | 180 |
| 18 | - | - | - | 90 | 0 | 0 |
| 19 | - | - | - | 270 | 180 | 180 |
| 20 | - | - | - | 180 | 90 | 0 |
| 21 | 180 | 180 | - | 180 | 0 | 270 |
| 22 | 90 | 90 | - | 0 | 180 | 90 |
| 23 | 270 | 270 | - | 180 | 0 | 270 |
| 24 | 0 | 0 | - | 180 | 0 | 270 |

## 2.5 Measurement results

Tables below show the comparison between simulation and measurement for the measured worst-cases at the evaluation plane. Simulation and measurement are both peak phasors. All results are calculated at 100 % duty cycle.

**Table 5 - Case 1#: EpB - Simulation vs. test results at 0 mm.**

| | Measurement Distance (mm) | Simulated | Measured | Max. Deviation (dB) |
|---|---|---|---|---|
| E-field (V/m) | 0 mm | 148.490 | 136.794 | 0.713 |
| H-field (A/m) | 0 mm | 0.408 | 0.415 | 0.145 |
| Single-point PD (mW/cm$^2$) | 0 mm | 4.494 | 2.697 | 2.217 |
| Average PD (mW/cm$^2$) | 0 mm | 1.006 | 0.754 | 1.252 |

**Table 6 - Case 2#: EpB - Simulation vs. test results at 0 mm.**

| | Measurement Distance (mm) | Simulated | Measured | Max. Deviation (dB) |
|---|---|---|---|---|
| E-field (V/m) | 0 mm | 142.226 | 138.181 | 0.251 |
| H-field (A/m) | 0 mm | 0.387 | 0.534 | 2.798 |
| Single-point PD (mW/cm$^2$) | 0 mm | 3.407 | 2.680 | 1.042 |
| Average PD (mW/cm$^2$) | 0 mm | 0.997 | 0.903 | 0.432 |

**Table 7 - Case 3#: EpA - Simulation vs. test results at 0 mm.**

| | Measurement Distance (mm) | Simulated | Measured | Max. Deviation (dB) |
|---|---|---|---|---|
| E-field (V/m) | 0 mm | 105.568 | 107.186 | 0.132 |
| H-field (A/m) | 0 mm | 0.300 | 0.419 | 2.919 |
| Single-point PD ($mW/cm^2$) | 0 mm | 2.000 | 1.567 | 1.061 |
| Average PD ($mW/cm^2$) | 0 mm | 0.762 | 0.807 | 0.246 |

**Table 8 - Case 4#: EpA1 - Simulation vs. test results at 0 mm.**

| | Measurement Distance (mm) | Simulated | Measured | Max. Deviation (dB) |
|---|---|---|---|---|
| E-field (V/m) | 0 mm | 116.679 | 109.482 | 0.553 |
| H-field (A/m) | 0 mm | 0.347 | 0.408 | 1.408 |
| Single-point PD ($mW/cm^2$) | 0 mm | 2.354 | 1.967 | 0.779 |
| Average PD ($mW/cm^2$) | 0 mm | 0.999 | 0.540 | 2.671 |

**Table 9 - Case 5#: EpB1 - Simulation vs. test results at 0 mm.**

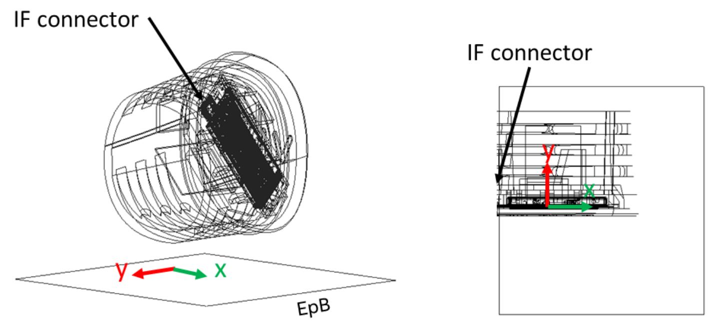
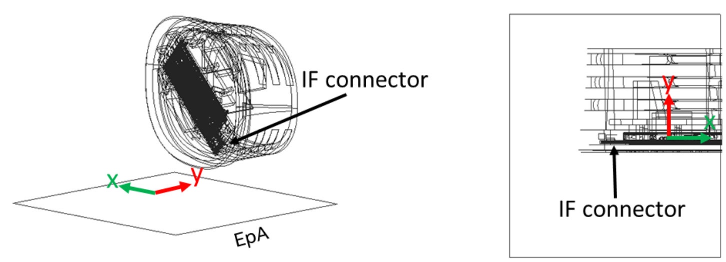
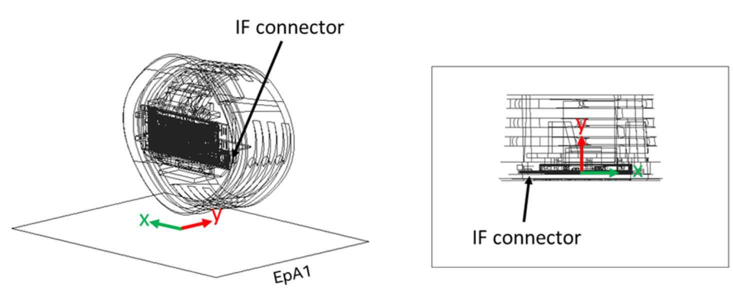
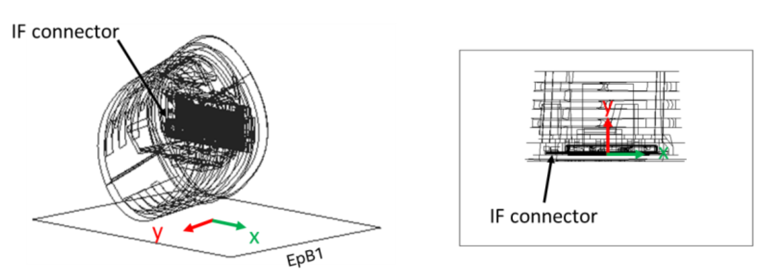
| | Measurement Distance (mm) | Simulated | Measured | Max. Deviation (dB) |
|---|---|---|---|---|
| **E-field (V/m)** | 0 mm | 117.887 | 135.105 | 1.184 |
| **H-field (A/m)** | 0 mm | 0.338 | 0.462 | 2.704 |
| **Single-point PD ($mW/cm^2$)** | 0 mm | 2.144 | 2.488 | 0.646 |
| **Average PD ($mW/cm^2$)** | 0 mm | 0.962 | 0.853 | 0.523 |

**Table 10 - Case 6#: EpB1 - Simulation vs. test results at 0 mm.**

| | Measurement Distance (mm) | Simulated | Measured | Max. Deviation (dB) |
|---|---|---|---|---|
| **E-field (V/m)** | 0 mm | 120.221 | 156.873 | 2.311 |
| **H-field (A/m)** | 0 mm | 0.322 | 0.438 | 2.670 |
| **Single-point PD ($mW/cm^2$)** | 0 mm | 2.624 | 2.652 | 0.045 |
| **Average PD ($mW/cm^2$)** | 0 mm | 0.944 | 0.950 | 0.027 |

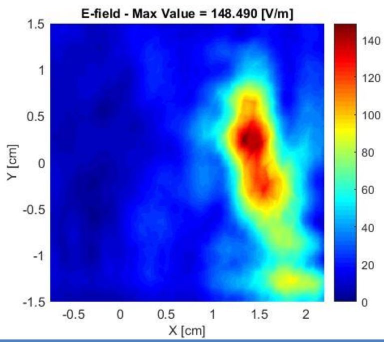
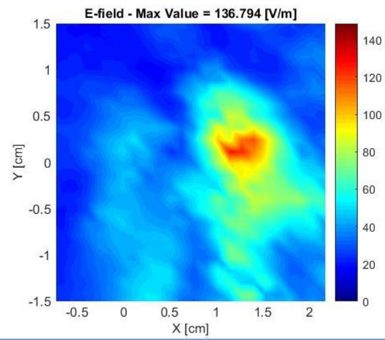
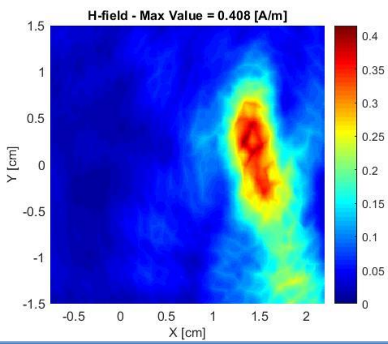
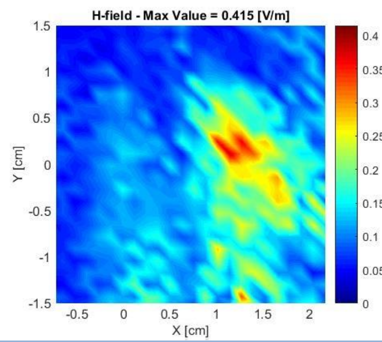
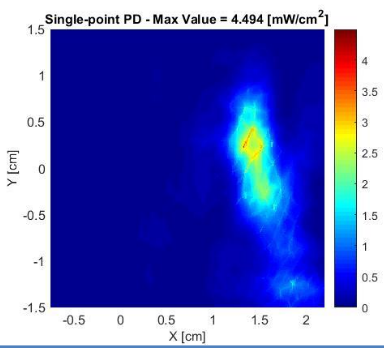
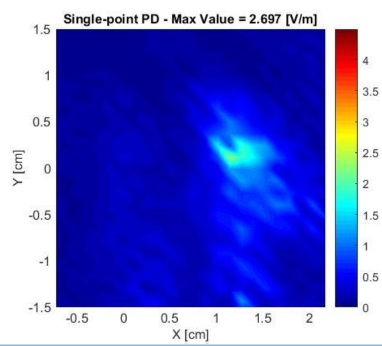
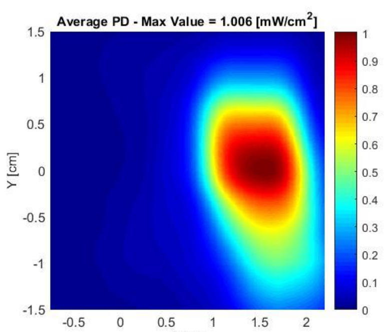
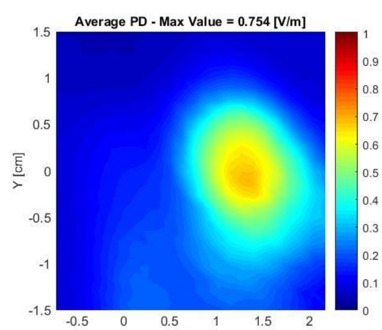
The footprints of the RFEM3-A and RFEM 3-B arrays with the corresponding measured evaluation plane are shown in Table 11

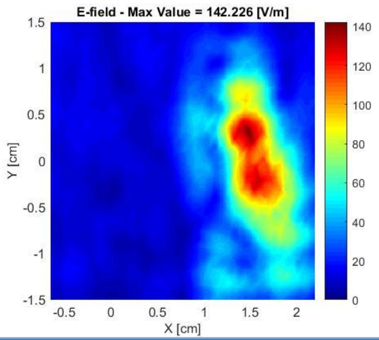
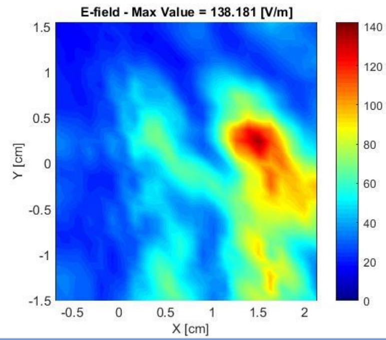
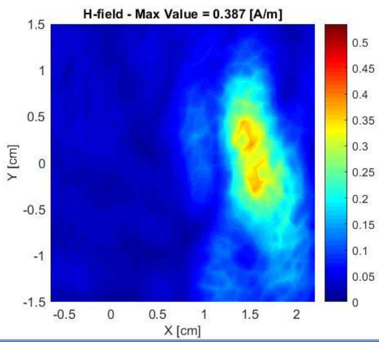
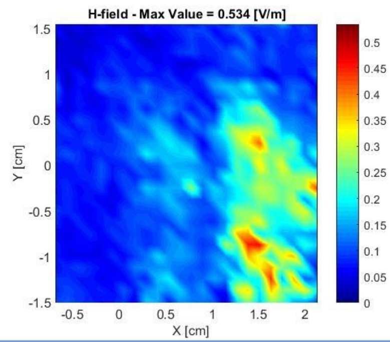
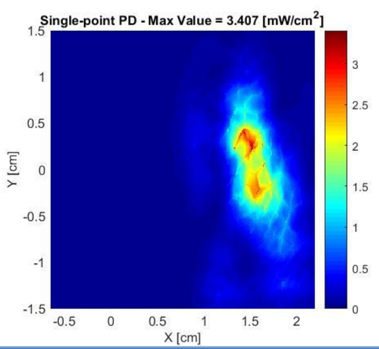
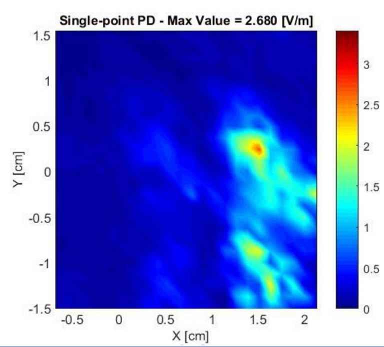
**Table 11 – Antenna arrays footprints.**

| Evaluation Plane | Measured case | Array Footprint |
|---|---|---|
| **EpB** | Case #1<br>Case #2 |  |
| **EpA** | Case #3 |  |
| **EpA1** | Case #4 |  |
| **EpB1** | Case #5<br>Case #6 |  |

The next plots show the comparison between simulation and measurement of E-field, H-field, free space power density and spatially averaged power density over 1 $cm^2$.

**Case #1 – EpB – DISTANCE = 0 mm**

| Simulated | Measured |
|---|---|
|  |  |
| **E-field (V/m) @ 0 mm – Deviation of Max Value: 0.713 dB** | |
|  |  |
| **H-field (V/m) @ 0 mm – Deviation of Max Value: 0.145 dB** | |
|  |  |
| **Localized free space PD (mW/cm2) @ 0 mm – Deviation of Max Value: 2.217 dB** | |
|  |  |
| **Spatially Averaged PD (mW/cm2) @ 0 mm – Deviation of Max Value: 1.252 dB** | |

<table>
<tr><th colspan="2">Case #2 – EpB – DISTANCE = 0 mm</th></tr>
<tr><th>Simulated</th><th>Measured</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">E-field (V/m) @ 0 mm – Deviation of Max Value: 0.251 dB</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">H-field (V/m) @ 0 mm – Deviation of Max Value: 2.798 dB</td></tr>
<tr><td>
</td><td>
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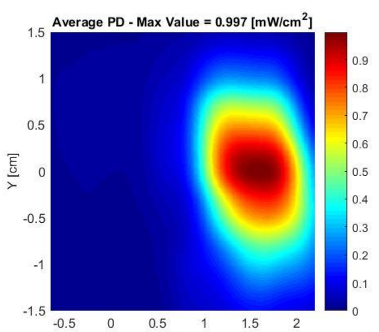
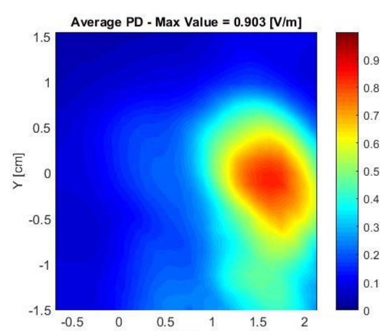
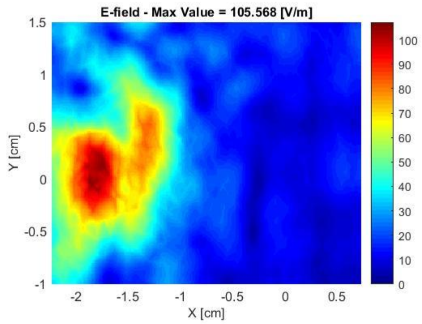
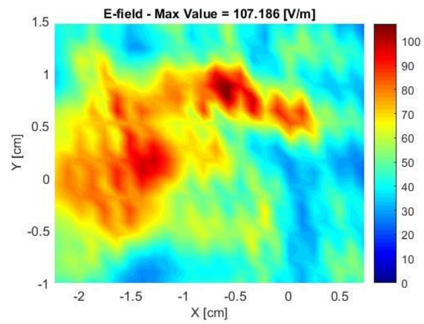
<tr><td colspan="2">Localized free space PD (mW/cm2) @ 0 mm – Deviation of Max Value: 1.042 dB</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Spatially Averaged PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.432 dB</td></tr>
</table>

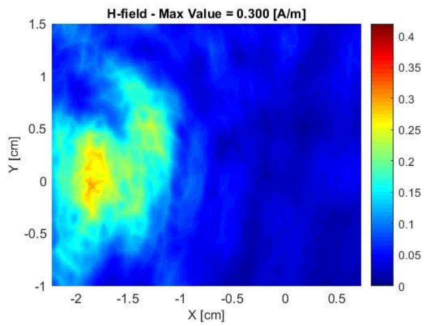
**Case #3 – EpA – DISTANCE = 0 mm**

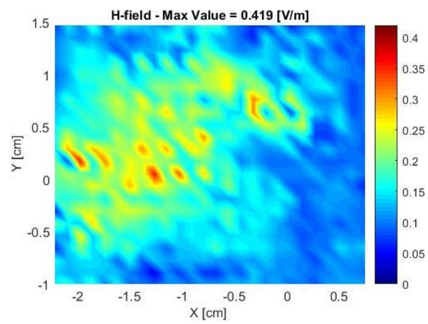
| Simulated | Measured |
|---|---|



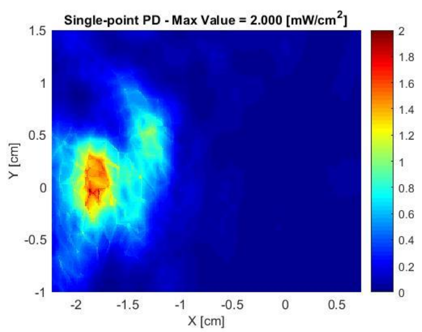



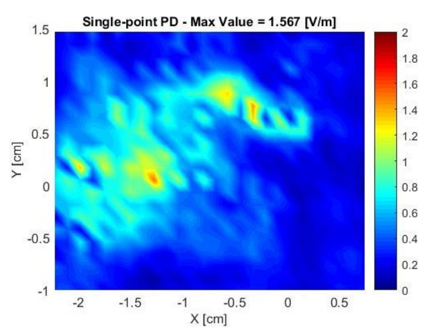

**E-field (V/m) @ 0 mm – Deviation of Max Value: 0.132 dB**



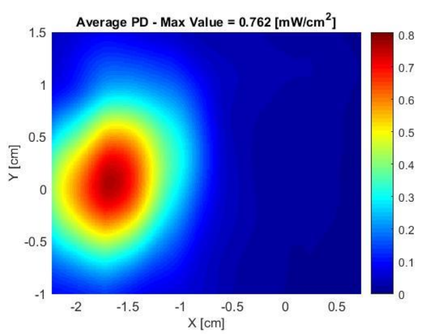



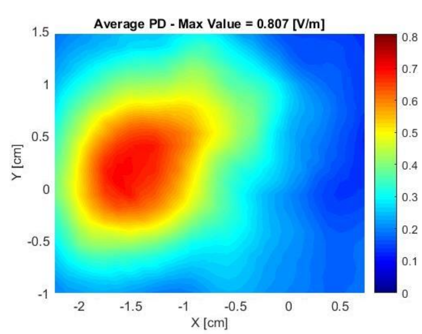

**H-field (V/m) @ 0 mm – Deviation of Max Value: 2.919 dB**



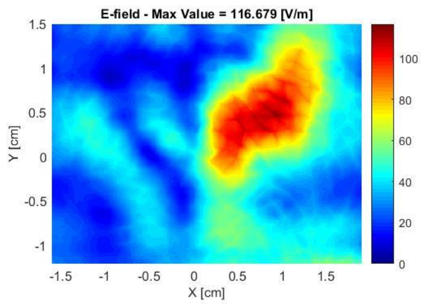
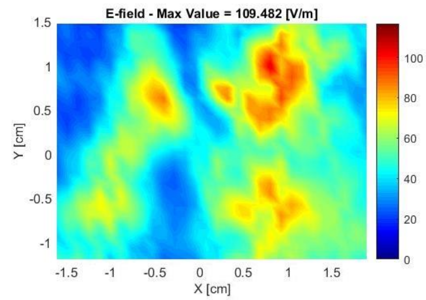
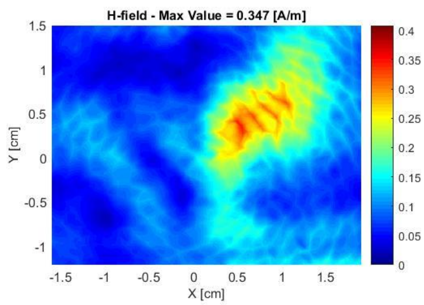
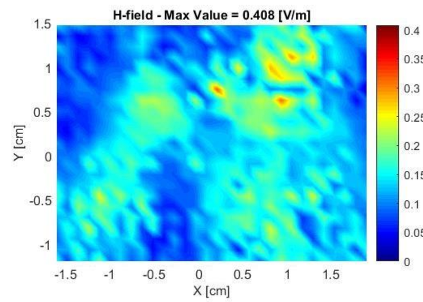
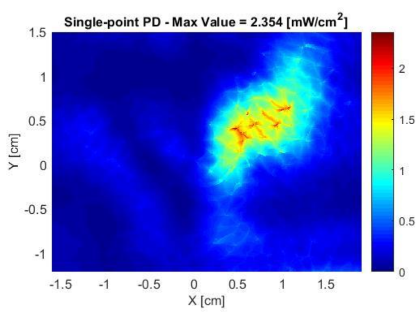
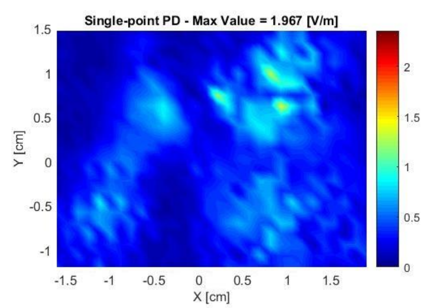
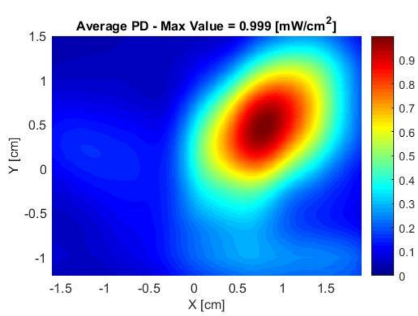
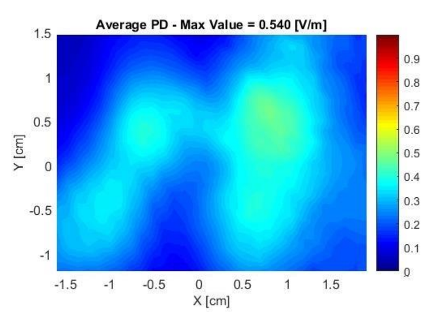

**Localized free space PD (mW/cm2) @ 0 mm – Deviation of Max Value: 1.061 dB**



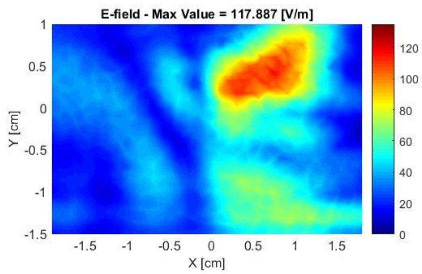

**Spatially Averaged PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.246 dB**

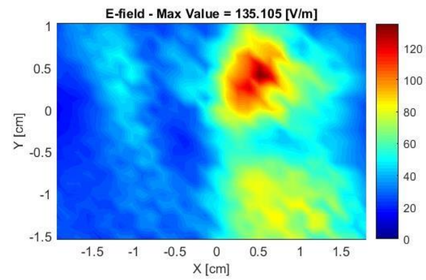
## Case #4 – EpA1 – DISTANCE = 0 mm

| Simulated | Measured |
|---|---|
|  |  |
| **E-field (V/m) @ 0 mm – Deviation of Max Value: 0.553 dB** | |
|  |  |
| **H-field (V/m) @ 0 mm – Deviation of Max Value: 1.408 dB** | |
|  |  |
| **Localized free space PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.779 dB** | |
|  |  |
| **Spatially Averaged PD (mW/cm2) @ 0 mm – Deviation of Max Value: 2.671 dB** | |

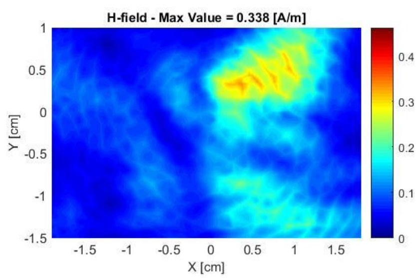
## Case #5 – EpB1 – DISTANCE = 0 mm

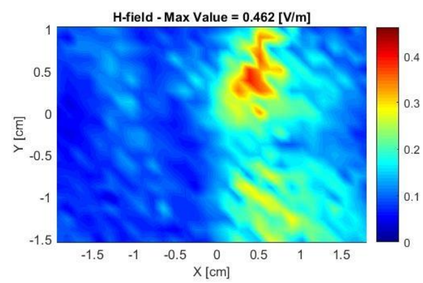
**Simulated** | **Measured**



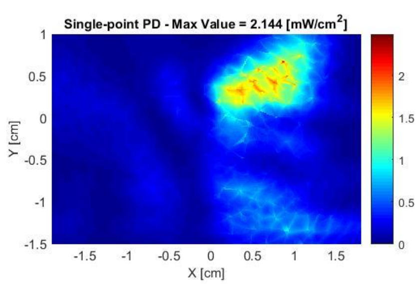



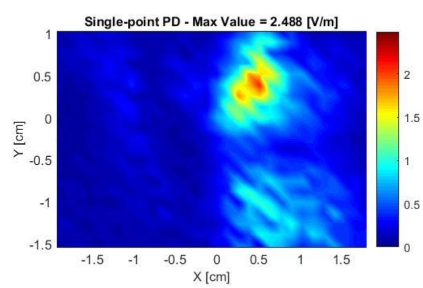

**E-field (V/m) @ 0 mm – Deviation of Max Value: 1.184 dB**



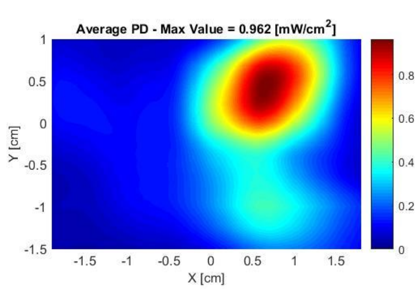



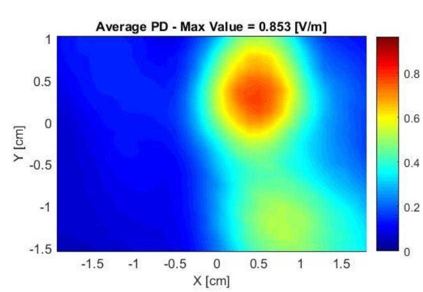

**H-field (V/m) @ 0 mm – Deviation of Max Value: 2.704 dB**



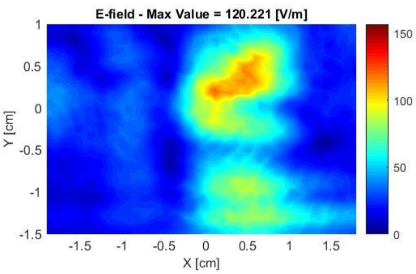

**Localized free space PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.646 dB**

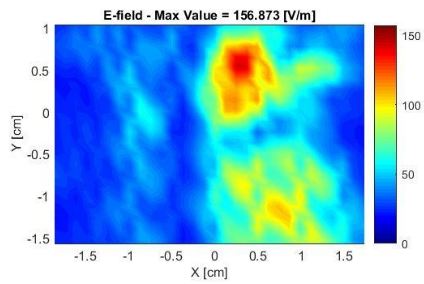


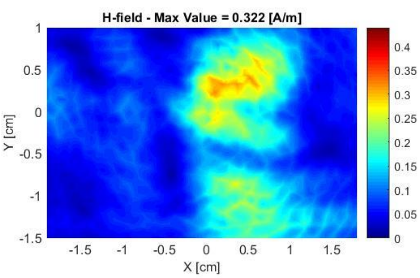

**Spatially Averaged PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.523 dB**

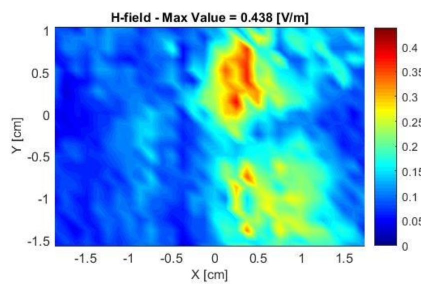
| Case #6 – EpB1 – DISTANCE = 0 mm | |
|---|---|
| **Simulated** | **Measured** |



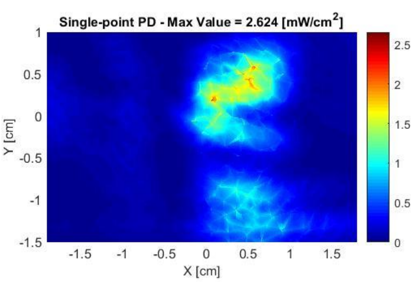



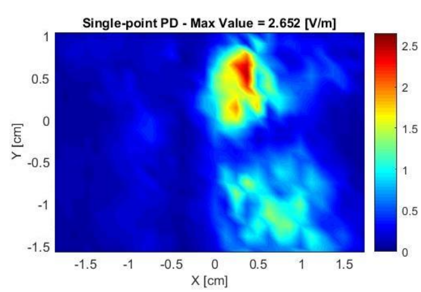

**E-field (V/m) @ 0 mm – Deviation of Max Value: 2.311 dB**



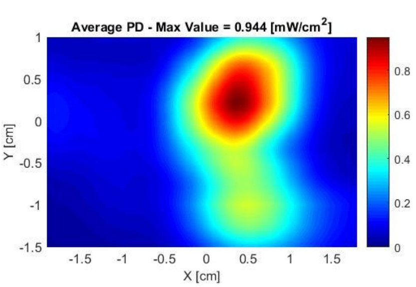



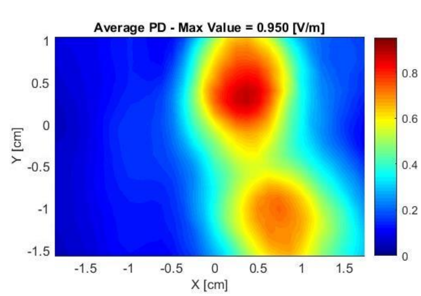

**H-field (V/m) @ 0 mm – Deviation of Max Value: 2.670 dB**




**Localized free space PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.045 dB**




**Spatially Averaged PD (mW/cm2) @ 0 mm – Deviation of Max Value: 0.027 dB**

## 2.6 Conclusion

The near field measurement shows a relatively good correlation with the near-field simulation with a maximum deviation below 3 dB for the measured distances.

Previous filings for similar devices (PD9, RFEM) showed on order of 3 dB differences when only the normal component of the Poynting vector was used to determine power density, vs. using all three vector components. In this filing, the simulations used three components of the Poynting vector (consistent with FCC procedures), whereas the version of the measurement system available at this time used only the normal component to determine maximum power density results. Intel is collaborating with the measurement system vendor so that future filings for similar devices may use other methods for power density calculations, and as consistent with technical considerations in the IEEE/IEC measurement standards working group. The highest reported power density results (0.553 mW/cm^2 simulated, 0.497 mW/cm^2; 11% relative difference) are on the order of half of the FCC limit (1 mW/cm^2). Additional margins for RF exposure compliance are provided by that the evaluations planes are selected relatively close to the device enclosure at 9.3 mm spacing, with closest portions of user's head at 12.1 mm.

# 3 Compliance Assessment

It was demonstrated by numerical simulation results in document [3] and measurement results in document [2] that the worst case power density is below the RF exposure FCC limit.

The comparison between simulation and measurement is performed at 0 mm from the evaluation plane. The results were presented in this document.

Table 12 shows the simulated and measured maximum spatially-averaged power density, over 1cm$^2$ in the evaluation plane, of the Intel 13110NGW module, embedded in the VR HDMA model HTC 2Q4L100.

**Table 12 –Results for RF exposure compliance at 0mm from evaluation planes**

| Parameter | Value |
|---|---|
| **Total conducted power [4]** | 13 dBm |
| **Maximum spatially averaged power density, over 1cm$^2$ – found by Simulation at 100% Duty Cycle** | 1.006 mW/cm$^2$ |
| **Maximum spatially averaged power density, over 1cm$^2$ – found by Measurement at 100% Duty Cycle** | 0. 903 mW/cm$^2$ |
| **Maximum TX duty-cycle** | 55% |
| **Maximum spatially averaged power density, over 1cm$^2$ – found by Simulation at 55% Duty Cycle** | **0.553 mW/cm$^2$** |
| **Maximum spatially averaged power density, over 1cm$^2$ – found by Measurement at 55% Duty Cycle** | **0.497 mW/cm$^2$** |

Therefore, with a spatially-averaged power density simulated value of 0.553 mW/cm$^2$ and measured value of 0.497 mW/ cm$^2$ the Intel 13110NGW module, embedded inside VR HDMA model HTC 2Q4L100, complies with the FCC rule located in Title 47 of the Code of Federal Regulations (CFR) parts §2.1093 and §15.255(f).

[4] Note that the maximum total average conducted power for modular approval is 12.94 dBm. Therefore the final maximum average power densities values are 0.06 dB lower.