A2481_5G_Product-mmWave-MPE_Simulation_Report-withsimPDPlots

Model No	FCC ID:
A2481	BCG-E3994A

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Apple Inc., Cupertino, CA, USA

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1 Introduction

This document provides an overview of the methodology used for MPE (averaged power density) RF exposure compliance of the 5G mmWave radios on next generation iPhone.

Due to the presence of multiple antenna arrays, and multiple antenna beams for each antenna array, we propose to use a combination of simulation and measurement to demonstrate MPE (PD) compliance. At a high level, the discussion is grouped into the following topics:

- Brief introduction to MPE simulation methodologies
- Explanation of the approach to demonstrate MPE (PD) compliance in a device with measurement to validate simulation
- Brief review of the device configuration and operation, and detailed description of the simulation methodology and results

A few things to be noted are

1. The simulation and validation methods described herein follow QC guidance for SAR Char and PD Char for determining the worst-case beam for static transmission measurements.
2. The PD simulation models are built with different CAD models for different programs.
3. Based on guidance, we intend to characterize the three highest MPE beams per polarization per module in order to choose the scaling factor for all other beams on that module/polarization.

2 MPE Simulation Methodology

3D full-wave simulation is used to evaluate power density (MPE) for each antenna array module's beam. Each beam is created by invoking a pre-defined codebook that has the proper array elements' excitation (i.e., magnitude and phase) to create the beam.

As is shown in Figure 1, the following steps are taken to verify the validity of the model used for MPE simulations and then the verified model is used for the MPE calculations:

1) **EM Simulation:**
   - Import a CAD model that represents the actual product in the simulation tool
   - Define material properties inside the product based on vendor's inputs
   - Perform mesh seeding and solve
2) **Apply Codebook:**
   - Apply array elements' excitation from the codebook and extract the fields
   - Codebook shows the magnitude and phase of each antenna element, which determines each beam of the antenna array
   - Codebook is generated to automate the simulation of different beams
3) **MPE Calculations:**
   - Post-process the extracted fields including averaging the power density on the evaluation surface

- Averaging area is 4 cm^2
- Calculate average power density (MPE)

4) **Validate Simulation Model:**
   - Measure MPE
   - Compare measurement vs simulation
   - Once a correlation is established, and model's accuracy is verified, this model will be used for computational MPE assessments

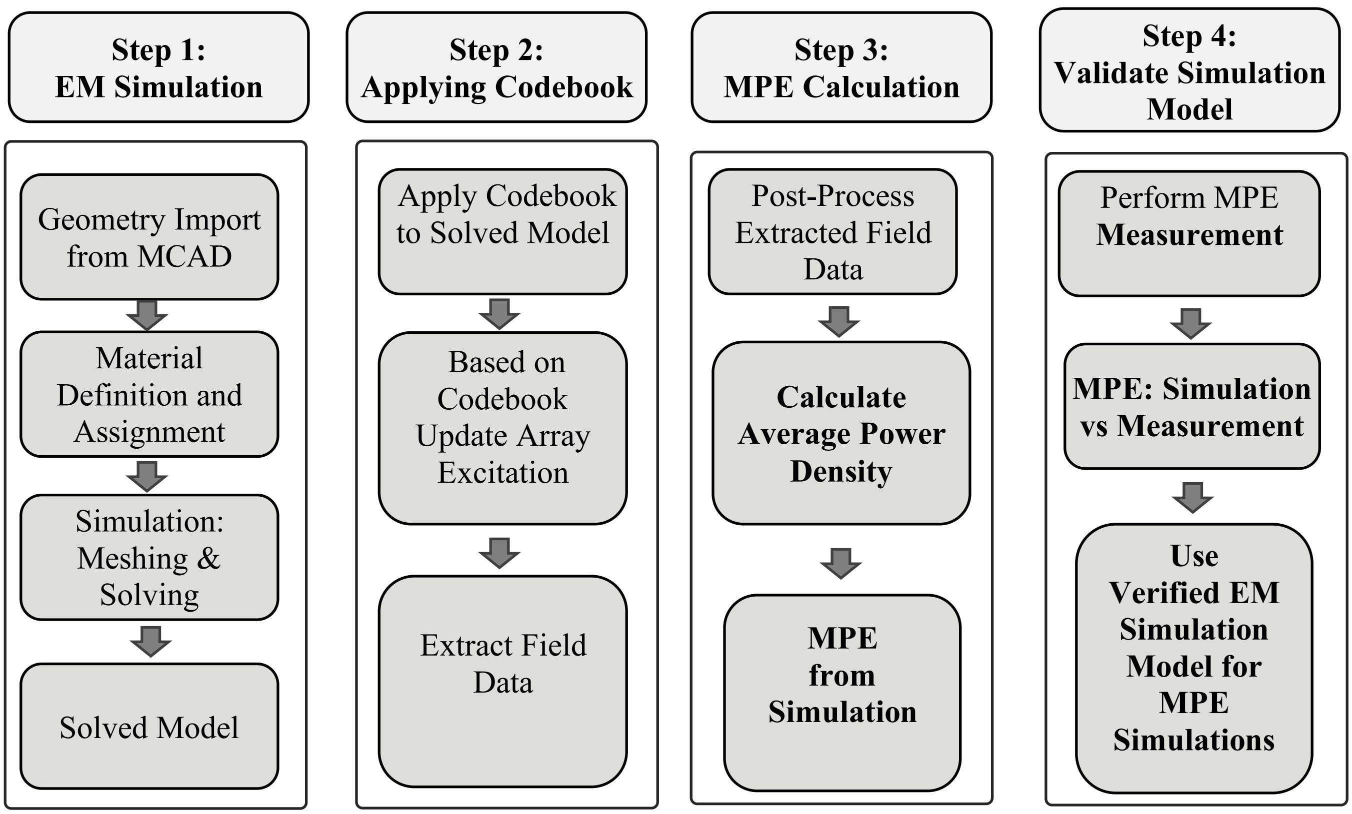


Figure 1. Model validation workflow for MPE simulation and evaluation.

3 MPE Measurements

A mmWave DAE SN 1411 module from SPEAG is used to measure the MPE (PD) above the DUT. Figure 2 shows the setup of measurement. The mmWave E-field probe is used to measure the electric field above DUT. The near-field magnetic field and MPE are further obtained using this setup. The measurement algorithm can be found in[1] in detail.

[1] S. Pfeifer , E. Carrasco, P. Crespo-Valero, E. Neufeld, S. Kuhn, T. Samaras, A. Christ, M. H. Capstick, and N. Kuster, "Total field reconstruction in the near field using pseudo-vector E-field measurement," *IEEE Trans. Electromagn. Compat*., vol. 61, no. 2, pp. 476–486, Apr. 2019.

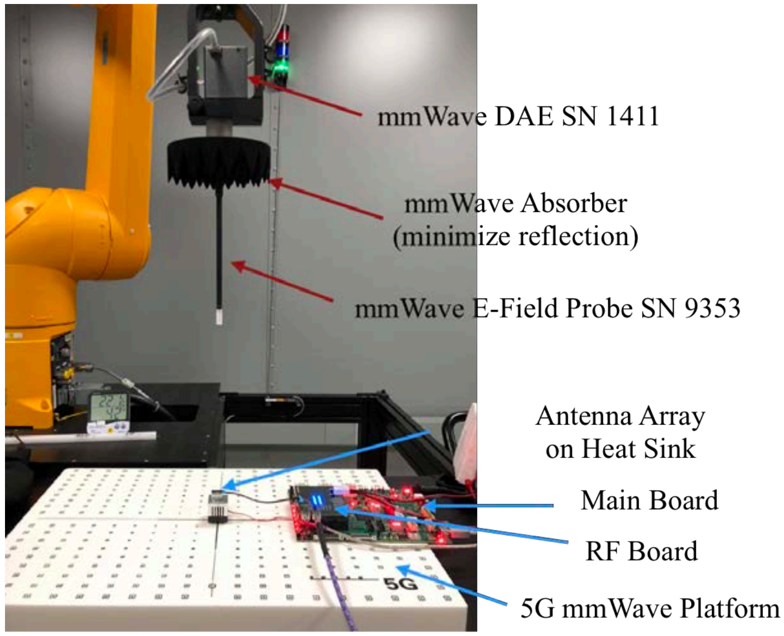


Figure 2. MPE measurement setup.

The distance from probe sensor tip to the edge of the housing is 1.5 mm, and there is 0.5 mm gap between probe tip and the DUT surface to prevent mechanical damage. Therefore, the closest distance that the setup can measure is 2 mm as shown below in Figure 3.

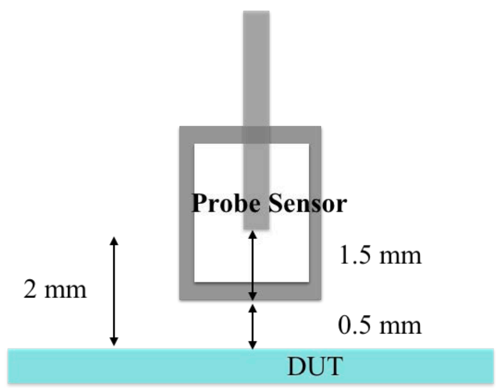


Figure 3. Sketch of the probe showing that the minimum measurable distance is 2 mm.

4 MPE (PD) Simulations

In 5G, MIMO antennas are designed to orient the beam to specific directions in order to improve link budgets. Most MIMOs can be configured by using the codebook with each code resulting in a different exposure. The number of codes in the codebook can be very large and measurements of all possible configurations have been shown to be impractical. Therefore, simulation is used to determine the modes/configurations that result in the highest MPE.

All elements are dual polarized patch antennas with horizontal and vertical feeds.

Simulation Models
Figure 4 is a schematic of the simulation model. There are three antenna arrays in the phone, which are back-firing array 1, back-firing array 2 and side-firing array.

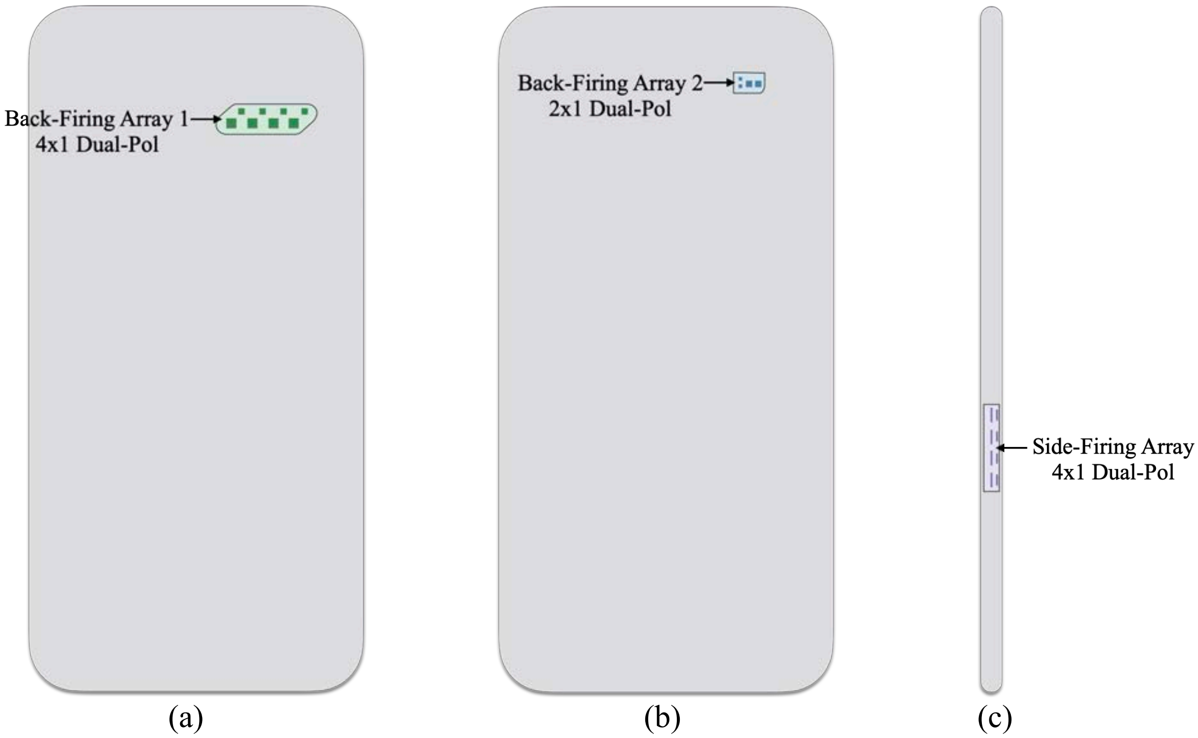


Figure 4. Schematic of the simulation mode, which consists of three 5G antenna arrays, (a) back-firing array 1 (rear view), (b) back-firing array 2 (rear view), and (c) side-firing array (side view).

The measurements and simulations are correlated across different evaluating surfaces 2 mm away from each DUT surface (drawn not to scale), as shown in Figure 5 below. Six surfaces will be evaluated, respectively: front (S1), back (S2), left (S3), right (S4), top (S5) and bottom (S6). As Table 1 shows, for the three antenna arrays, only the evaluating planes within 2.5 cm from the edges of the antenna modules will be considered. This does not apply to the back-to-front or front-to-back condition since fields from the back module will be blocked at the front evaluating plane (and vice versa) by the metal parts (such as battery, MLB) in between.

The “left” and “right” edges in the report are defined relative to the front of the device.

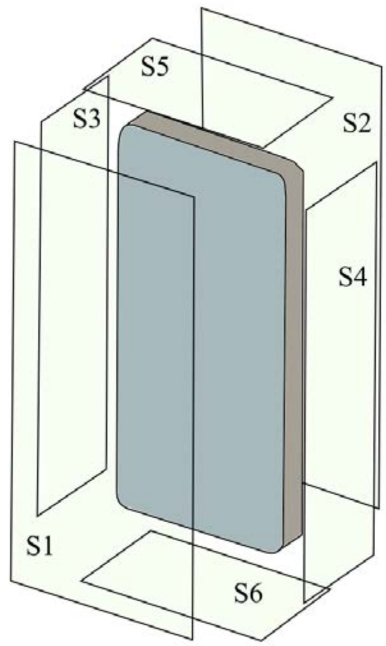


Figure 5. Evaluating surfaces for MPE (PD).

Table 1 - PD Evaluation Planes

	Front (S1)	Rear (S2)	Left from Front View (S3)	Right from Front View (S4)	Top (S5)	Bottom (S6)
Side Array	**Yes (0.4 cm)**	**Yes (0.4 cm)**	No (7 cm)	**Yes (0 cm)**	No (8 cm)	No (4 cm)
Back Array 1	No (0.6 cm)	**Yes (0 cm)**	**Yes (0.9 cm)**	No (4 cm)	No (2.7 cm)	No (12 cm)
Back Array 2	No (0.6 cm)	**Yes (0 cm)**	**Yes (0.9 cm)**	No (4 cm)	**Yes (0.8 cm)**	No (12 cm)

MPE (PD) Definition

After solving the 3D full-wave electromagnetic simulation, various physical quantities can be derived. To calculate PD evaluation, two physical quantities, an electric field $\vec{\mathrm{E}}$ and a magnetic field $\vec{\mathrm{H}}$ are needed. The actual consumption power can be expressed as the real term of the Poynting vector $\vec{\mathrm{S}}$ from the cross product of $\vec{\mathrm{E}}$ and complex conjugation of $\vec{\mathrm{H}}$ as shown below:

$$\vec{\mathrm{S}} = \frac{1}{2}\mathrm{Re}(\vec{\mathrm{E}} \times \vec{\mathrm{H}}^{*})$$

$\vec{\mathrm{S}}$ can be expressed as localized power density based on a peak value of each spatial point on mesh grid, and obtained directly from ANSYS Electromagnetics suite version 19.2 (HFSS).

From the localized power density $\vec{S}$, the spatial-averaged power density (PD) on an evaluated area (A) can be shown as below

$$\mathrm{PD} = \frac{1}{\mathrm{A}}\int_{\mathrm{A}} \vec{\mathrm{S}} \cdot d\vec{\mathrm{A}} = \frac{1}{2\mathrm{A}}\int_{\mathrm{A}} \mathrm{Re}(\vec{\mathrm{E}} \times \vec{\mathrm{H}}^{*}) \cdot \mathrm{d}\vec{\mathrm{A}}$$

For the purposes of these simulations, PD is the total power density value considering the contributions of x, y, and z components of localized power density $\vec{S}$. The evaluated area A is 4 cm^2. To capture worst-case power density conditions, simulations and measurements were performed assuming a 100% duty cycle.

Mesh and Convergence Criteria:
HFSS adapts the mesh based on field strength. The determination parameter of the number of iterations in HFSS is defined by the convergence criteria, ΔS, and the iterative adaptive mesh process repeats until ΔS is met, which in this case is 0.001. Figure 6 is an example of the final adaptive mesh of the device (cross-section of top view). The simulation results of this report are all calculated with a ΔS target of 0.02.

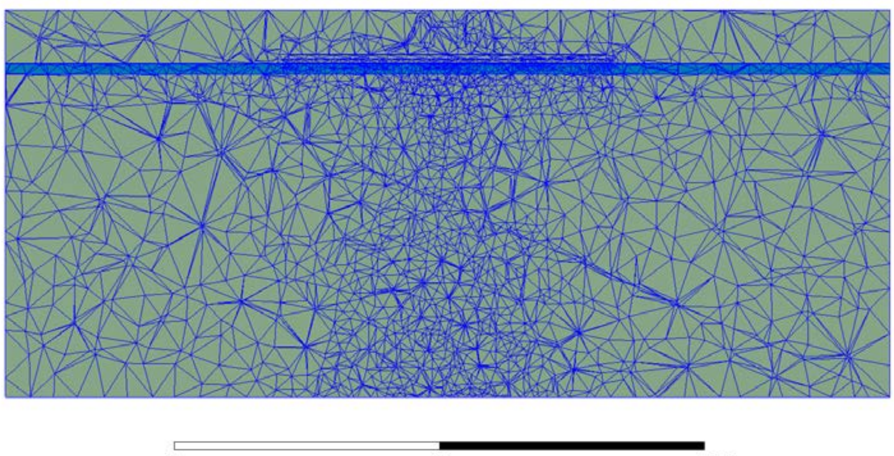


Figure 6. Example of the adaptive mesh technique (top view)

It is important to make sure the mesh is refined to capture MPE (PD) accurately. This can be done by monitoring MPE (PD) levels vs. different mesh densities, as Figure 7 depicts, showing that a fine enough mesh is needed to guarantee that the simulation gives converged and correct results. The first row in Figure 7 is simulation with coarse mesh, and the last row is with fine mesh. From the results we can see that for the third mesh, the simulated result is within 1% of the result for the finest mesh. In these simulations, the mesh in the third row is applied to ensure an accurate result with the shortest processing time.

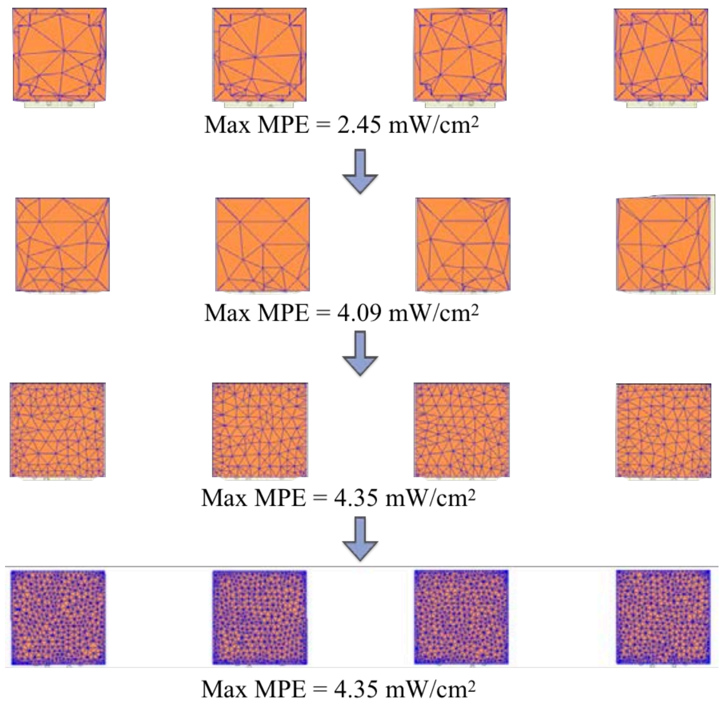


Figure 7. HFSS adaptive mesh shows that when the mesh is fine enough, MPE results will converge.

Boundary Conditions:

The boundary condition for simulating electromagnetic behavior in HFSS is to allow electromagnetic waves to be electrically open at the boundary and radiated far away without reflection. HFSS can support the absorption boundary condition (ABC) for radiation boundary and normally requires a quarter-wave separation from the structure. In this report, in order to cover all beamforming cases, a spacing of four full wavelengths is used.

Source Excitation and Example Codebook:

Figure 8 shows an example of the codebook for the antenna modules. The first column of the codebook is the beam ID. “Amplitude” and “Phase” are the excitation amplitude and phase for each antenna element. Each beam has a “Paired_With” beam for concurrent MIMO streams. The last column is the index of the beam which is paired with the index shown in the second column. The “Amplitude” is in dBm, and “Phase” is in degrees. In real applications, amplitude of the input power for n258 and n261 is 12 dBm, and for n260 is 11 dBm.

Band	Beam_ID	Module	Ant_Group	Subarray	Ant_Type	Ant_Feed	Amplitude	Phase	Paired_With
257	0	0	0	7	PATCH	10	0	0	128
257	1	0	0	9	PATCH	12	0	0	129
257	2	1	0	11	PATCH	13	0	0	130
257	3	0	0	7	PATCH	9	0	0	131
257	4	0	0	9	PATCH	11	0	0	132
257	5	1	0	11	PATCH	14	0	0	133
257	6	0	0	7	PATCH	10;9	0;0	202.5;11.25	134
257	7	0	0	7	PATCH	10;9	0;0	281.25;22.5	135
257	8	0	0	7	PATCH	10;9	0;0	0;0	136
257	9	0	0	7	PATCH	10;9	0;0	281.25;213.75	137
257	10	0	0	9	PATCH	12;11	0;0	112.5;56.25	138
257	11	0	0	9	PATCH	12;11	0;0	67.5;225	139
257	12	1	0	11	PATCH	9;13	0;0	303.75;45	140
257	13	1	0	11	PATCH	10;9	0;0	225;0	141
257	14	1	0	11	PATCH	9;13	0;0	168.75;78.75	142
257	15	1	0	11	PATCH	13;14	0;0	11.25;0	143
257	16	0	0	7	PATCH	10;9	0;0	78.75;225	144
257	17	0	0	7	PATCH	10;9	0;0	326.25;22.5	145
257	18	0	0	7	PATCH	10;9	0;0	213.75;168.75	146
257	19	0	0	9	PATCH	12;11	0;0	45;78.75	147
257	20	1	0	11	PATCH	9;13	0;0	281.25;0	148
257	21	1	0	11	PATCH	13;14	0;0	236.25;0	149
257	22	1	0	11	PATCH	10;9	0;0	213.75;191.25	150
257	23	0	0	7	PATCH	10;13;9;14	0;0;0;0	315;258.75;112.5;0	151
257	24	0	0	7	PATCH	10;13;9;14	0;0;0;0	191.25;348.75;281.25;0	152
257	25	0	0	7	PATCH	10;13;9;14	0;0;0;0	78.75;90;78.75;0	153
257	26	0	0	7	PATCH	10;13;9;14	0;0;0;0	247.5;112.5;180;0	154

Figure 8. An example version of the antenna codebook.

One thing to be noted is that the codebook is defined at the chipset, not at the antenna elements.

Averaging the Power Density for MPE (PD):
Spatial averaging is needed to determine the MPE values from power density simulation results over the 4 cm^2 area required by the FCC. Figure 9 illustrates how averaging is conducted inside the software.

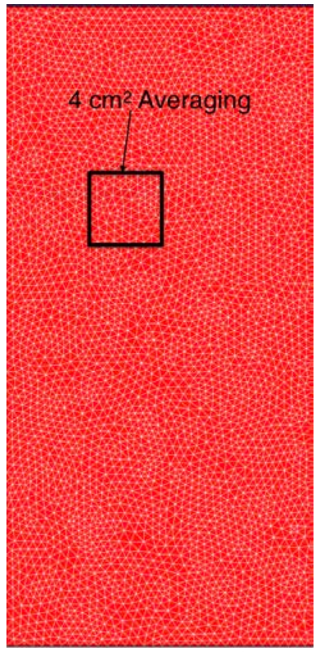


Figure 9. Averaging power density of $4cm^2$ area to get MPE (PD) results.

5 Uncertainty Budget for Simulation

5.1 Mesh resolution

5.1.1 FEM meshes

Either of the two strategies described below shall be applied to determine FEM mesh resolution, depending on whether the code used for the evaluation of the *psPD* employs adaptive mesh refinement or not.

If the applied finite-element code does not employ adaptive mesh refinement, the number of mesh elements per wavelength (material dependent) used for the initial mesh shall be set to a) 1.15 times and then to b) 1.3 times the value.

If the applied finite-element code uses adaptive mesh refinement, additional adaptive passes shall be performed until the number of mesh elements has increased by at least 20%.

In either case, the maximum deviation of the *psPD* shall be reported in Table assuming normal probability distribution.

5.2 Absorbing boundary conditions

The impact of the absorbing boundaries conditions should be determined by moving the boundaries outward by a $\lambda/4$ and $5\lambda/4$ spacing in all directions. The maximum deviation of the *psPD* shall be reported in Table assuming rectangular probability distribution.

NOTE: The location of the maximum electric or magnetic energy at the boundary may correspond to the main beam of a radiating structure or to its reactive field.

5.3 Power budget

The power fed into the computational domain shall be recorded at the sources (P_M or P_O). The sum of the power absorbed in the lossy dielectrics, lossy conductors and passive components in the computational domain and radiated into the ABCs shall be recorded and compared to P_M or P_O. The deviation shall be reported in Table assuming normal probability distribution.

NOTE: When simulating devices with multiple sources operating simultaneously, it is recommended to excite each port separately while loading the inactive ports with the reference impedance in order to compute the full S-matrix of the multiport system. As such, the *psPD* and the power budget for a given excitation vector can be calculated by superimposing the fields for any excitation vector and load. For details refer to:

IEC Technical Report 62630, "Guidance for evaluating exposure from multiple EM sources" IEC TC106 WG4, December 2009.

Kozlov, M. and Tumer, R., "SAR in interleaved excitation of an MRI RF array" Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE.

5.4 Convergence

5.4.1 Frequency domain FEM solvers

If the FEM solver has adaptive mesh refinement, the E-field vector components shall be recorded in the region (the relevant region) where the *psPD* is expected. The field components shall be recorded on a subvolume of this region, and the maximum element size in this subvolume shall be smaller than 20% of the maximum element size of the computational domain. (The element size is defined by the radius of a sphere circumscribed around the element.) The absolute value of the complex field vectors shall be calculated in each adaptive step. For a sufficiently converged adaptive process, the maximum field value shall be at the same mesh point and the deviation of this maximum field value from their mean value in the last two adaptive steps shall not be larger than 2%.

If the FEM solver does not have adaptive mesh refinement, the solution shall be generated on two meshes where the second mesh shall contain 30% more elements in the relevant region (e.g., in regions of high energy or fine geometrical details where the refinement is expected to have the biggest impact) than the first mesh does. The element number should be increased in the relevant region in a way that the maximum element size does not increase. Then the convergence shall be evaluated as in the adaptive refinement case.

5.4.2 Reporting the convergence uncertainty

The deviation shall be reported in Table 2 as uncertainty with rectangular probability distribution. Since the location of the *psPD* may not be known beforehand, it is recommended to select the relevant region large enough to avoid repeated simulation. Testing simulations with coarser meshes or simplified geometry may help to limit the computational expenses to identify the relevant regions for the recording of the signals.

5.5 Dielectric properties

The dielectric properties of the DUT model are usually affected by uncertainties according to their specification. The impact of these uncertainties on the *psPD* shall be evaluated by applying the minimum and maximum conductivity and permittivity (four different combinations). The minimum and maximum shall be chosen according to the uncertainty that is reported in the reference documentation of the dielectric properties *e.g.,* data sheet or other publication. In order to avoid excessive numbers of simulations for structures with a large number of different dielectrics, the changes in conductivity and permittivity may be limited to the region where most of the electromagnetic energy is confined or absorbed, or advanced statistical methods may be applied for the quantification of the uncertainty. In such cases, an appropriate rationale shall be given. The deviation shall be reported in Table as uncertainty with normal probability distribution.

5.6 Lossy conductors

The finite conductivity of the conductors of the DUT shall be varied according to their specification. The impact of these uncertainties shall be evaluated by applying the minimum and maximum conductivity of all conductors of the DUT (two simulations). The minimum and maximum shall be chosen according to the uncertainty that is reported in the reference documentation of the conductors, e.g., data sheet, publication. The deviation shall be reported in Table 2 as uncertainty with rectangular probability distribution.

Table 2 – Preliminary budget of the uncertainty contributions of the numerical algorithm for the validation- or testing-setup

Uncertainty component	Subclause	Probability distribution	Divisor f(d, h)[1]	c_i [2]	Uncertainty %
Mesh resolution	5.1	Normal	1	1	0.7%
ABC	5.2	Normal	1	1	0.7%
Power budget	5.3	Normal	1	1	0.5%
Convergence	5.5	Rectangular	1,73	1	0.1%
DUT dielectrics	5.6	Normal	1	1	5.5%
Lossy conductors	5.7	Rectangular	1,73	1	3.5%
Combined standard uncertainty (k = 1)					11.0%

Note 1: The divisor is a function of the probability distribution and degrees of freedom (v_i and v_{eff}).
Note 2: c_i is the sensitivity coefficient that is applied to convert the variability of the uncertainty component into a variability of psPD.

6 Simulation vs. Measurement

To validate the accuracy of the model, measured MPE and simulated MPE values for n258 are summarized below in Table 3, with unit mW/cm^2. The difference between simulated and measured

MPE values is in dB. Please be noted due to timeline, the simulation and measurement comparison is done not using the final version of codebook.

a) Side-Firing Array, n258

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S4	**S4**	S4
34	V	**7.90**	**3.93**	3.03
42	V	**8.18**	**3.94**	3.17
43	V	**8.09**	**3.90**	3.17
162	H	**5.15**	**3.06**	2.26
170	H	**5.43**	**2.96**	2.64
171	H	**5.06**	**2.99**	2.28

b) Back-Firing Array 1, n258

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
29	V	**4.99**	**5.00**	-0.01
30	V	**7.87**	**5.00**	1.97
39	V	**6.32**	**5.08**	0.95
156	H	**5.92**	**2.78**	3.28
158	H	**8.48**	**2.96**	4.57
167	H	**8.74**	**3.11**	4.49

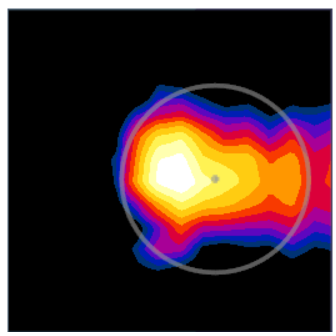
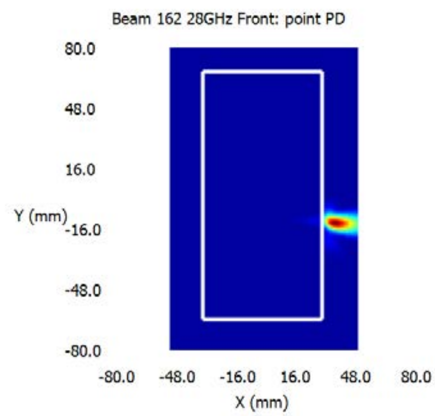
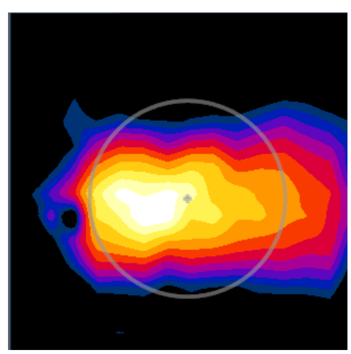
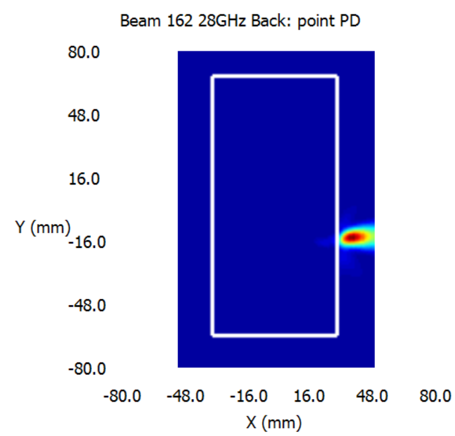
c) Back-Firing Array 2, n258

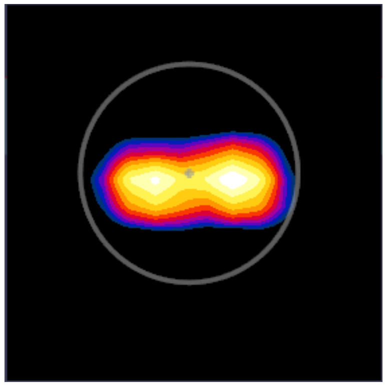
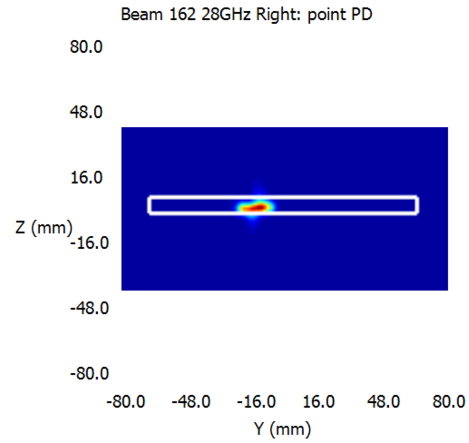
Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
11	V	**1.92**	**1.84**	0.18
21	V	**1.95**	**1.82**	0.30
22	V	**2.05**	**1.84**	0.47
139	H	**1.74**	**1.20**	1.61
141	H	**2.30**	**1.25**	2.65
150	H	**1.73**	**1.19**	1.62

Table 3 - Simulated and measured n258 MPE (PD) at 2 mm away from DUT.

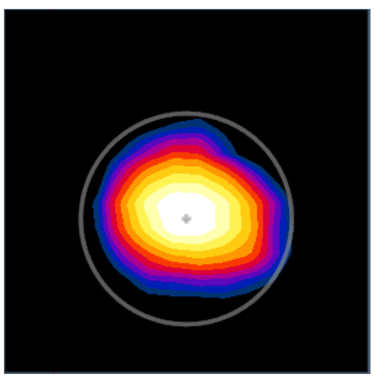
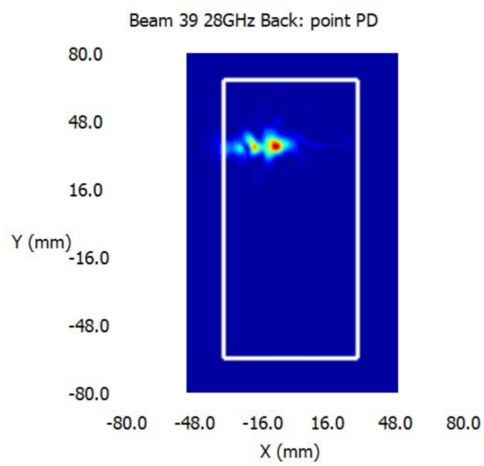
To validate the accuracy of the model, measured point PD patterns for the three arrays were compared to simulated point PD patterns for different beams for n261, as is shown in Figure 10. The plotted point PD pattern are normalized to its own maximum value, respectively. Please be noted due to timeline, the simulation and measurement comparison is done not using the final version of codebook.

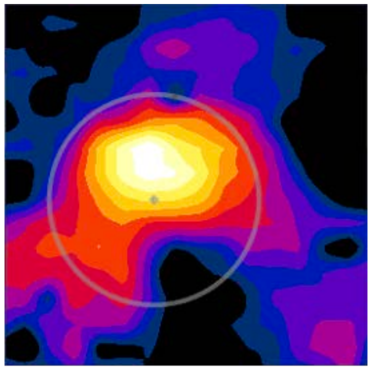
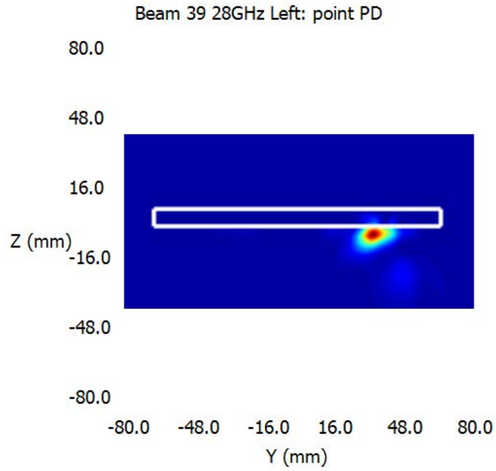
a) Side-Firing Array, n261

Beam ID	Surface	Measured Point PD	Simulated Point PD
162	S1		
	S2		

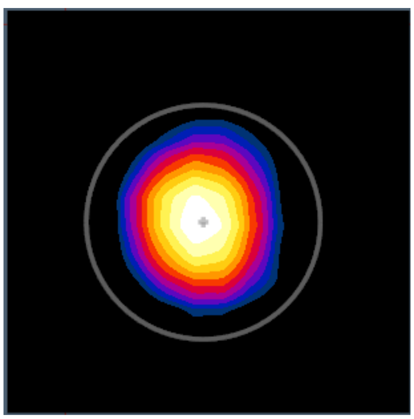
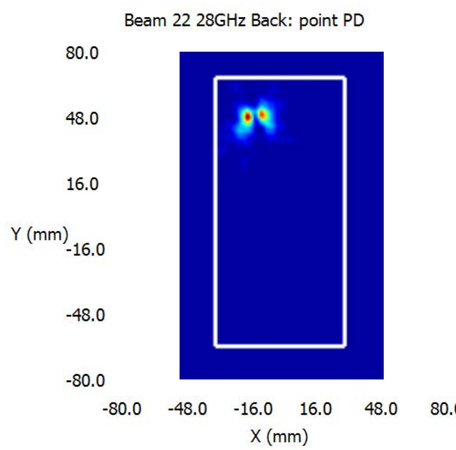
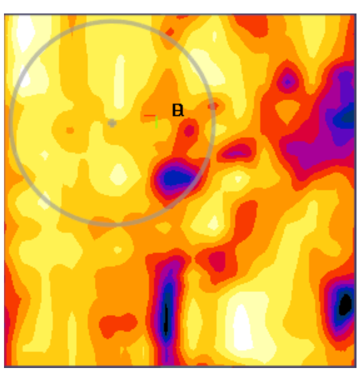
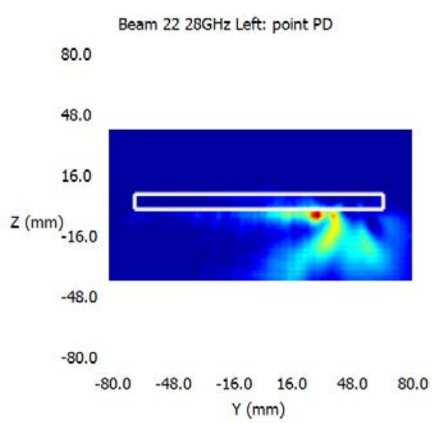
	S4		

b) Back-Firing Array 1, n261

Beam ID	**Surface**	**Measured Point PD**	**Simulated Point PD**
39	**S2**		

	S3		

c) Back-Firing Array 2, n261

Beam ID	Surface	Measured Point PD	Simulated Point PD
22	**S2**		
	S3		

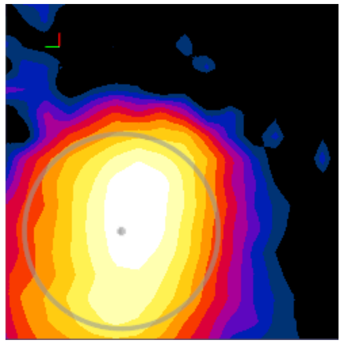
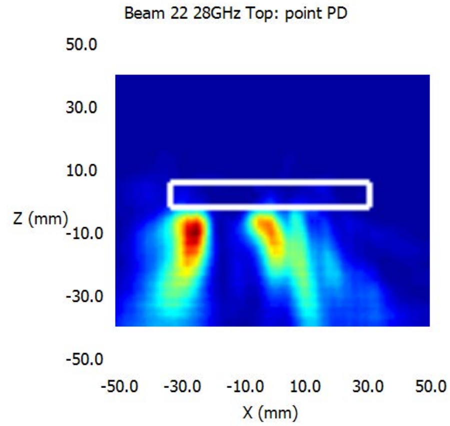
	S5		

Figure 10. Simulated and measured point PD for different beams for n261.

Measured MPE and simulated MPE values for n261 are summarized below in Table 4, with unit mW/cm^2. The difference between simulated and measured MPE values is in dB.

a) Side-Firing Array, n261

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S4	**S4**	S4
34	V	**8.23**	**4.92**	2.23
42	V	**8.31**	**4.92**	2.28
43	V	**8.14**	**4.52**	2.55
162	H	**7.51**	**4.76**	1.98
170	H	**7.62**	**4.72**	2.08
171	H	**7.43**	**4.28**	2.40

b) Back-Firing Array 1, n261

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
29	V	**5.26**	**5.04**	0.19
30	V	**4.36**	**4.96**	-0.56
39	V	**3.50**	**5.52**	-1.98
157	H	**7.94**	**3.78**	3.22
158	H	**8.16**	**3.60**	3.55
167	H	**8.04**	**3.61**	3.48

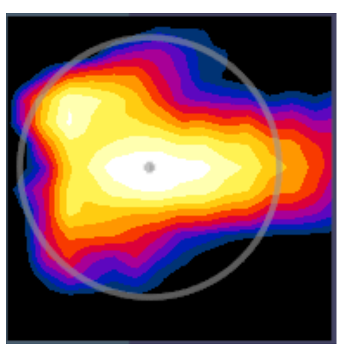
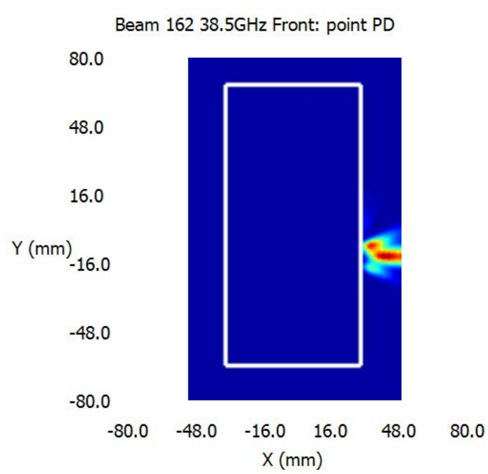
c) Back-Firing Array 2, n261

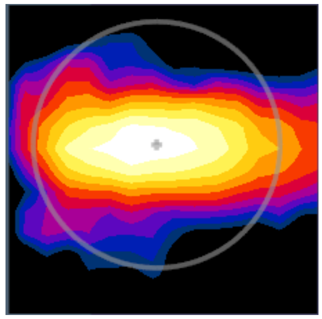
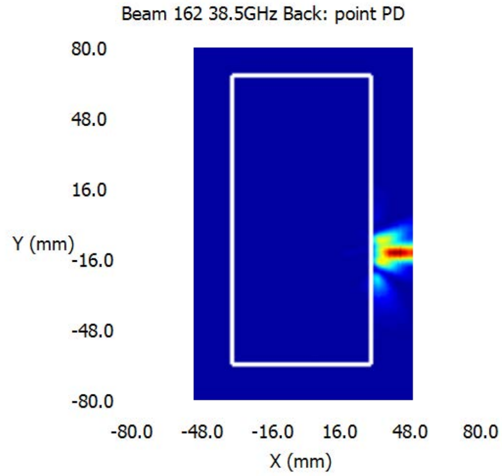
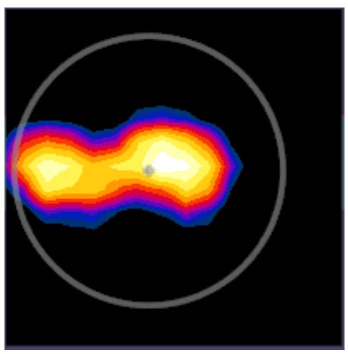
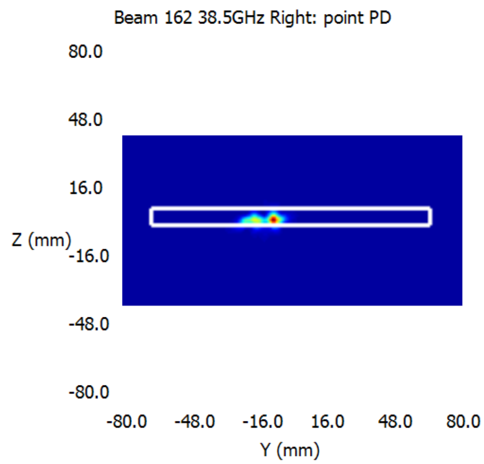
Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
11	V	**1.87**	**1.69**	0.44
21	V	**1.68**	**1.59**	0.24
22	V	**1.80**	**1.76**	0.10
139	H	**2.77**	**1.46**	2.78
140	H	**2.50**	**1.51**	2.19
150	H	**2.84**	**1.57**	2.57

Table 4 - Simulated and measured n261 MPE (PD) at 2 mm away from DUT.

To validate the accuracy of the model, measured point PD patterns for the three arrays were compared to simulated point PD patterns for different beams for n260, as is shown in Figure 11. The plotted point PD pattern are normalized to its own maximum value, respectively. Please be noted due to timeline, the simulation and measurement comparison is done not using the final version of codebook.

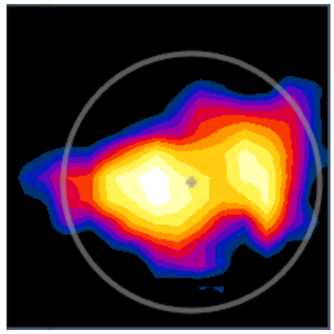
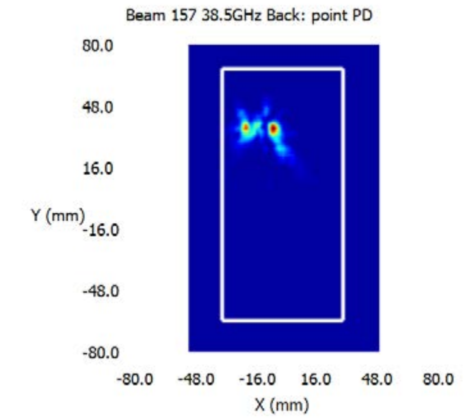
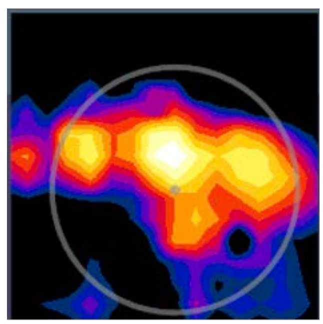
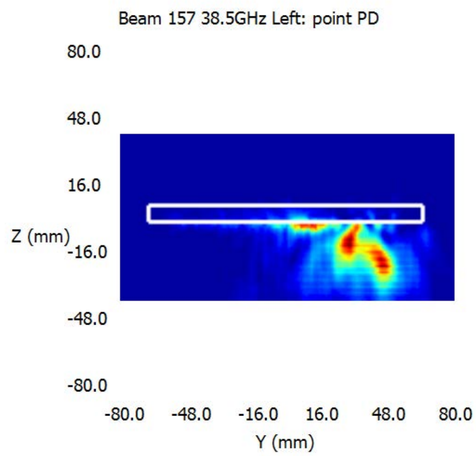
a) Side-Firing Array, n260

Beam ID	**Surface**	**Measured Point PD**	**Simulated Point PD**
162	S1		

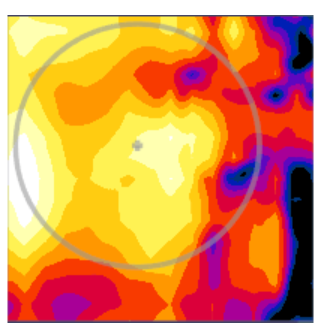
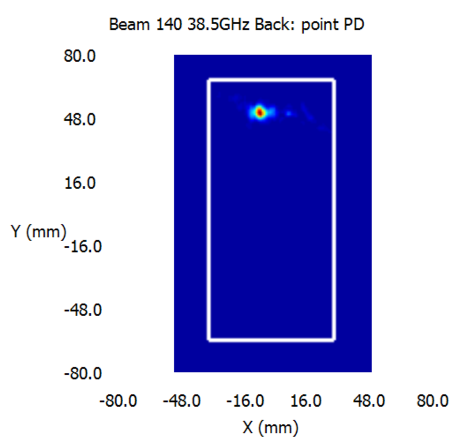
	S2		
	S4		

b) Back-Firing Array 1, n260

Beam ID	**Surface**	**Measured Point PD**	**Simulated Point PD**

<table>
<tr><td rowspan="2">157</td><td>S2</td><td></td><td>
</td></tr>
<tr><td>S3</td><td></td><td>
</td></tr>
</table>

c) Back-Firing Array 2, n260

<table>
<tr><th>Beam ID</th><th>Surface</th><th>Measured Point PD</th><th>Simulated Point PD</th></tr>
<tr><td>140</td><td>S2</td><td></td><td>
</td></tr>
</table>

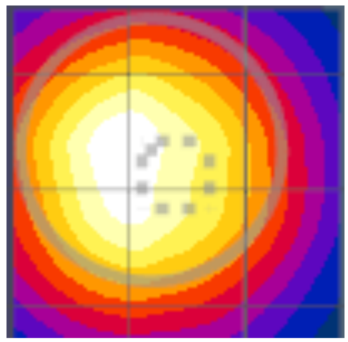
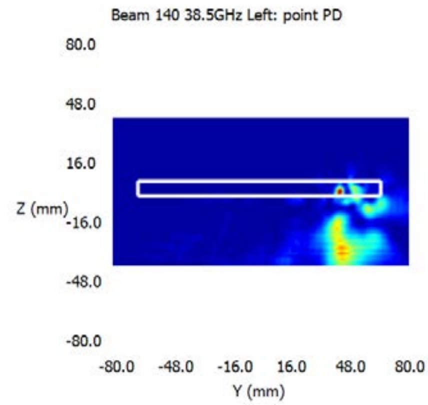
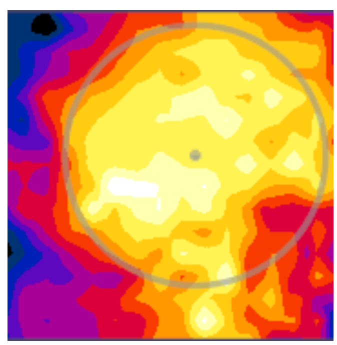
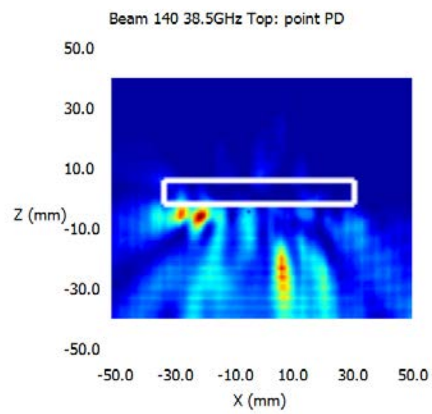
<table>
<tr><td></td><td>S3</td><td></td><td>
</td></tr>
<tr><td></td><td>S5</td><td></td><td>
</td></tr>
</table>

Figure 11. Simulated and measured point PD for different beams for n260.

Measured MPE and simulated MPE values for n260 are summarized below in Table 5, with unit mW/cm^2. The difference between simulated and measured MPE values is in dB.

d) Side-Firing Array, n260

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S4	**S4**	S4
34	V	**4.81**	**3.95**	0.86
42	V	**4.82**	**3.83**	1.00
43	V	**4.44**	**3.57**	0.95
162	H	**4.59**	**5.06**	-0.42
170	H	**4.15**	**4.58**	-0.43
171	H	**4.65**	**4.87**	-0.20

b) Back-Firing Array 1, n260

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
29	V	**4.41**	**3.67**	0.80
30	V	**3.64**	**3.35**	0.36
39	V	**3.71**	**3.76**	-0.06
157	H	**2.26**	**3.16**	-1.46
158	H	**3.95**	**2.54**	1.92
167	H	**2.37**	**2.83**	-0.77

c) Back-Firing Array 2, n260

Beam ID	Ant Pol	Simulation (mW/cm^2)	Measurement (mW/cm^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
13	V	**1.19**	**0.66**	2.56
22	V	**1.32**	**0.72**	2.63
23	V	**1.22**	**0.67**	2.60
140	H	**1.30**	**1.07**	0.85
141	H	**1.27**	**0.90**	1.50
151	H	**1.30**	**1.03**	1.01

Table 5 – Simulated and measured n260 MPE (PD) at 2 mm away from DUT.

Appendix A: Worst Phase Derivation for Beam Pair

For beam pairs, since the relative phase between two beams in unknown, so finding the worst-case PD by sweeping the relative phase for all possible angles is required for conservative assessments.

Assuming E-field and H-field for beam ID a are {Ex_a, Ey_a, Ez_a} and {Hx_a, Hy_a,Hz_a}, respectively; for beam pair which is ID b is {Ex_b,Ey_b,Ez_b} and {Hx_b,Hy_b,Hz_b}, respectively. The relative phase between beam a and b is θ, the combined E and H field after beam pairing is:

$$Ex\_pair\_i(\theta) = Ex\_a + Ex\_b \times e^{-j\omega\theta}$$
$$Ey\_pair\_i(\theta) = Ey\_a + Ey\_b \times e^{-j\omega\theta}$$
$$Ez\_pair\_i(\theta) = Ez\_a + Ez\_b \times e^{-j\omega\theta}$$

$$Hx\_pair\_i(\theta) = Hx\_a + Hx\_b \times e^{-j\omega\theta}$$
$$Hy\_pair\_i(\theta) = Hy\_a + Hy\_b \times e^{-j\omega\theta}$$
$$Hz\_pair\_i(\theta) = Hz\_a + Hz\_b \times e^{-j\omega\theta}$$

The combined PD can be calculated as:

$$PDx\_pair\_i(\theta) = Ey\_pair\_i(\theta)\times Hz\_pair\_i(\theta)^* - Ez\_pair\_i(\theta)\times Hy\_pair\_i(\theta)^*$$
$$PDy\_pair\_i(\theta) = Ez\_pair\_i(\theta)\times Hx\_pair\_i(\theta)^* - Ex\_pair\_i(\theta)\times Hz\_pair\_i(\theta)^*$$
$$PDz\_pair\_i(\theta) = Ex\_pair\_i(\theta)\times Hy\_pair\_i(\theta)^* - Ey\_pair\_i(\theta)\times Hx\_pair\_i(\theta)^*$$
$$PD(\theta) = \frac{1}{2}[(Re(PDx\_pair\_i(\theta)))^2 + (Re(PDy\_pair\_i(\theta)))^2 + (Re(PDz\_pair\_i(\theta)))^2]^{1/2}$$

Sweep θ from 0 degree to 360 degree to find the worst case beam pair.

Take side array as an example: at 28 GHz, beam 32 is paired with beam 160. By sweeping relative phase from 0 degree to 360 degree, it can be found that when θ = 120 degree, the combined PD is the worst case. Take θ = 0 degree as an example,

- θ = 0 degree, averaged PD = 19.86 mW/cm^2
- θ = 120 degree, averaged PD = 21.61 mW/cm^2

Appendix B: 4 cm^2 Averaging PD and Scaling Factor

4 cm^2 Averaging PD: The following tables show the simulated PD results for all three different arrays, at band n258, n261 and band n260. Table a), b), and c) show the results for n258, for side array, back array 1, and back array 2, respectively; table d), e), and f) show the results for n261, for side array, back array 1, and back array 2, respectively; table g), h) and i) show the results for n260, for side array, back array 1, and back array 2, respectively.

a) *Simulated PD (mW/cm^2) at 4 cm^2 averaging for side array at n258.*

			4 cm^2 PD (mW/cm^2) at 12 dBm per port, n258								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
1			S1	S2	**S4**	S1	S2	**S4**	S1	S2	**S4**
	2		0.40	0.48	**1.30**	0.74	0.59	**1.98**	0.56	0.57	1.89
	5		0.87	0.83	**2.47**	0.64	0.70	**2.09**	0.92	0.63	2.40
	14		0.48	0.53	**1.94**	1.58	0.97	**3.85**	1.55	0.90	3.98
	15		1.90	1.40	**4.19**	1.65	1.29	**3.92**	2.57	1.50	5.24
	16		1.33	1.64	**3.86**	1.87	2.11	**5.27**	1.94	1.74	5.08
	17		1.00	1.25	**2.83**	1.10	1.22	**3.06**	1.32	1.82	4.22
	24		0.55	0.48	**1.93**	1.70	1.05	**4.02**	1.63	0.96	3.99
	25		1.67	1.70	**4.18**	1.92	1.83	**4.77**	2.30	1.70	5.20
	26		0.92	1.31	**3.38**	1.62	2.08	**5.21**	1.40	1.44	4.62
	32		2.65	1.73	**6.21**	3.34	2.48	**8.44**	4.78	2.81	9.97
	33		3.08	1.94	**6.53**	4.27	2.88	**9.15**	4.71	2.55	8.87
	34		2.87	2.49	**6.31**	3.67	3.13	**8.04**	3.73	2.86	8.06
	35		2.27	3.23	**6.96**	3.44	4.09	**9.34**	3.29	3.90	8.99
	36		1.47	2.27	**5.82**	2.57	3.32	**8.66**	3.03	4.00	9.78
	41		2.99	1.93	**6.58**	3.96	2.78	**9.09**	4.91	2.72	9.59
Side Array	42		3.08	2.10	**6.25**	4.12	2.87	**8.41**	4.28	2.50	8.15
	43		2.64	2.82	**6.46**	3.47	3.56	**8.32**	3.32	3.10	7.70
	44		1.83	2.86	**6.62**	3.21	4.02	**9.68**	3.18	4.24	9.99
	130		0.38	0.29	**1.10**	0.43	0.41	**1.45**	0.75	0.65	2.45
	133		0.25	0.26	**0.90**	0.58	0.46	**1.83**	0.58	0.58	1.99
	142		0.70	1.14	**2.86**	0.89	0.84	**3.08**	1.40	1.76	4.96
	143		0.63	0.96	**2.26**	1.00	1.14	**3.10**	1.46	1.56	4.17
	144		0.96	0.65	**2.41**	1.38	1.16	**3.53**	1.70	1.38	4.21
	145		0.71	0.56	**2.54**	1.22	1.03	**3.54**	1.37	1.08	4.37
	152		0.57	1.04	**2.45**	0.94	1.06	**3.14**	1.32	1.52	4.38
	153		0.81	0.79	**2.18**	0.99	1.03	**2.80**	1.62	1.44	3.99
	154		1.12	0.51	**2.46**	0.96	0.82	**2.50**	1.90	1.32	4.40
	160		1.39	2.16	**5.36**	2.20	1.86	**6.11**	3.31	3.78	10.45
	161		1.38	2.57	**5.53**	2.27	2.52	**6.51**	2.86	3.92	9.04
	162		1.56	1.78	**4.40**	2.03	2.03	**5.18**	2.74	2.76	7.25
	163		2.27	1.32	**4.77**	2.56	1.85	**5.49**	3.37	2.34	7.15
	164		2.53	1.36	**5.60**	2.56	2.32	**6.76**	4.16	2.88	9.36

	169		1.48	2.49	**5.76**	2.37	2.26	**6.67**	3.26	4.12	10.42
	170		1.26	2.17	**4.78**	2.07	2.33	**5.72**	2.60	3.22	7.64
	171		1.73	1.35	**4.22**	2.14	1.72	**5.08**	2.78	2.20	7.10
	172		2.48	1.35	**5.39**	2.74	2.12	**6.30**	3.90	2.62	8.28
	2	130	1.26	1.16	**3.29**	1.66	1.32	**4.34**	1.60	1.40	4.54
	5	133	1.41	1.43	**4.02**	1.59	1.44	**4.50**	1.92	1.40	4.72
	14	142	1.14	1.85	**4.32**	2.34	2.44	**6.64**	3.02	3.31	8.36
	15	143	2.47	2.25	**6.17**	3.20	2.14	**7.11**	4.29	2.88	9.05
	16	144	3.17	2.52	**6.77**	4.48	4.66	**11.10**	4.95	3.79	9.54
	17	145	1.70	2.12	**5.22**	2.30	2.95	**7.12**	2.65	3.48	8.27
	24	152	1.45	2.02	**4.84**	4.18	3.19	**9.45**	4.47	3.20	8.83
	25	153	2.48	2.38	**6.10**	3.22	2.78	**7.28**	4.28	3.03	8.82
	26	154	2.38	1.76	**5.46**	3.30	3.17	**7.68**	4.13	3.06	8.88
	32	160	5.63	5.69	**12.93**	8.43	6.28	**17.52**	11.89	9.58	21.60
	33	161	5.98	6.74	**14.57**	10.00	7.97	**20.36**	10.77	8.99	19.64
	34	162	5.96	5.48	**13.46**	7.72	6.76	**16.72**	7.77	6.39	16.48
	35	163	6.76	5.43	**13.90**	8.67	8.30	**18.68**	9.04	8.22	16.98
	36	164	6.03	4.82	**12.42**	7.50	9.16	**19.29**	10.16	10.29	20.82
	41	169	6.12	6.51	**14.32**	9.59	7.34	**19.66**	11.76	9.72	21.43
	42	170	5.56	6.26	**14.16**	8.93	7.34	**18.43**	8.97	7.28	17.35
	43	171	6.20	4.79	**12.86**	7.71	6.80	**16.62**	7.58	6.08	15.28
	44	172	6.57	5.33	**13.58**	8.78	9.39	**20.30**	9.98	9.84	19.84

b) Simulated PD (mW/cm^2) at 4 cm^2 averaging for back array 1 at n258.

			4 cm^2 PD (mW/cm^2) at 12 dBm per port, n258								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
0			S1	**S2**	S3	S1	**S2**	S3	S1	**S2**	S3
Back Array 1	0		0.03	**2.59**	0.26	0.04	**2.67**	0.41	0.04	**2.19**	0.24
	3		0.01	**1.95**	0.16	0.02	**1.93**	0.20	0.01	**1.48**	0.18
	6		0.04	**3.70**	0.31	0.10	**4.74**	0.47	0.12	**3.78**	0.54
	7		0.07	**4.97**	0.26	0.11	**4.85**	0.20	0.08	**3.78**	0.14
	8		0.02	**3.58**	0.34	0.02	**4.17**	0.52	0.04	**3.26**	0.47
	9		0.04	**4.05**	0.53	0.08	**4.24**	0.49	0.09	**3.75**	0.56
	18		0.09	**4.65**	0.56	0.16	**4.55**	0.56	0.10	**3.60**	0.22
	19		0.02	**3.91**	0.15	0.02	**3.81**	0.15	0.04	**3.30**	0.15
	20		0.04	**4.33**	0.80	0.06	**4.76**	0.97	0.04	**3.35**	0.60
	27		0.11	**8.16**	0.50	0.24	**10.70**	0.47	0.24	**7.16**	0.50
	28		0.07	**8.93**	0.44	0.06	**8.45**	0.68	0.07	**6.98**	0.40
	29		0.03	**5.52**	0.11	0.05	**5.28**	0.15	0.08	**3.60**	0.30
	30		0.03	**6.94**	0.58	0.04	**7.75**	0.56	0.06	**6.30**	0.59
	31		0.09	**10.39**	2.13	0.12	**11.66**	2.76	0.10	**10.22**	1.86
	37		0.08	**9.95**	0.23	0.10	**11.49**	0.30	0.10	**8.44**	0.41
	38		0.07	**7.22**	0.22	0.14	**6.06**	0.30	0.14	**4.49**	0.28
	39		0.03	**6.49**	0.16	0.04	**7.17**	0.36	0.07	**5.66**	0.55

	40		0.05	**8.44**	1.50	0.08	**9.34**	1.74	0.08	**8.54**	1.57
	128		0.02	**1.46**	0.20	0.04	**1.22**	0.17	0.03	**1.04**	0.12
	131		0.01	**1.80**	0.21	0.02	**1.55**	0.19	0.02	**1.33**	0.14
	134		0.08	**4.84**	1.16	0.16	**4.07**	0.92	0.11	**3.04**	0.55
	135		0.05	**4.70**	0.66	0.09	**4.12**	0.59	0.08	**3.88**	0.48
	136		0.01	**3.90**	0.24	0.02	**3.89**	0.17	0.02	**4.10**	0.15
	137		0.04	**4.21**	0.52	0.05	**4.16**	0.28	0.02	**4.15**	0.19
	146		0.04	**4.89**	0.12	0.05	**3.74**	0.08	0.06	**3.24**	0.22
	147		0.02	**5.56**	0.08	0.03	**5.43**	0.06	0.04	**5.08**	0.10
	148		0.02	**3.96**	0.26	0.02	**4.06**	0.16	0.02	**4.26**	0.17
	155		0.12	**7.94**	1.92	0.24	**5.53**	1.41	0.24	**6.27**	1.37
	156		0.12	**8.12**	1.45	0.32	**7.08**	1.34	0.28	**5.94**	0.92
	157		0.04	**9.60**	0.49	0.06	**9.64**	0.62	0.07	**8.83**	0.42
	158		0.06	**7.84**	1.01	0.04	**7.71**	0.70	0.04	**6.40**	0.36
	159		0.10	**5.14**	0.26	0.08	**4.50**	0.31	0.06	**4.47**	0.36
	165		0.13	**7.51**	1.83	0.32	**5.09**	1.39	0.30	**5.98**	1.42
	166		0.06	**9.40**	0.99	0.11	**9.54**	1.11	0.10	**8.12**	0.64
	167		0.03	**9.06**	0.42	0.04	**8.52**	0.18	0.05	**8.11**	0.13
	168		0.07	**4.65**	0.88	0.04	**4.66**	0.74	0.05	**4.12**	0.57
	0	128	0.06	**4.13**	0.64	0.13	**4.28**	0.74	0.13	**3.56**	0.52
	3	131	0.03	**3.94**	0.44	0.06	**3.76**	0.46	0.06	**2.99**	0.44
	6	134	0.18	**7.82**	1.77	0.38	**7.76**	1.68	0.37	**7.31**	1.51
	7	135	0.16	**9.85**	1.04	0.35	**9.37**	0.84	0.26	**9.20**	0.82
	8	136	0.04	**8.00**	0.62	0.04	**8.71**	0.64	0.06	**8.03**	0.60
	9	137	0.15	**8.93**	1.41	0.18	**8.86**	0.92	0.14	**8.18**	0.74
	18	146	0.20	**9.96**	0.82	0.38	**8.46**	0.65	0.25	**7.86**	0.44
	19	147	0.04	**9.60**	0.22	0.08	**9.22**	0.24	0.09	**8.95**	0.25
	20	148	0.09	**9.12**	1.16	0.10	**9.58**	1.22	0.07	**8.17**	0.73
	27	155	0.37	**14.44**	2.70	0.80	**14.91**	2.16	0.83	**14.56**	2.38
	28	156	0.26	**18.26**	2.48	0.60	**16.33**	2.43	0.45	**17.18**	2.11
	29	157	0.08	**15.81**	0.77	0.15	**15.97**	0.94	0.26	**13.36**	0.91
	30	158	0.10	**16.25**	1.80	0.10	**16.47**	1.33	0.16	**13.20**	1.15
	31	159	0.25	**15.09**	2.67	0.22	**15.40**	3.39	0.18	**15.50**	2.46
	37	165	0.26	**15.52**	2.21	0.59	**15.69**	2.10	0.62	**16.61**	2.71
	38	166	0.18	**17.37**	1.48	0.40	**16.78**	1.45	0.44	**14.82**	1.10
	39	167	0.06	**16.04**	0.56	0.08	**17.07**	0.48	0.18	**15.00**	0.77
	40	168	0.19	**13.97**	2.63	0.18	**14.94**	2.76	0.18	**12.98**	2.28

c) *Simulated PD (mW/cm^2) at 4 cm^2 averaging for back array 2 at n258.*

			4 cm^2 PD (mW/cm^2) at 12 dBm per port, n258								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
0			**S2**	S3	S5	**S2**	S3	S5	**S2**	S3	S5
	1		**1.13**	0.06	0.15	**1.21**	0.07	0.15	**1.30**	0.08	0.10

Back Array 2	4		**0.32**	0.03	0.06	**0.88**	0.05	0.07	**1.34**	0.06	0.06
	10		**1.23**	0.11	0.17	**1.92**	0.12	0.31	**2.56**	0.16	0.16
	11		**1.10**	0.10	0.11	**1.93**	0.16	0.22	**2.56**	0.24	0.14
	12		**1.29**	0.08	0.14	**2.12**	0.18	0.31	**2.68**	0.24	0.18
	13		**1.63**	0.10	0.27	**2.16**	0.12	0.33	**2.58**	0.13	0.18
	21		**1.12**	0.10	0.14	**1.92**	0.15	0.26	**2.55**	0.22	0.16
	22		**1.19**	0.08	0.10	**2.05**	0.18	0.26	**2.66**	0.26	0.17
	23		**1.40**	0.09	0.19	**2.17**	0.17	0.34	**2.68**	0.20	0.19
	129		**0.35**	0.05	0.03	**1.14**	0.11	0.12	**1.63**	0.15	0.14
	132		**0.37**	0.03	0.03	**0.84**	0.07	0.06	**1.32**	0.14	0.08
	138		**0.74**	0.03	0.06	**1.76**	0.05	0.18	**2.71**	0.19	0.23
	139		**0.71**	0.04	0.06	**1.75**	0.14	0.15	**3.04**	0.50	0.19
	140		**0.66**	0.08	0.06	**1.90**	0.26	0.18	**2.98**	0.54	0.25
	141		**0.76**	0.14	0.08	**2.32**	0.28	0.29	**2.55**	0.21	0.31
	149		**0.73**	0.02	0.06	**1.74**	0.06	0.17	**2.84**	0.28	0.21
	150		**0.72**	0.03	0.06	**1.74**	0.12	0.16	**3.03**	0.46	0.18
	151		**0.71**	0.13	0.07	**2.20**	0.30	0.28	**2.72**	0.36	0.28
	1	129	**1.70**	0.12	0.19	**2.72**	0.26	0.29	**3.15**	0.26	0.34
	4	132	**0.82**	0.09	0.10	**2.31**	0.16	0.18	**2.82**	0.24	0.22
	10	138	**2.13**	0.18	0.28	**4.50**	0.23	0.76	**6.14**	0.38	0.56
	11	139	**1.96**	0.22	0.25	**4.25**	0.37	0.60	**6.26**	0.84	0.56
	12	140	**2.11**	0.20	0.29	**4.68**	0.48	0.55	**5.91**	0.88	0.73
	13	141	**2.60**	0.26	0.36	**5.48**	0.53	0.80	**5.41**	0.42	0.63
	21	149	**2.00**	0.18	0.26	**4.30**	0.26	0.71	**6.21**	0.56	0.59
	22	150	**1.94**	0.17	0.24	**4.20**	0.34	0.46	**6.02**	0.83	0.58
	23	151	**2.33**	0.24	0.30	**5.17**	0.53	0.76	**5.58**	0.65	0.70

d) Simulated PD (mW/cm²) at 4 cm² averaging for side array at n261.

			4 cm² PD (mW/cm²) at 12 dBm per port, n261								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
1			S1	S2	**S4**	S1	S2	**S4**	S1	S2	**S4**
Side Array	2		0.82	0.75	**2.63**	0.94	0.58	**2.56**	0.62	0.33	**1.54**
	5		0.42	0.40	**1.25**	0.90	0.69	**2.43**	0.75	0.44	**1.98**
	14		1.65	1.15	**4.20**	1.81	1.27	**4.62**	1.64	0.93	**3.93**
	15		1.66	1.22	**3.64**	2.57	1.59	**5.21**	1.71	0.58	**2.95**
	16		1.31	1.71	**4.15**	2.01	1.62	**4.90**	1.42	1.06	**3.48**
	17		0.96	1.44	**3.86**	1.20	1.16	**4.33**	0.97	1.04	**3.85**
	24		1.58	0.94	**3.51**	2.44	1.56	**5.16**	1.74	0.68	**3.20**
	25		1.53	1.12	**3.36**	1.56	1.50	**3.86**	1.55	1.34	**3.70**
	26		0.98	1.03	**2.76**	1.56	1.91	**4.56**	1.22	1.33	**3.85**
	32		3.19	2.03	**7.29**	4.21	3.05	**9.70**	3.74	2.01	**7.89**
	33		3.83	2.34	**7.49**	4.63	2.82	**8.95**	3.72	1.79	**6.76**
	34		2.99	2.56	**6.29**	3.82	3.06	**8.26**	2.97	1.91	**6.10**
	35		2.77	3.24	**7.32**	3.58	3.69	**8.80**	2.70	2.53	**6.50**
	36		2.52	3.34	**8.38**	3.20	3.87	**9.81**	2.38	3.02	**7.69**
	41		3.60	2.27	**7.76**	4.56	3.05	**9.81**	3.81	1.89	**7.51**

	42		3.39	2.30	**6.42**	4.14	2.81	**8.27**	3.22	1.76	**6.26**
	43		2.73	2.82	**6.42**	3.60	3.28	**8.15**	2.82	2.16	**6.16**
	44		2.82	3.63	**8.51**	3.46	4.10	**9.86**	2.53	3.08	**7.37**
	130		0.60	0.50	**2.00**	0.76	0.78	**2.71**	0.41	0.51	**1.46**
	133		0.46	0.35	**1.32**	0.60	0.54	**1.92**	0.43	0.52	**1.53**
	142		1.09	1.17	**3.43**	1.69	1.52	**5.08**	1.06	1.20	**3.76**
	143		1.36	1.04	**3.17**	1.67	1.54	**4.23**	0.94	1.20	**2.76**
	144		1.32	1.20	**3.37**	1.89	1.55	**4.50**	1.87	1.17	**3.96**
	145		1.17	1.17	**3.17**	2.17	1.60	**5.09**	1.78	1.22	**4.03**
	152		0.95	0.87	**3.61**	1.22	1.03	**4.71**	1.08	1.21	**4.59**
	153		1.41	1.34	**3.90**	1.61	1.56	**4.34**	1.81	1.43	**4.37**
	154		1.41	1.12	**3.81**	1.63	1.47	**4.52**	1.51	1.33	**3.87**
	160		2.42	2.12	**6.41**	3.60	3.13	**9.54**	1.86	2.70	**6.96**
	161		2.47	2.50	**6.27**	3.15	3.36	**8.12**	2.52	2.86	**6.84**
	162		2.76	2.04	**5.91**	3.27	2.69	**7.50**	2.67	2.20	**6.18**
	163		3.04	2.01	**6.34**	3.57	2.81	**7.75**	3.01	2.10	**6.26**
	164		2.84	2.56	**7.35**	4.05	3.32	**9.74**	3.30	2.25	**7.20**
	169		2.75	2.55	**7.08**	3.51	3.52	**9.50**	2.18	3.04	**7.40**
	170		2.44	2.18	**5.74**	3.16	2.97	**7.54**	2.57	2.49	**6.37**
	171		2.87	1.98	**5.94**	3.35	2.66	**7.46**	2.76	2.04	**6.02**
	172		3.06	2.16	**6.90**	3.78	3.05	**8.58**	3.28	2.16	**6.77**
	2	130	1.92	1.62	**5.65**	2.21	1.56	**5.48**	1.42	1.22	**3.85**
	5	133	1.47	1.32	**4.04**	1.99	1.54	**4.89**	1.50	1.18	**3.95**
	14	142	4.21	3.34	**9.10**	5.45	3.98	**10.54**	4.34	2.99	**8.32**
	15	143	4.80	3.40	**9.72**	5.70	3.63	**10.40**	3.15	1.92	**5.90**
	16	144	3.02	2.99	**7.18**	4.42	3.28	**8.94**	3.88	2.41	**7.38**
	17	145	2.82	3.02	**7.00**	4.18	3.23	**8.96**	3.39	2.71	**7.17**
	24	152	3.45	1.78	**7.18**	4.53	2.63	**9.66**	3.22	2.04	**6.90**
	25	153	4.19	3.08	**9.03**	4.04	3.22	**8.41**	3.79	2.96	**7.72**
	26	154	3.00	3.36	**8.10**	3.72	4.72	**9.84**	3.30	3.64	**8.14**
	32	160	8.93	5.96	**17.99**	12.14	8.74	**21.61**	8.30	7.12	**15.10**
	33	161	10.18	6.80	**19.55**	11.29	8.08	**19.40**	8.66	6.30	**14.10**
	34	162	8.38	6.27	**16.57**	8.90	6.48	**17.48**	6.97	4.74	**12.63**
	35	163	8.61	7.65	**17.97**	9.74	9.05	**18.40**	8.18	6.64	**13.75**
	36	164	7.84	9.70	**20.75**	10.42	11.04	**22.00**	8.51	8.21	**15.75**
	41	169	10.48	6.85	**20.74**	12.52	9.12	**22.09**	8.70	7.23	**15.13**
	42	170	8.63	6.14	**16.86**	9.36	6.53	**17.62**	7.18	4.73	**12.84**
	43	171	8.13	6.62	**16.34**	9.03	7.52	**17.23**	7.45	5.63	**12.82**
	44	172	8.75	8.96	**20.16**	10.10	10.56	**20.64**	8.61	7.65	**15.10**

e) Simulated PD (mW/cm^2) at 4 cm^2 averaging for back array 1 at n261.

			4 cm^2 PD (mW/cm^2) at 12 dBm per port, n261								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
0			S1	**S2**	S3	S1	**S2**	S3	S1	**S2**	S3
	0		x	**1.70**	0.17	x	**1.42**	0.19	x	**1.29**	0.16

Back Array 1	3		x	**2.47**	0.12	x	**2.24**	0.14	x	**2.23**	0.14
	6		x	**3.76**	0.48	x	**3.36**	0.50	x	**3.28**	0.48
	7		x	**3.56**	0.22	x	**3.00**	0.20	x	**2.75**	0.16
	8		x	**4.16**	0.26	x	**3.52**	0.36	x	**3.29**	0.31
	9		x	**2.05**	0.08	x	**1.43**	0.08	x	**1.52**	0.08
	18		x	**3.94**	0.42	x	**2.84**	0.37	x	**2.63**	0.31
	19		x	**3.82**	0.15	x	**3.26**	0.26	x	**3.00**	0.21
	20		x	**3.96**	0.45	x	**2.82**	0.39	x	**3.23**	0.35
	27		x	**11.20**	2.19	x	**8.97**	1.78	x	**8.89**	1.68
	28		x	**8.74**	0.46	x	**7.20**	0.54	x	**6.28**	0.47
	29		x	**5.88**	0.27	x	**4.18**	0.54	x	**4.12**	0.50
	30		x	**6.33**	0.67	x	**5.14**	0.55	x	**5.30**	0.55
	31		x	**8.62**	0.50	x	**6.80**	0.36	x	**6.06**	0.28
	37		x	**10.05**	1.56	x	**8.96**	1.60	x	**8.64**	1.41
	38		x	**8.37**	0.18	x	**6.30**	0.36	x	**4.98**	0.30
	39		x	**4.98**	0.44	x	**3.78**	0.56	x	**4.36**	0.54
	40		x	**7.41**	0.91	x	**6.20**	0.55	x	**5.84**	0.55
	128		x	**1.62**	0.20	x	**1.38**	0.14	x	**1.12**	0.10
	131		x	**2.26**	0.09	x	**1.81**	0.06	x	**2.13**	0.11
	134		x	**2.56**	0.43	x	**2.29**	0.30	x	**2.55**	0.34
	135		x	**3.79**	0.52	x	**3.36**	0.30	x	**2.78**	0.10
	136		x	**4.25**	0.30	x	**3.37**	0.14	x	**3.62**	0.15
	137		x	**4.52**	0.10	x	**3.53**	0.10	x	**3.29**	0.15
	146		x	**4.45**	0.20	x	**4.08**	0.11	x	**3.68**	0.04
	147		x	**5.03**	0.06	x	**4.77**	0.04	x	**4.35**	0.06
	148		x	**4.24**	0.86	x	**3.59**	0.56	x	**2.90**	0.47
	155		x	**5.50**	0.51	x	**3.98**	0.35	x	**3.80**	0.45
	156		x	**6.23**	0.85	x	**4.89**	0.40	x	**4.60**	0.20
	157		x	**8.77**	0.36	x	**7.64**	0.30	x	**8.52**	0.58
	158		x	**10.01**	1.13	x	**8.23**	0.66	x	**8.27**	0.64
	159		x	**5.82**	1.00	x	**6.21**	0.90	x	**5.81**	0.94
	165		x	**4.68**	0.82	x	**3.56**	0.46	x	**3.52**	0.41
	166		x	**6.86**	0.33	x	**5.97**	0.20	x	**5.96**	0.21
	167		x	**9.56**	0.86	x	**8.10**	0.54	x	**8.84**	0.69
	168		x	**8.18**	1.34	x	**6.65**	0.88	x	**5.68**	0.88
	0	128	x	**3.52**	0.44	x	**2.94**	0.40	x	**2.64**	0.32
	3	131	x	**5.08**	0.26	x	**4.47**	0.24	x	**4.80**	0.29
	6	134	x	**6.83**	1.00	x	**5.96**	0.84	x	**6.16**	0.82
	7	135	x	**7.69**	0.72	x	**6.39**	0.54	x	**5.81**	0.32
	8	136	x	**8.86**	0.53	x	**7.41**	0.57	x	**7.29**	0.46
	9	137	x	**6.96**	0.16	x	**5.32**	0.24	x	**5.03**	0.28
	18	146	x	**8.84**	0.62	x	**7.41**	0.51	x	**7.00**	0.36
	19	147	x	**9.43**	0.28	x	**8.27**	0.42	x	**7.74**	0.33
	20	148	x	**9.20**	1.22	x	**7.44**	1.03	x	**7.84**	0.92
	27	155	x	**16.14**	2.96	x	**14.24**	2.19	x	**13.90**	2.10

	28	156	x	**16.14**	1.45	x	**12.83**	1.10	x	**11.17**	0.78
	29	157	x	**16.28**	0.70	x	**12.54**	1.13	x	**14.55**	1.14
	30	158	x	**18.71**	1.84	x	**16.12**	1.46	x	**14.55**	1.35
	31	159	x	**16.54**	1.82	x	**15.47**	1.77	x	**13.26**	1.40
	37	165	x	**15.82**	2.67	x	**13.24**	2.14	x	**12.62**	1.84
	38	166	x	**17.07**	0.64	x	**13.04**	0.53	x	**12.10**	0.54
	39	167	x	**15.29**	1.32	x	**12.92**	1.27	x	**14.66**	1.34
	40	168	x	**18.74**	2.51	x	**16.88**	1.98	x	**13.09**	1.50

f) Simulated PD (mW/cm^2) at 4 cm^2 averaging for back array 2 at n261.

			4 cm^2 PD (mW/cm^2) at 12 dBm per port, n261								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
0			**S2**	S3	S5	**S2**	S3	S5	**S2**	S3	S5
Back Array 2	1		**1.23**	0.10	0.09	**0.96**	0.07	0.10	**1.32**	0.07	0.16
	4		**0.69**	0.04	0.06	**1.12**	0.05	0.16	**1.26**	0.06	0.13
	10		**2.02**	0.08	0.20	**2.07**	0.05	0.35	**2.39**	0.08	0.34
	11		**1.94**	0.13	0.24	**1.69**	0.13	0.18	**2.12**	0.17	0.17
	12		**1.74**	0.18	0.16	**1.80**	0.17	0.11	**2.31**	0.20	0.16
	13		**1.69**	0.17	0.18	**2.16**	0.16	0.19	**2.65**	0.18	0.34
	21		**2.01**	0.11	0.25	**1.77**	0.11	0.23	**2.14**	0.14	0.21
	22		**1.78**	0.17	0.18	**1.74**	0.17	0.11	**2.25**	0.20	0.14
	23		**1.72**	0.15	0.19	**2.28**	0.16	0.22	**2.76**	0.17	0.40
	129		**1.34**	0.10	0.13	**1.54**	0.14	0.15	**1.60**	0.13	0.15
	132		**1.21**	0.12	0.07	**1.18**	0.11	0.08	**1.04**	0.10	0.08
	138		**2.28**	0.09	0.21	**2.52**	0.16	0.24	**2.57**	0.24	0.20
	139		**2.29**	0.16	0.22	**2.77**	0.33	0.21	**2.72**	0.36	0.18
	140		**2.46**	0.34	0.18	**2.82**	0.47	0.25	**2.61**	0.37	0.18
	141		**2.76**	0.36	0.30	**2.36**	0.21	0.29	**2.27**	0.12	0.34
	149		**2.29**	0.14	0.22	**2.72**	0.29	0.22	**2.69**	0.34	0.18
	150		**2.33**	0.24	0.22	**2.86**	0.43	0.20	**2.72**	0.41	0.15
	151		**2.77**	0.34	0.30	**2.31**	0.17	0.29	**2.24**	0.11	0.35
	1	129	**3.21**	0.27	0.26	**2.65**	0.24	0.35	**3.15**	0.23	0.26
	4	132	**2.46**	0.23	0.15	**2.66**	0.18	0.31	**2.46**	0.20	0.26
	10	138	**5.95**	0.19	0.50	**5.14**	0.28	0.77	**5.36**	0.37	0.74
	11	139	**5.54**	0.35	0.64	**5.16**	0.59	0.57	**5.26**	0.68	0.50
	12	140	**5.09**	0.61	0.49	**5.14**	0.78	0.58	**5.31**	0.76	0.44
	13	141	**5.18**	0.58	0.68	**4.75**	0.47	0.62	**5.55**	0.36	0.66
	21	149	**5.77**	0.30	0.63	**5.15**	0.51	0.64	**5.27**	0.59	0.57
	22	150	**5.04**	0.48	0.58	**5.24**	0.74	0.47	**5.32**	0.80	0.39
	23	151	**5.29**	0.53	0.68	**4.83**	0.44	0.61	**5.64**	0.33	0.69

g) Simulated PD (mW/cm^2) at 4 cm^2 averaging for side array at n260.

			4 cm^2 PD (mW/cm^2) at 11 dBm per port, n260		
Module ID	Beam ID 1	Beam ID 2	LB	MB	HB

1			S1	S2	**S4**	S1	S2	**S4**	S1	S2	**S4**
	2		0.36	0.30	**1.03**	0.53	0.35	**1.26**	0.57	0.48	**1.56**
	5		0.28	0.56	**1.19**	0.48	0.46	**1.38**	0.62	0.40	**1.56**
	14		0.79	0.35	**1.87**	0.99	0.37	**2.24**	0.83	0.63	**2.33**
	15		0.95	0.80	**2.08**	1.14	0.64	**2.24**	1.08	0.91	**2.54**
	16		0.92	0.97	**2.44**	1.05	0.81	**2.35**	1.02	0.91	**2.60**
	17		0.54	0.70	**2.00**	1.02	0.52	**2.68**	0.95	0.86	**2.94**
	24		0.64	0.95	**2.25**	1.32	0.82	**2.99**	1.38	0.85	**3.16**
	25		0.74	1.09	**2.21**	0.96	1.05	**2.42**	1.41	0.90	**2.91**
	26		0.84	0.40	**2.04**	0.84	0.44	**1.93**	0.72	0.69	**2.00**
	32		1.04	0.96	**2.66**	1.88	0.86	**4.28**	1.90	1.11	**4.74**
	33		1.57	1.64	**4.18**	2.37	1.27	**4.78**	2.55	1.38	**5.13**
	34		1.66	2.14	**4.65**	2.12	2.03	**4.98**	2.71	1.89	**5.63**
	35		1.54	1.13	**3.70**	1.63	0.90	**3.62**	1.33	1.58	**3.98**
	36		1.26	1.03	**3.43**	1.50	1.07	**3.89**	1.41	1.44	**4.23**
	41		1.18	0.81	**2.83**	2.16	0.76	**4.28**	2.08	1.26	**4.76**
	42		1.66	2.09	**4.57**	2.27	1.88	**5.01**	2.90	1.64	**5.66**
	43		1.82	2.00	**4.70**	1.96	1.73	**4.50**	2.16	1.83	**4.95**
	44		1.36	1.03	**3.52**	1.62	0.95	**3.75**	1.22	1.61	**4.13**
	130		0.28	0.29	**0.84**	0.42	0.39	**1.34**	0.48	0.58	**1.52**
	133		0.78	0.33	**1.70**	0.64	0.43	**1.69**	0.52	0.22	**1.06**
	142		1.04	0.43	**2.59**	0.94	0.83	**3.00**	0.77	0.60	**2.02**
	143		1.01	1.11	**2.61**	0.61	0.71	**1.83**	1.01	0.86	**2.41**
Side	144		0.90	0.90	**2.70**	0.69	0.67	**2.06**	1.25	0.91	**2.86**
Array	145		0.60	0.95	**2.77**	0.62	0.60	**2.13**	0.98	0.63	**2.54**
	152		0.64	0.90	**2.10**	0.54	0.57	**1.79**	1.04	0.92	**2.81**
	153		1.07	0.84	**2.29**	1.13	0.92	**2.64**	1.15	1.08	**2.75**
	154		0.72	0.83	**2.72**	0.67	0.61	**2.14**	1.19	0.73	**2.80**
	160		1.39	1.37	**4.14**	1.42	1.43	**4.68**	1.60	1.14	**4.23**
	161		1.43	1.62	**4.28**	1.18	1.19	**3.68**	1.45	1.42	**3.94**
	162		1.98	2.06	**4.92**	1.86	1.78	**4.69**	2.29	1.92	**5.28**
	163		2.01	1.73	**5.13**	1.54	1.25	**4.21**	2.24	1.48	**4.90**
	164		1.99	1.17	**4.86**	1.48	1.27	**4.37**	1.95	0.92	**4.31**
	169		1.20	1.38	**3.93**	1.27	1.31	**4.26**	1.45	1.29	**4.10**
	170		2.14	2.01	**5.02**	1.55	1.68	**4.11**	1.86	1.77	**4.54**
	171		2.00	1.96	**5.16**	1.85	1.38	**4.42**	2.41	1.75	**5.28**
	172		1.97	1.34	**4.80**	1.18	1.06	**3.77**	2.03	1.15	**4.45**
	2	130	0.90	0.77	**2.35**	1.24	0.80	**2.94**	1.32	1.21	**3.35**
	5	133	1.17	1.01	**3.35**	1.40	0.90	**3.28**	1.31	0.95	**2.88**
	14	142	1.38	0.84	**3.66**	1.65	1.60	**4.81**	1.29	1.38	**4.34**
	15	143	2.13	2.31	**5.29**	2.18	1.65	**4.71**	2.36	2.21	**5.66**
	16	144	2.02	2.37	**5.88**	2.31	1.59	**5.00**	2.48	2.11	**5.72**
	17	145	1.28	1.41	**4.34**	1.68	1.14	**4.40**	2.11	1.30	**5.18**
	24	152	1.55	2.11	**5.08**	2.50	1.47	**5.32**	2.86	1.84	**6.26**
	25	153	2.06	2.60	**5.47**	2.41	2.31	**5.31**	2.78	2.21	**6.11**
	26	154	1.70	1.75	**5.92**	1.79	1.37	**4.75**	2.08	1.51	**5.79**
	32	160	2.32	1.99	**7.51**	3.87	3.51	**10.79**	3.72	2.65	**9.87**

	33	161	3.58	4.00	**10.35**	4.60	3.11	**9.80**	4.92	3.79	**11.45**
	34	162	4.11	5.53	**11.31**	4.68	4.84	**11.00**	5.35	4.56	**12.43**
	35	163	4.26	3.22	**10.02**	4.10	2.87	**9.29**	3.76	3.42	**9.44**
	36	164	3.53	2.78	**8.46**	3.13	2.61	**9.11**	3.62	2.54	**9.85**
	41	169	2.16	2.24	**7.58**	4.35	3.24	**10.07**	4.21	3.24	**10.16**
	42	170	4.53	5.52	**12.06**	4.59	4.16	**10.18**	5.49	4.39	**12.48**
	43	171	4.64	4.81	**11.32**	4.47	3.44	**9.80**	4.85	4.13	**10.84**
	44	172	3.65	2.99	**8.63**	3.57	2.54	**9.01**	3.48	2.94	**9.45**

h) Simulated PD (mW/cm^2) at 4 cm^2 averaging for back array 1 at n260.

				4 cm^2 PD (mW/cm^2) at 11 dBm per port, n260							
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
0			S1	**S2**	S3	S1	**S2**	S3	S1	**S2**	S3
Back Array 1	0		x	**1.08**	0.10	x	**1.02**	0.09	x	**1.01**	0.06
	3		x	**1.20**	0.06	x	**1.14**	0.04	x	**1.08**	0.04
	6		x	**3.05**	0.14	x	**2.92**	0.17	x	**2.48**	0.17
	7		x	**1.87**	0.12	x	**1.83**	0.11	x	**1.89**	0.10
	8		x	**2.91**	0.12	x	**2.72**	0.09	x	**2.45**	0.06
	9		x	**2.20**	0.21	x	**2.08**	0.15	x	**1.87**	0.12
	18		x	**1.55**	0.18	x	**1.54**	0.16	x	**1.65**	0.15
	19		x	**2.35**	0.09	x	**2.07**	0.11	x	**2.13**	0.09
	20		x	**2.73**	0.16	x	**2.54**	0.11	x	**2.24**	0.07
	27		x	**5.55**	0.57	x	**5.31**	0.54	x	**4.35**	0.47
	28		x	**5.35**	0.34	x	**5.20**	0.34	x	**5.08**	0.32
	29		x	**4.81**	0.26	x	**4.24**	0.20	x	**4.37**	0.20
	30		x	**3.82**	0.20	x	**3.58**	0.20	x	**3.29**	0.18
	31		x	**2.57**	0.16	x	**2.61**	0.17	x	**2.38**	0.13
	37		x	**5.73**	0.52	x	**5.77**	0.50	x	**5.33**	0.46
	38		x	**5.13**	0.15	x	**4.52**	0.17	x	**4.64**	0.16
	39		x	**3.84**	0.18	x	**3.41**	0.20	x	**3.55**	0.15
	40		x	**2.63**	0.12	x	**2.77**	0.13	x	**2.62**	0.14
	128		x	**1.34**	0.14	x	**1.19**	0.11	x	**0.97**	0.08
	131		x	**1.12**	0.07	x	**1.04**	0.07	x	**1.02**	0.07
	134		x	**2.44**	0.11	x	**2.37**	0.14	x	**2.28**	0.16
	135		x	**2.11**	0.10	x	**1.69**	0.09	x	**1.80**	0.09
	136		x	**1.24**	0.06	x	**1.27**	0.09	x	**1.17**	0.12
	137		x	**2.23**	0.22	x	**2.21**	0.13	x	**1.82**	0.11
	146		x	**1.26**	0.07	x	**1.35**	0.12	x	**1.23**	0.10
	147		x	**2.37**	0.19	x	**2.05**	0.22	x	**2.10**	0.20
	148		x	**1.54**	0.09	x	**1.71**	0.12	x	**1.52**	0.15
	155		x	**4.72**	0.33	x	**5.22**	0.26	x	**4.23**	0.33
	156		x	**4.48**	0.18	x	**3.61**	0.24	x	**3.92**	0.24
	157		x	**2.06**	0.18	x	**1.93**	0.20	x	**1.88**	0.16
	158		x	**5.55**	0.40	x	**4.89**	0.46	x	**4.37**	0.38
	159		x	**4.67**	0.34	x	**4.76**	0.26	x	**4.68**	0.34
	165		x	**4.09**	0.14	x	**3.94**	0.19	x	**3.50**	0.22

	166		x	**3.48**	0.32	x	**2.98**	0.34	x	**3.23**	0.24
	167		x	**3.33**	0.23	x	**2.88**	0.23	x	**2.56**	0.20
	168		x	**5.71**	0.32	x	**5.20**	0.46	x	**4.77**	0.45
	0	128	x	**2.52**	0.23	x	**2.33**	0.20	x	**2.08**	0.15
	3	131	x	**2.55**	0.14	x	**2.43**	0.15	x	**2.27**	0.13
	6	134	x	**5.56**	0.32	x	**5.47**	0.50	x	**5.02**	0.45
	7	135	x	**4.36**	0.29	x	**3.78**	0.27	x	**4.16**	0.24
	8	136	x	**4.13**	0.24	x	**4.06**	0.23	x	**3.69**	0.20
	9	137	x	**4.56**	0.36	x	**4.64**	0.25	x	**3.87**	0.25
	18	146	x	**3.17**	0.28	x	**3.20**	0.29	x	**3.08**	0.27
	19	147	x	**4.77**	0.38	x	**4.30**	0.52	x	**4.61**	0.46
	20	148	x	**4.47**	0.30	x	**4.55**	0.32	x	**4.05**	0.30
	27	155	x	**11.04**	0.87	x	**11.85**	1.19	x	**9.74**	1.09
	28	156	x	**10.30**	0.64	x	**9.01**	0.86	x	**9.35**	0.85
	29	157	x	**6.98**	0.60	x	**6.74**	0.67	x	**7.48**	0.59
	30	158	x	**9.23**	0.76	x	**9.02**	0.93	x	**8.25**	0.73
	31	159	x	**7.55**	0.52	x	**7.69**	0.55	x	**7.35**	0.71
	37	165	x	**10.12**	0.87	x	**9.94**	1.06	x	**9.15**	0.96
	38	166	x	**8.98**	0.62	x	**7.94**	0.75	x	**8.64**	0.67
	39	167	x	**7.26**	0.53	x	**6.63**	0.69	x	**6.44**	0.52
	40	168	x	**8.46**	0.61	x	**8.48**	0.81	x	**7.79**	0.70

i) Simulated PD (mW/cm²) at 4 cm² averaging for back array 2 at n260.

			4 cm² PD (mW/cm²) at 11 dBm per port, n260								
Module ID	Beam ID 1	Beam ID 2	LB			MB			HB		
0			**S2**	S3	S5	**S2**	S3	S5	**S2**	S3	S5
Back Array 2	1		**1.00**	0.06	0.14	**0.84**	0.04	0.11	**0.60**	0.02	0.09
	4		**0.95**	0.04	0.08	**0.47**	0.03	0.04	**0.62**	0.03	0.06
	10		**1.86**	0.10	0.31	**1.22**	0.05	0.19	**1.20**	0.03	0.24
	11		**1.77**	0.10	0.10	**1.33**	0.10	0.09	**1.14**	0.07	0.09
	12		**1.82**	0.11	0.14	**1.30**	0.12	0.09	**1.14**	0.08	0.07
	13		**1.93**	0.08	0.36	**1.17**	0.06	0.20	**1.20**	0.03	0.25
	21		**1.78**	0.09	0.17	**1.30**	0.07	0.13	**1.17**	0.06	0.15
	22		**1.77**	0.10	0.09	**1.33**	0.11	0.08	**1.13**	0.08	0.06
	23		**1.94**	0.09	0.23	**1.25**	0.08	0.15	**1.18**	0.06	0.12
	129		**0.79**	0.05	0.09	**0.69**	0.03	0.07	**0.49**	0.02	0.06
	132		**0.76**	0.03	0.07	**0.56**	0.03	0.06	**0.35**	0.02	0.03
	138		**1.45**	0.09	0.11	**1.11**	0.05	0.17	**0.87**	0.03	0.11
	139		**1.40**	0.07	0.10	**1.29**	0.07	0.04	**0.61**	0.03	0.04
	140		**1.54**	0.08	0.18	**1.30**	0.06	0.08	**0.73**	0.04	0.05
	141		**1.64**	0.09	0.24	**1.26**	0.05	0.19	**0.97**	0.04	0.10
	149		**1.42**	0.08	0.07	**1.17**	0.06	0.12	**0.75**	0.03	0.09
	150		**1.57**	0.08	0.20	**1.30**	0.06	0.10	**0.77**	0.04	0.06
	151		**1.61**	0.09	0.22	**1.29**	0.05	0.14	**0.85**	0.04	0.08
	1	129	**2.06**	0.12	0.31	**1.75**	0.09	0.24	**1.30**	0.05	0.15
	4	132	**1.82**	0.08	0.14	**1.25**	0.08	0.10	**1.19**	0.07	0.12

	10	138	**3.52**	0.18	0.54	**2.78**	0.13	0.43	**2.46**	0.08	0.39
	11	139	**3.52**	0.19	0.27	**3.15**	0.22	0.15	**2.10**	0.14	0.15
	12	140	**3.68**	0.26	0.42	**3.04**	0.23	0.23	**2.28**	0.16	0.19
	13	141	**4.05**	0.17	0.75	**2.82**	0.11	0.49	**2.54**	0.08	0.34
	21	149	**3.43**	0.18	0.31	**3.03**	0.19	0.30	**2.22**	0.11	0.26
	22	150	**3.68**	0.26	0.42	**2.99**	0.22	0.26	**2.28**	0.15	0.16
	23	151	**3.97**	0.26	0.52	**2.92**	0.19	0.34	**2.51**	0.14	0.27

Scaling factor calculation: The following tables show the scaling factor results for all three different modules, at band n258, n261 and band n260. The scaling factor is defined as the MPE internal design limit (0.6 mW/cm^2) divided by the simulated averaged power density. Table a), b), and c) show the results for n258, for side, back, and front modules, respectively; table d), e), and f) show the results for n261, for side, back, and front modules, respectively; table g), h) and i) show the results for n260, for side, back, and front modules, respectively.

a) *Scaling factor for side array n258*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
2		0.46	0.30	0.32	0.30
5		0.24	0.29	0.25	0.24
14		0.31	0.16	0.15	0.15
15		0.14	0.15	0.11	0.11
16		0.16	0.11	0.12	0.11
17		0.21	0.20	0.14	0.14
24		0.31	0.15	0.15	0.15
25		0.14	0.13	0.12	0.12
26		0.18	0.12	0.13	0.12
32		0.10	0.07	0.06	0.06
33		0.09	0.07	0.07	0.07
34		0.10	0.07	0.07	0.07
35		0.09	0.06	0.07	0.06
36		0.10	0.07	0.06	0.06
41		0.09	0.07	0.06	0.06
42		0.10	0.07	0.07	0.07
43		0.09	0.07	0.08	0.07
44		0.09	0.06	0.06	0.06
130		0.54	0.41	0.25	0.25
133		0.66	0.33	0.30	0.30
142		0.21	0.19	0.12	0.12
143		0.27	0.19	0.14	0.14
144		0.25	0.17	0.14	0.14
145		0.24	0.17	0.14	0.14
152		0.25	0.19	0.14	0.14
153		0.28	0.21	0.15	0.15
154		0.24	0.24	0.14	0.14
160		0.11	0.10	0.06	0.06
161		0.11	0.09	0.07	0.07

162		0.14	0.12	0.08	0.08
163		0.13	0.11	0.08	0.08
164		0.11	0.09	0.06	0.06
169		0.10	0.09	0.06	0.06
170		0.13	0.10	0.08	0.08
171		0.14	0.12	0.08	0.08
172		0.11	0.10	0.07	0.07
2	130	0.18	0.14	0.13	0.13
5	133	0.15	0.13	0.13	0.13
14	142	0.14	0.09	0.07	0.07
15	143	0.10	0.08	0.07	0.07
16	144	0.09	0.05	0.06	0.05
17	145	0.11	0.08	0.07	0.07
24	152	0.12	0.06	0.07	0.06
25	153	0.10	0.08	0.07	0.07
26	154	0.11	0.08	0.07	0.07
32	160	0.05	0.03	0.03	0.03
33	161	0.04	0.03	0.03	0.03
34	162	0.04	0.04	0.04	0.04
35	163	0.04	0.03	0.04	0.03
36	164	0.05	0.03	0.03	0.03
41	169	0.04	0.03	0.03	0.03
42	170	0.04	0.03	0.03	0.03
43	171	0.05	0.04	0.04	0.04
44	172	0.04	0.03	0.03	0.03

b) *Scaling factor for back array 1 n258*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
0		0.23	0.22	0.27	0.22
3		0.31	0.31	0.41	0.31
6		0.16	0.13	0.16	0.13
7		0.12	0.12	0.16	0.12
8		0.17	0.14	0.18	0.14
9		0.15	0.14	0.16	0.14
18		0.13	0.13	0.17	0.13
19		0.15	0.16	0.18	0.15
20		0.14	0.13	0.18	0.13
27		0.07	0.06	0.08	0.06
28		0.07	0.07	0.09	0.07
29		0.11	0.11	0.17	0.11
30		0.09	0.08	0.10	0.08
31		0.06	0.05	0.06	0.05
37		0.06	0.05	0.07	0.05
38		0.08	0.10	0.13	0.08
39		0.09	0.08	0.11	0.08
40		0.07	0.06	0.07	0.06
128		0.41	0.49	0.58	0.41
131		0.33	0.39	0.45	0.33

134		0.12	0.15	0.20	0.12
135		0.13	0.15	0.15	0.13
136		0.15	0.15	0.15	0.15
137		0.14	0.14	0.14	0.14
146		0.12	0.16	0.19	0.12
147		0.11	0.11	0.12	0.11
148		0.15	0.15	0.14	0.14
155		0.08	0.11	0.10	0.08
156		0.07	0.08	0.10	0.07
157		0.06	0.06	0.07	0.06
158		0.08	0.08	0.09	0.08
159		0.12	0.13	0.13	0.12
165		0.08	0.12	0.10	0.08
166		0.06	0.06	0.07	0.06
167		0.07	0.07	0.07	0.07
168		0.13	0.13	0.15	0.13
0	128	0.15	0.14	0.17	0.14
3	131	0.15	0.16	0.20	0.15
6	134	0.08	0.08	0.08	0.08
7	135	0.06	0.06	0.07	0.06
8	136	0.07	0.07	0.07	0.07
9	137	0.07	0.07	0.07	0.07
18	146	0.06	0.07	0.08	0.06
19	147	0.06	0.07	0.07	0.06
20	148	0.07	0.06	0.07	0.06
27	155	0.04	0.04	0.04	0.04
28	156	0.03	0.04	0.03	0.03
29	157	0.04	0.04	0.04	0.04
30	158	0.04	0.04	0.05	0.04
31	159	0.04	0.04	0.04	0.04
37	165	0.04	0.04	0.04	0.04
38	166	0.03	0.04	0.04	0.03
39	167	0.04	0.04	0.04	0.04
40	168	0.04	0.04	0.05	0.04

c) *Scaling factor for back array 2 n258*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
1		0.53	0.50	0.46	0.46
4		1.85	0.68	0.45	0.45
10		0.49	0.31	0.23	0.23
11		0.55	0.31	0.23	0.23
12		0.47	0.28	0.22	0.22
13		0.37	0.28	0.23	0.23
21		0.54	0.31	0.24	0.24
22		0.50	0.29	0.23	0.23
23		0.43	0.28	0.22	0.22
129		1.72	0.53	0.37	0.37
132		1.63	0.71	0.45	0.45

138		0.82	0.34	0.22	0.22
139		0.85	0.34	0.20	0.20
140		0.91	0.32	0.20	0.20
141		0.79	0.26	0.24	0.24
149		0.82	0.35	0.21	0.21
150		0.83	0.34	0.20	0.20
151		0.84	0.27	0.22	0.22
1	129	0.35	0.22	0.19	0.19
4	132	0.74	0.26	0.21	0.21
10	138	0.28	0.13	0.10	0.10
11	139	0.31	0.14	0.10	0.10
12	140	0.28	0.13	0.10	0.10
13	141	0.23	0.11	0.11	0.11
21	149	0.30	0.14	0.10	0.10
22	150	0.31	0.14	0.10	0.10
23	151	0.26	0.12	0.11	0.11

d) *Scaling factor for side array n261*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
2		0.23	0.23	0.39	0.23
5		0.48	0.25	0.30	0.25
14		0.14	0.13	0.15	0.13
15		0.17	0.12	0.20	0.12
16		0.14	0.12	0.17	0.12
17		0.16	0.14	0.16	0.14
24		0.17	0.12	0.19	0.12
25		0.18	0.16	0.16	0.16
26		0.22	0.13	0.16	0.13
32		0.08	0.06	0.08	0.06
33		0.08	0.07	0.09	0.07
34		0.10	0.07	0.10	0.07
35		0.08	0.07	0.09	0.07
36		0.07	0.06	0.08	0.06
41		0.08	0.06	0.08	0.06
42		0.09	0.07	0.10	0.07
43		0.09	0.07	0.10	0.07
44		0.07	0.06	0.08	0.06
130		0.30	0.22	0.41	0.22
133		0.45	0.31	0.39	0.31
142		0.18	0.12	0.16	0.12
143		0.19	0.14	0.22	0.14
144		0.18	0.13	0.15	0.13
145		0.19	0.12	0.15	0.12
152		0.17	0.13	0.13	0.13
153		0.15	0.14	0.14	0.14
154		0.16	0.13	0.16	0.13
160		0.09	0.06	0.09	0.06

161		0.10	0.07	0.09	0.07
162		0.10	0.08	0.10	0.08
163		0.09	0.08	0.10	0.08
164		0.08	0.06	0.08	0.06
169		0.08	0.06	0.08	0.06
170		0.10	0.08	0.09	0.08
171		0.10	0.08	0.10	0.08
172		0.09	0.07	0.09	0.07
2	130	0.11	0.11	0.16	0.11
5	133	0.15	0.12	0.15	0.12
14	142	0.07	0.06	0.07	0.06
15	143	0.06	0.06	0.10	0.06
16	144	0.08	0.07	0.08	0.07
17	145	0.09	0.07	0.08	0.07
24	152	0.08	0.06	0.09	0.06
25	153	0.07	0.07	0.08	0.07
26	154	0.07	0.06	0.07	0.06
32	160	0.03	0.03	0.04	0.03
33	161	0.03	0.03	0.04	0.03
34	162	0.04	0.03	0.05	0.03
35	163	0.03	0.03	0.04	0.03
36	164	0.03	0.03	0.04	0.03
41	169	0.03	0.03	0.04	0.03
42	170	0.04	0.03	0.05	0.03
43	171	0.04	0.03	0.05	0.03
44	172	0.03	0.03	0.04	0.03

e) *Scaling factor for back array 1 n261*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
0		0.35	0.21	0.23	0.21
3		0.24	0.13	0.13	0.13
6		0.16	0.09	0.09	0.09
7		0.17	0.10	0.11	0.10
8		0.14	0.09	0.09	0.09
9		0.29	0.21	0.20	0.20
18		0.15	0.11	0.11	0.11
19		0.16	0.09	0.10	0.09
20		0.15	0.11	0.09	0.09
27		0.05	0.03	0.03	0.03
28		0.07	0.04	0.05	0.04
29		0.10	0.07	0.07	0.07
30		0.09	0.06	0.06	0.06
31		0.07	0.04	0.05	0.04
37		0.06	0.03	0.03	0.03
38		0.07	0.05	0.06	0.05
39		0.12	0.08	0.07	0.07
40		0.08	0.05	0.05	0.05
128		0.37	0.22	0.27	0.22

131		0.27	0.17	0.14	0.14
134		0.23	0.13	0.12	0.12
135		0.16	0.09	0.11	0.09
136		0.14	0.09	0.08	0.08
137		0.13	0.09	0.09	0.09
146		0.13	0.07	0.08	0.07
147		0.12	0.06	0.07	0.06
148		0.14	0.08	0.10	0.08
155		0.11	0.08	0.08	0.08
156		0.10	0.06	0.07	0.06
157		0.07	0.04	0.04	0.04
158		0.06	0.04	0.04	0.04
159		0.10	0.05	0.05	0.05
165		0.13	0.08	0.09	0.08
166		0.09	0.05	0.05	0.05
167		0.06	0.04	0.03	0.03
168		0.07	0.05	0.05	0.05
0	128	0.17	0.10	0.11	0.10
3	131	0.12	0.07	0.06	0.06
6	134	0.09	0.05	0.05	0.05
7	135	0.08	0.05	0.05	0.05
8	136	0.07	0.04	0.04	0.04
9	137	0.09	0.06	0.06	0.06
18	146	0.07	0.04	0.04	0.04
19	147	0.06	0.04	0.04	0.04
20	148	0.07	0.04	0.04	0.04
27	155	0.04	0.02	0.02	0.02
28	156	0.04	0.02	0.03	0.02
29	157	0.04	0.02	0.02	0.02
30	158	0.03	0.02	0.02	0.02
31	159	0.04	0.02	0.02	0.02
37	165	0.04	0.02	0.02	0.02
38	166	0.04	0.02	0.02	0.02
39	167	0.04	0.02	0.02	0.02
40	168	0.03	0.02	0.02	0.02

f) Scaling factor for back array 2 n261

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
1		0.49	0.63	0.45	0.45
4		0.87	0.54	0.48	0.48
10		0.30	0.29	0.25	0.25
11		0.31	0.35	0.28	0.28
12		0.34	0.33	0.26	0.26
13		0.36	0.28	0.23	0.23
21		0.30	0.34	0.28	0.28
22		0.34	0.35	0.27	0.27
23		0.35	0.26	0.22	0.22
129		0.45	0.39	0.37	0.37

132		0.50	0.51	0.57	0.50
138		0.26	0.24	0.23	0.23
139		0.26	0.22	0.22	0.22
140		0.24	0.21	0.23	0.21
141		0.22	0.25	0.26	0.22
149		0.26	0.22	0.22	0.22
150		0.26	0.21	0.22	0.21
151		0.22	0.26	0.27	0.22
1	129	0.19	0.23	0.19	0.19
4	132	0.24	0.23	0.24	0.23
10	138	0.10	0.12	0.11	0.10
11	139	0.11	0.12	0.11	0.11
12	140	0.12	0.12	0.11	0.11
13	141	0.12	0.13	0.11	0.11
21	149	0.10	0.12	0.11	0.10
22	150	0.12	0.11	0.11	0.11
23	151	0.11	0.12	0.11	0.11

g) *Scaling factor for side array n260*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
2		0.58	0.47	0.39	0.39
5		0.50	0.44	0.38	0.38
14		0.32	0.27	0.26	0.26
15		0.29	0.27	0.24	0.24
16		0.25	0.26	0.23	0.23
17		0.30	0.22	0.20	0.20
24		0.27	0.20	0.19	0.19
25		0.27	0.25	0.21	0.21
26		0.29	0.31	0.30	0.29
32		0.23	0.14	0.13	0.13
33		0.14	0.13	0.12	0.12
34		0.13	0.12	0.11	0.11
35		0.16	0.17	0.15	0.15
36		0.18	0.15	0.14	0.14
41		0.21	0.14	0.13	0.13
42		0.13	0.12	0.11	0.11
43		0.13	0.13	0.12	0.12
44		0.17	0.16	0.15	0.15
130		0.71	0.45	0.40	0.40
133		0.35	0.35	0.56	0.35
142		0.23	0.20	0.30	0.20
143		0.23	0.33	0.25	0.23
144		0.22	0.29	0.21	0.21
145		0.22	0.28	0.24	0.22
152		0.29	0.33	0.21	0.21
153		0.26	0.23	0.22	0.22
154		0.22	0.28	0.21	0.21
160		0.14	0.13	0.14	0.13

161		0.14	0.16	0.15	0.14
162		0.12	0.13	0.11	0.11
163		0.12	0.14	0.12	0.12
164		0.12	0.14	0.14	0.12
169		0.15	0.14	0.15	0.14
170		0.12	0.15	0.13	0.12
171		0.12	0.14	0.11	0.11
172		0.12	0.16	0.13	0.12
2	130	0.26	0.20	0.18	0.18
5	133	0.18	0.18	0.21	0.18
14	142	0.16	0.12	0.14	0.12
15	143	0.11	0.13	0.11	0.11
16	144	0.10	0.12	0.10	0.10
17	145	0.14	0.14	0.12	0.12
24	152	0.12	0.11	0.10	0.10
25	153	0.11	0.11	0.10	0.10
26	154	0.10	0.13	0.10	0.10
32	160	0.08	0.06	0.06	0.06
33	161	0.06	0.06	0.05	0.05
34	162	0.05	0.05	0.05	0.05
35	163	0.06	0.06	0.06	0.06
36	164	0.07	0.07	0.06	0.06
41	169	0.08	0.06	0.06	0.06
42	170	0.05	0.06	0.05	0.05
43	171	0.05	0.06	0.06	0.05
44	172	0.07	0.07	0.06	0.06

h) Scaling factor for back array 1 n260

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
0		0.56	0.59	0.59	0.56
3		0.50	0.53	0.56	0.50
6		0.20	0.21	0.24	0.20
7		0.32	0.33	0.32	0.32
8		0.21	0.22	0.25	0.21
9		0.27	0.29	0.32	0.27
18		0.39	0.39	0.36	0.39
19		0.26	0.29	0.28	0.26
20		0.22	0.24	0.27	0.22
27		0.11	0.11	0.14	0.11
28		0.11	0.12	0.12	0.11
29		0.12	0.14	0.14	0.12
30		0.16	0.17	0.18	0.16
31		0.23	0.23	0.25	0.23
37		0.10	0.10	0.11	0.10
38		0.12	0.13	0.13	0.12
39		0.16	0.18	0.17	0.16
40		0.23	0.22	0.23	0.23
128		0.45	0.50	0.62	0.45

131		0.53	0.58	0.59	0.53
134		0.25	0.25	0.26	0.25
135		0.28	0.35	0.33	0.28
136		0.49	0.47	0.51	0.49
137		0.27	0.27	0.33	0.27
146		0.48	0.45	0.49	0.48
147		0.25	0.29	0.29	0.25
148		0.39	0.35	0.40	0.39
155		0.13	0.12	0.14	0.13
156		0.13	0.17	0.15	0.13
157		0.29	0.31	0.32	0.29
158		0.11	0.12	0.14	0.11
159		0.13	0.13	0.13	0.13
165		0.15	0.15	0.17	0.15
166		0.17	0.20	0.19	0.17
167		0.18	0.21	0.23	0.18
168		0.11	0.12	0.13	0.11
0	128	0.24	0.26	0.29	0.24
3	131	0.24	0.25	0.26	0.24
6	134	0.11	0.11	0.12	0.11
7	135	0.14	0.16	0.14	0.14
8	136	0.15	0.15	0.16	0.15
9	137	0.13	0.13	0.15	0.13
18	146	0.19	0.19	0.20	0.19
19	147	0.13	0.14	0.13	0.13
20	148	0.13	0.13	0.15	0.13
27	155	0.05	0.05	0.06	0.05
28	156	0.06	0.07	0.06	0.06
29	157	0.09	0.09	0.08	0.09
30	158	0.07	0.07	0.07	0.07
31	159	0.08	0.08	0.08	0.08
37	165	0.06	0.06	0.07	0.06
38	166	0.07	0.08	0.07	0.07
39	167	0.08	0.09	0.09	0.08
40	168	0.07	0.07	0.08	0.07

i) *Scaling factor for back array 2 n260*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
1		0.60	0.72	1.00	0.60
4		0.63	1.28	0.97	0.63
10		0.32	0.49	0.50	0.32
11		0.34	0.45	0.53	0.34
12		0.33	0.46	0.53	0.33
13		0.31	0.51	0.50	0.31
21		0.34	0.46	0.51	0.34
22		0.34	0.45	0.53	0.34
23		0.31	0.48	0.51	0.31
129		0.76	0.87	1.22	0.76

132		0.79	1.08	1.71	0.79
138		0.41	0.54	0.69	0.41
139		0.43	0.47	0.98	0.43
140		0.39	0.46	0.83	0.39
141		0.37	0.48	0.62	0.37
149		0.42	0.51	0.80	0.42
150		0.38	0.46	0.78	0.38
151		0.37	0.47	0.71	0.37
1	129	0.29	0.34	0.46	0.29
4	132	0.33	0.48	0.50	0.33
10	138	0.17	0.22	0.24	0.17
11	139	0.17	0.19	0.29	0.17
12	140	0.16	0.20	0.26	0.16
13	141	0.15	0.21	0.24	0.15
21	149	0.17	0.20	0.27	0.17
22	150	0.16	0.20	0.26	0.16
23	151	0.15	0.21	0.24	0.15

Appendix C: MPE (PD) Simulation Using New Guideline from Qualcomm

This document provides the changes from what we have submitted from last year, following the new guidelines from Qualcomm, that 2nd generation of Smart Transmit (Smart-Tx GEN2) is used in this year's iPhone program.

The 1st generation of Smart Transmit (GEN1) assumes all transmit antennas are co-located and RF exposure is 100% overlapped, while the 2nd generation of Smart Transmit (GEN2) operates based on pre-defined antenna groups. In this revision, the antenna grouping is based on mmW module placement.

As an example of a wireless device having three mmW antenna (i.e., back-firing antenna 1 (BF1), back-firing antenna 2 (BF2) and side-firing (SF) antenna), Figure C.1 illustrates GEN1 and GEN2 operation.

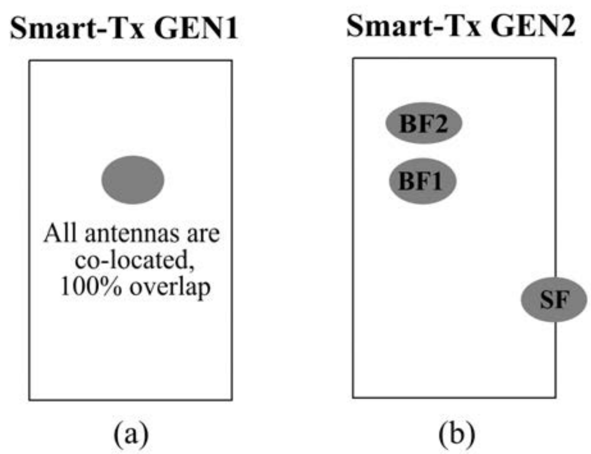


Figure C.1. Smart transmit generate illustration, (a) GEN1, and (b) GEN2

The requirement and guidelines stated for GEN1 in all previous sections apply to GEN2. The additional requirement to characterize PD for GEN2 is described in this inclusion.

- All mmW modules need to be included in each simulation model
- 2D PD plots for different surfaces are not needed for Smart-Tx GEN2

C.1 Changes in Modeling Approach Using Smart-Tx GEN2

Simulation model needs to be large enough to include all the antenna modules located inside the EUT, so that the mutual coupling can be properly calculated. Unlike GEN1, simulation of a part of the EUT (right part of Figure C.2) will not work. Instead, the entire EUT must be simulated as illustrated in the left side example in Figure C.2 for GEN2.

Additionally, the simulation domain needs to be sufficiently large for "Qualcomm MG Script" to extract valid E- and H-fields from all adjacent exposure surfaces of the EUT extended by at least 35 mm in all directions. To accomplish this, if HFSS is used, recommended setting for the "radiation boundary" is at least 40 mm away from EUT to well contain all adjacent exposure surfaces (S1~S6 in Figure 2).

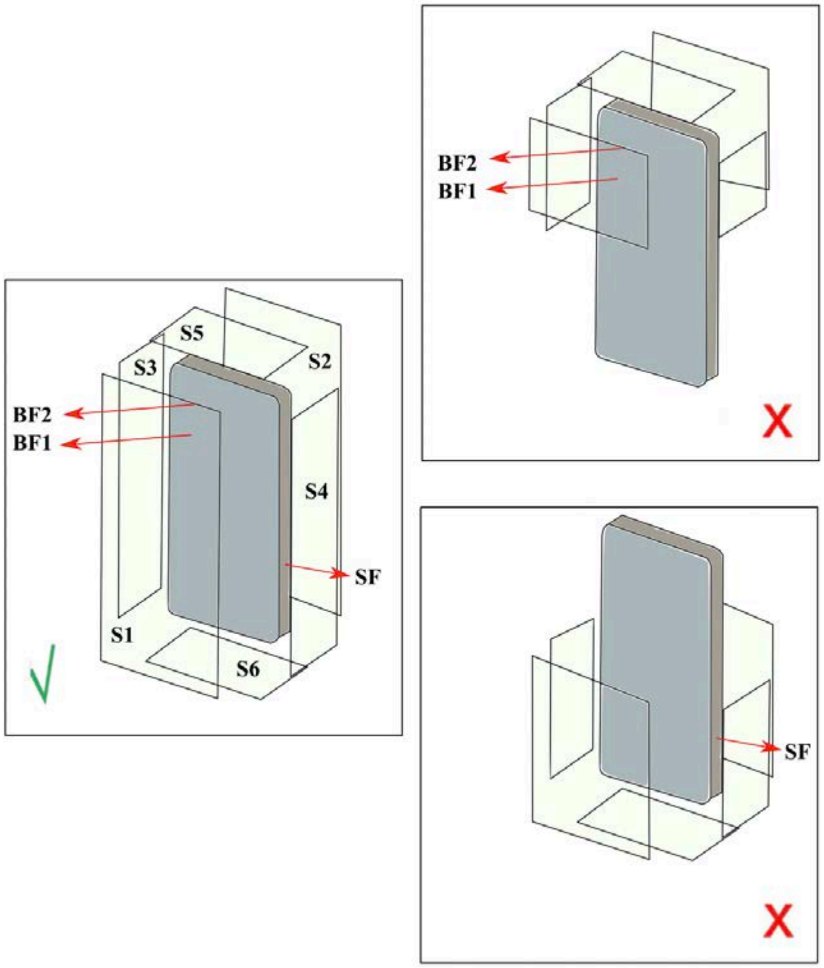


Figure C.2. Simulation model examples.

C.2 GEN2 PD Generation Using Qualcomm MG Script

Use “Qualcomm MG script” to extract E- and H-fields from the validated simulation and to assess the mutual coupling between all the mmW modules and all the beams in the codebook to determine the backoff value for each mmW module. Note the assessment and backoff value derivation are automated with “Qualcomm MG script”. Once the script is done with assessment, it will provide the $sim.power_{limit}$ (backoff is already included) for all the beams for all three channels for the specified *PD_design_target*.

C.3 Additional Verifications for GEN2

The PD for GEN2 cannot be finalized until the additional verifications described in this section are performed and passed. The below steps are followed for verifications in the mid channel.

VERIFICATION 1: Use “Qualcomm MG script” to print the PD plots for all the beams selected and evaluated for model validation. Compare the printed PD plot to the corresponding simulated/measured PD, the printed PD distributions should match the simulated PD distributions as shown in Table C.1 and C.4 to verify that "Qualcomm MG script" is properly used.

VERIFICATION 2: "Qualcomm MG script" identifies the worst-case $4cm^2$ PD and its location (*x,y,z*). This worst-case $4cm^2$ PD is maximum $4cm^2$ PD value out of all exposure surfaces when assuming the worst beam from each of the antenna modules are active. The script will then identify the worst beam from each module that contributes the most to the worst $4cm^2$ PD and print their contribution factor, as well as the worst surface corresponding to the worst-case $4cm^2$ PD, backoff value for each antenna module and *verification.sim.powerlimit* (before backoff) value for each identified beams.

Use HFSS (or other EM simulation tool) to calculate the simulated contribution factor for the identified beams. The simulated contribution factor, $c_{simulated}(i,j)$, for beam *i* from QTM *j* can be computed by

$$csimulated\ (i, j) = 4cm^2\ PD\ at\ (x, y, z)\ at\ verification.\ sim.\ power\ limit\ /\ PD\_design\_target$$

Verify:

1. the printed contribution factor, *c(i,j),* matches the simulated contribution factor, $c_{simulated}(i,j)$, obtained from HFSS (or other EM simulation tool) within 2% of numerical tolerance.
2. the normalized *combined PD* does not exceed 1.0, i.e., *normalized combined PD* = $\sum(b_j * c(i,j)) \leq 1.0$

where *combined PD* = PD from current antenna module + PD contributions from other antenna modules; b_j = backoff value for antenna module *j*, *j* = antenna module #; *c(i,j)* = contribution factor of beam *i* from antenna module *j* to the worst $4cm^2$ PD. Both *bj* and *c(i,j)* are printed from "Qualcomm MG script".

VERIFICATION 3: Measure power density for the beams identified by "Qualcomm MG script" on their corresponding worst surfaces printed from the script. Set the device in FTM mode, the PD measurement should be performed at the reference power level with CW modulation. Scale the measured PD to obtain $4cm^2$ PD(*i,j*) for beam *i* from antenna module *j* at their *input.power.limit*. Demonstrate that the *combined PD* (i.e., $\sum[c(i,j)*PD(i,j)]$) is less than or equal to *PD_design_target* within the uncertainty at reference power level, i.e., *combined PD* = $\sum[c(i,j)*measured\ 4cm^2\ PD(i,j)] \leq PD\_design\_target$ + uncertainty **at reference power level.**

As an example of one of the iPhone programs, which contains 2 antenna modules (i.e., Module0 (back-firing array 1 and back-firing array 2) and Module1 (side-firing array)), the following verifications are for n258, n261 and n260, respectively.

1) Band n258

"Qualcomm MG script" identifies beam *28* and *5* from Module0 and Module1, respectively. The script prints below information corresponding to the identified worst-case $4cm^2$ PD:

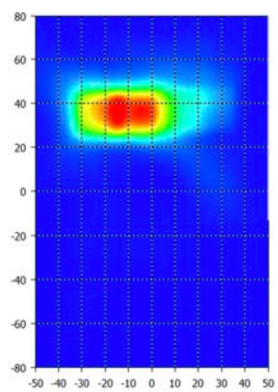
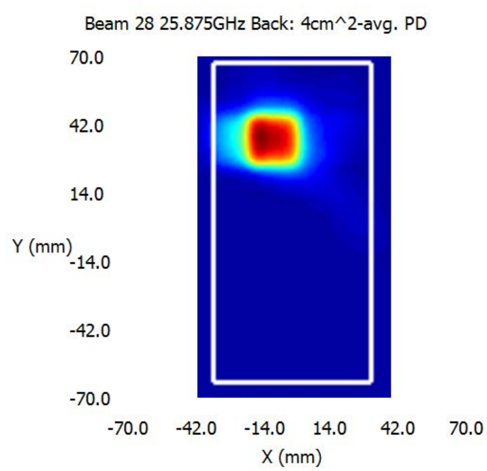
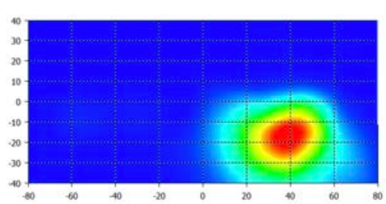
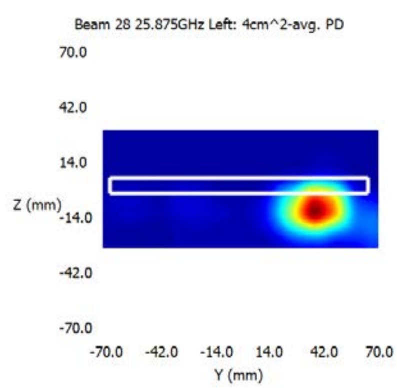
- the backoff values (in linear) for Module0 and Module1: b_0 = 0.9772; b_1 = 0.9550
- the worst location coordinates (*x, y, z*) in meter = (0.03411, -0.00900, -0.00100)

- the worst-surface = S4 (right surface, see Figure C.2)
- the *verification.sim.power$_{limit}$* (before backoff) for the beams *28* and *5* is 0.53 dBm and 6.61 dBm, respectively.
- worst surface for Module0 is S2 (back); worst surface for Module1 is S4 (right)
- the contribution factors *c*(*28, 0*) = 0.0236 and *c*(*5, 1*) = 0.9994 at the worst-case 4cm^2 PD location (0.03411, -0.00900, -0.00100)

As shown in Table C.2, the printed contribution factor matches the simulated contribution factor within 2%, and the *normalized combined PD* is less than 1.0. Thus, the verification 2 is completed for this program.

As shown in Table C.3, the *combined* measured *PD* at the worst location ≤ *PD_design_target* uncertainty at reference power level. Thus, the verification 3 is competed for this program.

Table C.1 - Simulated PD distributions for selected beams.

<table>
<tr><th>Beam ID</th><th>Surface</th><th>Simulated PD</th><th>Printed out from Qualcomm MG Script</th></tr>
<tr><td rowspan="2">28</td><td>S2</td><td></td><td></td></tr>
<tr><td>S3</td><td></td><td></td></tr>
</table>

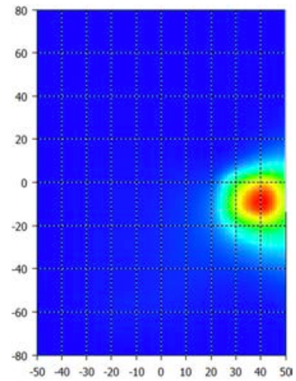
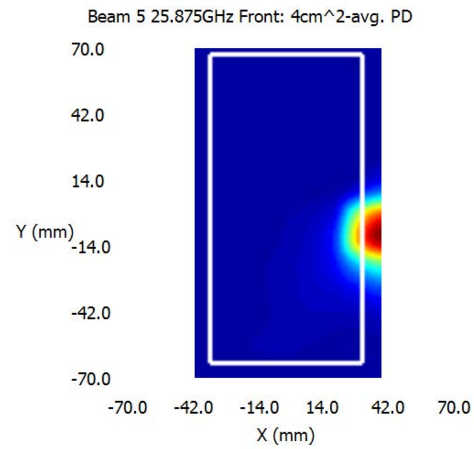
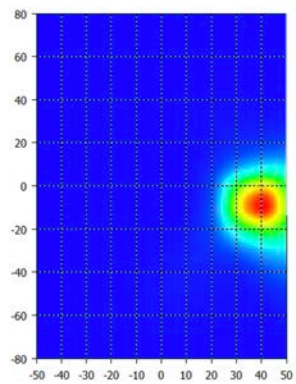
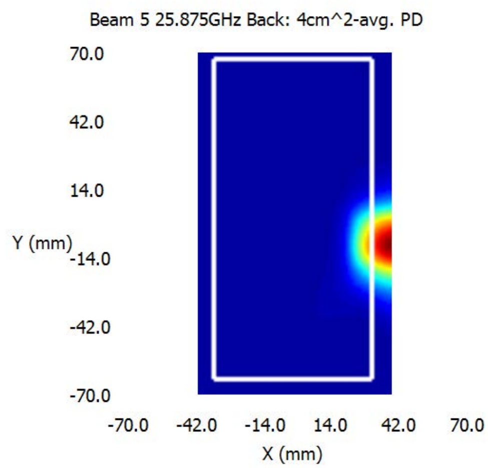
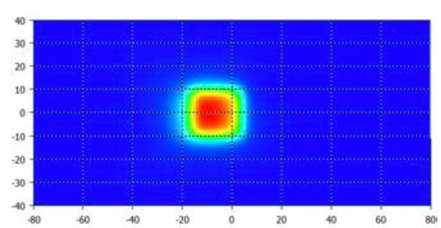
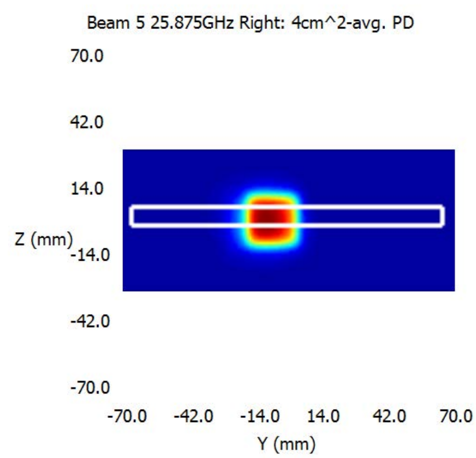
5	S1		Beauty 5 25.875GHz Front: 4cm^2-avg. PD Y (mm) X (mm)
	S2		Beam 5 25.875GHz Back: 4cm^2-avg. PD Y (mm) X (mm)
	S4		Beam 5 25.875GHz Right: 4cm^2-avg. PD Z (mm) Y (mm)

Table C.2 - Contribution factors from Qualcomm MG script and from HFSS for selected beams, and normalized *combined PD* verification, for device with 2 antenna modules.

Worse-case surface					S4 (right surface)	
Worst-case location *(x,y,z)* in meters					(0.03411, -0.00900, -0.00100)	
PD_design_target (mW/cm^2)					0.6	
Value printed by MG Script					Value by EM tool	
Module #	Beam ID	*c(i ,j)*, *i*=beam ID, *j*=module #	Backoff factor b_j	*verification.sim.power*$_{limit}$ (before backoffs) [dBm]	Simulated 4cm^2 PD at (0.03411, -0.00900, -0.00100) with *verification.sim.power*$_{limit}$ on S4 (mW/cm^2)	$c_{simulated}(i, j)$
0	28	0.0236	0.9772	0.53	0.0141	0.0141/0.6 = 0.0235
1	5	0.9994	0.9550	6.61	0.5996	0.5996/0.6 = 0.9993
Verify 1	$uujc(i, j) = c_{simulated}(i, j)$, i = 28, 5; j = 0, 1					
Verify 2	b_0 x $c(28,0)$ + b_1 x $c(5,1)$ = 0.9772 x 0.0236 + 0.9550 x 0.9994 = 0.9775 ≤ 1					

Table C.3: Measured 4cm^2 PD on worst surface and *combined PD* at worst-case location for device with 2 antenna modules.

Module#	Beam ID	Dominant Surface	Measured 4cm^2 PD at input.power.limit on dominant surface (mW/cm^2)
0	28	S2 (Back)	0.6235
1	5	S4 (Right)	0.5847
combined PD at the worst-case location (*x,y,z*)			*c(28,0)*xmeas.4cm^{2}PD*(28,0)* + *c(5,1)*xmeas.4cm^{2}PD*(5,1)* = 0.0236 x 0.6235 + 0.9994 x 0.5847 = 0.5991 mW/cm^2

PD_design_target + uncertainty at reference power level of 0.75 dB	$= 0.6*10^{(+0.75/10)} = 0.71$ mW/cm^2
Verify	combined PD < PD_design_target + uncertainty at reference power level

Note *c(i,j)* is obtained from Table C.2.

2) Band n261

"Qualcomm MG script" identifies beam *31* and *133* from Module0 and Module1, respectively. The script prints below information corresponding to the identified worst-case 4cm^2 PD:

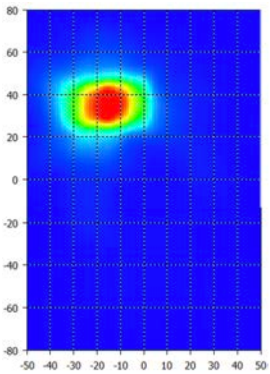
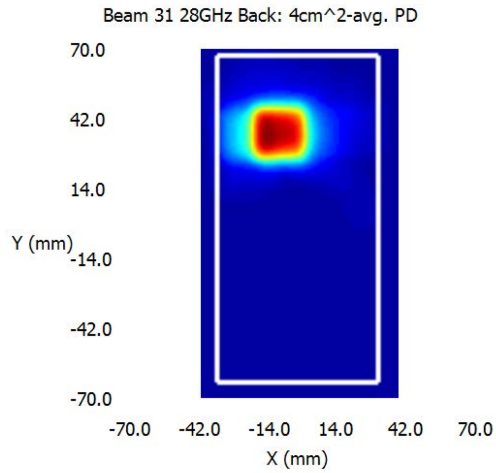
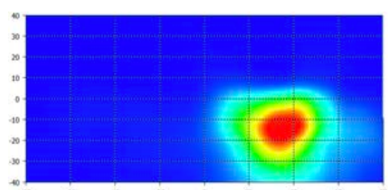
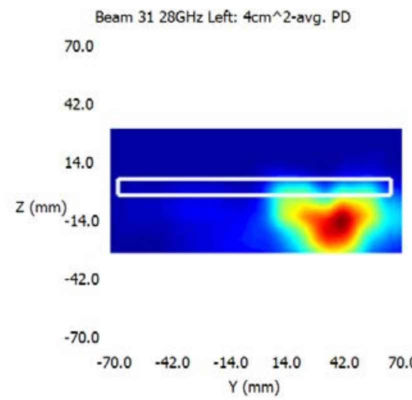
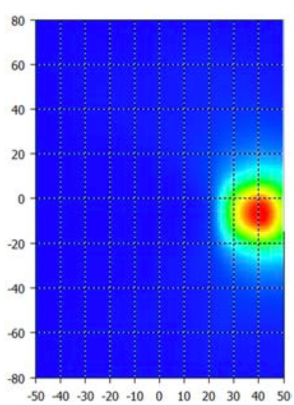
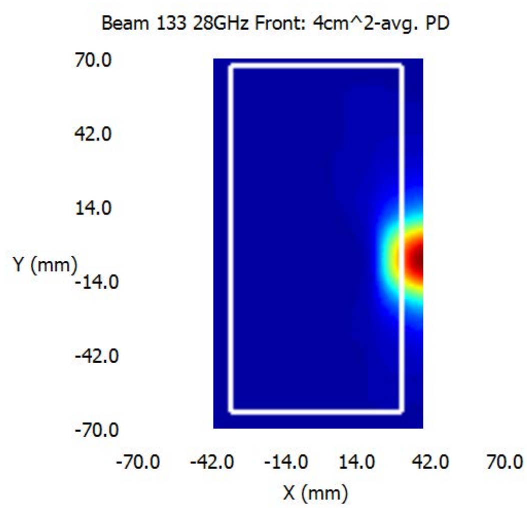
- the backoff values (in linear) for Module0 and Module1: $b_0 = 0.9772$; $b_1 = 0.9772$
- the worst location coordinates (*x, y, z*) in meter = (0.03411, -0.00700, 0.00000)
- the worst-surface = S4 (right surface, see Figure C.2)
- the *verification.sim.power$_{limit}$* (before backoff) for the beams *31* and *133* is 1.48 dBm and 6.97 dBm, respectively.
- worst surface for Module0 is S2 (back); worst surface for Module1 is S4 (right)
- the contribution factors *c*(*31, 0*) = 0.0092 and *c*(*133, 1*) = 0.9998 at the worst-case 4cm^2 PD location (0.03411, -0.00700, 0.00000)

As shown in Table C.5, the printed contribution factor matches the simulated contribution factor within 2%, and the *normalized combined PD* is less than 1.0. Thus, the verification 2 is completed for this program.

As shown in Table C.6, the *combined* measured *PD* at the worst location ≤ *PD_design_target* uncertainty at reference power level. Thus, the verification 3 is competed for this program.

Table C.4 - Simulated PD distributions for selected beams.

Beam ID	Surface	Simulated PD	Printed out from Qualcomm MG Script

31	S2		
	S3		
133	S1		

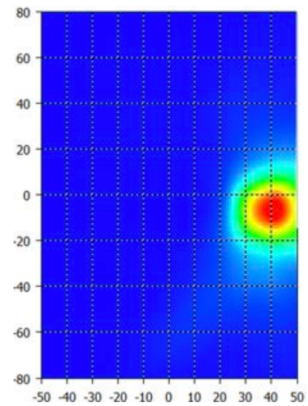
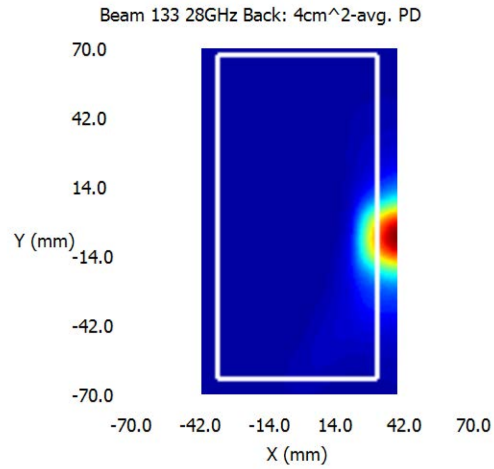
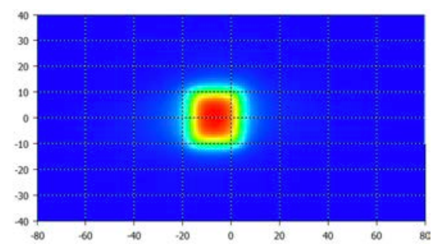
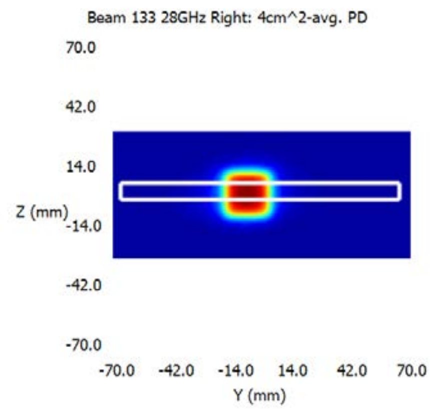
	S2		
	S4		

Table C.5 - Contribution factors from Qualcomm MG script and from HFSS for selected beams, and normalized *combined PD* verification, for device with 2 antenna modules.

Worse-case surface					S4 (right surface)	
Worst-case location *(x,y,z)* in meters					(0.03411, -0.00700, 0.00000)	
PD_design_target (mW/cm^2)					0.6	
Value printed by MG Script					Value by EM tool	
Module #	Beam ID	*c(i ,j), i*=beam ID,	Backoff factor b_j	*verification.sim.power*$_{limit}$ (before backoffs) [dBm]	Simulated 4cm^2 PD at (0.03411, -0.00700, 0.00000) with	$c_{simulated}(i\ ,j)$

		j=module #			*verification.sim.power$_{limit}$* on S4 (mW/cm^2)	
0	31	0.0092	0.9772	1.48	0.0055	0.0055/0.6 = 0.0091
1	133	0.9998	0.9772	6.97	0.5998	0.5998/0.6 = 0.9996
Verify 1	$uujc(i,j)=c_{simulated}(i,j)$, i = 31, 133; j = 0, 1					
Verify 2	b_0 x $c(31,0)$ + b_1 x $c(133,1)$ = 0.9772 x 0.0092 + 0.9772 x 0.9998 = 0.9860 ≤ 1					

Table C.6: Measured 4cm^2 PD on worst surface and *combined PD* at worst-case location for device with 2 antenna modules.

Module#	Beam ID	Dominant Surface	Measured 4cm^2 PD at input.power.limit on dominant surface (mW/cm^2)
0	31	S2 (Back)	0.6824
1	133	S4 (Right)	0.6095
combined PD at the worst-case location (*x,y,z*)			*c(31,0)*xmeas.4cm^{2}PD*(31,0)* + *c(133,1)*xmeas.4cm^{2}PD*(133,1)* = 0.0092 x 0.6824 + 0.9998 x 0.6095 = 0.6157 mW/cm^2
PD_design_target + uncertainty at reference power level of 0.75 dB			= 0.6*10$^{(+0.75/10)}$ = 0.71 mW/cm^2
Verify			combined PD < PD_design_target + uncertainty at reference power level

Note *c(i,j)* is obtained from Table C.5.

3) Band n260

"Qualcomm MG script" identifies beam *146* and *25* from Module0 and Module1, respectively. The script prints below information corresponding to the identified worst-case 4cm^2 PD:

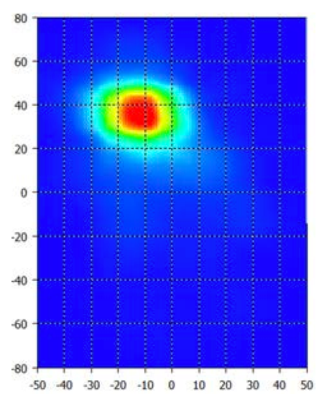
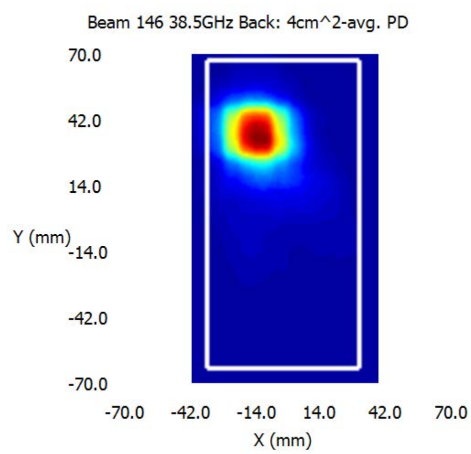
- the backoff values (in linear) for Module0 and Module1: b_0 = 0.9772; b_1 = 0.9550
- the worst location coordinates (*x, y, z*) in meter = (0.03411, -0.01000, -0.00100)

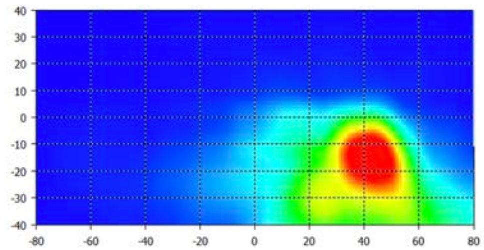
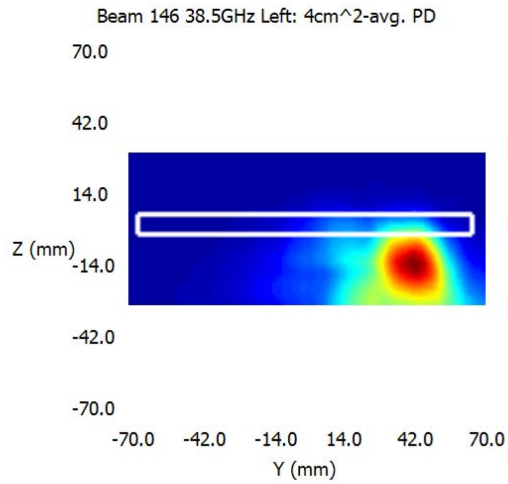
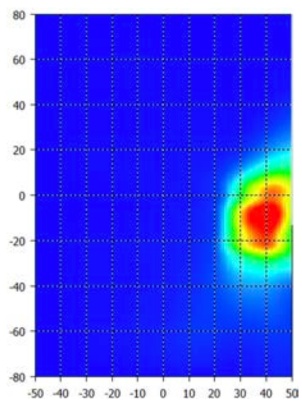
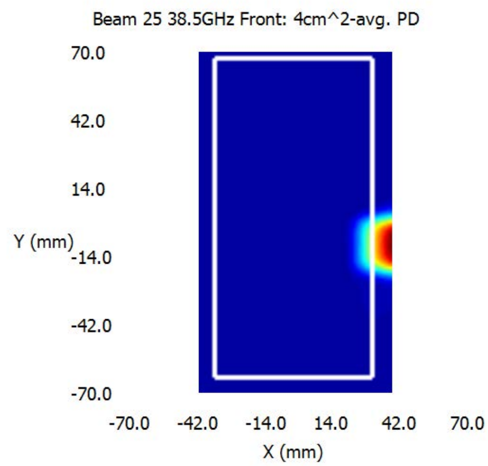
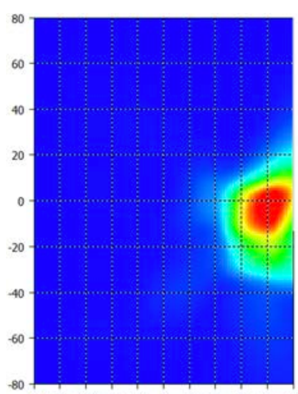
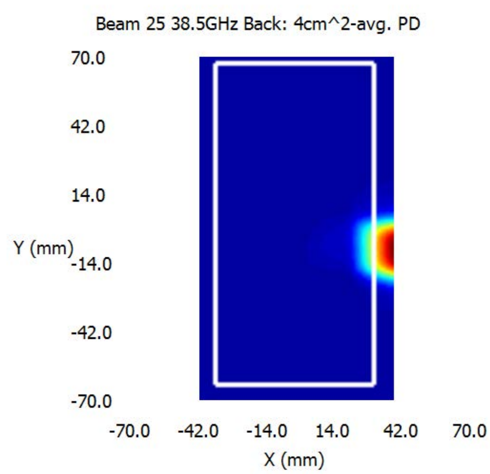
- the worst-surface = S4 (right surface, see Figure C.2)
- the *verification.sim.power$_{limit}$* (before backoff) for the beams *146* and *25* is 7.49 dBm and 4.95 dBm, respectively.
- worst surface for Module0 is S2 (back); worst surface for Module1 is S4 (right)
- the contribution factors *c*(*146, 0*) = 0.0154 and *c*(*25, 1*) = 1.0000 at the worst-case 4cm^2 PD location (0.03411, -0.01000, -0.00100)

As shown in Table C.8, the printed contribution factor matches the simulated contribution factor within 2%, and the *normalized combined PD* is less than 1.0. Thus, the verification 2 is completed for this program.

As shown in Table C.9, the *combined* measured *PD* at the worst location ≤ *PD_design_target* uncertainty at reference power level. Thus, the verification 3 is competed for this program.

Table C.7 - Simulated PD distributions for selected beams.

Beam ID	Surface	Simulated PD	Printed out from Qualcomm MG Script
146	S2		

<table>
<tr><td></td><td>S3</td><td></td><td>
</td></tr>
<tr><td rowspan="2">25</td><td>S1</td><td></td><td>
</td></tr>
<tr><td>S2</td><td></td><td>
</td></tr>
</table>

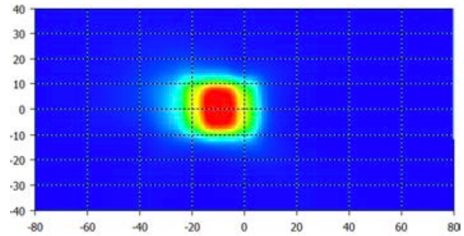
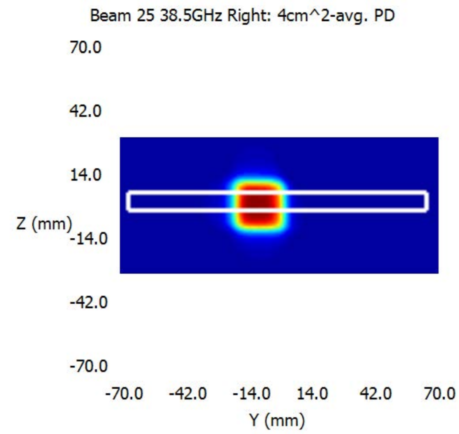
	S4		

Table C.8 - Contribution factors from Qualcomm MG script and from HFSS for selected beams, and normalized *combined PD* verification, for device with 2 antenna modules.

Worse-case surface					S4 (right surface)	
Worst-case location *(x,y,z)* in meters					(0.03411, -0.01000, -0.00100)	
PD_design_target (mW/cm^2)					0.6	
Value printed by MG Script					Value by EM tool	
Module #	Beam ID	*c(i ,j), i*=beam ID, *j*=module #	Backoff factor b_j	$verification.sim.power_{limit}$ (before backoffs) [dBm]	Simulated 4cm^2 PD at (0.03411, -0.01000, -0.00100) with $verification.sim.power_{limit}$ on S4 (mW/cm^2)	$c_{simulated}(i\ ,j)$
0	146	0.0154	0.9772	7.49	0.0092	0.0092/0.6 = 0.0153
1	25	1.0000	0.9550	4.95	0.5946	0.5946/0.6 = 0.9910

Verify 1	$c(i,j)=c_{simulated}(i,j)$, i = 146, 25; j = 0, 1
Verify 2	b_0 x $c(146,0)$ + b_1 x $c(25,1)$ = 0.9772 x 0.0154 + 0.9550 x 1.0000 = 0.9700 ≤ 1

Table C.9 - Measured 4cm^2 PD on worst surface and *combined PD* at worst-case location for device with 2 antenna modules.

Module#	Beam ID	Dominant Surface	Measured 4cm^2 PD at input.power.limit on dominant surface (mW/cm^2)
0	146	S2 (Back)	0.5798
1	25	S4 (Right)	0.6235
combined PD at the worst-case location (*x,y,z*)			*c(146,0)*xmeas.4cm^{2}PD*(146,0)* + *c(25,1)*xmeas.4cm^{2}PD*(25,1)* = 0.0154 x 0.5798 + 1.0000 x 0.6235 = 0.6324 mW/cm^2
PD_design_target + uncertainty at reference power level of 0.75 dB			= 0.6*10$^{(+0.75/10)}$ = 0.71 mW/cm^2
Verify			combined PD < PD_design_target + uncertainty at reference power level

Note *c(i,j)* is obtained from Table C.8.