

HUAQIN AX6175 mmW Power Density Simulation Report

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Revision history

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1 Electromagnetic simulation method for power density

1.1 EM simulation

1.1.1 EM simulation tool description

The mmWave power density (PD) simulation method for calculating PD (Power Density) for mobile phones with mmWave antenna modules is available in ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1) is used. ANSYS HFSS is one of several commercial tools for 3D full-wave electromagnetic simulation used for antenna and RF structure design of high frequency component. ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1) is implemented based on Finite Element Method (FEM), which operates in the frequency domain.

1.1.2 Mesh and convergence criteria

ANSYS Electromagnetic suite HFSS ver. 21.1 (2021 R1) uses the Finite Element Method (FEM) to solve the structure for 3D EM simulations to analyze power density. The volume area containing the simulated object should be subdivided into electrically small parts called finite elements with unknown functions. To subdivide system, the adaptive mesh technique in ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1) is used. ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1) starts to refine the initial mesh based on wavelength and calculate the error to iterative process for adaptive mesh refinement. The determination parameter of the number of iteration in ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1) is defined as convergence criteria, delta S, and the iterative adaptive mesh process repeats until the delta S is met. In ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1), the accuracy of converged results depends on the delta S. Figure 1 is an example of final adaptive mesh of the device (cross-section of top view).

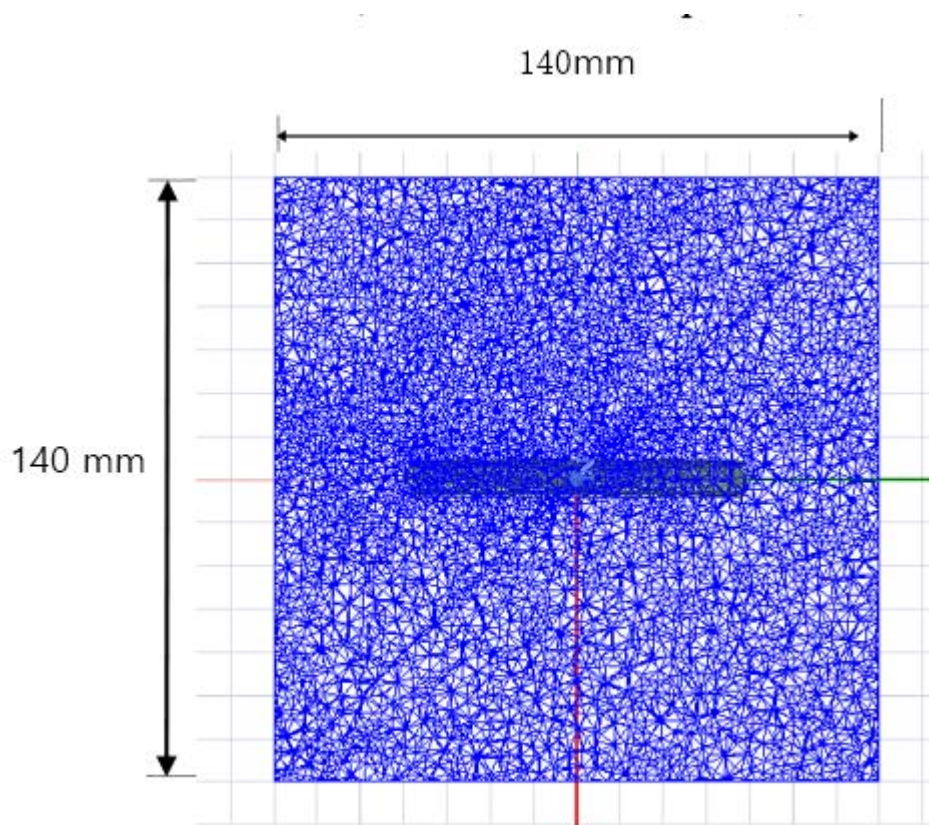


Figure 1-1: Example of HFSS mesh in a model of the device (Top view)

1.1.3 Time-averaged power density calculation

It is possible to get various kinds of physical quantities can be obtained after finishing 3D full-wave electromagnetic simulation. 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 time-averaged Poynting vector (\mathcal{S}) from the cross product of \vec{E} and complex conjugation of \vec{H} as shown below:

(S) can be expressed as point power density based on a peak value of each spatial point on mesh grids, and obtained directly from ANSYS Electromagnetics suite HFSS ver. 21.1 (2021 R1).

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

From the point power density(S), the spatial-averaged power density (PD_{av}) on an evaluated area (A) can be derived as shown below:

$$PD_{av} = \frac{1}{A} \int_A \vec{S} \cdot d\vec{s} = \frac{1}{2A} \int_A |\text{Re}(\vec{E} \times \vec{H}^*)| \cdot ds$$

1.2 Simulation setup

1.2.1 Modeling for simulation

The simulation approach to perform PD assessment for a smartphone requires accurate modeling for mmWave antenna module as well as the smartphone itself. Figure 1-2 shows the simulation model which is mounted two mmWave antenna modules. The simulation modeling includes most of the entire structure of device itself such as PCB, metal frame, battery, cables, and legacy antennas as well as mmWave antenna modules called as QMT0# and QMT1#. On the front side view, QMT0# is placed at the back side and antennas are facing the back side of the device. QMT1# is placed on the right side and antennas are facing the right side.

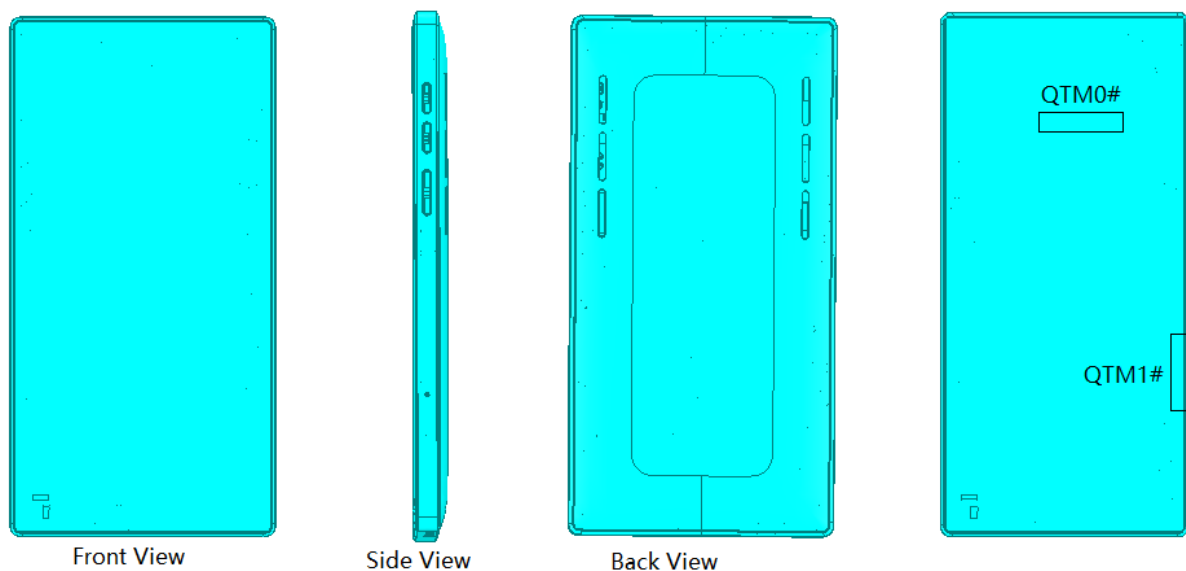


Figure 1-2: HFSS simulation model which is mounted two mmWave antenna modules

1.2.2 PD evaluation surfaces

Figure 1-3 shows the PD evaluation planes and truncation area of the simulation model to find worst case surfaces for evaluation. Table 1-1 shows the surfaces selected for PD evaluation planes for QTM#0 and QTM#1.

Please note that the “right” and “left” edge of mentioned in this report are defined from the perspective of looking at the device from the front side.

Table 1-1: PD evaluation surfaces

	Front	Back	Left From Front View	Right From Front View	Top	Bottom
	S1	S2	S3	S4	S5	S6
QTM#0	√	√	√	√	√	√
QTM#1	√	√	√	√	√	√

1.2.3 Radiation boundary condition

For radiation boundary, the 2nd order absorbing boundary condition (ABC) is used for all simulations in this report. This radiation boundary simulates an electrically open surface that allows waves to radiate infinitely far into space. The system absorbs the wave via the 2nd order radiation boundary, essentially ballooning the boundary infinitely far away from the structure and into space. The radiation boundaries may also be placed relatively close to a structure and can be of arbitrary shape.

Per ANSYS recommendations for their simulation tool, the radiation boundary plane must be located at least a quarter wavelength from strongly radiating structure, or at least a tenth of a wavelength from a weakly radiating structure. In this simulation report, about two or three wavelengths spacing from the device surfaces in all main beam directions are applied to ensure convergence.

By changing convergence error (i.e., maximum magnitude delta S) from 2% to 4% and moving the radiation boundary closer towards the device by 20%, the combined influence in PD value is < 0.04 dB which confirms that the simulation model is reliable using this setup.

1.2.4 Source excitation condition

Each of the three 5G mmWave array modules is the same part containing a 1x4 element array of dual-polarization patch antennas. The number of antenna ports of QTM#0 and QTM#1 for source excitation is equal to 16. The port of each patch antenna is separated in frequency and polarization. That is, the ports of each patch antenna are divided into a feed for 28 GHz and a feed for 39 GHz, and a vertical polarity feed and a horizontal polarity feed are divided.

Figure 1-3 shows the QTM#1 module structure and surrounding structure. The QTM#1 module is encrypted in the ANSYS Electromagnetics suite (HFSS) and can only check the feeding position

is encrypted in the ANSYS Electromagnetics suite (HFSS) and can only check the feeding position.

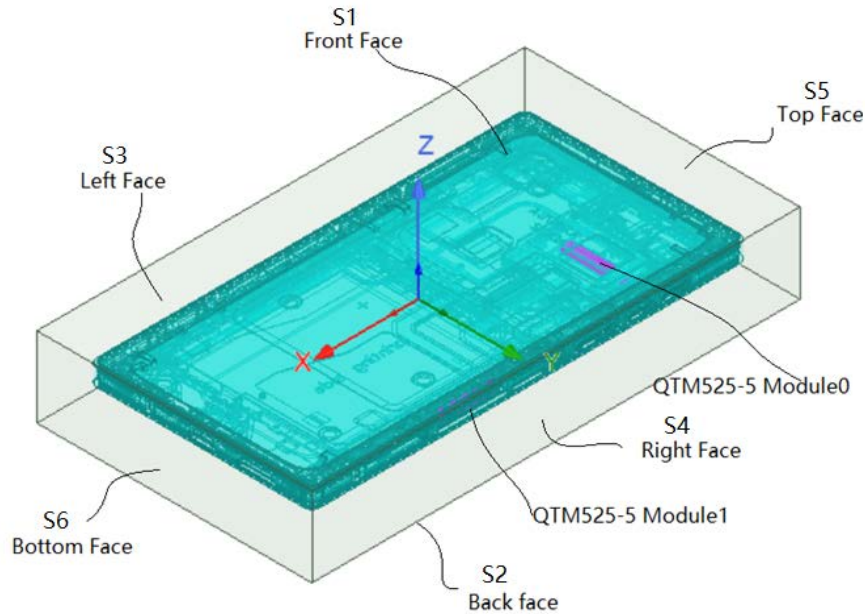


Figure 1-3: EUT simulation model

After finishing 3D full wave electromagnetic simulation of modeling structure, the magnitude and phase information can be loaded for each port by using “Edit Sources” function in ANSYS Electromagnetics suite (HFSS). Figure 4 shows an example of antenna port excitations.

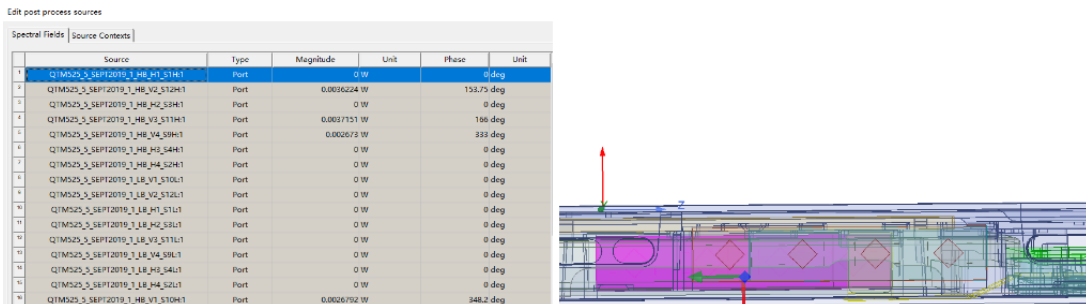


Figure 1-4: An example of port excitation (QTM#1)

Since ANSYS Electromagnetics suite (HFSS) uses FEM solver based on frequency domain analysis method, the input source for the port excitation applies sinusoidal waveform for each frequency.

1.2.5 Condition of simulation completion

The simulation completion condition of ANSYS Electromagnetics suite (HFSS) is defined as delta S. The ANSYS Electromagnetics suite (HFSS) calculates the S-parameter for the mesh conditions of each step and determines whether to proceed with the operation of the next step by comparing the difference between the S-parameters in the previous step. A difference between the previous step and the current step of S-parameter is expressed as delta S, and the delta S generally sets 0.02. The simulation result of this report is the result of setting delta S to 0.02.

2 Codebook

The codebook supported by this EUT is shown in Table 2-1 below.

Table 2-1: EUT codebook

- N261 codebook

Band	Shared_Bands	Beam_ID	Module	Ant_Type	Ant_Feed	Paired_With
261		0	1	PATCH	1	128
261		1	0	PATCH	1	129
261		2	1	PATCH	1	130
261		3	0	PATCH	1	131
261		4	1	PATCH	1	132
261		5	0	PATCH	1	133
261		6	1	PATCH	1	134
261		7	0	PATCH	1	135
261		8	1	PATCH	2	136
261		9	1	PATCH	2	137
261		10	1	PATCH	2	138
261		11	1	PATCH	2	139
261		12	0	PATCH	2	140
261		13	0	PATCH	2	141
261		14	0	PATCH	2	142
261		15	0	PATCH	2	143
261		16	1	PATCH	2	144
261		17	1	PATCH	2	145
261		18	1	PATCH	2	146
261		19	0	PATCH	2	147
261		20	0	PATCH	2	148
261		21	0	PATCH	2	149
261		22	1	PATCH	4	150
261		23	1	PATCH	4	151
261		24	1	PATCH	4	152
261		25	1	PATCH	4	153
261		26	1	PATCH	4	154
261		27	0	PATCH	4	155
261		28	0	PATCH	4	156

261		29	0	PATCH	4	157
261		30	0	PATCH	4	158
261		31	0	PATCH	4	159
261		32	1	PATCH	4	160
261		33	1	PATCH	4	161
261		34	1	PATCH	4	162
261		35	1	PATCH	4	163
261		36	0	PATCH	4	164
261		37	0	PATCH	4	165
261		38	0	PATCH	4	166
261		39	0	PATCH	4	167
261		128	1	PATCH	1	0
261		129	0	PATCH	1	1
261		130	1	PATCH	1	2
261		131	0	PATCH	1	3
261		132	1	PATCH	1	4
261		133	0	PATCH	1	5
261		134	1	PATCH	1	6
261		135	0	PATCH	1	7
261		136	1	PATCH	2	8
261		137	1	PATCH	2	9
261		138	1	PATCH	2	10
261		139	1	PATCH	2	11
261		140	0	PATCH	2	12
261		141	0	PATCH	2	13
261		142	0	PATCH	2	14
261		143	0	PATCH	2	15
261		144	1	PATCH	2	16
261		145	1	PATCH	2	17
261		146	1	PATCH	2	18
261		147	0	PATCH	2	19
261		148	0	PATCH	2	20
261		149	0	PATCH	2	21
261		150	1	PATCH	4	22
261		151	1	PATCH	4	23
261		152	1	PATCH	4	24
261		153	1	PATCH	4	25
261		154	1	PATCH	4	26
261		155	0	PATCH	4	27
261		156	0	PATCH	4	28
261		157	0	PATCH	4	29

261		158	0	PATCH	4	30
261		159	0	PATCH	4	31
261		160	1	PATCH	4	32
261		161	1	PATCH	4	33
261		162	1	PATCH	4	34
261		163	1	PATCH	4	35
261		164	0	PATCH	4	36
261		165	0	PATCH	4	37
261		166	0	PATCH	4	38
261		167	0	PATCH	4	39

- N260 codebook

Band	Shared_Bands	Beam_ID	Module	Ant_Type	Ant_Feed	Paired_With
260		0	1	PATCH	1	128
260		1	0	PATCH	1	129
260		2	1	PATCH	1	130
260		3	0	PATCH	1	131
260		4	1	PATCH	1	132
260		5	0	PATCH	1	133
260		6	1	PATCH	1	134
260		7	0	PATCH	1	135
260		8	1	PATCH	2	136
260		9	1	PATCH	2	137
260		10	1	PATCH	2	138
260		11	1	PATCH	2	139
260		12	0	PATCH	2	140
260		13	0	PATCH	2	141
260		14	0	PATCH	2	142
260		15	0	PATCH	2	143
260		16	1	PATCH	2	144
260		17	1	PATCH	2	145
260		18	1	PATCH	2	146
260		19	0	PATCH	2	147
260		20	0	PATCH	2	148
260		21	0	PATCH	2	149
260		22	1	PATCH	4	150
260		23	1	PATCH	4	151
260		24	1	PATCH	4	152
260		25	1	PATCH	4	153
260		26	1	PATCH	4	154

260		27	0	PATCH	4	155
260		28	0	PATCH	4	156
260		29	0	PATCH	4	157
260		30	0	PATCH	4	158
260		31	0	PATCH	4	159
260		32	1	PATCH	4	160
260		33	1	PATCH	4	161
260		34	1	PATCH	4	162
260		35	1	PATCH	4	163
260		36	0	PATCH	4	164
260		37	0	PATCH	4	165
260		38	0	PATCH	4	166
260		39	0	PATCH	4	167
260		128	1	PATCH	1	0
260		129	0	PATCH	1	1
260		130	1	PATCH	1	2
260		131	0	PATCH	1	3
260		132	1	PATCH	1	4
260		133	0	PATCH	1	5
260		134	1	PATCH	1	6
260		135	0	PATCH	1	7
260		136	1	PATCH	2	8
260		137	1	PATCH	2	9
260		138	1	PATCH	2	10
260		139	1	PATCH	2	11
260		140	0	PATCH	2	12
260		141	0	PATCH	2	13
260		142	0	PATCH	2	14
260		143	0	PATCH	2	15
260		144	1	PATCH	2	16
260		145	1	PATCH	2	17
260		146	1	PATCH	2	18
260		147	0	PATCH	2	19
260		148	0	PATCH	2	20
260		149	0	PATCH	2	21
260		150	1	PATCH	4	22
260		151	1	PATCH	4	23
260		152	1	PATCH	4	24
260		153	1	PATCH	4	25
260		154	1	PATCH	4	26
260		155	0	PATCH	4	27

260		156	0	PATCH	4	28
260		157	0	PATCH	4	29
260		158	0	PATCH	4	30
260		159	0	PATCH	4	31
260		160	1	PATCH	4	32
260		161	1	PATCH	4	33
260		162	1	PATCH	4	34
260		163	1	PATCH	4	35
260		164	0	PATCH	4	36
260		165	0	PATCH	4	37
260		166	0	PATCH	4	38
260		167	0	PATCH	4	39

3 Simulation verification

The beams selected for simulation verification are highlighted in yellow in Table 2-1. Input power level used for comparison is listed in Table 3-1.

Table 3-1: Input power used in simulation validation

Mode/Band	Antenna	Input Power (dBm)	
		SISO	MIMO
5G NR n261 (28 GHz)	QTM#0 Patch	6	6
	QTM#1 Patch	6	6
5G NR n260 (39 GHz)	QTM#0 Patch	6	6
	QTM#1 Patch	6	6

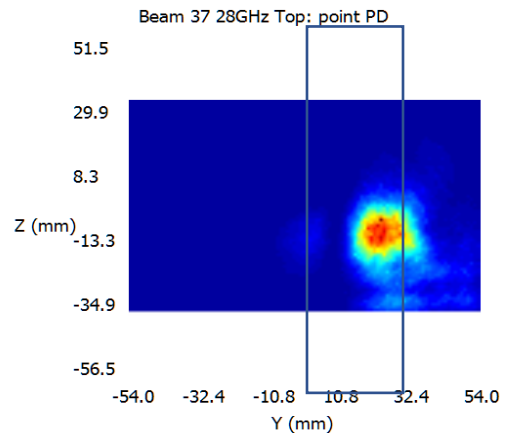
The simulation and measurement were performed at 2mm evaluation distance. The simulated and measured 4cm² averaged PD results are shown in Table 3-2.

Table 3-2: Simulated and measured 4cm² averaged PD comparison

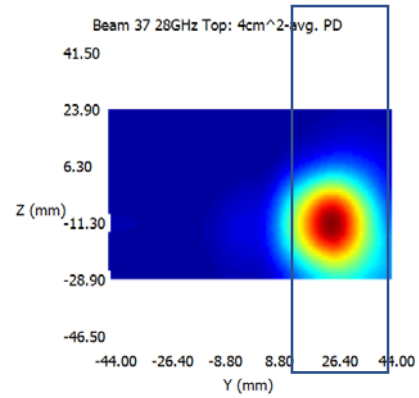
Band	Ant Type	Module	Ant Group (Ant Polarization)	beam ID	Surface	Channel	Measured Total	Simulated	Delta (Simulated-Measured)
n261	Patch	QTM0	AG0(V)	37	Topface	Mid		2.37	
					Backface	Mid		17.58	
			AG1(H)	158	Topface	Mid		2.12	
				165	Backface	Mid		16.74	
		QTM1	AG0(V)	33	Right	Mid		10.45	
				24	Backface	Mid		5.36	
			AG1(H)	152	Right	Mid		9.96	
				153	Backface	Mid		5.26	
n260	Patch	QTM0	AG0(V)	27	Topface	Mid		1.66	
				39	Backface	Mid		15.79	
			AG1(H)	158	Topface	Mid		1.41	
				159	Backface	Mid		14.54	
		QTM1	AG0(V)	23	Right	Mid		14.82	
					Backface	Mid		5.94	
			AG1(H)	151	Right	Mid		14	
				154	Backface	Mid		5.79	

Below Figures show Measured and simulated PD distributions for selected beams. As can be seen, the Simulated point PD distribution and Measured point PD distribution have good correlation on all surfaces evaluated.

- N261 Patch antenna QTM0: Ant_Group0(V-polarization) beam ID 37 Topface -side Mid ch



(a) Measurement (b) Simulation
Patch antenna QTM0 AG0(V-polarization) beam ID 37 , Point power density

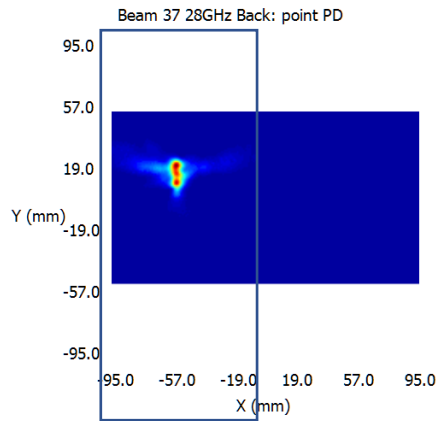


(a) Measurement

(b) Simulation

Patch antenna QTM0 AG0(V-polarization) beam ID 37 , 4cm² Averaged power density

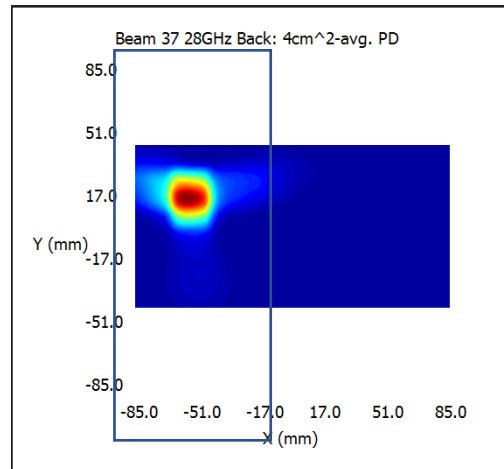
- N261 Patch antenna QTM0: Ant_Group0(V-polarization) beam ID 37 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM0 AG0(V-polarization) beam ID 37 , Point power density

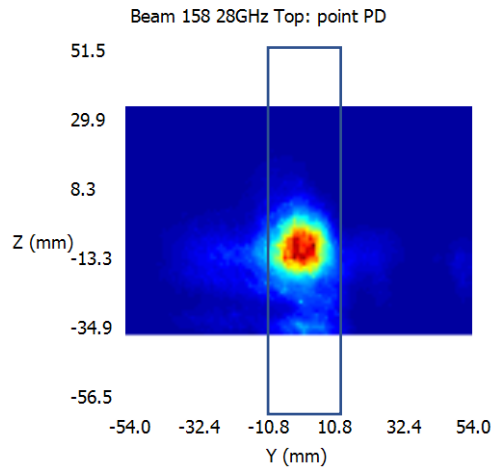


(a) Measurement

(b) Simulation

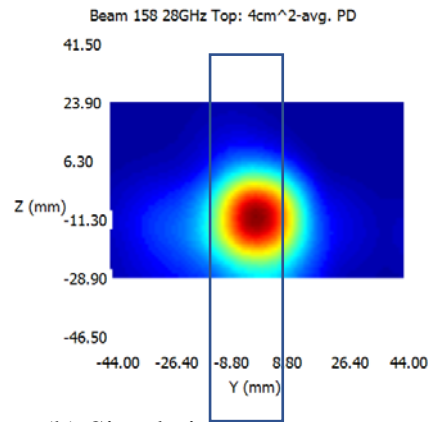
Patch antenna QTM0 AG0(V-polarization) beam ID 37 , 4cm² Averaged power density

- N261 Patch antenna QTM0: Ant_Group1(H-polarization) beam ID 158 Topface -side Mid ch



(a) Measurement (b) Simulation

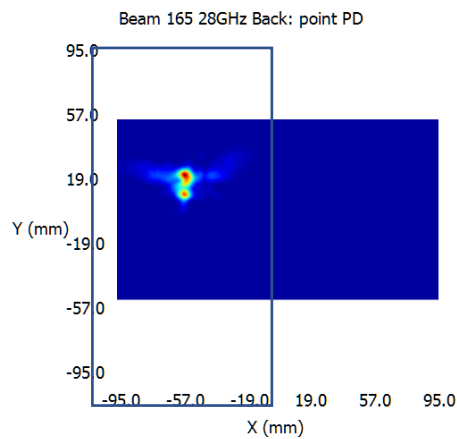
Patch antenna QTM0 AG1(H-polarization) beam ID 158 , Point power density



(a) Measurement (b) Simulation

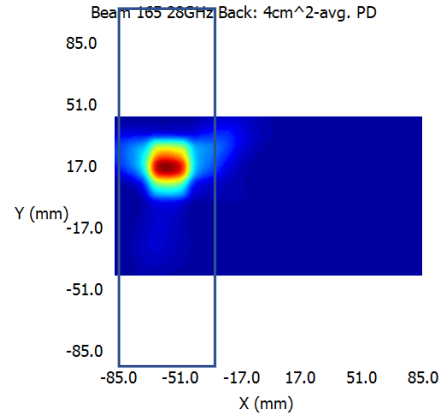
Patch antenna QTM0 AG1(H-polarization) beam ID 158 , 4cm² Averaged power density

- N261 Patch antenna QTM0: Ant_Group1(H-polarization) beam ID 165 Backface -side Mid ch



(a) Measurement (b) Simulation

Patch antenna QTM0 AG1(H-polarization) beam ID 165 , Point power density

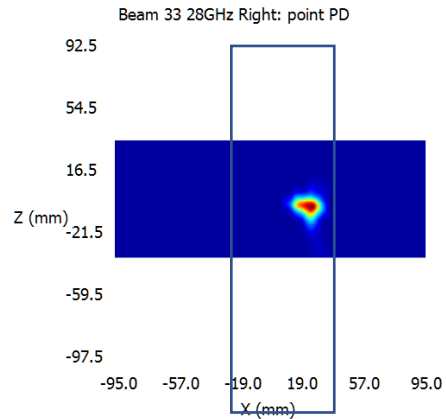


(a) Measurement

(b) Simulation

Patch antenna QTM0 AG1(H-polarization) beam ID 165 , 4cm² Averaged power density

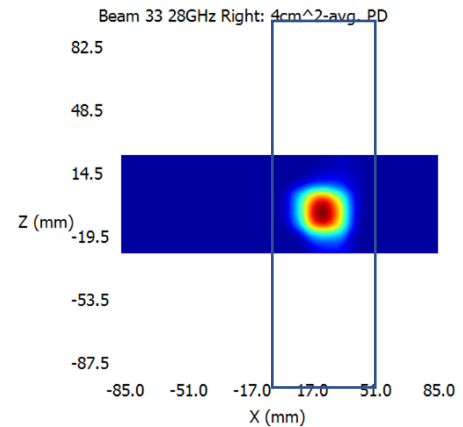
- N261 Patch antenna QTM1: Ant_Group0(V-polarization) beam ID 33 Right -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 33 , Point power density

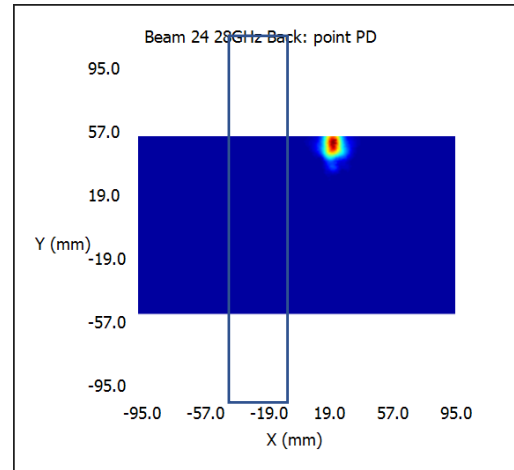


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 33, 4cm² Averaged power density

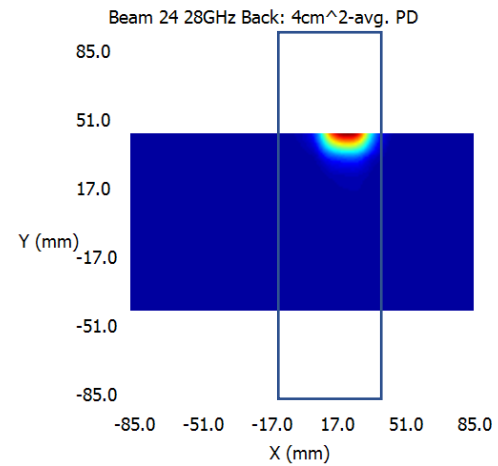
- N261 Patch antenna QTM1: Ant_Group0(V-polarization) beam ID 24 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 24 , Point power density

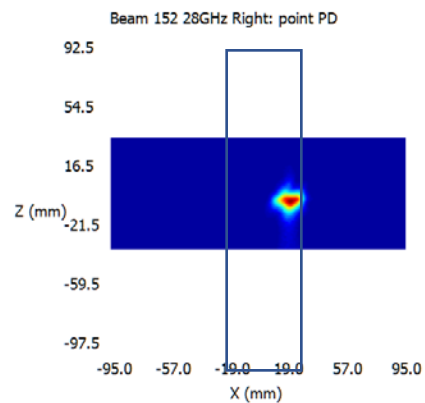


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 24 , 4cm² Averaged power density

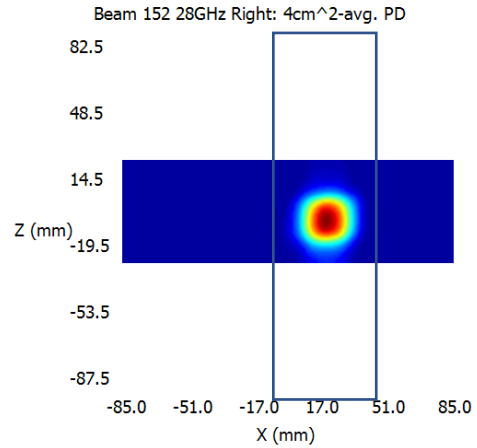
- N261 Patch antenna QTM1: Ant_Group1(H-polarization) beam ID 152 Right -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 152 , Point power density

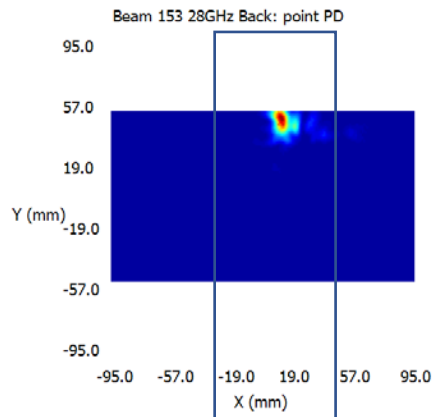


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 152, 4cm² Averaged power density

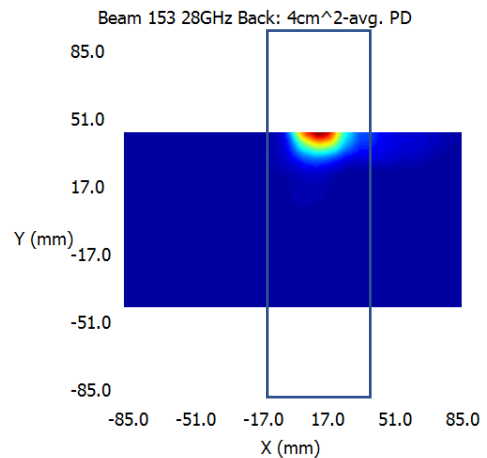
- N261 Patch antenna QTM1: Ant_Group1(H-polarization) beam ID 153 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 153, Point power density

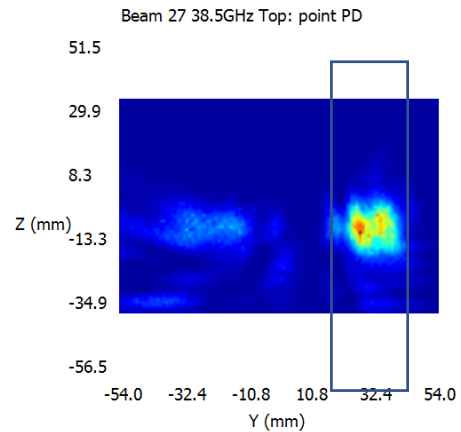


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 153, 4cm² Averaged power density

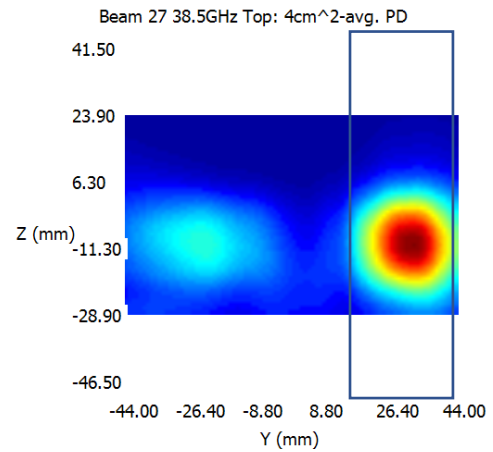
- N260 Patch antenna QTM0: Ant_Group0(V-polarization) beam ID 27 Topface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM0 AG0(V-polarization) beam ID 27 , Point power density

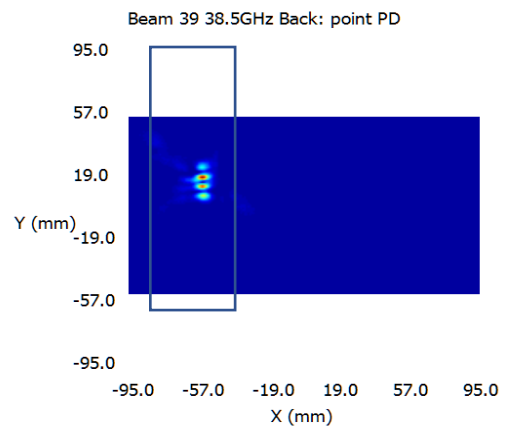


(a) Measurement

(b) Simulation

Patch antenna QTM0 AG0(V-polarization) beam ID 27 , 4cm² Averaged power density

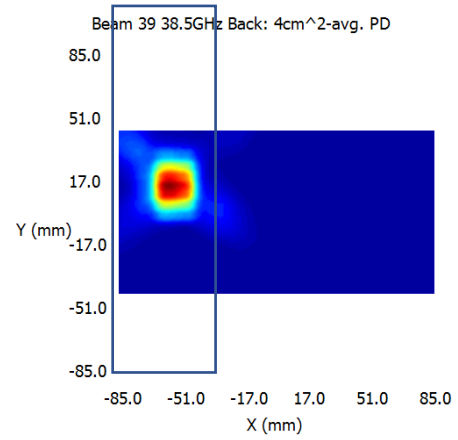
- N260 Patch antenna QTM0: Ant_Group0(V-polarization) beam ID 39 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM0 AG0(V-polarization) beam ID 39 , Point power density

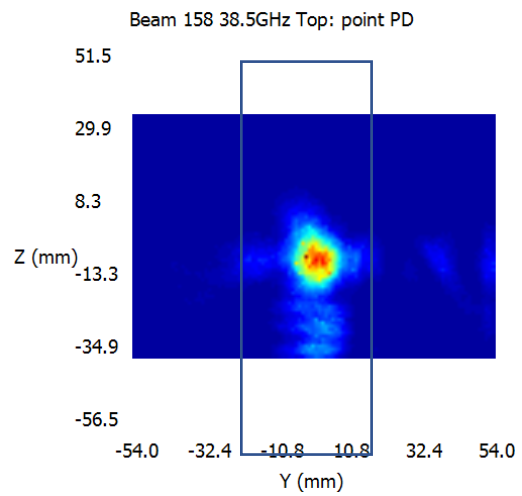


(a) Measurement

(b) Simulation

Patch antenna QTM0 AG0(V-polarization) beam ID 39, 4cm² Averaged power density

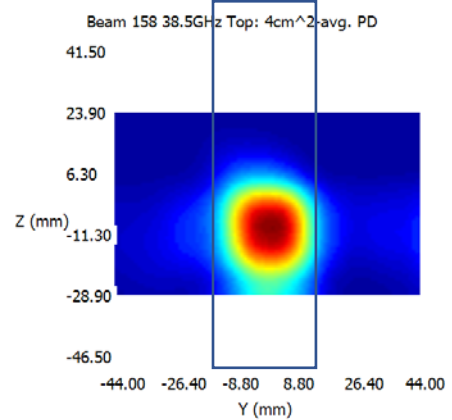
- N260 Patch antenna QTM0: Ant_Group1(H-polarization) beam ID 158 Topface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM0 AG1(H-polarization) beam ID 158, Point power density

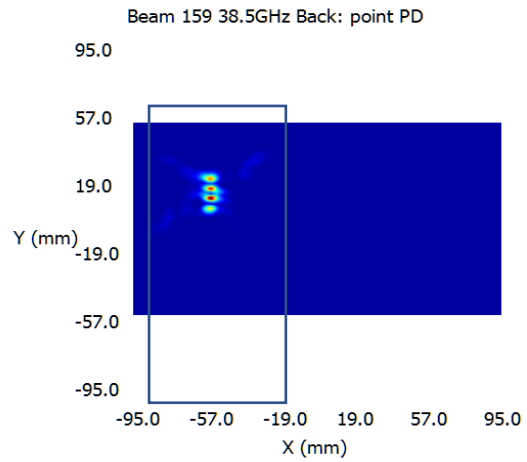


(a) Measurement

(b) Simulation

Patch antenna QTM0 AG1(H-polarization) beam ID 158, 4cm² Averaged power density

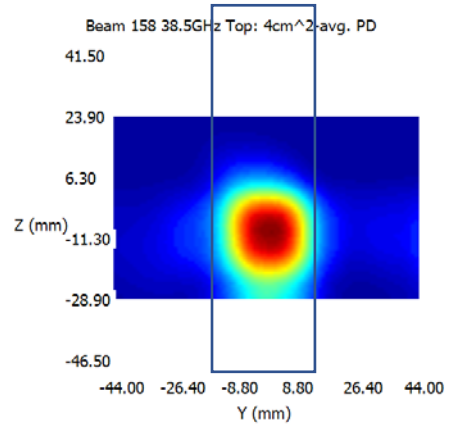
- N260 Patch antenna QTM0: Ant_Group1(H-polarization) beam ID 159 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM0 AG1(H-polarization) beam ID 159 , Point power density

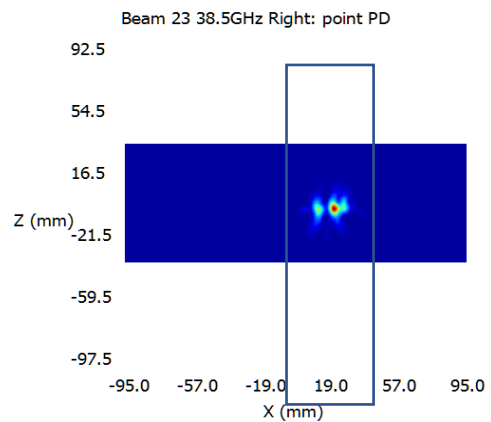


(a) Measurement

(b) Simulation

Patch antenna QTM0 AG1(H-polarization) beam ID 159, 4cm² Averaged power density

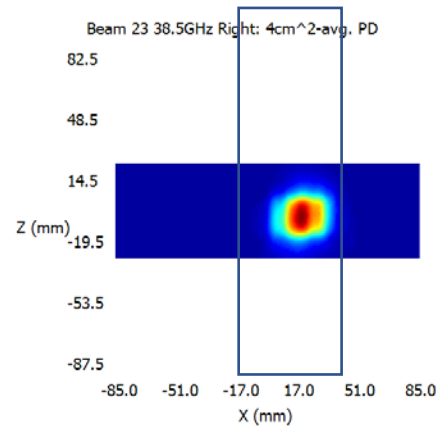
- N260 Patch antenna QTM1: Ant_Group0(V-polarization) beam ID 23 Right -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 23 , Point power density

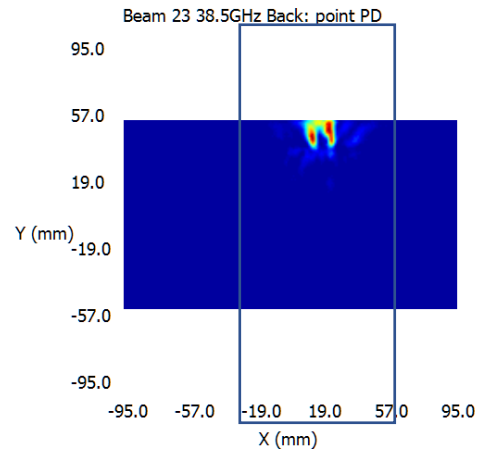


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 23, 4cm² Averaged power density

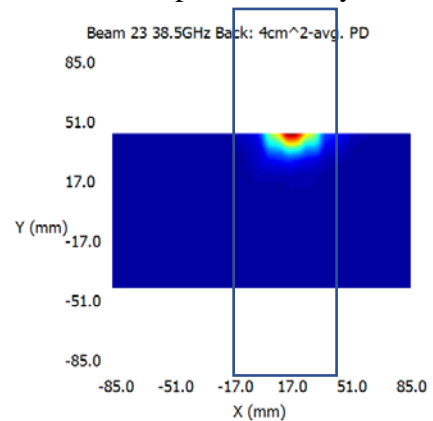
- N260 Patch antenna QTM1: Ant_Group0(V-polarization) beam ID 23 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 23, Point power density

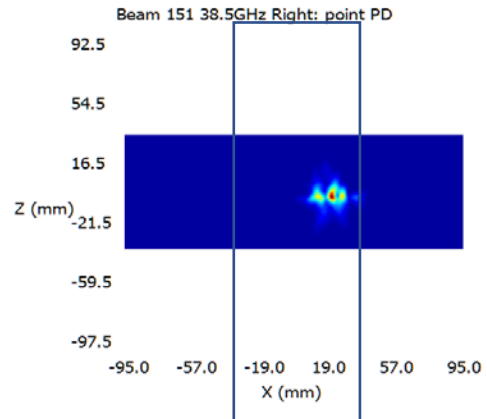


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG0(V-polarization) beam ID 23, 4cm² Averaged power density

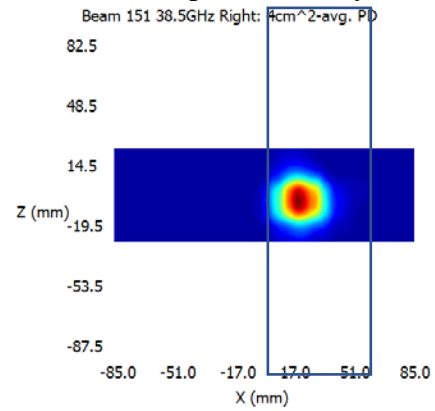
- N260 Patch antenna QTM1: Ant_Group1(H-polarization) beam ID 151 Right -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 151 , Point power density

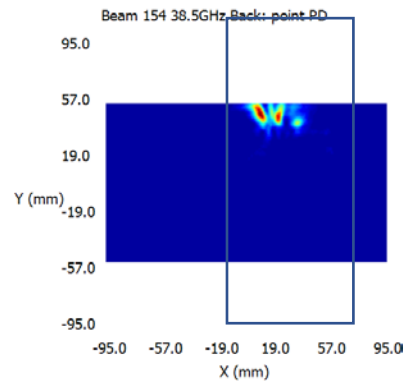


(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 151, 4cm^2 Averaged power density

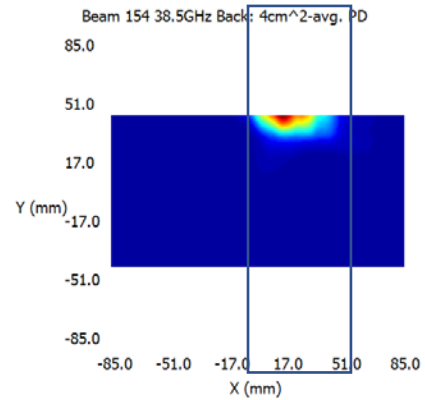
- N260 Patch antenna QTM1: Ant_Group1(H-polarization) beam ID 154 Backface -side Mid ch



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 154 , Point power density



(a) Measurement

(b) Simulation

Patch antenna QTM1 AG1(H-polarization) beam ID 154, 4cm^2 Averaged power density

4 Simulation Result

The model is validated in Section 3, the PD exposure of EUT can be reliably assessed using the validated simulation approach. The PD simulation was performed at n261 and n260. The simulated PD results are reported in this section. The Ratio of PD exposure from front surface to the worst surface at 2mm, and the ratio of PD exposure from 2mm to 10mm evaluation distance for each beam are also reported for simultaneous transmission analysis

The relative phase between beam pairs is not controlled in the chipset design. Therefore, the relative phase between each beam pair was considered mathematically to identify the worst case conditions, the below PD result for each MIMO beam represents the highest PD value after sweeping the relative phase between two SISO beams with a '5 degree' step interval from 0 degree to 360 degree.

4.1 PD for Low/Mid/High Channel at n261 and n260

Below Tables show the PD simulation evaluation of QTM0 at N261 and N260 for all surfaces as shown in Figure 1-3.

- QTM0 N261 Low channel SISO

Table with columns: Band, Beam_ID, Ant module, Ant Type, Meters of Feeds, and Max Ratio. It contains simulation data for various beam configurations and ratios.

QTM0 N261 Low channel MIMO

Table for QTM0 N261 Low channel MIMO simulation, including columns for Band, Beam_ID, Ant module, Ant Type, Meters of Feeds, and Max Ratio.

QTM1 N261 Low channel SISO

QTM0 N261 Middle channel SISO

Table with columns: Band, Beam_ID, Ant. include, Ant. Type, Meters of Feeds, and Max Ratio (0.032, 0.136, 0.055, 0.152, 0.014, 0.012, 0.500, 0.040, 0.081, 0.105, 0.000). Rows list various beam configurations and their performance metrics.

QTM0 N261 Middle channel MIMO

Table with columns: Band, Beam_ID, Ant. include, Ant. Type, Meters of Feeds, and Max Ratio (0.032, 0.167, 0.063, 0.138, 0.014, 0.015, 0.462, 0.046, 0.110, 0.106, 0.000). Rows list various beam configurations and their performance metrics.

■ QTM1 N261 Middle channel SISO

Table with columns for Max Ratio (0.510, 0.005, 0.546, 0.021, 0.028), Antenna ID, Beam ID, Antenna Type, and various performance metrics like Front, Back, Left, Right, Top, Bottom.

■ QTM1 N261 Middle channel MIMO

Table with columns for Max Ratio (0.500, 0.005, 0.560, 0.018, 0.038), Antenna ID, Beam ID, Antenna Type, and various performance metrics like Front, Back, Left, Right, Top, Bottom.

■ QTM0 N261 High channel SISO

Table with columns for Band, Beam_ID, Ant module, Ant Type, Numers of Feeds, and multiple columns for Max Ratio (0.032, 0.128, 0.061, 0.161, 0.013) and 4x4 PD(Wd) at 15mm evaluation surfaces (Front, Back, Left, Right, Top, Bottom).

■ QTM0 N261 High channel MIMO

Table with columns for Band, Beam_ID, Ant module, Ant Type, Numers of Feeds, and multiple columns for Max Ratio (0.032, 0.128, 0.070, 0.143, 0.012) and 4x4 PD(Wd) at 15mm evaluation surfaces (Front, Back, Left, Right, Top, Bottom).

QTM1 N261 High channel SISO

Table with columns for Band, Beam ID, Ant. module, Ant. Type, Elements of Feeds, Front/Back/Left/Right/Top/Bottom (relative phase word PD by MIMO), and Max Ratio (0.488, 0.004, 0.557, 0.022, 0.029) and Max Ratio (0.215, 0.215, 0.004, 0.610, 0.019, 0.000).

QTM1 N261 High channel MIMO

Table with columns for Band, Beam ID, Ant. module, Ant. Type, Elements of Feeds, Front/Back/Left/Right/Top/Bottom (relative phase word PD by MIMO), and Max Ratio (0.486, 0.005, 0.577, 0.019, 0.027) and Max Ratio (0.187, 0.187, 0.004, 0.656, 0.017, 0.000).

■ QTM0 N260 LOW channel SISO

Table with columns for Band, Beam_ID, Ant. module, Ant. Type, Num of antennas, Max Ratio (0.028, 0.183, 0.099, 0.131, 0.008), and various surface ratios (Front, Back, Left, Right, Top, Bottom) for 4x4 PDW(N) at 10mm evaluation surface distance.

■ QTM0 N260 LOW channel MIMO

Table with columns for Band, Beam_ID, Ant. module, Ant. Type, Num of antennas, Max Ratio (0.033, 0.236, 0.127, 0.130, 0.099), and various surface ratios (Front, Back, Left, Right, Top, Bottom) for 4x4 PDW(N) at 10mm evaluation surface distance.

QTM1 N260 LOW channel SISO

Table with columns for Band, Beam_ID, Ant. mode, Ant. Type, Manoeuv. Feeds, and Max Ratio (0.387, 0.003, 0.469, 0.007, 0.019). It lists simulation results for various beam IDs from N260 0 to N260 163.

QTM1 N260 LOW channel MIMO

Table with columns for Band, Beam_ID, Ant. mode, Ant. Type, Manoeuv. Feeds, and Max Ratio (0.167, 0.197, 0.003, 0.838, 0.007, 0.000). It lists simulation results for various beam IDs from N260 128 to N260 163.

■ QTM0 N260 Middle channel SISO

Table with columns for antenna ID, antenna type, and radiation pattern (Front, Back, Left, Right, Top, Bottom) for SISO configuration. Includes Max Ratio values for various directions.

■ QTM0 N260 Middle channel MIMO

Table with columns for antenna ID, antenna type, and radiation pattern (Front, Back, Left, Right, Top, Bottom) for MIMO configuration. Includes Max Ratio values for various directions.

■ QTM1 N260 Middle channel SISO

Table with columns for Antenna ID, Antenna Type, Feed, and various Max Ratio values (0.423, 0.004, 0.542, 0.012, 0.022, 0.174, 0.260, 0.003, 0.582, 0.010, 0.000).

■ QTM1 N260 Middle channel MIMO

Table with columns for Antenna ID, Antenna Type, Feed, and various Max Ratio values (0.533, 0.004, 0.617, 0.010, 0.020, 0.216, 0.280, 0.003, 0.648, 0.009, 0.000).

QTM0 N260 High channel SISO

Table with columns for Band, Beam_ID, Ant. module, Ant. Type, Num. of Feed, Material of Feeds, Max Ratio (0.031, 0.198, 0.081, 0.118, 0.008), and various surface loss metrics for 4092 PDRW0.01 at 20mm evaluation surface distance.

QTM0 N260 High channel MIMO

Table with columns for Band, Beam_ID, Ant. module, Ant. Type, Num. of Feed, Material of Feeds, Max Ratio (0.024, 0.190, 0.073, 0.106, 0.009), and various surface loss metrics for 4092 PDRW0.01 at 20mm evaluation surface distance.

5 Power Density Characterization

5.1 PD design target

For Qualcomm SDX55/QTM525, the total device uncertainty for mmW radio is 2.1dB.

To account for the total design related uncertainty, PD_design_target needs to be:

$$PD_design_target < PD_{regulatory_limit} \times 10^{\frac{-total\ uncertainty}{10}}$$

With FCC 4cm²-averaged PD requirement of 10 W/m² and the declared 2.1 dB device design related uncertainty, the PD_design_target for the EUT is determined as:

$$PD_design_target = 6\ W/m^2$$

5.2 Worst-case housing influence determination

For non-metal material, the material property cannot be accurately characterized at mmW frequencies to date. The estimated material property for the device housing is used in the simulation model, which could influence the accuracy in simulation for PD amplitude quantification. Since the housing influence on PD could vary from surface to surface where the EM field propagates through, the most underestimated surface is used to quantify the worst-case housing influence for conservative assessment.

Since the mmW antenna modules are placed at different location as shown in Figure 1-3, only material/housing surrounded has impact on EM field propagation, in turn impact on power density. Therefore, only adjacent surfaces for each QTM (as listed in Table 3-2) were used to evaluate the worst-case housing influence for each frequency band. For this EUT, when comparing a simulated 4cm²-averaged PD and measured 4 cm²-averaged PD, the worst error introduced for each antenna module operating at each band when using the estimated material property in the simulation is highlighted yellow in Table 3-2. Thus, the worst-case housing influence, denoted as $\Delta_{min} = Sim.PD - Meas.PD$, is determined as:

Table 5-1: Δ_{min} for QTM0 and QTM1

Band	QTM	Δ_{min} (dB)
N261	0	
	1	
N260	0	
	1	

Δmin represents the worst case where RF exposure is underestimated the most in simulation when using the estimated material property for glass/plastics of the housing. For conservative assessment, the Δmin is used as the worst-case factor and applied to all the beams in the corresponding beam group to determine input power limits in PD char for compliance (see Section 5.3 for details).

5.3 PD Char of the EUT

This section describes the PD Char generation that complies with the PD_design_target determined in Section 5.1 and is in compliance with the regulatory power density limit.

5.3.1 Scaling factor for SISO beams

Determine scaling factor for low, mid, high channel, $s(i)_{low_or_mid_or_high}$ by:

$$s(i)_{low_or_mid_or_high} = \frac{PD\ design\ target}{sim.PD_{surface}(i)}, i \in SISO\ beams$$

Then finalize scaling factor, $s(i)$, by using equation below:

$$s(i) = \min\{slow(i), smid(i), shigh(i)\}, i \in SISO\ beams$$

and this scaling factor, $s(i)$, is applied to the input power at each antenna port to determine *input.power.limit* for SISO beams.

5.3.2 Scaling factor for MIMO beams

The relative phase between beam pair is not controlled in the EUT and could vary from run to run. Therefore, for beam pair, based on the simulation results, the worst-case scaling factor needs to be determined mathematically to ensure the compliance.

For beam pair, extract the E-fields and H-fields from the corresponding single beams at low, mid and high channel for each supported band and for all identified surfaces of the EUT.

For a given beam pair containing *beam_a* and *beam_b*, and for a given channel, let relative phase between *beam_a* and *beam_b* = \varnothing , and the total PD of the beam pair can be expressed as:

$$\begin{aligned} total\ PD(\varnothing) &= \frac{1}{2} \sqrt{Re\{PD_x(\varnothing)\}^2 + Re\{PD_y(\varnothing)\}^2 + Re\{PD_z(\varnothing)\}^2} \\ &= \frac{1}{2} Re\left\{\left(\overrightarrow{E_a} + \overrightarrow{E_b}e^{j\omega\varnothing}\right) \times \left(\overrightarrow{H_a} + \overrightarrow{H_b}e^{j\omega\varnothing}\right)^*\right\} \quad (4) \end{aligned}$$

where, $PD_x(\varnothing)$, $PD_y(\varnothing)$ and $PD_z(\varnothing)$ are the three components of the *total PD* (\varnothing); E_a and H_a are the extracted E-fields and H-fields of *beam_a*, while E_b and H_b are the extracted E-fields and H-fields of *beam_b*. Sweep \varnothing with a 5° step from 0° to 360° to determine the worst-case, $\varnothing_{worstcase}$, which results in the highest *total PD* (\varnothing) among all identified surfaces for this MIMO beam at this channel.

Follow the above procedure to determine $\varnothing_{worstcase}$ for all three channels of all bands supported, and obtain the scaling factor given by the below equation for low, mid and high channels:

$$s(i)_{low_or_mid_or_high} = \frac{PD\ design\ target}{total\ PD\ (\varnothing(i)_{worstcase})}, i \in MIMO\ beams$$

Similar to SISO beam, the worst-case scaling factor, $s(i)$, for MIMO beam i is determined as:

$$s(i) = \min\{s_{low}(i), s_{mid}(i), s_{high}(i)\}, i \in MIMO\ beams$$

and this scaling factor, $s(i)$, is applied to the input power at each antenna port to determine *input.power.limit* for MIMO beams.

5.3.3 Input power limit when only mmW radio is ON

When only mmW radio is on, the power limit specifies the power level (denoted as *input.power.limit*) at antenna port that corresponds to PD_design_target for all the beams. The reference power used in simulation is 6dBm and denoted as *Pref*.

The logic to determine *input.power.limit* is as shown below:

If -TxAGC uncertainty at reference power level $< \Delta_{min} <$ TxAGC uncertainty at reference power level, then

$$input.power.limit(i) = Pref + 10 * \log(s(i)), i \in all\ beams \quad (1)$$

else if $\Delta_{min} < -$ TxAGC uncertainty at reference power level,

$$input.power.limit(i) = Pref + 10 * \log(s(i)) + (\Delta_{min} + TxAGC\ uncertainty\ at\ reference\ power\ level), i \in all\ beams \quad (2)$$

else if $\Delta_{min} >$ TxAGC uncertainty at reference power level,

$$input.power.limit(i) = Pref + 10 * \log(s(i)) + (\Delta_{min} - TxAGC\ uncertainty\ at\ reference\ power\ level), i \in all\ beams \quad (3)$$

Following above logic, the *input.power.limit* for this EUT can be calculated as:

Table 5-2: power.limit calculation

Band#	QTM #	Δ_{min} (dB)	<i>input.power.limit</i> (dBm)	Notes
N261	0	0.7	6dBm + 10log(s(i)) + (0.7-0.5)	Using Eq.3
	1	2.2	6dBm + 10log(s(i)) + (2.2-0.5)	Using Eq.3
N260	0	0.2	6dBm + 10log(s(i))	Using Eq.1
	1	1.2	6dBm + 10log(s(i)) + (1.2-0.5)	Using Eq.3

Note the Δ_{min} (dB) used is the minimum of Hpol and Vpol per QTM per band (see Table 3-2).

Resulted *input.power.limit* for all beams is listed in Table below:

Table 5-3: input.power.limit

