A3081_5G_Product-mmWave-MPE_Simulation_Report-withsimPDPlots

Model No	FCC ID:
A3081	BCG-E8688A

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Location:
Apple Inc., Cupertino, CA, USA

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1 Introduction

This document provides an overview of the methodology used for Maximum Permissible Exposure (MPE) compliance of the 5G mmWave radios on next generation iPhone.

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

- Brief introduction to MPE simulation methodology
- Explanation of the approach to demonstrate MPE (sPD) compliance in a device using measurements
- 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 to choose the scaling factor for all other beams on that polarization.

2 MPE Simulation Methodology

3D full-wave simulation is used to evaluate MPE for each antenna array 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.

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) **Compile Fields and Codebook:**
    - Extract field data from solved model and arrange in format required by Qualcomm Module Group (MG) Script [1]
    - Input PD char codebook generated by Qualcomm Webchar tool
3) **MPE Calculations:**

- Set averaging area to $4cm^2$ using MG Script configuration xml file
- Run MG script to generate MPE and power limit tables for each beam ID in codebook

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

5) Run Additional Verifications:

- Use verification data generated by MG Script
- Measure MPE for worst case beams given by MG Script
- Use EM tools, MG Script to complete additional verifications

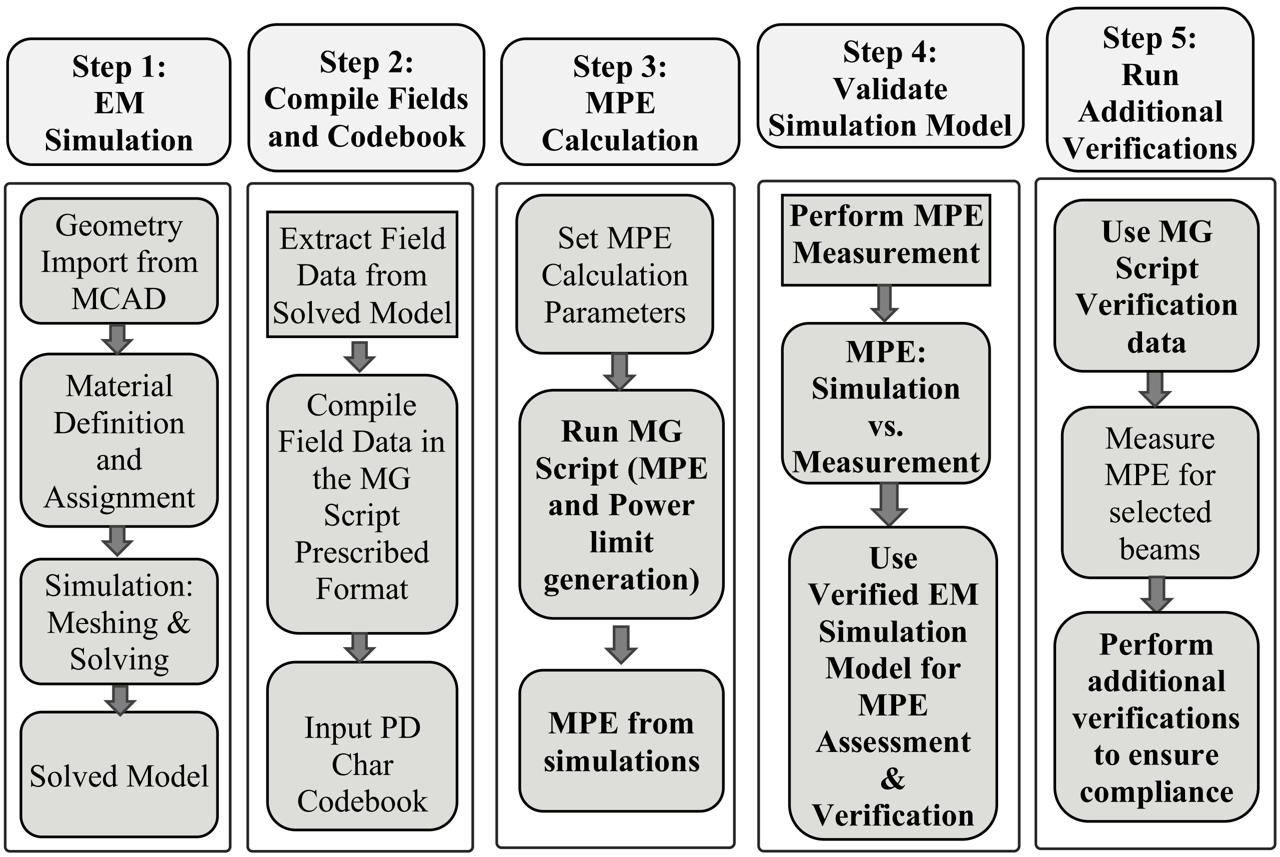


Figure 1. Model validation workflow for MPE simulation and evaluation.

3 MPE Measurements

A mmWave DAE SN 1411 module from SPEAG is used to measure the MPE (sPD) 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 [2] in detail.

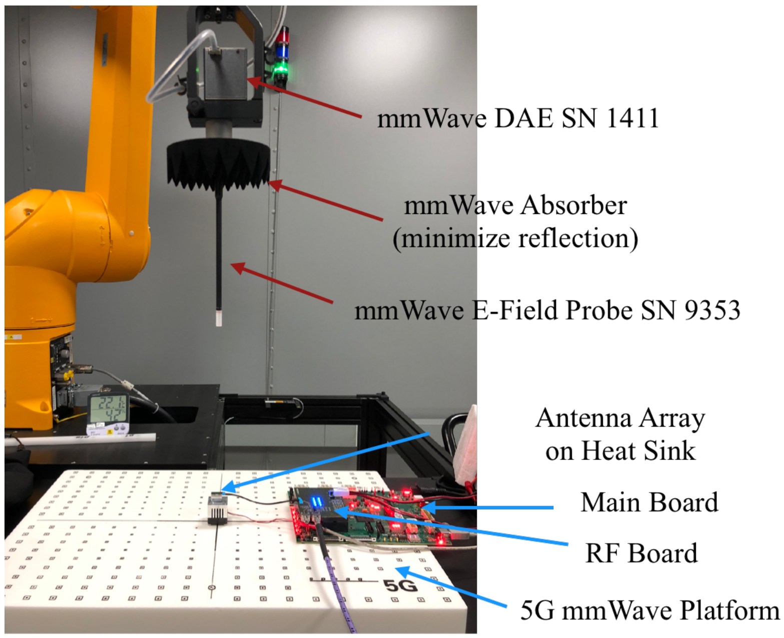


Figure 2. MPE measurement setup.

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.

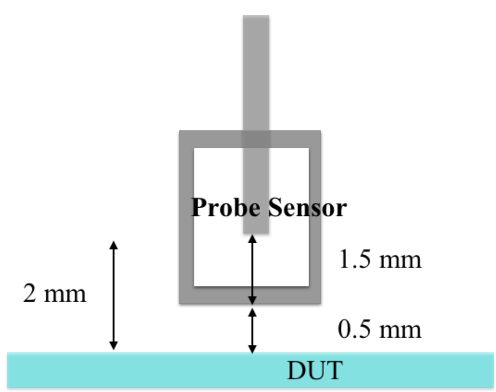


Figure 3. Sketch of the probe showing that the minimum measurable distance is 2 mm.

4 MPE (sPD) Simulations

In 5G, MIMO antennas are designed to orient the beam to specific directions 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 is a single antenna array in the phone, which is back-firing array.

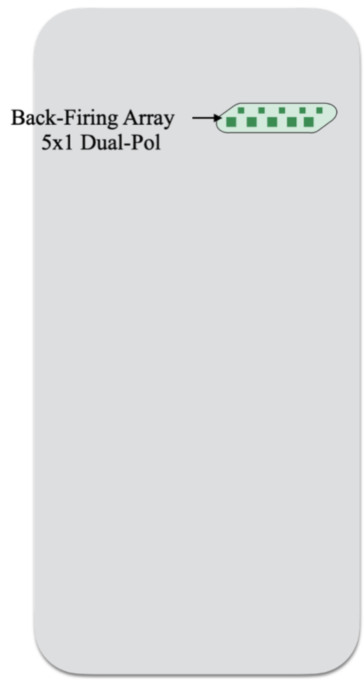


Figure 4. Schematic of the simulation model consisting of a back-firing 5G antenna array.

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 an antenna array, only the evaluating planes within 2.5 cm from the edges of the antenna module 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.

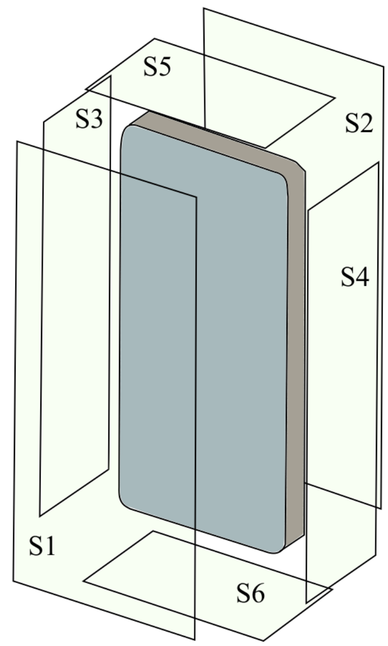


Figure 5. Evaluating surfaces for MPE (sPD).

Table 1- PD Evaluation Planes (any distance less than 2.5 cm is reported as 0 cm)

	Front (S1)	**Rear (S2)**	**Left from Front View (S3)**	**Right from Front View (S4)**	**Top (S5)**	**Bottom (S6)**
Back Array	No (0 cm)	**Yes (0 cm)**	**Yes (0 cm)**	No (4 cm)	**Yes (0 cm)**	No (12 cm)

Power Density 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 $\vec{E}$ and a magnetic field $\vec{H}$ are needed. The actual consumption power can be expressed as the real term of the Poynting vector $\vec{S}$ from the cross product of $\vec{E}$ and complex conjugation of $\vec{H}$ as shown below:

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

$\vec{S}$ can be expressed as localized power density based on a peak value of each spatial point on mesh grid. From the localized power density $\vec{S}$, the spatial-averaged power density (PD) on an evaluated area (A) can be shown as below:

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

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. The quantities described in this section are evaluated using Qualcomm MG Script. Please refer to Appendix A for worst case total power density derivation.

Simulation Methodology:
A time domain 3D Full-Wave Electromagnetic Simulation is performed using CST Studio Suite. The solver calculates electric and magnetic fields at discrete locations and time samples. To achieve high accuracy at all locations, the total electromagnetic energy inside the calculation domain is used as a convergence criterion. The solvers terminate when the normalized energy is decayed to -40 dB. This ensures -40 dB decay at all locations and ensures high accuracy of simulation output.

Boundary Conditions:
The boundary condition for simulating electromagnetic behavior in CST is to allow the electromagnetic waves to be electrically open at the boundary and radiated far away without reflection. CST can support the absorption boundary condition (ABC) for radiation boundary and normally requires a quarter-wavelength separation from the structure.

Source Excitation and Example Codebook:
Figure **6**6 shows an example of the codebook for a back firing antenna module. The third column of the codebook is the beam ID. The other notable columns are “Amplitude” and “Phase” columns which 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 third column. The “Amplitude” is in dBm, and “Phase” is in degrees. In real applications, amplitude of the input power for n258, n261 and n260 is 6 dBm. One thing to be noted is that the codebook is defined at the chipset, not at the antenna elements.

Band	Shared_Banc	Beam_ID	Module	Ant_Group	Subarray	Ant_Type	Ant_Feed	Amplitude	Phase	Paired_With
257	261	0	0	0	3	PATCH	9	0	0	128
257	261	1	0	0	3	PATCH	10	0	0	129
257	261	2	0	0	3	PATCH	11	0	0	130
257	261	3	0	0	3	PATCH	12	0	0	131
257	261	4	0	0	3	PATCH	13	0	0	132
257	261	5	0	0	3	PATCH	12;13	0;0	315;0	133
257	261	6	0	0	3	PATCH	9;10	0;0	281.25;0	134
257	261	7	0	0	3	PATCH	10;11	0;0	0;0	135
257	261	8	0	0	3	PATCH	9;10	0;0	101.25;0	136
257	261	9	0	0	3	PATCH	10;11	0;0	213.75;146.2	137
257	261	10	0	0	3	PATCH	9;10	0;0	168.75;315	138
257	261	11	0	0	3	PATCH	11;12	0;0	146.25;146.2	139
257	261	12	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	247.5;258.75	140
257	261	13	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	78.75;135;78	141
257	261	14	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	168.75;292.5	142
257	261	15	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	292.5;123.75	143
257	261	16	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	67.5;326.25;	144
257	261	17	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	191.25;213.7	145
257	261	18	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	281.25;11.25	146
257	261	19	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	56.25;213.75	147
257	261	20	0	0	3	PATCH	9;10;11;12;1	0;0;0;0;0	146.25;22.5;	148
257	261	128	0	1	2	PATCH	2	0	0	0
257	261	129	0	1	2	PATCH	3	0	0	1
257	261	130	0	1	2	PATCH	4	0	0	2
257	261	131	0	1	2	PATCH	1	0	0	3
257	261	132	0	1	2	PATCH	5	0	0	4
257	261	133	0	1	2	PATCH	1;5	0;0	168.75;0	5

Figure 6. An example version of the antenna codebook.

Averaging the Power Density for MPE (sPD):
Qualcomm MG script performs spatial averaging needed to determine the MPE values from the power density simulation results over the 4 cm^2 area required by the FCC.

5 Uncertainty Budget for Simulation

Below is a table summarizing the budget of the uncertainty contributions of the numerical algorithm and of the rendering of the simulation setup. The table was filled using the IEC 62704-1, 2017 [3].

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

Uncertainty component	Probability distribution	Divisor f(d, h)[1]	c_i [2]	Uncertainty %
Mesh resolution	Normal	1	1	1.1
ABC	Normal	1	1	0.4
Power budget	Normal	1	1	0.4
Convergence	Rectangular	1,73	1	0.005
DUT dielectrics	Normal	1	1	7.5
Lossy conductors	Rectangular	1,73	1	0.69
Combined standard uncertainty (k = 1)				10.09

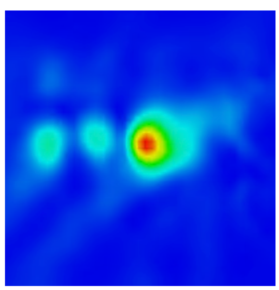
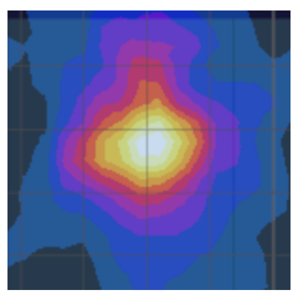
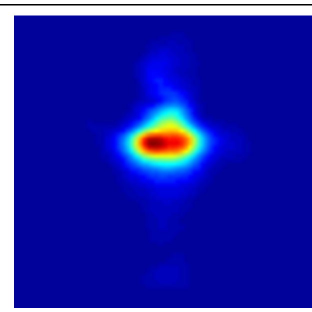
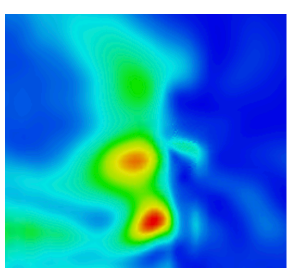
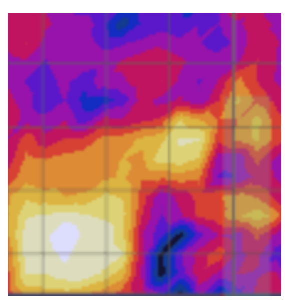
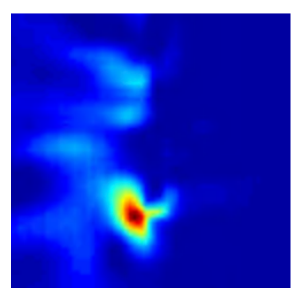
Note 1: The divisor is a function of the probability distribution and degrees of freedom (v_i and v_{eff}).
Note 2: c_i is the sensitivity coefficient that is applied to convert the variability of the uncertainty component into a variability of psPD.

6 Simulation vs. Measurement

The measured MPE and simulated MPE values for band n258 are summarized below in Table 3, with unit W/m². The difference between simulated and measured MPE values is in dB. Simulated and measured point PD for different beams for n258 are shown in Figure 7. The comparison is performed as per guidelines in [4].

Beam ID	Ant Pol	Simulation (W/m2)	Measurement (W/m2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
14	V	**20.78**	**16.70**	0.95
15	V	**19.32**	**13.30**	1.62
19	V	**19.02**	**14.80**	1.09
148	H	**20.48**	**17.70**	0.63
143	H	**19.63**	**18.10**	0.35
147	H	**18.86**	**17.40**	0.35

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

Beam ID	**Surface**	**Simulated Point PD**	**Measured Point PD**	**Print out from MG Script**
14	**S2**			
	S3			

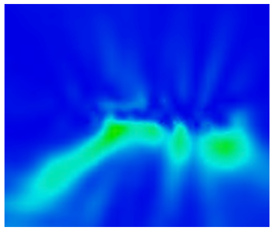
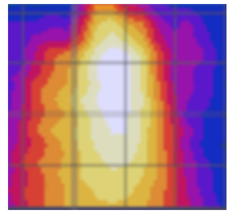
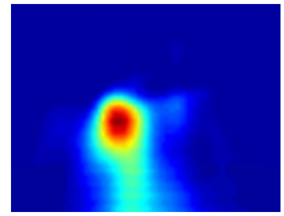
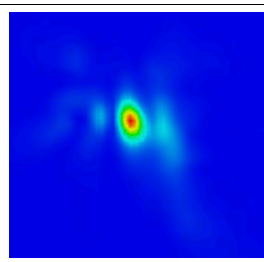
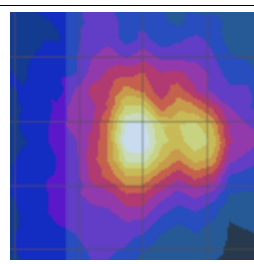
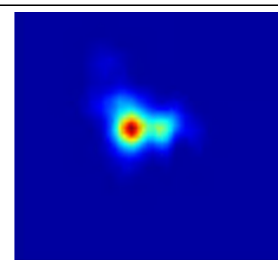
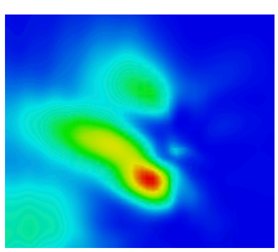
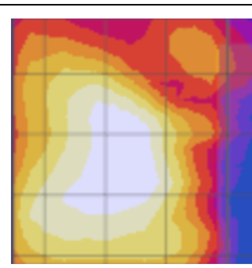
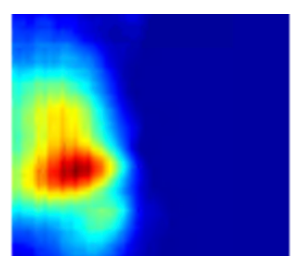
	S5			

Figure 7. Simulated and measured point PD for different beams for n258.

Measured MPE and simulated MPE values for band n261 are summarized below in Table 4, with unit W/m^2. The difference between simulated and measured MPE values is in dB. Simulated and measured point PD for different beams for n261 are shown in Figure 8.

Beam ID	Ant Pol	Simulation (W/m2)	Measurement (W/m2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
20	V	**19.34**	**11.80**	2.15
15	V	**20.04**	**16.20**	0.92
12	V	**18.79**	**13.60**	1.40
140	H	**25.01**	**12.50**	3.01
142	H	**23.71**	**13.90**	2.32
147	H	**23.65**	**14.40**	2.15

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

Beam ID	**Surface**	**Simulated Point PD**	**Measured Point PD**	**Print out from MG Script**
140	**S2**			
	S3			

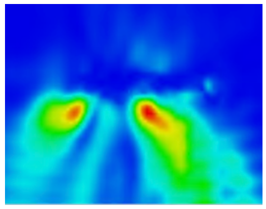
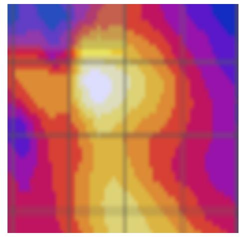
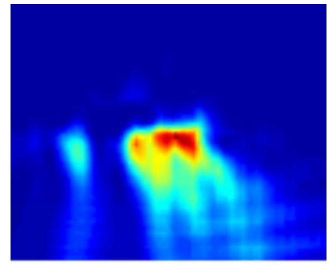
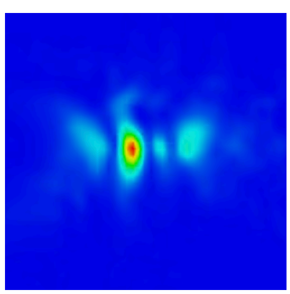
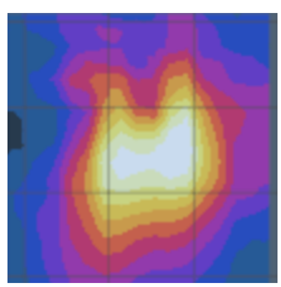
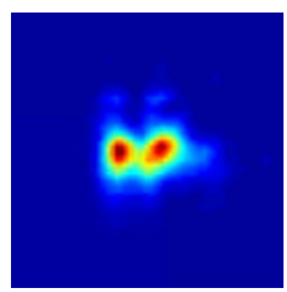
	S5			

__Figure 8.__ Simulated and measured point PD for different beams for n261.

Measured MPE and simulated MPE values for band n260 are summarized below in Table 5, with unit W/m2. The difference between simulated and measured MPE values is in dB. Simulated and measured point PD for different beams for n260 are shown in Figure 9.

Beam ID	Ant Pol	Simulation (W/m^2)	Measurement (W/m^2)	Delta = Sim – Meas. (dB)
		S2	**S2**	S2
19	V	**17.96**	**8.30**	3.35
15	V	**17.84**	**8.70**	3.12
20	V	**17.26**	**8.20**	3.23
146	H	**17.80**	**9.00**	2.96
141	H	**18.81**	**8.50**	3.45
145	H	**18.77**	**8.80**	3.29

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

Beam ID	**Surface**	**Simulated Point PD**	**Measured Point PD**	**Print out from MG Script**
141	**S2**			

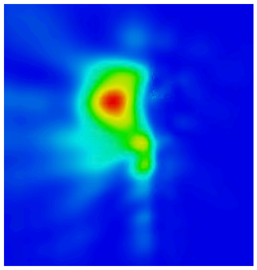
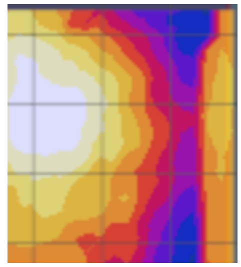
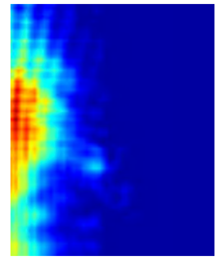
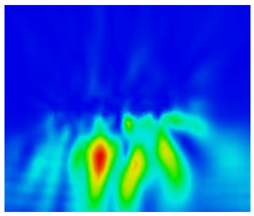
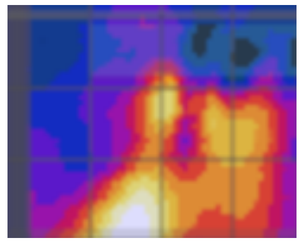
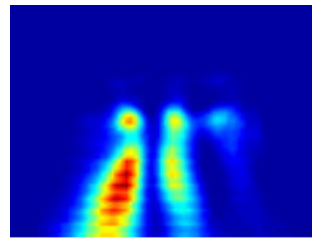
	S3			
	S5			

Figure 9. *Simulated and measured point PD for different beams for n260.*

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. For more details, please refer to [4].

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

4 cm^2 Averaging PD: The simulated sPD results for all three bands n258, n261 and band n260 are shown in tables a), b), and c) respectively.

a) Simulated sPD (W/m^2) at 4 cm^2 averaging for n258.

		4 cm^2 sPD (W/m^2) at 6 dBm per port, n258								
Beam ID 1	Beam ID 2	LB			MB			HB		
		S2	S3	S5	**S2**	S3	S5	**S2**	S3	S5
0		1.93	0.4	0.13	2.33	0.42	0.17	2.69	0.47	0.21
1		3.29	0.29	0.41	3.17	0.34	0.38	2.83	0.31	0.34
2		1.99	0.22	0.22	2.08	0.23	0.2	2.14	0.29	0.17
3		2.7	0.13	0.29	3.27	0.16	0.34	3.55	0.2	0.35
4		2.72	0.3	0.23	2.59	0.26	0.25	2.6	0.26	0.29
5		3.37	0.45	0.4	3.46	0.41	0.38	3.66	0.37	0.39
6		6.48	0.24	0.61	7.24	0.25	0.78	7.83	0.38	0.8
7		6.73	0.71	0.94	6.68	0.76	0.87	6.35	0.82	0.71
8		6.84	1.04	0.77	7.33	1.19	0.84	7.24	1.27	0.85
9		4.78	0.34	0.58	4.93	0.31	0.52	5.2	0.29	0.5
10		7.31	0.27	0.72	8.12	0.32	0.71	8.17	0.31	0.6
11		7.03	0.43	0.74	7.46	0.48	0.92	8.02	0.58	0.93
12		9.64	0.71	1.01	10.54	0.66	1.16	10.58	0.67	1.3
13		15.59	1.44	1.95	16.72	1.4	2.06	16.98	1.59	2.05
14		19.38	0.6	2.54	20.78	0.52	2.78	21.18	0.47	2.75
15		17.41	0.96	2.66	19.32	1.16	2.78	20.56	1.52	2.65
16		14.2	3.45	1.88	15.17	3.82	2	16.05	4.33	2.08
17		12.53	0.91	1.53	13.56	0.93	1.75	13.84	1.15	1.86
18		17.8	1.51	2.26	19.19	1.3	2.12	19.65	1.32	2.14
19		17.58	0.41	2.63	19.02	0.32	2.96	19.73	0.35	2.79
20		16.18	1.6	2.75	17.94	1.79	2.7	19.34	2.26	2.67
128		1.94	0.19	0.14	1.95	0.24	0.13	2.16	0.31	0.17
129		2.47	0.44	0.27	2.92	0.54	0.3	3.19	0.63	0.37
130		3.06	0.29	0.29	3.12	0.35	0.34	3.03	0.34	0.31
131		2.98	0.29	0.39	3.58	0.31	0.41	4.04	0.33	0.44
132		2.85	0.25	0.2	2.79	0.23	0.24	2.92	0.24	0.24
133		4.82	0.23	0.53	5.49	0.23	0.67	6.29	0.28	0.78
134		5.13	0.27	0.59	5.21	0.25	0.6	5.22	0.19	0.67
135		7.05	0.81	0.75	7.73	1.01	0.76	8.12	1.03	0.82
136		5.53	0.91	0.44	6.3	1.13	0.51	7.06	1.39	0.7
137		4.76	0.27	0.56	4.84	0.27	0.56	4.86	0.21	0.62
138		6.19	0.44	0.63	6.4	0.47	0.68	6.51	0.45	0.82
139		8.3	0.5	0.93	8.96	0.5	1.05	9.5	0.56	1.03

140		10.15	0.78	1.28	12.35	0.72	1.87	14	0.63	2.14
141		17.16	0.78	3.24	18.32	0.6	3.42	19.32	0.56	3.25
142		16.84	0.42	2.51	18.24	0.32	2.51	19.43	0.26	2.31
143		18.1	0.44	2.23	19.63	0.69	2.37	21.02	0.71	2.75
144		18.11	4.28	2.9	19.32	4.92	2.91	19.8	5.34	3.2
145		16	0.87	2.88	17.5	0.7	3.39	18.69	0.68	3.42
146		16.84	0.6	2.89	18.09	0.43	2.96	19.18	0.38	2.69
147		17.47	0.37	2.2	18.86	0.32	2.11	20.17	0.25	2.24
148		18.95	1.71	2.45	20.48	2.31	2.77	21.25	2.45	3.11
0	128	4.81	0.8	0.33	5.12	0.93	0.34	5.36	1	0.42
1	129	7.51	1.08	0.72	7.99	1.21	0.9	7.81	1.31	1.03
2	130	5.7	0.68	0.61	5.91	0.76	0.61	6.29	0.91	0.56
3	131	5.92	0.52	0.92	7.24	0.53	1.06	8.24	0.61	1.09
4	132	6.69	0.6	0.48	6.21	0.5	0.57	6.62	0.59	0.61
5	133	8.74	0.76	0.96	9.44	0.78	1.11	9.77	0.82	1.28
6	134	11.81	0.68	1.55	12.64	0.58	1.57	12.96	0.64	1.74
7	135	14.46	2.05	1.73	15.12	2.26	1.76	15.5	2.38	1.6
8	136	16	2.2	1.28	17.25	2.63	1.55	17.9	3	2.05
9	137	11.86	1.03	1.43	12.02	0.97	1.52	11.96	0.87	1.57
10	138	14.41	0.96	1.85	16.03	0.9	1.59	16.27	0.91	1.67
11	139	18.68	1.17	2.35	19.64	1.14	2.72	20	1.39	2.76
12	140	21.48	2.34	2.98	25.29	1.98	3.57	28.84	1.68	4.32
13	141	39.74	3.59	7.44	42.02	3.25	7.37	43.13	3.36	7
14	142	37.52	1.49	5.82	40.94	1.23	6.06	43.68	1.03	5.96
15	143	37.83	1.61	5.86	42.45	2.2	6.03	45.83	3.01	7
16	144	38.29	9.32	5.52	38.76	10.1	5.65	39.54	11.28	6.41
17	145	34.05	3.07	6.27	38.16	2.49	6.74	40.05	2.83	7
18	146	39.16	3.39	6.33	41.17	2.76	6.29	43.44	2.55	6.08
19	147	37.43	0.82	5.72	41.51	0.8	5.74	44.03	0.94	6.25
20	148	38.56	4	5.8	40.82	5.01	6.46	42.46	5.47	7.43

b) *Simulated sPD (W/m^2) at 4 cm^2 averaging for n261.*

		4 cm^2 sPD (W/m^2) at 6 dBm per port, n261								
Beam ID 1	Beam ID 2	LB			MB			HB		
		S2	S3	S5	**S2**	S3	S5	**S2**	S3	S5
0		3.4	0.54	0.22	3.21	0.57	0.23	3.09	0.64	0.23
1		3.38	0.57	0.25	3.42	0.57	0.3	3.42	0.54	0.33
2		3.62	0.51	0.32	3.82	0.4	0.31	3.95	0.34	0.31
3		3.08	0.22	0.27	3.11	0.21	0.3	3.22	0.19	0.3
4		3.25	0.4	0.32	3.45	0.4	0.36	3.7	0.44	0.32
5		7.26	1.07	0.59	6.65	0.95	0.52	6.44	0.88	0.53
6		7.93	1.41	0.59	7.51	1.37	0.63	7.17	1.43	0.62
7		6.88	0.3	0.56	7.29	0.38	0.69	7.77	0.45	0.78

8		6.74	0.51	0.49	6.26	0.6	0.58	5.94	0.58	0.6
9		7.63	1.75	0.63	7.36	1.73	0.67	7.13	1.81	0.6
10		8.05	0.5	0.69	8.31	0.44	0.77	8.81	0.5	0.77
11		7.47	0.26	0.53	6.83	0.32	0.6	6.43	0.3	0.64
12		19.9	5.01	1.68	18.79	5	1.56	18.76	5.4	1.34
13		19.54	1.78	1.78	19.26	1.78	1.92	19.33	2.03	2.04
14		19.82	0.71	2.2	19.16	0.81	2.09	19	0.81	2.14
15		20.03	0.54	2.18	20.04	0.62	2.23	20.53	0.72	2.24
16		15.15	0.97	2.34	17.42	1.12	3	19.35	1.2	3.6
17		19.52	3.04	1.59	18.56	3.07	1.7	18.62	3.55	1.5
18		19.58	0.57	1.9	19.28	0.62	2.02	19.04	0.69	2.04
19		19.29	1.11	2.07	19.02	1.23	2.06	19.24	1.3	2.1
20		17.54	0.55	2.67	19.34	0.63	3.17	20.75	0.68	3.59
128		3.65	0.33	0.28	3.61	0.33	0.29	3.67	0.43	0.29
129		3.68	0.49	0.29	3.59	0.58	0.25	3.5	0.71	0.24
130		3.23	0.36	0.26	3.2	0.42	0.24	3.21	0.47	0.25
131		4.21	0.53	0.43	4.2	0.64	0.4	4.21	0.67	0.38
132		4.17	0.3	0.33	4.23	0.34	0.37	4.1	0.3	0.43
133		7.75	1.41	0.71	7.76	1.48	0.67	7.85	1.79	0.56
134		9.83	0.67	1	9.81	0.74	1.06	9.65	0.74	1.09
135		10.32	0.18	1.27	10.26	0.22	1.28	9.82	0.21	1.31
136		5.67	0.58	0.39	5.79	0.72	0.41	5.98	0.98	0.42
137		8.34	1.34	0.66	8.63	1.54	0.71	8.85	1.56	0.81
138		9.41	0.38	0.8	8.97	0.36	0.76	8.16	0.35	0.72
139		6.49	0.53	0.77	6.98	0.65	0.71	7.57	0.68	0.77
140		26.12	6.94	3.53	25.01	6.8	3.21	23.75	7.02	2.48
141		22.91	0.72	2.83	22.31	0.83	3.05	21.42	0.85	3.04
142		24.69	0.83	2.45	23.71	0.72	2.42	22.02	0.74	2.51
143		21.55	0.5	2.74	22.15	0.51	2.8	21.87	0.46	2.89
144		13.92	0.61	1.5	17.05	0.61	1.74	20.05	0.67	2.11
145		23.96	3.41	3.14	23.3	3.47	3.15	22.23	3.61	2.84
146		24.02	1.05	2.95	22.07	1.14	2.84	20.51	1.2	2.93
147		24.13	0.49	2.55	23.65	0.57	2.38	21.88	0.56	2.31
148		21.11	0.43	2.75	22.13	0.39	2.84	22.29	0.56	3.01
0	128	7.44	0.9	0.65	7.35	0.96	0.7	7.8	1.22	0.72
1	129	8.61	1.27	0.87	8.4	1.23	0.78	8.01	1.39	0.68
2	130	7.53	1	0.79	7.39	0.96	0.77	7.86	0.86	0.8
3	131	7.59	0.94	1.2	8.15	1.17	1.2	8.75	1.24	1.13
4	132	8.43	0.93	0.82	8.53	1.06	0.97	8.74	0.96	0.95
5	133	15.29	2.87	1.38	14.81	2.76	1.33	14.54	3.06	1.34
6	134	15.77	2.83	1.55	15.45	2.59	1.72	15.16	2.59	1.93
7	135	19.5	0.82	2.57	19.69	1.08	2.72	19.71	1.13	2.74
8	136	15.71	1.4	1.41	14.85	1.79	1.39	13.87	2.26	1.56
9	137	15.08	4.01	1.44	14.94	3.94	1.67	15.03	4.01	1.82
10	138	18.55	1.08	2.1	17.87	1.03	2.05	17.2	1.14	1.96

11	139	13.39	1.24	1.76	13.04	1.62	1.77	12.9	1.59	1.87
12	140	48.52	14.61	8.18	45.71	13.76	7.73	43.72	13.79	6.29
13	141	44.92	3.18	6.68	43.63	3.45	7.66	42.77	3.51	7.68
14	142	46.82	2.27	5.96	45.19	2.63	5.94	43.68	2.65	6.03
15	143	47.93	1.31	7.67	46.52	1.43	7.67	44.23	1.57	7.51
16	144	35.63	1.83	5.61	42.24	2.3	7.14	45.27	2.39	8.42
17	145	45.6	7.16	7.3	43.34	6.71	7.64	42.15	7.03	6.65
18	146	47.2	2.34	6.45	45.43	2.33	6.81	43.59	2.48	7.24
19	147	45.38	2.69	6.21	43.62	2.94	6	42.7	2.98	5.77
20	148	46.38	1.44	8.15	48.2	1.61	8.58	46.61	2	8.91

c) *Simulated sPD (W/m²) at 4 cm² averaging for n260.*

		4 cm² sPD (W/m²) at 6 dBm per port, n260								
Beam ID 1	Beam ID 2	LB			MB			HB		
		S2	S3	S5	**S2**	S3	S5	**S2**	S3	S5
0		2.07	0.51	0.14	3.52	0.66	0.25	3.28	0.68	0.29
1		1.77	0.21	0.2	3.2	0.26	0.35	3.22	0.31	0.35
2		2.13	0.15	0.2	3.13	0.25	0.19	3.41	0.23	0.25
3		1.91	0.21	0.22	3.33	0.25	0.39	3.32	0.27	0.43
4		3.46	0.2	0.37	4	0.16	0.31	3.86	0.16	0.27
5		5.69	0.59	0.99	6.73	0.66	1.16	6.14	0.69	1.04
6		5.41	0.21	0.9	7.78	0.26	0.98	7.43	0.41	1.03
7		4.13	0.19	0.25	6.69	0.32	0.59	7.14	0.3	0.65
8		3.57	0.98	0.34	5.97	1.17	0.48	5.86	1.18	0.55
9		3.2	0.37	0.51	6.03	1.14	0.95	5.91	1.38	0.97
10		4.06	0.14	0.59	7.15	0.25	0.78	7.64	0.25	0.93
11		3.91	1.06	0.29	6.52	0.96	0.46	6.49	0.85	0.43
12		10.34	2.53	2.05	12.46	4.24	2.34	12	4.76	2.39
13		10.14	0.66	2.4	16.35	0.69	3.44	15.79	1.07	3.4
14		9.83	0.92	1.69	15.99	0.9	2.03	17.63	0.57	2.54
15		10.93	1.75	0.47	17.84	0.84	1.17	18.69	0.75	1.02
16		7.12	1.99	1.04	11.24	2.67	0.88	12.94	1.98	1.04
17		10.94	1.58	2.37	15.41	3.25	3.52	15.42	4.1	3.7
18		9.92	1.25	2.16	15.93	0.56	2.89	16.18	0.63	3.02
19		10.14	0.54	0.85	17.96	0.92	1.42	19.29	0.76	1.57
20		11.1	1.01	0.87	17.26	0.77	0.97	17.68	0.93	0.91
128		2.44	0.55	0.24	3.57	0.84	0.26	3.27	0.65	0.25
129		1.88	0.27	0.31	3.37	0.44	0.41	3.2	0.35	0.46
130		1.99	0.27	0.13	3.4	0.36	0.28	3.46	0.32	0.32
131		2.3	0.22	0.23	3.73	0.29	0.34	3.6	0.27	0.39
132		2.76	0.13	0.21	4.43	0.21	0.46	4.32	0.26	0.48
133		5.32	0.51	0.24	7.98	0.8	0.65	7.74	0.92	0.48
134		4.23	0.39	0.67	6.92	0.53	0.93	6.78	0.7	0.78
135		3.82	0.37	0.57	6.84	0.19	1.11	6.86	0.16	1.16
136		5.03	0.62	0.53	7.29	0.78	0.9	6.51	0.82	0.99

137		4.29	0.72	0.43	7.06	0.99	0.7	6.74	1.14	0.54
138		4.46	0.09	0.51	8.28	0.17	1	8.75	0.24	1.11
139		4.65	0.5	0.66	7.36	0.58	1.16	6.87	0.6	1.27
140		11.31	3.31	0.63	17.48	5.88	1.11	16.05	5.68	0.94
141		10.53	0.69	0.64	18.81	1.64	1.84	18.98	2.74	1.57
142		8.94	0.64	1.63	16.19	1.4	2.64	17.32	0.96	2.4
143		9.64	1.85	1.61	15.98	1.35	3.71	15.52	1.29	4.06
144		7.23	2.4	0.95	10.23	4.4	1.3	11.2	3.56	2.14
145		11.43	2.3	0.42	18.77	4.57	1.59	17.96	5.8	1.3
146		9.68	0.37	0.94	17.8	0.42	2.13	19.35	0.61	1.75
147		10.04	1.26	2.27	16.18	1.55	3.43	15.69	1.32	2.93
148		9.36	1.59	1.08	14.47	1.02	2.93	15.08	1.14	4.06
0	128	6.07	1.47	0.51	7.5	2.02	0.6	6.87	1.99	0.62
1	129	5.91	0.69	0.62	7.66	0.78	1	6.56	0.79	1.05
2	130	6.54	0.51	0.45	7.95	0.76	0.54	7.76	0.63	0.71
3	131	6.54	0.48	0.64	8.15	0.57	1.01	7.28	0.61	1.04
4	132	7.72	0.4	0.66	9.34	0.48	0.87	8.93	0.62	0.92
5	133	13.92	1.35	1.75	16.68	1.66	2.47	15.16	1.76	2.1
6	134	8.7	0.67	1.74	13.7	0.8	2.09	13.36	0.96	1.85
7	135	12.44	0.55	1.4	15.26	0.73	2.13	14.73	0.63	2.06
8	136	7.19	1.84	0.68	10.3	2.24	1.15	9.66	2.27	1.4
9	137	12	1.45	1.49	13.98	2.47	1.72	12.76	2.59	1.67
10	138	12.12	0.32	1.39	16.12	0.51	1.9	17.06	0.5	2.46
11	139	7.04	1.88	0.92	11.5	1.84	1.51	11.08	1.79	1.8
12	140	30.8	7.62	3.46	36.48	11.28	4.67	32.42	10.43	4.07
13	141	33.21	1.86	4.7	39.41	2.4	6.21	37.52	3.87	5.87
14	142	31.68	1.73	5.63	36.3	3.43	5.95	36.1	2.43	6.29
15	143	29.86	4.12	2.97	37.14	3.04	5.65	34.47	3.16	6.06
16	144	16.76	5.7	2.28	26.09	8.81	2.31	27.49	7.71	3.18
17	145	34.84	5.35	4.31	40.08	7.48	6.49	36.22	8.98	5.82
18	146	32.74	2.06	5.28	38.01	1.26	6.16	37.25	1.42	6.31
19	147	32.77	2.33	4.73	36.17	3.12	5.66	35.89	2.4	5.11
20	148	25.9	2.88	2.13	37.02	2.33	4.16	34.95	2.75	5.37

Scaling factor calculation:
The simulated scaling factor results for all three bands n258, n261 and band n260 are shown in tables a), b), and c) respectively. The scaling factor is defined as the MPE internal design limit (5 W/m^2) divided by the simulated averaged power density.

a) *Scaling factor for n258*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
0		2.59	2.15	1.86	1.86
1		1.52	1.58	1.77	1.52
2		2.51	2.4	2.34	2.34
3		1.85	1.53	1.41	1.41
4		1.84	1.93	1.92	1.84
5		1.48	1.45	1.37	1.37
6		0.77	0.69	0.64	0.64
7		0.74	0.75	0.79	0.74
8		0.73	0.68	0.69	0.68

9		1.05	1.01	0.96	0.96
10		0.68	0.62	0.61	0.61
11		0.71	0.67	0.62	0.62
12		0.52	0.47	0.47	0.47
13		0.32	0.3	0.29	0.29
14		0.26	0.24	0.24	0.24
15		0.29	0.26	0.24	0.24
16		0.35	0.33	0.31	0.31
17		0.4	0.37	0.36	0.36
18		0.28	0.26	0.25	0.25
19		0.28	0.26	0.25	0.25
20		0.31	0.28	0.26	0.26
128		2.58	2.56	2.31	2.31
129		2.02	1.71	1.57	1.57
130		1.63	1.6	1.65	1.6
131		1.68	1.4	1.24	1.24
132		1.75	1.79	1.71	1.71
133		1.04	0.91	0.79	0.79
134		0.97	0.96	0.96	0.96
135		0.71	0.65	0.62	0.62
136		0.9	0.79	0.71	0.71
137		1.05	1.03	1.03	1.03
138		0.81	0.78	0.77	0.77
139		0.6	0.56	0.53	0.53
140		0.49	0.4	0.36	0.36
141		0.29	0.27	0.26	0.26
142		0.3	0.27	0.26	0.26
143		0.28	0.25	0.24	0.24
144		0.28	0.26	0.25	0.25
145		0.31	0.29	0.27	0.27
146		0.3	0.28	0.26	0.26
147		0.29	0.27	0.25	0.25
148		0.26	0.24	0.24	0.24
0	128	1.04	0.98	0.93	0.93
1	129	0.67	0.63	0.64	0.63
2	130	0.88	0.85	0.79	0.79
3	131	0.84	0.69	0.61	0.61
4	132	0.75	0.81	0.76	0.75
5	133	0.57	0.53	0.51	0.51
6	134	0.42	0.4	0.39	0.39
7	135	0.35	0.33	0.32	0.32
8	136	0.31	0.29	0.28	0.28
9	137	0.42	0.42	0.42	0.42
10	138	0.35	0.31	0.31	0.31
11	139	0.27	0.25	0.25	0.25
12	140	0.23	0.2	0.17	0.17
13	141	0.13	0.12	0.12	0.12
14	142	0.13	0.12	0.11	0.11
15	143	0.13	0.12	0.11	0.11

16	144	0.13	0.13	0.13	0.13
17	145	0.15	0.13	0.12	0.12
18	146	0.13	0.12	0.12	0.12
19	147	0.13	0.12	0.11	0.11
20	148	0.13	0.12	0.12	0.12

b) Scaling factor for n261

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
0		1.47	1.56	1.62	1.47
1		1.48	1.46	1.46	1.46
2		1.38	1.31	1.27	1.27
3		1.62	1.61	1.55	1.55
4		1.54	1.45	1.35	1.35
5		0.69	0.75	0.78	0.69
6		0.63	0.67	0.7	0.63
7		0.73	0.69	0.64	0.64
8		0.74	0.8	0.84	0.74
9		0.66	0.68	0.7	0.66
10		0.62	0.6	0.57	0.57
11		0.67	0.73	0.78	0.67
12		0.25	0.27	0.27	0.25
13		0.26	0.26	0.26	0.26
14		0.25	0.26	0.26	0.25
15		0.25	0.25	0.24	0.24
16		0.33	0.29	0.26	0.26
17		0.26	0.27	0.27	0.26
18		0.26	0.26	0.26	0.26
19		0.26	0.26	0.26	0.26
20		0.29	0.26	0.24	0.24
128		1.37	1.39	1.36	1.36
129		1.36	1.39	1.43	1.36
130		1.55	1.56	1.56	1.55
131		1.19	1.19	1.19	1.19
132		1.2	1.18	1.22	1.18
133		0.65	0.64	0.64	0.64
134		0.51	0.51	0.52	0.51
135		0.48	0.49	0.51	0.48
136		0.88	0.86	0.84	0.84
137		0.6	0.58	0.56	0.56
138		0.53	0.56	0.61	0.53
139		0.77	0.72	0.66	0.66
140		0.19	0.2	0.21	0.19
141		0.22	0.22	0.23	0.22
142		0.2	0.21	0.23	0.2
143		0.23	0.23	0.23	0.23
144		0.36	0.29	0.25	0.25
145		0.21	0.21	0.22	0.21
146		0.21	0.23	0.24	0.21

147		0.21	0.21	0.23	0.21
148		0.24	0.23	0.22	0.22
0	128	0.67	0.68	0.64	0.64
1	129	0.58	0.6	0.62	0.58
2	130	0.66	0.68	0.64	0.64
3	131	0.66	0.61	0.57	0.57
4	132	0.59	0.59	0.57	0.57
5	133	0.33	0.34	0.34	0.33
6	134	0.32	0.32	0.33	0.32
7	135	0.26	0.25	0.25	0.25
8	136	0.32	0.34	0.36	0.32
9	137	0.33	0.33	0.33	0.33
10	138	0.27	0.28	0.29	0.27
11	139	0.37	0.38	0.39	0.37
12	140	0.1	0.11	0.11	0.1
13	141	0.11	0.11	0.12	0.11
14	142	0.11	0.11	0.11	0.11
15	143	0.1	0.11	0.11	0.1
16	144	0.14	0.12	0.11	0.11
17	145	0.11	0.12	0.12	0.11
18	146	0.11	0.11	0.11	0.11
19	147	0.11	0.11	0.12	0.11
20	148	0.11	0.1	0.11	0.1

c) *Scaling factor for n260*

Beam ID 1	Beam ID 2	S_LB	S_MB	S_HB	S
0		2.42	1.42	1.52	1.42
1		2.82	1.56	1.55	1.55
2		2.35	1.6	1.47	1.47
3		2.62	1.5	1.51	1.5
4		1.45	1.25	1.3	1.25
5		0.88	0.74	0.81	0.74
6		0.92	0.64	0.67	0.64
7		1.21	0.75	0.7	0.7
8		1.4	0.84	0.85	0.84
9		1.56	0.83	0.85	0.83
10		1.23	0.7	0.65	0.65
11		1.28	0.77	0.77	0.77
12		0.48	0.4	0.42	0.4
13		0.49	0.31	0.32	0.31
14		0.51	0.31	0.28	0.28
15		0.46	0.28	0.27	0.27
16		0.7	0.44	0.39	0.39
17		0.46	0.32	0.32	0.32
18		0.5	0.31	0.31	0.31
19		0.49	0.28	0.26	0.26
20		0.45	0.29	0.28	0.28
128		2.05	1.4	1.53	1.4
129		2.66	1.48	1.56	1.48

130		2.51	1.47	1.45	1.45
131		2.17	1.34	1.39	1.34
132		1.81	1.13	1.16	1.13
133		0.94	0.63	0.65	0.63
134		1.18	0.72	0.74	0.72
135		1.31	0.73	0.73	0.73
136		0.99	0.69	0.77	0.69
137		1.17	0.71	0.74	0.71
138		1.12	0.6	0.57	0.57
139		1.08	0.68	0.73	0.68
140		0.44	0.29	0.31	0.29
141		0.47	0.27	0.26	0.26
142		0.56	0.31	0.29	0.29
143		0.52	0.31	0.32	0.31
144		0.69	0.49	0.45	0.45
145		0.44	0.27	0.28	0.27
146		0.52	0.28	0.26	0.26
147		0.5	0.31	0.32	0.31
148		0.53	0.35	0.33	0.33
0	128	0.82	0.67	0.73	0.67
1	129	0.85	0.65	0.76	0.65
2	130	0.76	0.63	0.64	0.63
3	131	0.76	0.61	0.69	0.61
4	132	0.65	0.54	0.56	0.54
5	133	0.36	0.3	0.33	0.3
6	134	0.57	0.36	0.37	0.36
7	135	0.4	0.33	0.34	0.33
8	136	0.7	0.49	0.52	0.49
9	137	0.42	0.36	0.39	0.36
10	138	0.41	0.31	0.29	0.29
11	139	0.71	0.43	0.45	0.43
12	140	0.16	0.14	0.15	0.14
13	141	0.15	0.13	0.13	0.13
14	142	0.16	0.14	0.14	0.14
15	143	0.17	0.13	0.15	0.13
16	144	0.3	0.19	0.18	0.18
17	145	0.14	0.12	0.14	0.12
18	146	0.15	0.13	0.13	0.13
19	147	0.15	0.14	0.14	0.14

Since only single antenna array is used next generation iPhone the guidance regarding Smart-TX GEN2 is not fully applicable. However, guidelines relevant to the single antenna array simulations are still retained.

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

Simulation model needs to be large enough to include an antenna module located inside the EUT. 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, recommended setting in CST design studio for the "radiation boundary" is at least 40 mm away from EUT to well contain all adjacent exposure surfaces (S1~S6 in Figure 2).

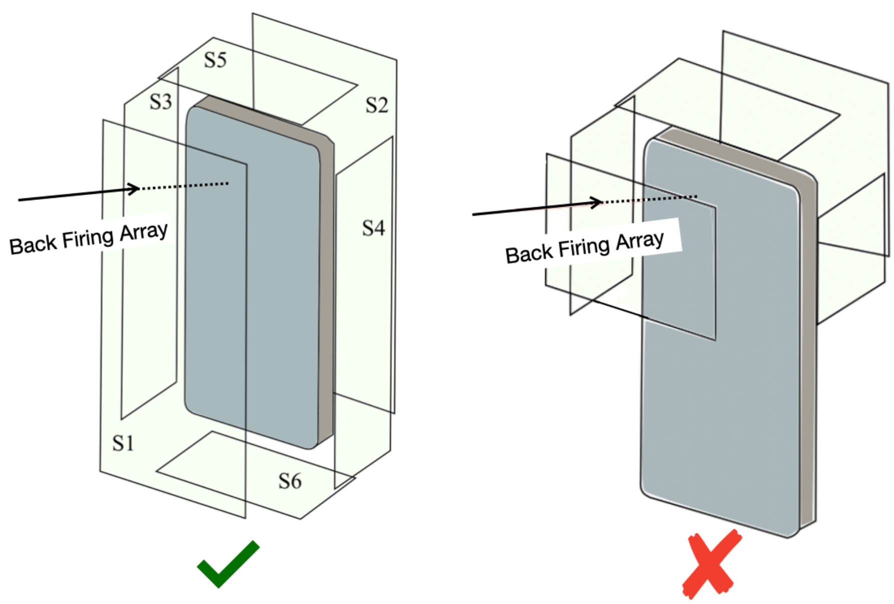


Figure C.2. Simulation model examples.

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 s*PD_design_target*.

C.3 Additional Verifications for GEN2

The sPD 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 sPD plots for all the beams selected and evaluated for model validation. Compare the printed sPD plot to the corresponding simulated/measured sPD, the printed sPD distributions should match the simulated sPD distributions as shown in Figure 7, 8 and 9 to verify that "Qualcomm MG script" is properly used.

VERIFICATION 2: "Qualcomm MG script" identifies the worst-case 4cm^2 sPD and its location (*x,y,z*). This worst-case 4cm^2 sPD is maximum 4cm^2 sPD value out of all exposure surfaces when assuming the worst beam from an antenna module is active. As only single antenna module is used the *contribution factors* are not calculated. However, for the worst beam at given location sPD can be evaluated using CST (or other EM simulation tool). In this report, the verification is completed when sPD values using MG script and CST are within 2% of numerical tolerance.

VERIFICATION 3: Measure power density for the beam identified by "Qualcomm MG script" on their corresponding worst surfaces. Set the device in FTM mode, the sPD measurement should be performed at the reference power level with CW modulation. Scale the measured sPD to obtain 4cm^2 *sPD(i)* for beam *i* at the *sim.power.limit*. Demonstrate that the measured *sPD sim.power.limit* is less than or equal to s*PD_design_target* within the uncertainty at reference power level.

For the iPhone, which contains the back firing antenna module, the following verifications are for n258, n261 and n260, respectively.

1) Band n258

"Qualcomm MG script" identifies the worst-case beam 14. The script prints below information corresponding to the identified worst-case 4cm^2 sPD:

- the worst location coordinates (*x, y, z*) in meter = (-0.01481, 0.05418, -0.00776)
- the worst-surface = S2 (back surface, see Figure C.2)
- the worst-*sPD* = 20.78 W/m^2
- *sim.power.limit* at worst-case beam = -0.19 dBm

As shown in Table C.1, the printed *sPD* matches the simulated *sPD* factor within 2%, and the *normalized combined sPD* is less than 1.0. Thus, the verification 2 is completed for this program.

As shown in Table C.2, the measured *sPD* at the worst location ≤ *sPD_design_target* uncertainty at reference power level. Thus, the verification 3 is competed for this program.

Table C.1 - Contribution factors from Qualcomm MG script and from CST for selected beams, and normalized *combined sPD* verification, for device with 2 antenna modules.

<table>
<tr><td colspan="2">Worse-case surface</td><td>S2 (Back surface)</td></tr>
<tr><td colspan="2">Worst-case location (x,y,z) in meters</td><td>(-0.01481, 0.05418, -0.00776)</td></tr>
<tr><td colspan="2">sPD_design_target (W/m²)</td><td>5</td></tr>
<tr><td colspan="2">Value printed by MG Script</td><td>Value by EM tool</td></tr>
<tr><td rowspan="2">Beam ID 14</td><td>MG script sPD (W/m²)</td><td>Simulated 4cm² sPD (W/m²)</td></tr>
<tr><td>20.78</td><td>20.80</td></tr>
<tr><td>Verify</td><td colspan="2">MG script sPD ≈ Simulated 4cm² sPD</td></tr>
</table>

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

<table>
<tr><td>Module#</td><td>Beam ID</td><td>Dominant Surface</td><td>Measured 4cm² sPD at sim.power.limit on dominant surface (W/m²)</td></tr>
<tr><td>0</td><td>14</td><td>S2 (Back)</td><td>4.02</td></tr>
<tr><td colspan="3">sPD_design_target + uncertainty at reference power
level of 1 dB</td><td>= 5*10^(+1/10) = 6.3 W/m²</td></tr>
<tr><td colspan="3">Verify</td><td>Measured worst case 4cm² sPD < sPD_design_target + uncertainty at reference power level</td></tr>
</table>

Note *c(i,j)* is obtained from Table C.1.

2) Band n261

“Qualcomm MG script” identifies the worst-case beam 140. The script prints below information corresponding to the identified worst-case 4cm^2 sPD:

- the worst location coordinates (*x, y, z*) in meter = (-0.02081, 0.05518, -0.00776)
- the worst-surface = S2 (back surface, see Figure C.2)
- the worst-*sPD* = 25.01W/m^2
- *sim.power.limit* at worst-case beam = -0.99dBm

As shown in Table C.3, the printed *sPD* matches the simulated *sPD* factor within 2%, and the *normalized combined sPD* is less than 1.0. Thus, the verification 2 is completed for this program.

As shown in Table C.4, the measured *sPD* at the worst location ≤ *sPD_design_target* uncertainty at reference power level. Thus, the verification 3 is competed for this program.

Table C.3 - Contribution factors from Qualcomm MG script and from CST for selected beams, and normalized *combined sPD* verification, for device with 2 antenna modules.

Worse-case surface		S2 (Back surface)
Worst-case location *(x,y,z)* in meters		(-0.02081, 0.05518, -0.00776)
sPD_design_target (W/m^2)		5
Value printed by MG Script		Value by EM tool
Beam ID 140	MG script *sPD* (W/m^2)	Simulated $4cm^2$ *sPD* (W/m^2)
	25.01	25.07
Verify	MG script *sPD* ≈ Simulated $4cm^2$ *sPD*	

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

Module#	Beam ID	Dominant Surface	Measured $4cm^2$ sPD at *sim.power.limit* on dominant surface (W/m^2)
0	140	S2 (Back)	2.50
sPD_design_target + uncertainty at reference power level of 1 dB			$= 5*10^{(+1/10)} = 6.3\ W/m^2$
Verify			Measured worst case $4cm^2$ sPD < *sPD_design_target* + uncertainty at reference power level

Note *c(i,j)* is obtained from Table C.3.

3) Band n260

"Qualcomm MG script" identifies the worst-case beam 141. The script prints below information corresponding to the identified worst-case 4cm^2 sPD:

- the worst location coordinates (*x, y, z*) in meter = (-0.01681, 0.05418, -0.00776)
- the worst-surface = S2 (back surface, see Figure C.2)
- the worst-*sPD* = 18.81W/m^2
- *sim.power.limit* at worst-case beam = 0.25 dBm

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

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

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

<table>
<tr><td colspan="2">Worse-case surface</td><td>S2 (Back surface)</td></tr>
<tr><td colspan="2">Worst-case location (x,y,z) in meters</td><td>(-0.01681, 0.05418, -0.00776)</td></tr>
<tr><td colspan="2">sPD_design_target (W/m²)</td><td>5</td></tr>
<tr><td colspan="2">Value printed by MG Script</td><td>Value by EM tool</td></tr>
<tr><td rowspan="2">Beam ID 141</td><td>MG script sPD (W/m²)</td><td>Simulated 4cm² sPD (W/m²)</td></tr>
<tr><td>18.81</td><td>19.20</td></tr>
<tr><td>Verify</td><td colspan="2">MG script sPD ≈ Simulated 4cm² sPD</td></tr>
</table>

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

<table>
<tr><td>Module#</td><td>Beam ID</td><td>Dominant Surface</td><td>Measured 4cm² sPD at sim.power.limit on dominant surface (W/m²)</td></tr>
<tr><td>0</td><td>141</td><td>S2 (Back)</td><td>2.26</td></tr>
<tr><td colspan="3">sPD_design_target + uncertainty at reference power level of 1 dB</td><td>= 5*10$^{(+1/10)}$ = 6.3 W/m²</td></tr>
</table>

Verify	Measured worst case $4cm^2$ sPD < *sPD_design_target* + uncertainty at reference power level

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

References

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