

FCC ID: A3LSMS937U

Power Density Simulation Report

Revision A

February 10, 2025

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 module, ANSYS Electromagnetics suite version 2024.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 2024.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 2024.R2 (HFSS) is used. ANSYS Electromagnetics suite version 2024.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 2024.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 2024.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).

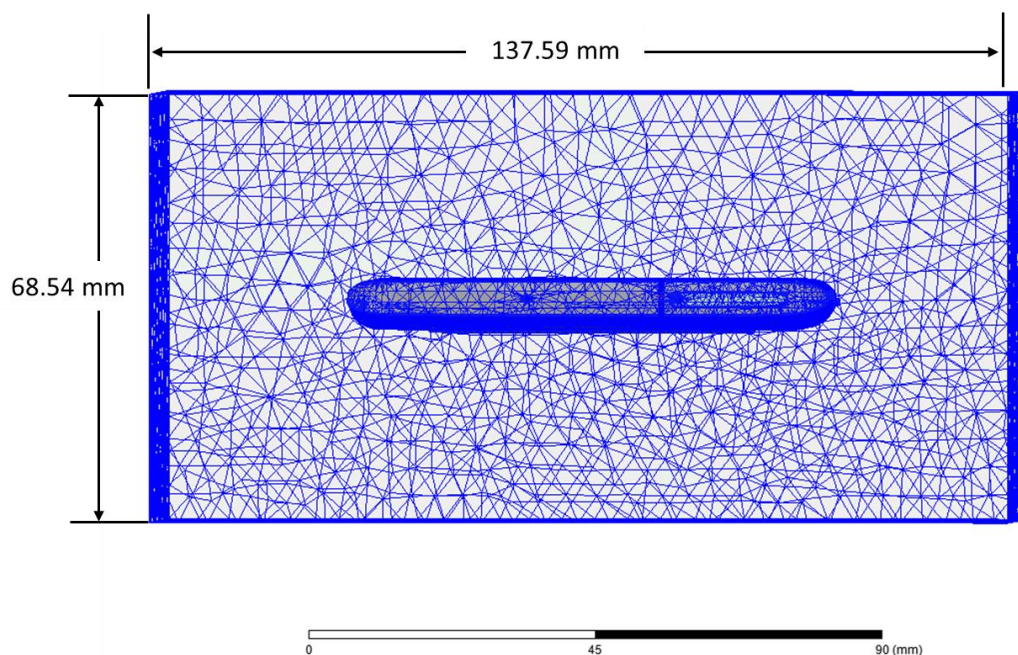


Figure 1 Example of the adaptive mesh technique (Top view)

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 2024.R2 (HFSS).

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

$$PD_{\text{aaaa}} = \frac{1}{AA} \langle \vec{S} \rangle \cdot dddd = \frac{1}{2AA_{\text{aaaa}}} \left\| \text{RRRR}\{EEEEHH^*\} \right\| ddAA$$

, where the spatial-averaged power density (PD_{aaaa}) 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 4cm².

1.2 Simulation setup

1.2.1 3D modeling

Figure 2 shows the simulation model which is mounted a 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 right side and antennas are facing the right side of the device.

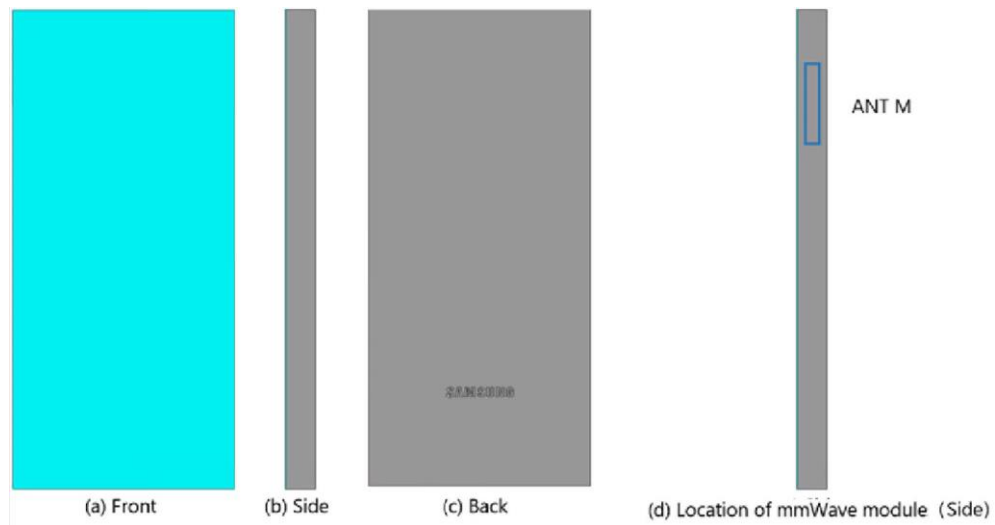


Figure 2. Simulation model which is mounted a mmWave antenna module

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

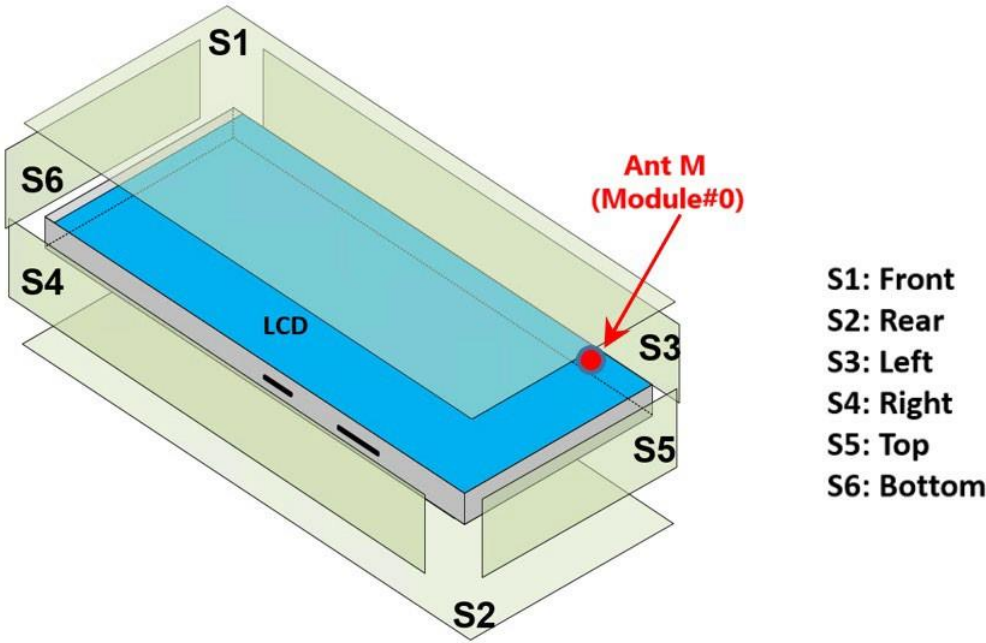


Figure 3. PD evaluation planes

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 2024.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 modules, 40 mm spacing from the device for each surfaces were adopted. This distance is sufficiently large enough for “Qualcomm IPLG script” to extract valid E- and H-fields from all adjacent exposure surfaces of the EUT.

1.2.4 Source excitation condition

The number of antenna ports of ANT M for source excitation are the same. 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.

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).

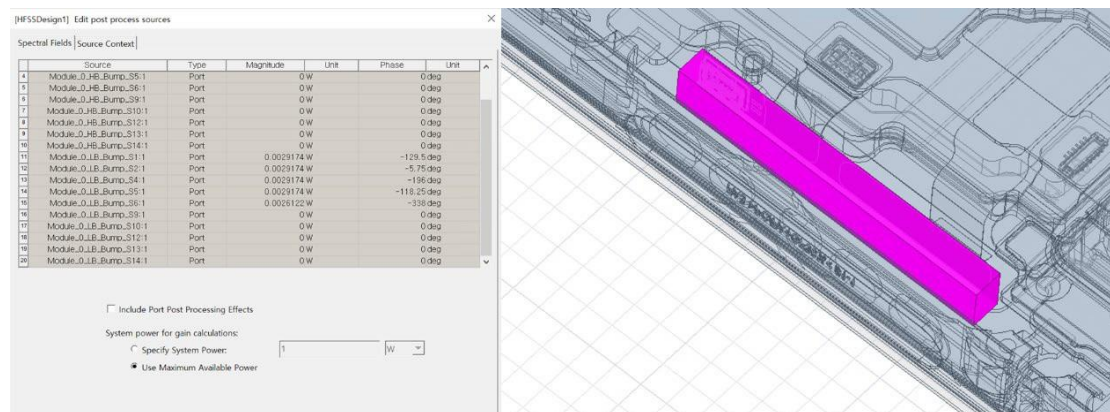


Figure 4. An example of port excitation (ANT M)

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 `sim.power_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 5 shows examples of the distribution plot of point power density and the averaged power density.

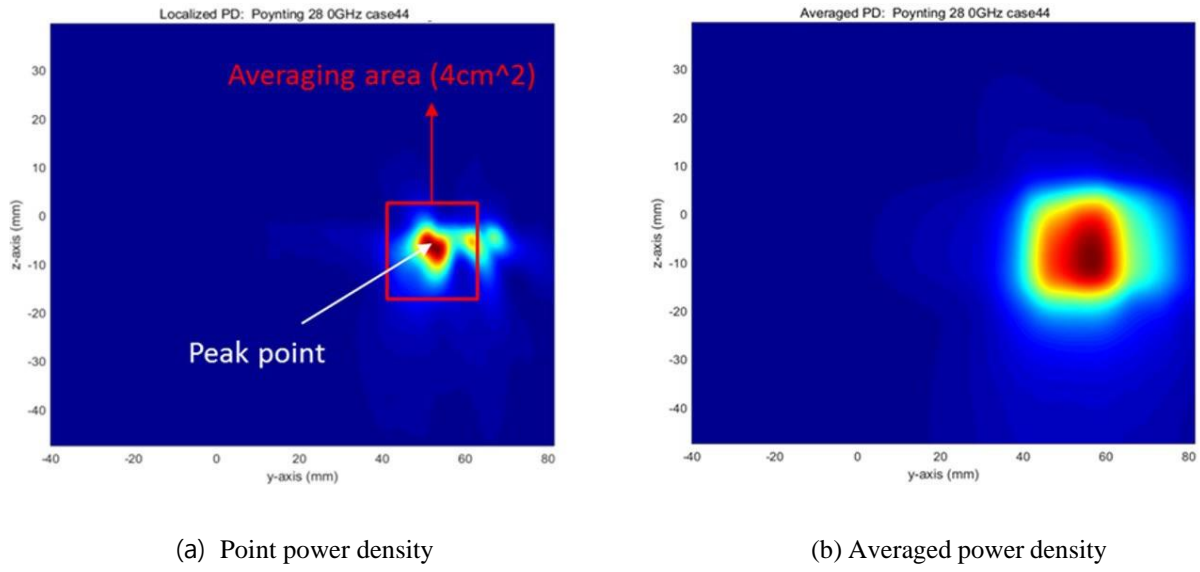


Figure 5. Power density distribution (Example)

For the Smart Transmit, the “Qualcomm Input Power Limit Generator(Qualcomm IPLG script)” were used to assess the mutual coupling between all the mmWave module and all the beams in the codebook for each mmWave module. Once the script is done with assessment, it will provide the `sim.power_limit` for all the beams for all three channels for the specified `PD_design_target`. This mode take the minimum `sim.power_limit` out of all three channels (low, mid and high) and use the resulted `sim.power_limit`.

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. Furthermore, to verify the Smart transmit GEN1, the PD distributions printing out from the “Qualcomm IPLG script” are added.

“Qualcomm IPLG script” prints the simulated 4cm^2 averaged PD values at the reference level (6dBm) for all channels on all surfaces.

Based on comparison of power density distributions, the power densities of simulated, measured and the “Qualcomm IPLG Script” have a good correlation. The discrepancy in amplitude between the “Qualcomm IPLG Script” 4cm^2 averaged power density and measured 4cm^2 averaged power density is

considered as housing influence and used in determining input power limit for each beam for RF exposure compliance.

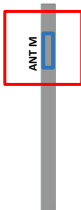
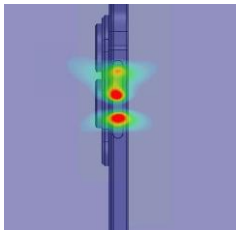
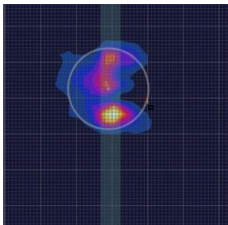
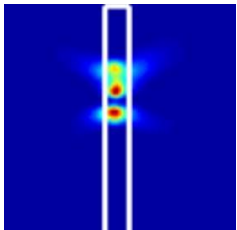
The input powers per each active port are listed below for both Simulation and Measurement validation and power density characterization. For Simulation, these values were entered directly into HFSS model. For measurement, FTM S/W was used to input these values for each active port also.

Mode/Band	Antenna	Input Power (dBm) SISO	Input Power (dBm) MIMO
5G NR n261	M Patch	6.0	6.0
5G NR n260	M Patch	6.0	6.0
5G NR n258	M Patch	6.0	6.0

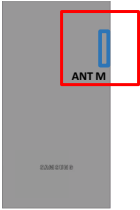
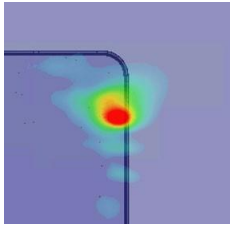
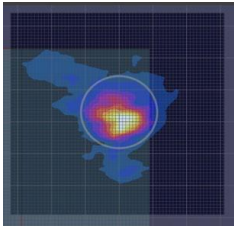
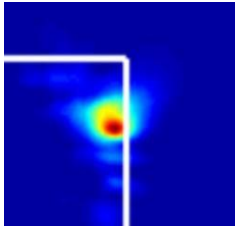
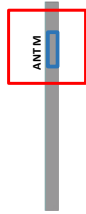
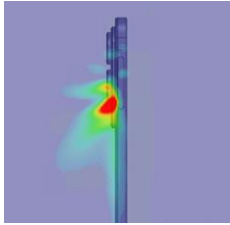
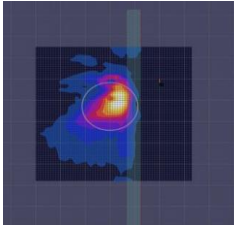
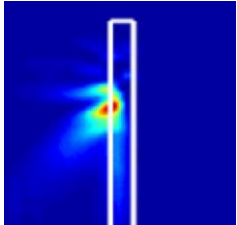
* The below simulation and measurement result were performed at 2mm evaluation distance and 28GHz / 38.5GHz / 24.8 GHz. The *input.power.limit* was determined based on below results.

4Cm^2								
Band	Channel	Module	Type	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	Left	15	60	1.458	0.55
				Rear	276		1.210	0.89
				Left	268		0.850	0.50
n260	Mid Ch. 2254165 (38499.96 MHz)	M	Patch	Rear	14	60	1.070	0.57
				Left			1.187	0.76
				Left	268		0.957	0.74
				Front	272		0.574	0.32
n258	Mid Ch. 2025833 (24800.04 MHz)	M	Patch	Rear	14	60	0.399	0.16
				Left	15		0.718	0.47
				Front			0.417	0.27
				Rear	273		1.510	0.79
				Left	275		1.003	0.53

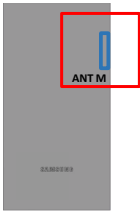
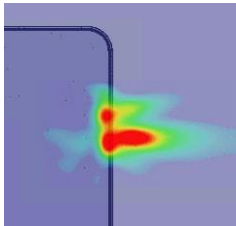
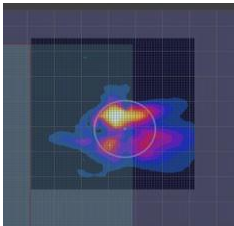
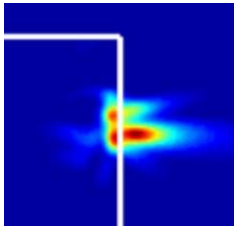
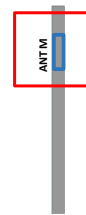
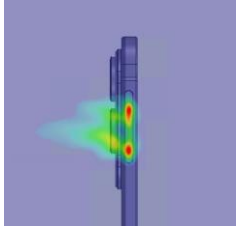
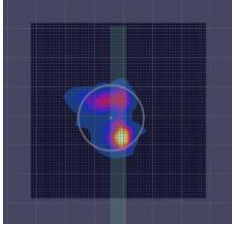
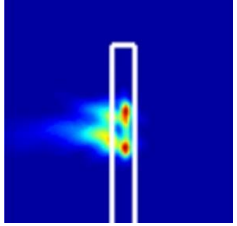
● Table 2-1, n261 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
15	S3 (Left)				

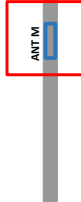
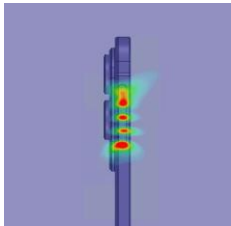
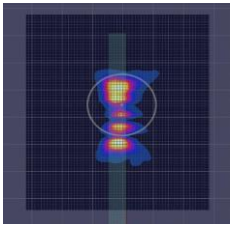
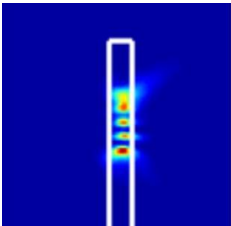
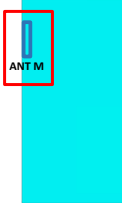
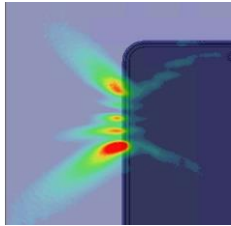
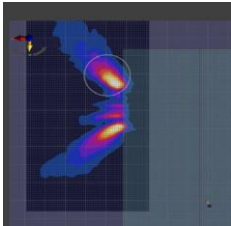
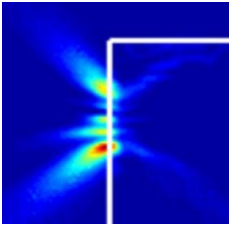
● Table 2-2, n261 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
276	S2 (Rear)				
	S3 (Left)				

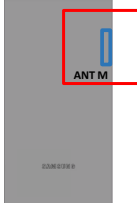
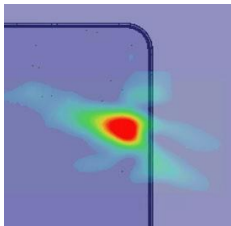
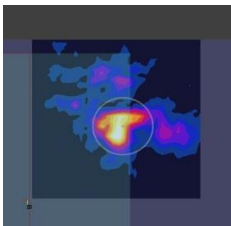
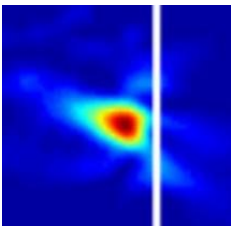
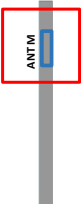
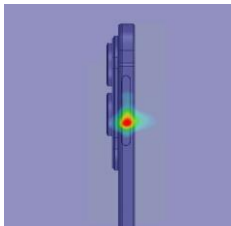
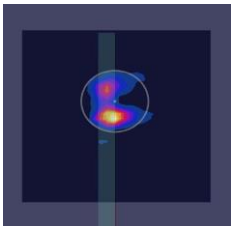
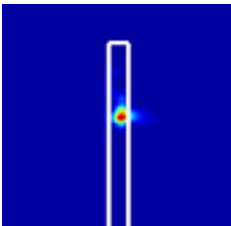
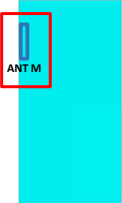
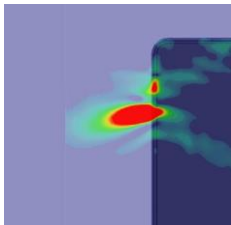
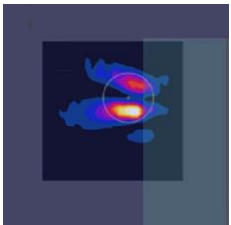
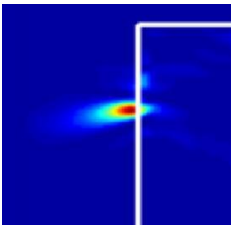
● Table 2-3, n260 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
14	S2 (Rear)				
	S3 (Left)				

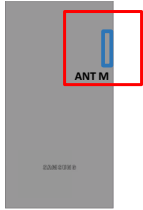
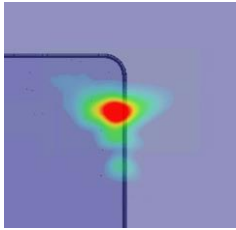
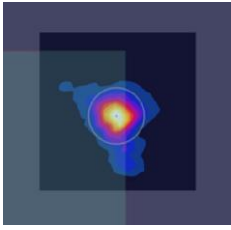
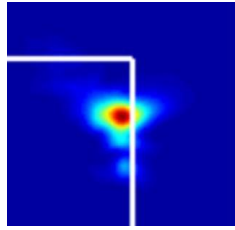
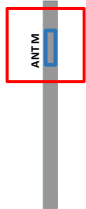
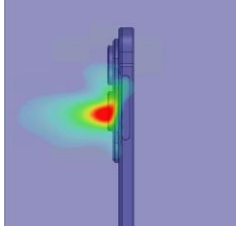
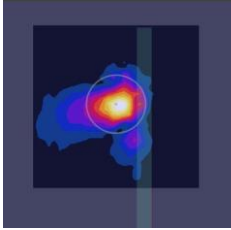
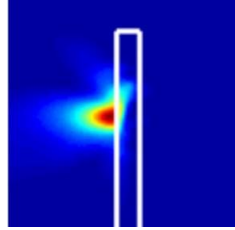
● Table 2-4, n260 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
268	S3 (Left)				
	S1 (Front)				

● Table 2-5, n258 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
14	S2 (Rear)				
15	S3 (Left)				
	S1 (Front)				

● Table 2-6, n258 ANT M-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
273	S2 (Rear)				
275	S3 (Left)				

The Smart transmit GEN1 cannot be finalized until the additional verifications are performed and passed. Follow the below steps for verifications in the mid channel:

VERIFICATION 1: Use “Qualcomm IPLG script” to print the PD plots for all the beams selected and evaluated for model validation.

- Throughout above comparisons (Table 2-1 to 2-6), the model validation including IPLG script were verified.

This model take “GEN2_SUB6” mode(mmWave operate as GEN1), thus, only verification 1 is required.

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 three separation distances of 2mm, 5mm 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 and the ratio of PD exposure from 2mm to 5mm 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.

- ### 3.1.1 Ant M- Patch Antenna

- M-patch High CH

[illegible]

Table 4. PD of Ant M – patch antenna (39GHz – n260)

- M-patch Low CH

[illegible]

- M-patch Mid CH

[illegible]

- M-patch High CH

[illegible]

Table 5. PD of Ant M – patch antenna (24GHz – n258)

- M-patch Low CH

[illegible]

- M-patch Mid CH

[illegible]

- M-patch High CH

No.	Model	Type	Beam D1	Beam D2	Feed-in	4-m2 TC(90deg/2)										max ratio out of all beams at 30mm evaluation distance										max ratio out of all beams at 10mm evaluation distance										max ratio out of all beams at 30mm evaluation distance																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
						10deg	15deg	20deg	30deg	45deg	60deg	75deg	90deg	105deg	120deg	135deg	150deg	165deg	180deg	195deg	210deg	225deg	240deg	255deg	270deg	285deg	300deg	315deg	330deg	345deg	360deg	375deg	390deg	405deg	420deg	435deg	450deg	465deg	480deg	495deg	510deg	525deg	540deg	555deg	570deg	585deg	600deg	615deg	630deg	645deg	660deg	675deg	690deg	705deg	720deg	735deg	750deg	765deg	780deg	795deg	810deg	825deg	840deg	855deg	870deg	885deg	900deg	915deg	930deg	945deg	960deg	975deg	990deg	1005deg	1020deg	1035deg	1050deg	1065deg	1080deg	1095deg	1110deg	1125deg	1140deg	1155deg	1170deg	1185deg	1200deg	1215deg	1230deg	1245deg	1260deg	1275deg	1290deg	1305deg	1320deg	1335deg	1350deg	1365deg	1380deg	1395deg	1410deg	1425deg	1440deg	1455deg	1470deg	1485deg	1500deg	1515deg	1530deg	1545deg	1560deg	1575deg	1590deg	1605deg	1620deg	1635deg	1650deg	1665deg	1680deg	1695deg	1710deg	1725deg	1740deg	1755deg	1770deg	1785deg	1800deg	1815deg	1830deg	1845deg	1860deg	1875deg	1890deg	1905deg	1920deg	1935deg	1950deg	1965deg	1980deg	1995deg	2010deg	2025deg	2040deg	2055deg	2070deg	2085deg	2100deg	2115deg	2130deg	2145deg	2160deg	2175deg	2190deg	2205deg	2220deg	2235deg	2250deg	2265deg	2280deg	2295deg	2310deg	2325deg	2340deg	2355deg	2370deg	2385deg	2400deg	2415deg	2430deg	2445deg	2460deg	2475deg	2490deg	2505deg	2520deg	2535deg	2550deg	2565deg	2580deg	2595deg	2610deg	2625deg	2640deg	2655deg	2670deg	2685deg	2700deg	2715deg	2730deg	2745deg	2760deg	2775deg	2790deg	2805deg	2820deg	2835deg	2850deg	2865deg	2880deg	2895deg	2910deg	2925deg	2940deg	2955deg	2970deg	2985deg	3000deg																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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