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Power Density Simulation Report

Revision A

July 27, 2023

SAMSUNG ELECTRONICS

1. Simulation methodology for Power Density (PD)

1.1 Simulation tool

1.1.1 Tool description

For the simulation approach to calculating power density (PD) evaluation for mobile phone with mmWave antenna modules, ANSYS Electromagnetics suite version 2022.R2 (HFSS) 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 version 2022.R2 (HFSS) is implemented based on Finite Element Method (FEM), which operates in the frequency domain.

1.1.2 Mesh and Convergence criteria

To solve the PD analysis using FEM, volume area containing simulated objects should be subdivided into electrically small parts that are called finite elements as the unknown functions. To subdivide system, the adaptive mesh technique in ANSYS Electromagnetics suite version 2022.R2 (HFSS) is used. ANSYS Electromagnetics suite version 2022.R2 (HFSS) 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 version 2022.R2 (HFSS) is defined as convergence criteria, delta S, and the iterative adaptive mesh process repeats until the delta S is met. In ANSYS Electromagnetics suite version 2022.R2 (HFSS), the accuracy of converged results depends on the delta S. Figure 1 is an example of adaptive mesh of the device (cross-section of top view).

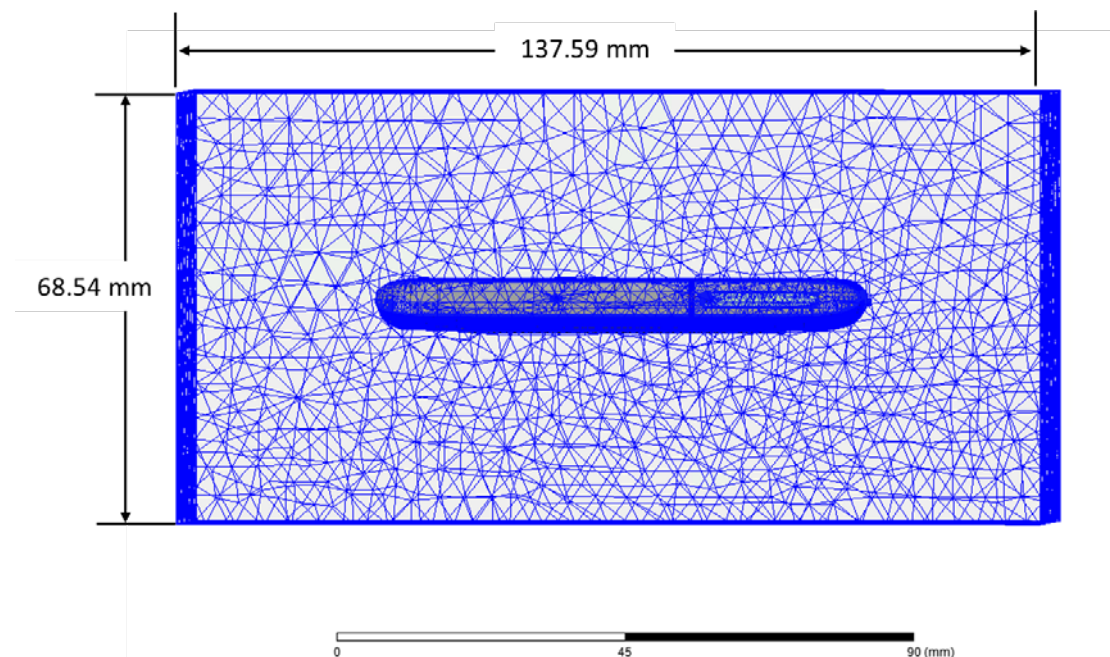


Figure 1 Example of the adaptive mesh technique (Top view)

1.1.3 Power density calculation

After solving 3D full-wave electromagnetic simulation, various kinds of physical quantities can be obtained. 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:

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

$\langle \vec{S} \rangle$ 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 version 2022.R2 (HFSS).

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

$$PD_{av} = \frac{1}{A} \int_A \langle \vec{S} \rangle \cdot d\vec{s} = \frac{1}{2A_{av}} \iint_{A_{av}} \| \text{Re}\{E \times H^*\} \| dA$$

, where the spatial-averaged power density (PD_{av}) is total power density value considering on x, y and z components of point power density $\langle \vec{S} \rangle$ and the evaluated area (A) is 4cm^2 .

1.2 Simulation setup

1.2.1 3D modeling

Figure 2 shows the simulation model which is mounted one mmWave antenna module. 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 module called as Ant M. The modeling contains the entire EUT to enable a Smart transmit GEN1, as well. Ant M is placed on the left side and antennas are facing the left side of the device.

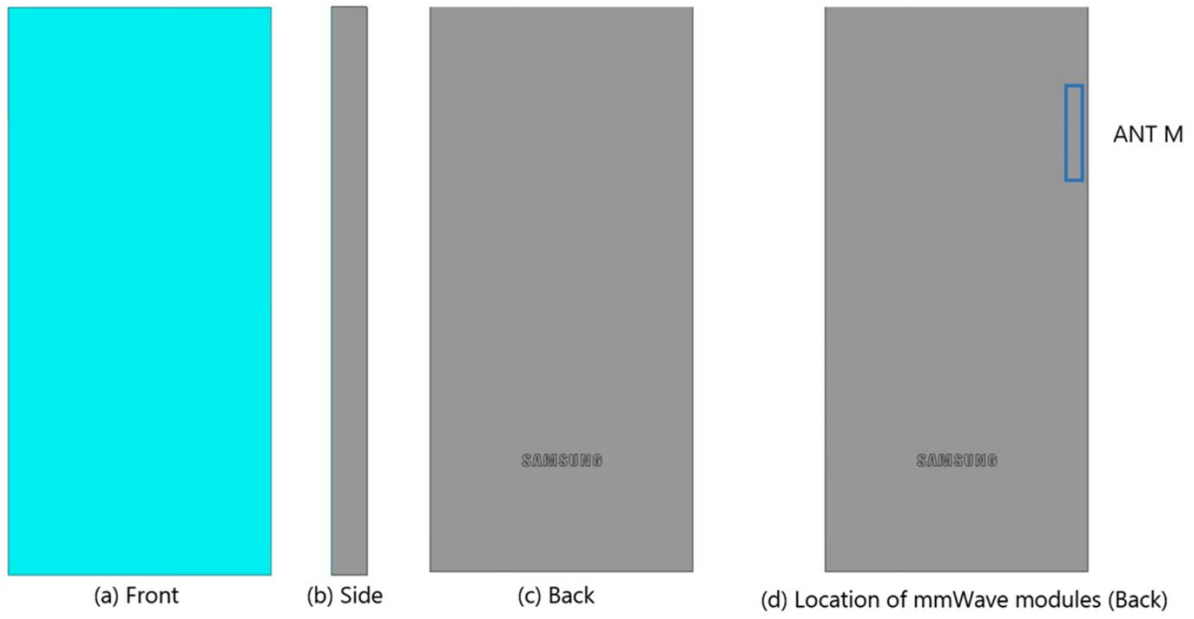


Figure 2 Simulation model which is mounted one mmWave antenna module

1.2.2 PD evaluation planes

Table 1 shows the PD evaluation planes for each mmWave antenna module and Figure 3 shows the PD evaluation planes and truncation area of the simulation model to find worst case of beamforming cases.

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. PD evaluation planes

Module	Front	Back	Left From Front View	Right From Front View	Top	Bottom
	S1	S2	S3	S4	S5	S6
Ant M	O	O	O	O	O	O

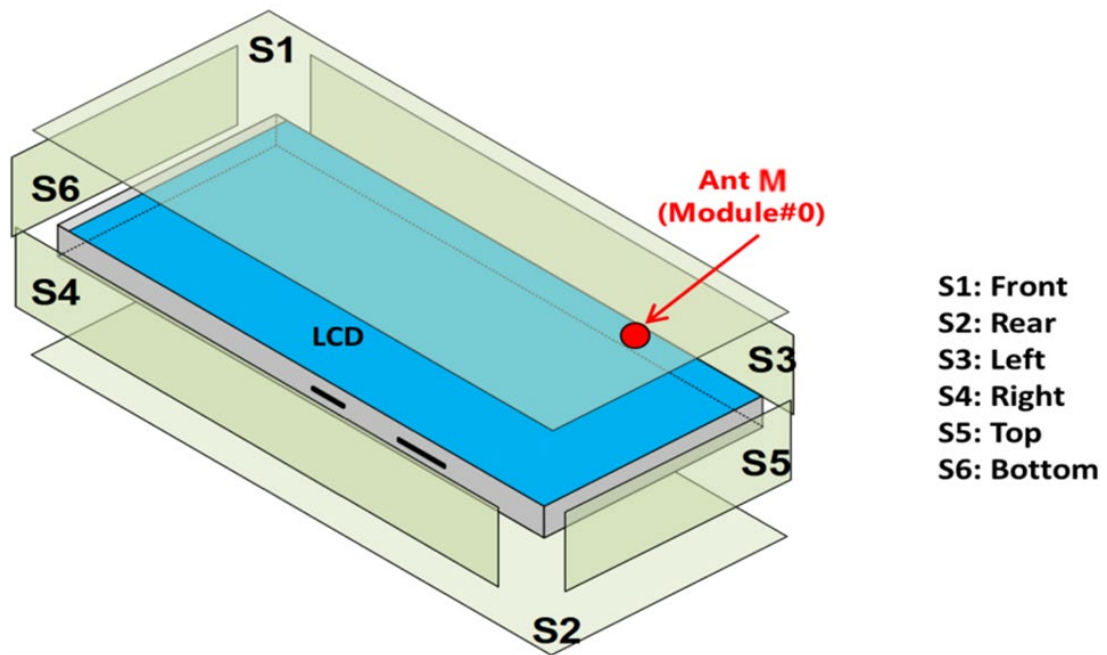


Figure 3. PD evaluation planes

1.2.3 Boundary condition

To simulate electromagnetic tool based on FEM, the boundary condition allows electromagnetic waves to be electrically open at the boundary and radiated far away without reflection. ANSYS Electromagnetics suite version 2022.R2 (HFSS) can support the absorbing boundary condition (ABC) for radiation boundary and make normally a quarter wave length from the radiating structure. In this report, to cover all beamforming cases of mmWave antenna module, 40 mm spacing from the device for each surfaces were adopted.

1.2.4 Source excitation condition

The antenna port of ANT M is divided into 10 ports for n261 and n258 1 x 5 patch array antennas, 10 ports for n260 1 x 5 patch array antennas. In the 10 ports included in each patch antenna, 5 ports are divided into vertical polarization feeding, and the other 5 ports are divided into horizontal polarization feeding.

Figure 4 shows the ANT M module structure and surrounding structure. The ANT M module is encrypted in the ANSYS Electromagnetics suite (HFSS) and can only check the feeding position.

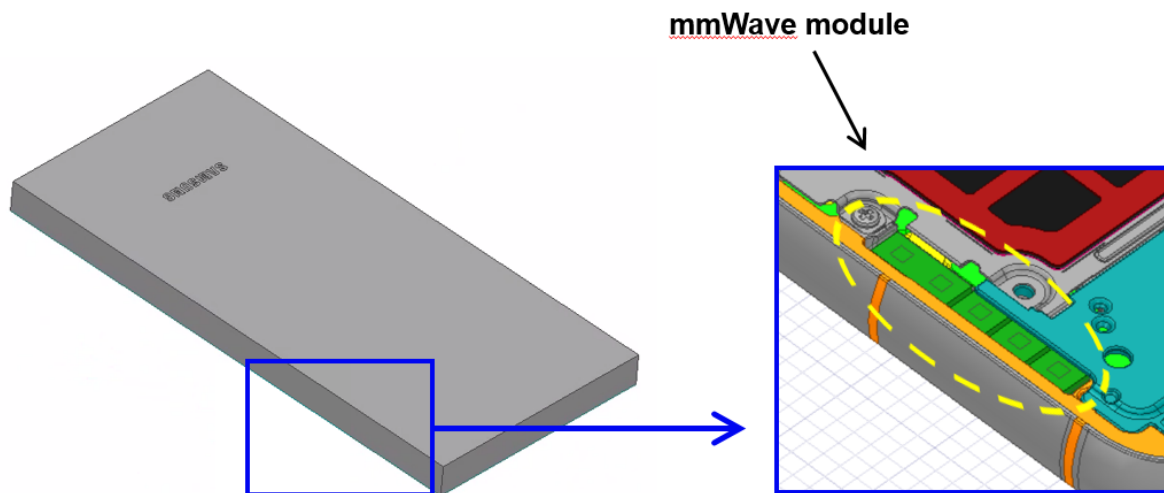


Figure 4. mmWave module (ANT M)

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 5 shows an example of antenna port excitations.

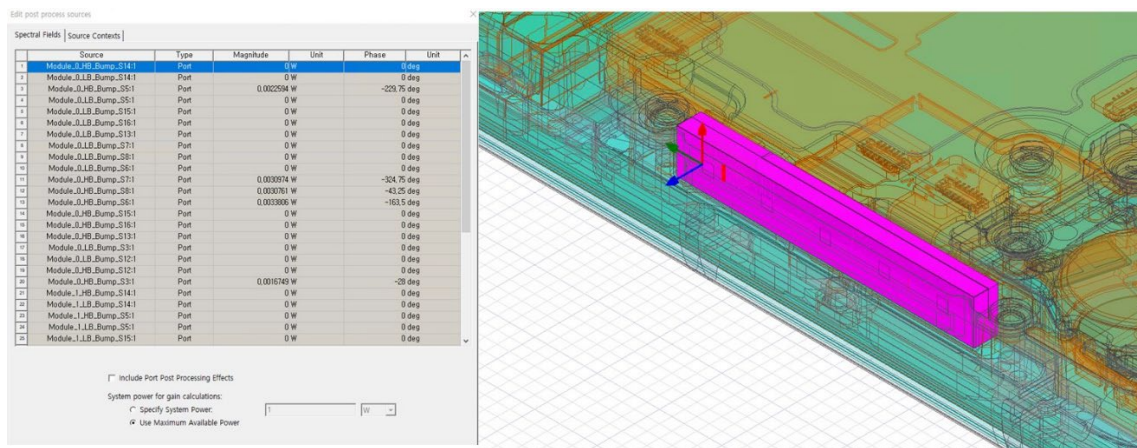


Figure 5. An example of port excitation (ANT M)

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. Simulation verification

2.1 Spatial-averaged power density and $\text{sim.power}_{\text{limit}}$

As mentioned in the previous chapter, the Poynting vector (\vec{S}) can be obtained through cross product of an electric field (\vec{E}) and complex conjugate of a magnetic field (\vec{H}). The real term of the Poynting vector can be described as the point power density or peak power density. Using the point power density, the spatial-averaged power density can be obtained by the integral of 4 cm^2 at 2.5 mm intervals of the point power density result. Figure 6 shows examples of the distribution plot of point power density and the averaged power density.

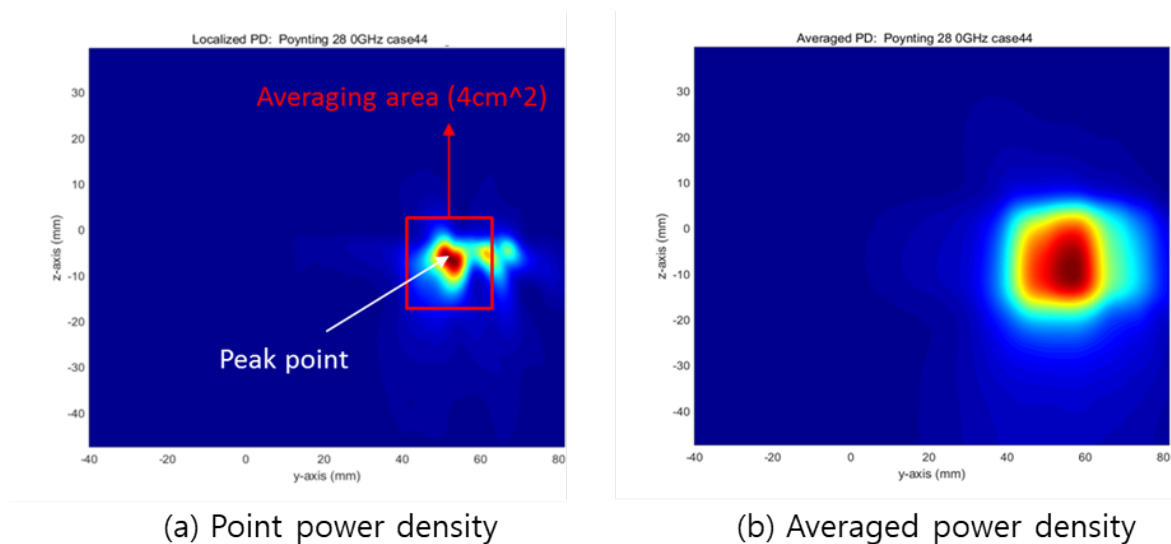


Figure 6. Power density distribution (Example)

2.2 Comparison between simulation, measurement

In this section, the simulated-power density distributions and measured-power density distributions are compared to each mmWave antenna.

Based on comparison of power density distributions, simulated power density and measured power density have a good correlation. The discrepancy in amplitude between simulated 4 cm^2 averaged power density and measured 4 cm^2 averaged power density is considered as housing influence and used in determining input power limit for each beam for RF exposure compliance.

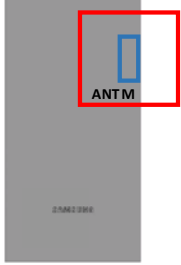
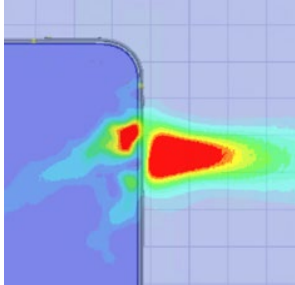
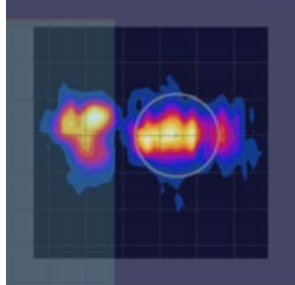
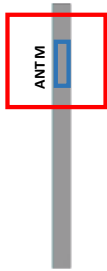
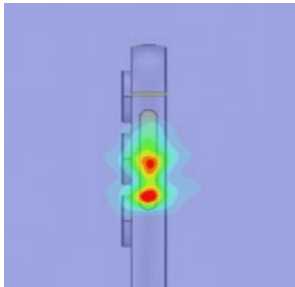
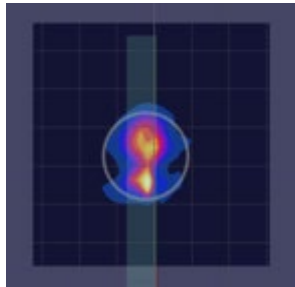
The input powers per each active port are listed below for both Simulation and Measurement validation and power density characterization. For Simulation, these values were entered directly into HFSS model. For measurement, FTM S/W was used to input these values for each active port also.

Mode/Band	Antenna	Input Power (dBm) SISO	Input Power (dBm) MIMO
5G NR n261	M Patch	6	6
5G NR n260	M Patch	6	6
5G NR n258	M Patch	6	6

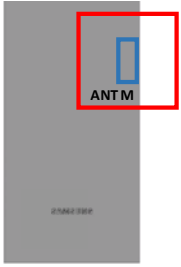
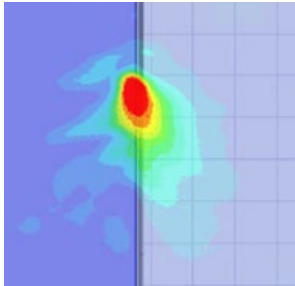
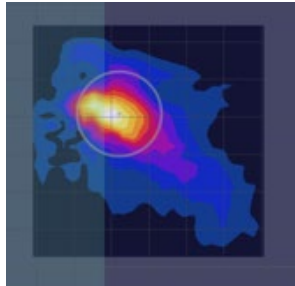
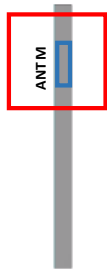
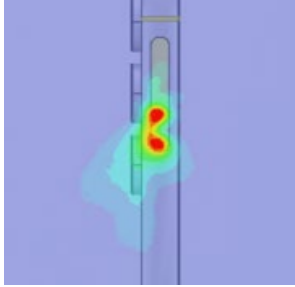
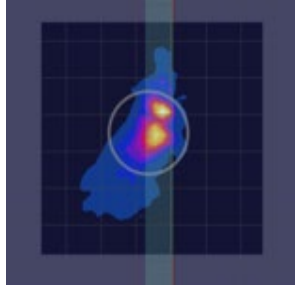
* The below simulation and measurement result were performed at 2mm evaluation distance and 28GHz / 38.5GHz / 24.8 GHz. The *input.power.limit* was determined based on below results.

Band	Channel	Module	Type(P or D)	Side	Beam ID	PLS (10 dBm)	Sim. PD (mW/cm2)	Meas. PD (mW/cm2) * Circle Avg
n261	Mid Ch. 2077915 (27924.96 MHz)	M	Patch	Rear	19	60	0.744	0.232
				Left	15		1.449	0.878
				Rear	144		0.656	0.327
				Left			1.091	0.593
n260	Mid Ch. 2254165 (38499.96 MHz)	M	Patch	Left	18	60	1.265	0.76
				Front			0.645	0.357
				Left	147		0.910	0.678
				Front	146		0.537	0.332
n258	Mid Ch. 2025833 (24800.04 MHz)	M	Patch	Left	13	60	2.106	1.36
				Front	14		1.017	0.376
				Rear	143		0.661	0.36
				Left			0.889	0.428

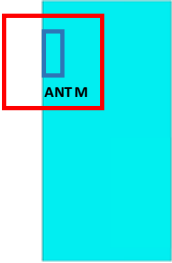
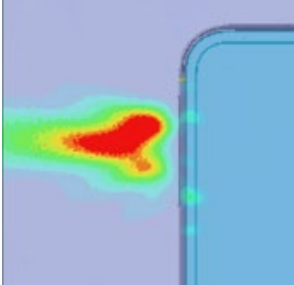
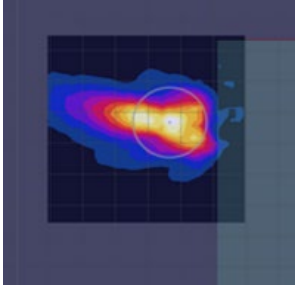
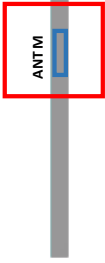
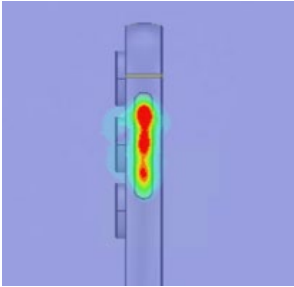
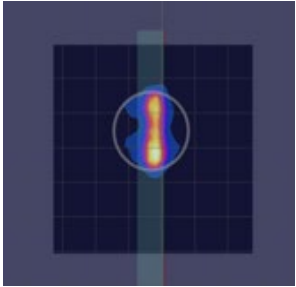
● Table 2-1, n261 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD
19	S2 (Rear)			
15	S3 (Left)			

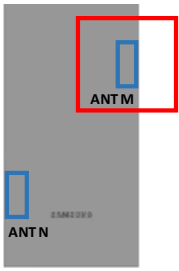

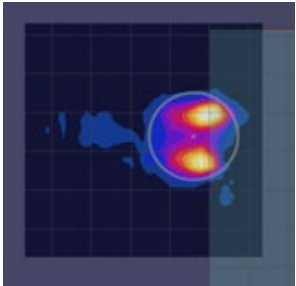
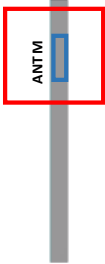
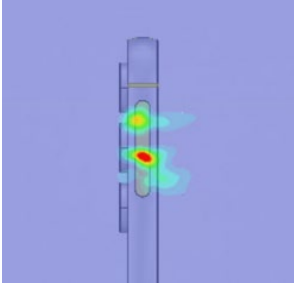
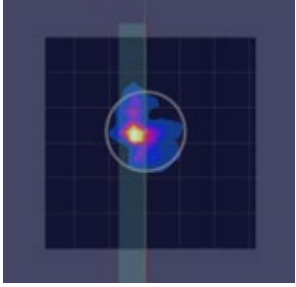
● Table 2-2, n261 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD
144	S2 (Rear)			
	S3 (Left)			

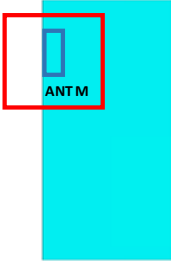
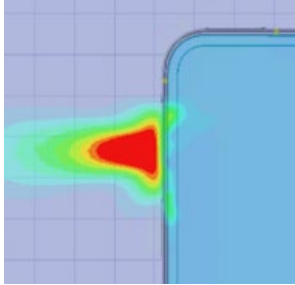
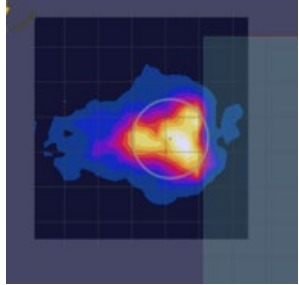
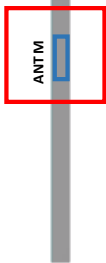
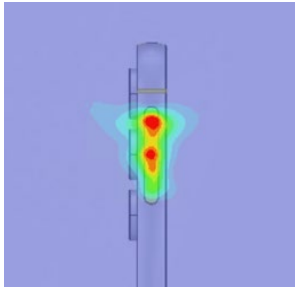
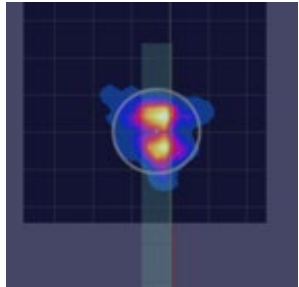
● Table 2-3, n260 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD
18	S1 (Front)			
	S3 (Left)			

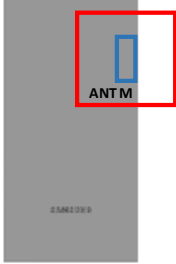
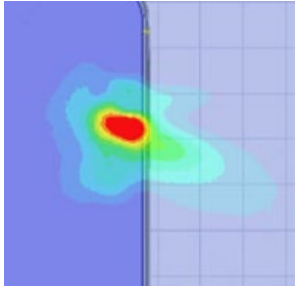
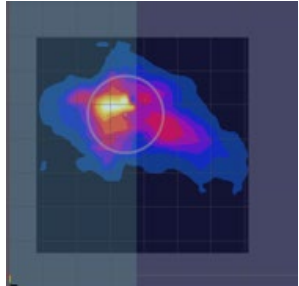
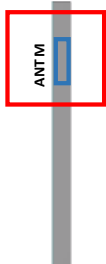
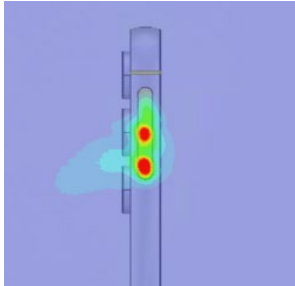
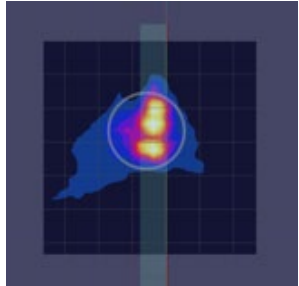
● Table 2-4, n260 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD
146	S1 (Front)			
147	S3 (Left)			

● Table 2-5, n258 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD
14	S1 (Front)			
13	S3 (Left)			

● Table 2-6, n258 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD
143	S2 (Rear)			
	S3 (Left)			

3 Simulation results

This section shows the PD simulation results of Ant M at 28GHz, 39GHz and 24GHz for each evaluation plane specified in Table 1 at two separation distances of 2mm and 10mm. 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 in this section to support RF exposure analysis for simultaneous transmission scenarios performed in the Part 1 Near Field PD report.

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 MIMO results represent the highest reported MIMO simulation results after sweeping across the relative phase between beams a 5° step interval from 0° to 360°,

The worst-case simulated PD determined from the tables in this section were used for conservativeness in *input.power.limit* determination in RF Exposure Part 0 Report.

3.1 PD for Low/Mid/High Channel at 28GHz / 39GHz / 24GHz

3.1.1 Ant M– Patch Antenna

Table 3 to 5 show the PD simulation evaluation of Ant M patch antenna at 28GHz / 39GHz / 24GHz for the all surfaces.

Table 3. PD of Ant M – patch antenna (28GHz – n261)

- M-patch Low CH

No.	Module	Type	Beam ID	Beam E1	Beam E2	Beam no.	4x4 4x4MIMO2							max ratio out of all beams															
							150deg	135deg	120deg	105deg	90deg	75deg	60deg	45deg	30deg	15deg	0deg	15deg	30deg	45deg	60deg	75deg	90deg	105deg	120deg	135deg	150deg	min ratio	max ratio
M1	Patch	M-patch	1	2	1	1	150deg	135deg	120deg	105deg	90deg	75deg	60deg	45deg	30deg	15deg	0deg	15deg	30deg	45deg	60deg	75deg	90deg	105deg	120deg	135deg	150deg	min ratio	max ratio

