FCC ID: A3LSMS921U

Power Density Simulation Report

Revision A

October 19, 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 2023.R1 (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 2023.R1 (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 2023.R1 (HFSS) is used. ANSYS Electromagnetics suite version 2023.R1 (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 2023.R1 (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 2023.R1 (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).

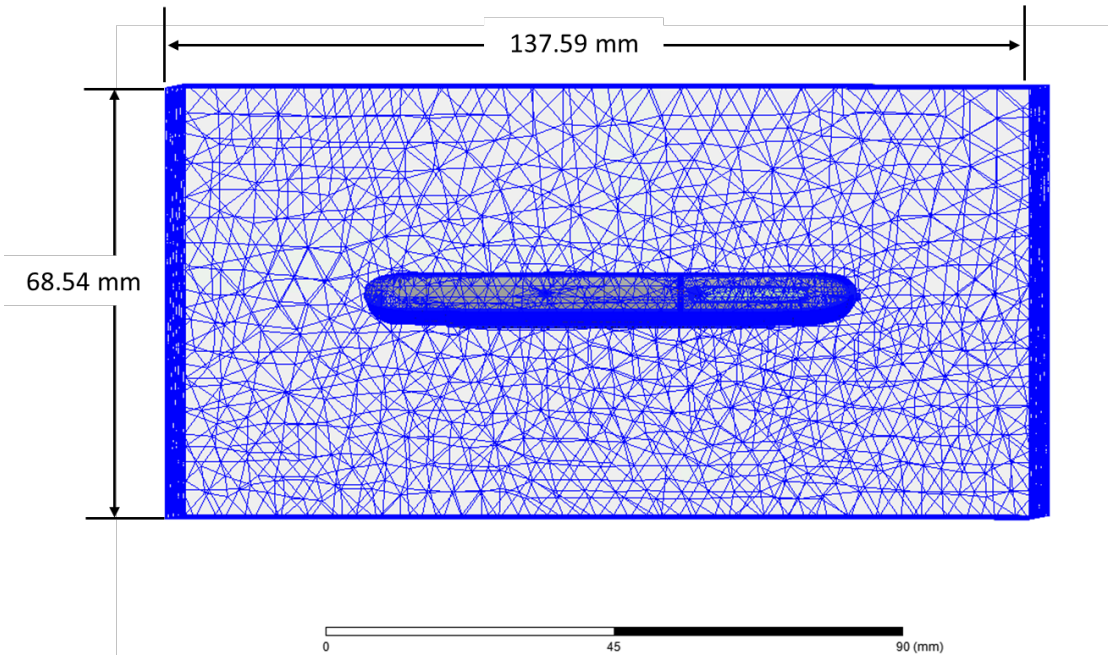


Figure 1 Example of the adaptive mesh technique (Top view)

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:

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

$\langle\vec{S}\rangle$ 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 2023.R1 (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:

$$\mathrm{PD}_{av} = \frac{1}{A}\int_{A} \langle\vec{S}\rangle \cdot ds = \frac{1}{2A_{av}}\iint_{A_{av}} \|Re\{ExH^{*}\}\| \, dA$$

, 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 $4\mathrm{cm}^2$.

1.2 Simulation setup

1.2.1 3D modeling

Figure 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 Ant M and Ant N. The modeling contains the entire EUT to enable a Smart transmit GEN2, as well. Ant M is placed on the left side and antennas are facing the back side, and Ant N is placed on the right side and antennas are facing the right side of the device.

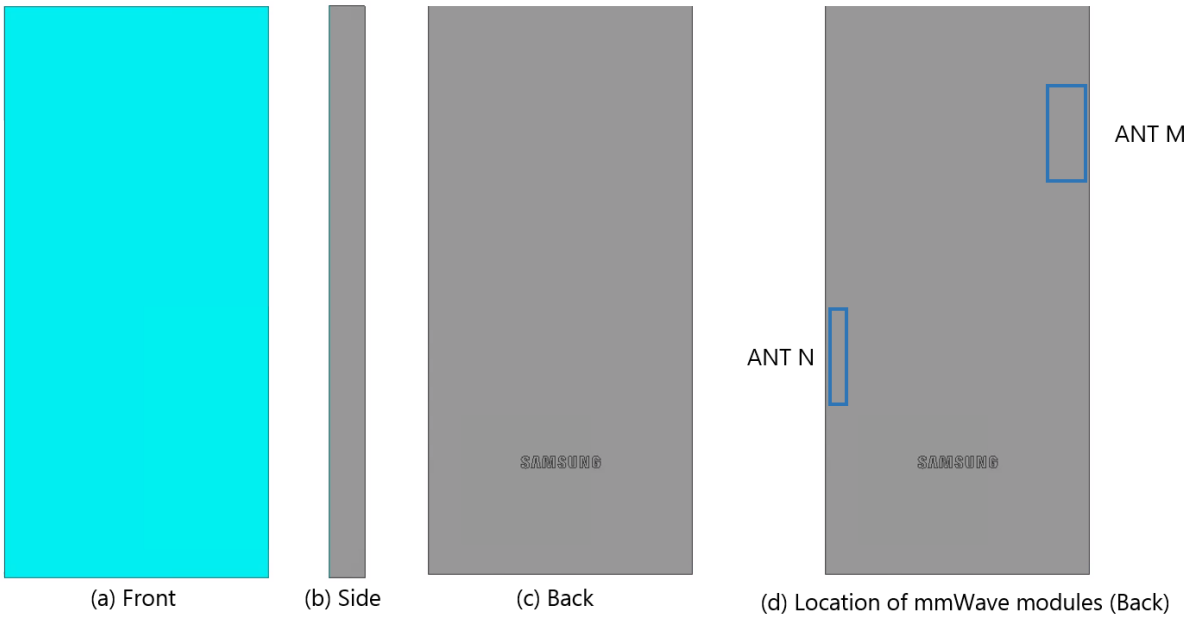


Figure 2 Simulation model which is mounted two mmWave antenna modules

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
Ant N	O	O	O	O	O	O

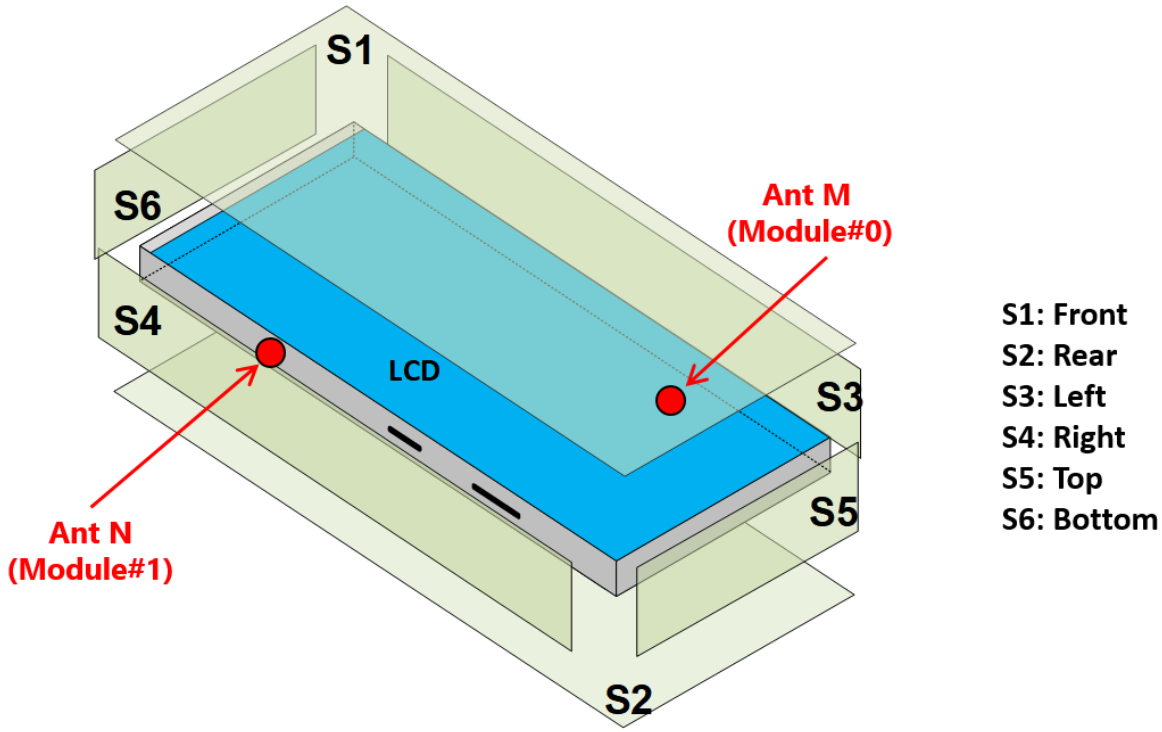


Figure 3. PD evaluation planes

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 2023.R1 (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 MG 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 and ANT N for source excitation are the same. The antenna port of ANT M and N 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.

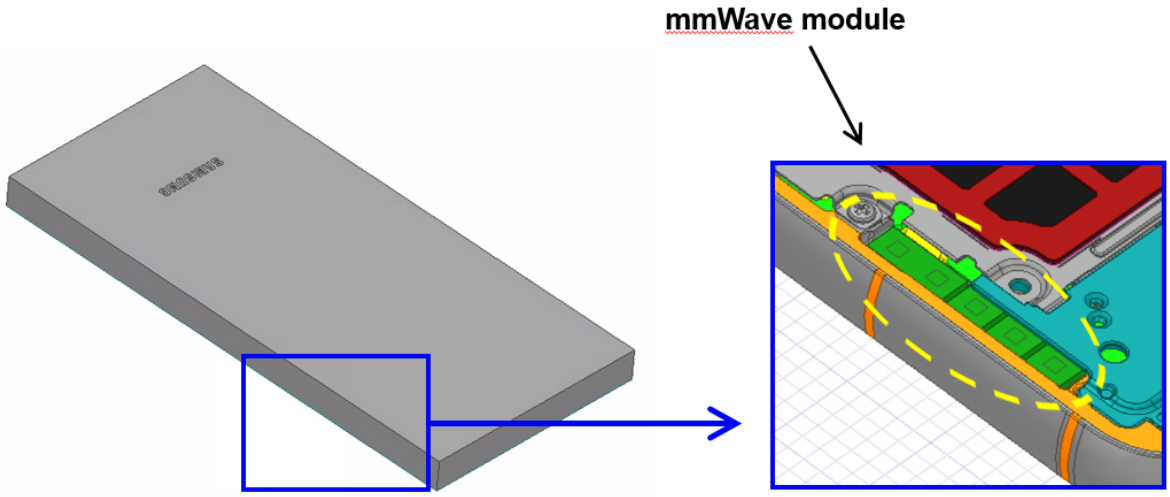


Figure 4. mmWave module (ANT M)

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.

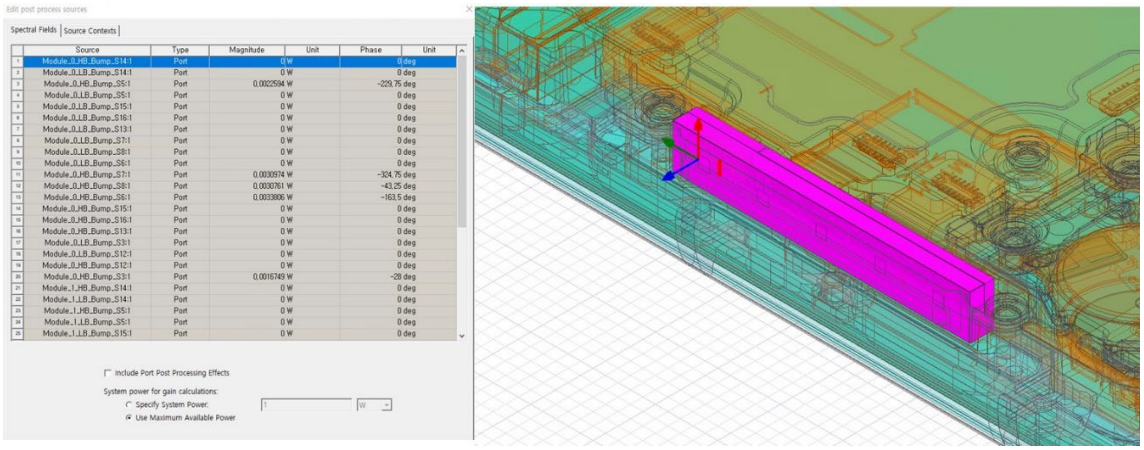


Figure 5. An example of port excitation (ANT N)

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

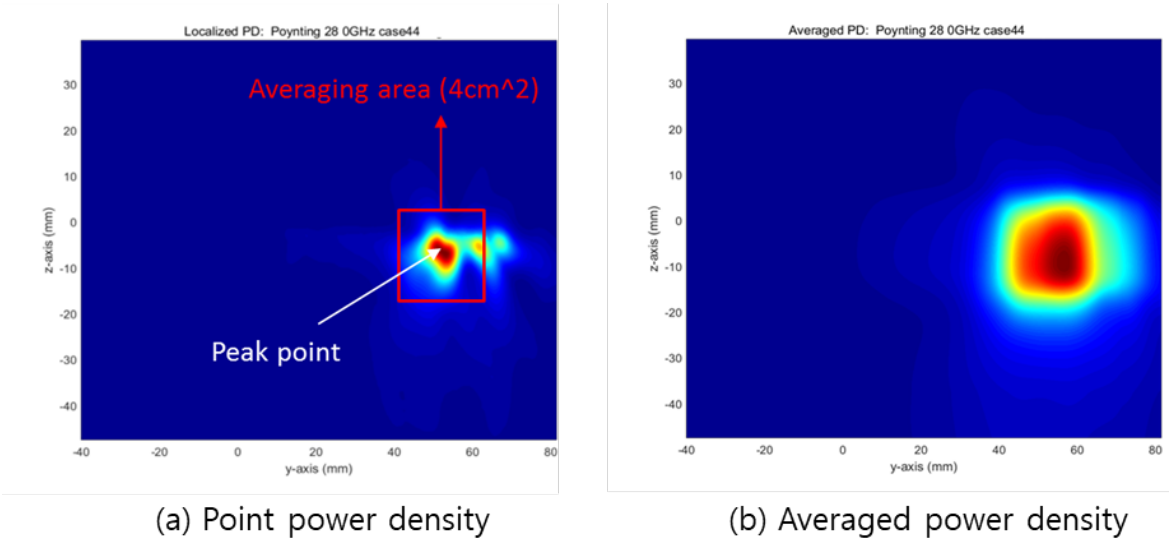
The simulation completion condition of ANSYS Electromagnetics suite (HFSS) is defined as delta S. The ANSYS Electromagnetics suite (HFSS) calculates the S-parameter for the mesh conditions of each step and determines whether to proceed with the operation of the next step by comparing the difference

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 6 shows examples of the distribution plot of point power density and the averaged power density.



(a) Point power density (b) Averaged power density

Figure 6. Power density distribution (Example)

For the Smart transmit GEN2, the "Qualcomm IPLG script" were used to extract E- and H-fields from the validated simulation and to assess the mutual coupling between all the mmWave antenna modules and all the beams in the codebook to determine the backoff value for each mmWave module. Note the assessment and backoff value derivation are automated with "Qualcomm IPLG script". Once the script is done with assessment, it will provide the sim.$power_{limit}$ (backoff is already included) for all the beams for all three channels for the specified PD_design_target. This mode take the minimum sim.$power_{limit}$ out of all three channels (low, mid and high) of each band 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 GEN2, the PD distributions printing out from the "Qualcomm IPLG script" are added.

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.

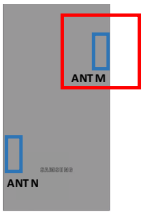
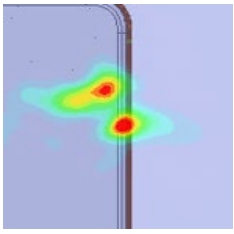
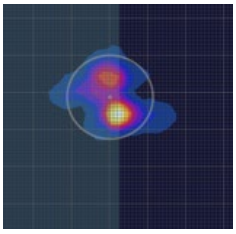
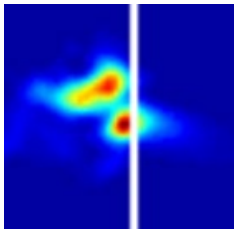
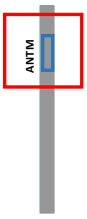
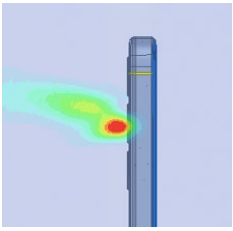
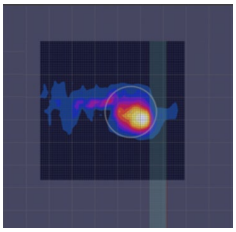
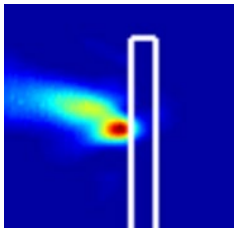
The input powers per each active port are listed below for both Simulation and Measurement validation and power density characterization. For Simulation, these values were entered directly into HFSS model. For measurement, FTM S/W was used to input these values for each active port also.

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

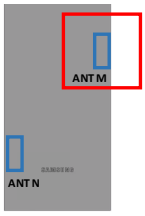
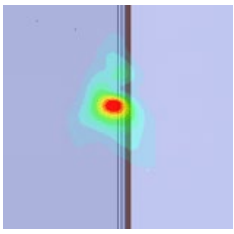
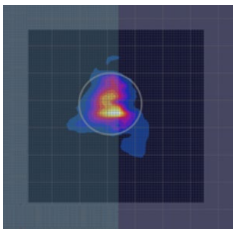
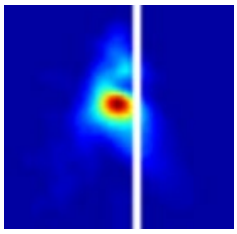
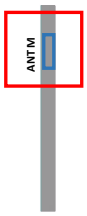
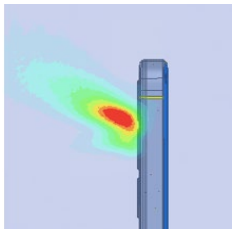
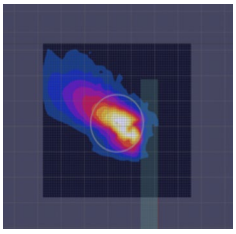
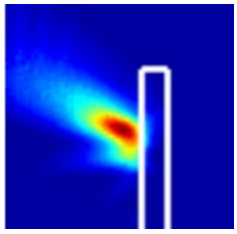
* The below simulation and measurement result were performed at 2mm evaluation distance and 28GHz / 38.5GHz / 24.8 GHz. The *input.power.limit* was determined based on below results.

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	27	60	1.466	0.736
				Left	35		0.908	0.39
				Rear	284		2.261	1.01
				Left	280		1.184	0.689
		N	Patch	Rear	39		0.677	0.374
				Right			1.183	0.693
				Front	31		0.611	0.317
				Rear	289		0.833	0.352
				Right	295		1.511	1.26
				Front			0.795	0.532
n260	Mid Ch. 2254165 (38499.96 MHz)	M	Patch	Rear	28	60	1.152	0.545
				Left	36		0.561	0.389
				Rear	282		1.288	0.682
				Left	281		0.731	0.363
		N	Patch	Right	33		1.985	0.862
				Front	31		0.879	0.453
				Right	295		1.714	0.932
				Front			1.269	0.591
n258	Mid Ch. 2025833 (24800.04 MHz)	M	Patch	Rear	25	60	1.501	0.77
				Left	26		0.869	0.383
				Rear	293		2.088	1.18
				Left			1.083	0.499
		N	Patch	Rear	32		1.246	0.538
				Right	38		1.624	0.7
				Rear	289		0.616	0.322
				Right	286		0.954	0.6

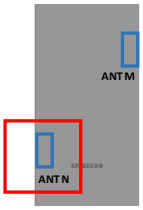
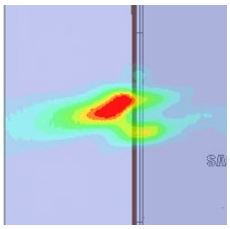
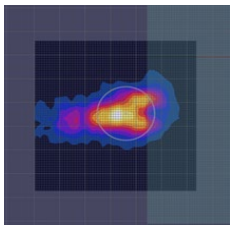
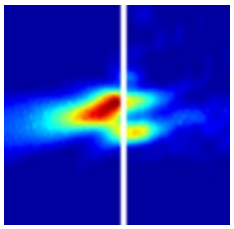
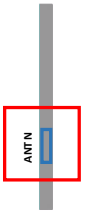
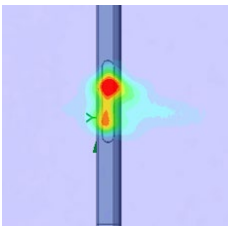
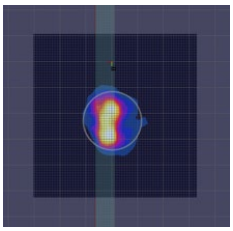
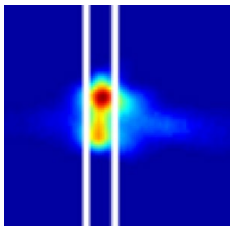
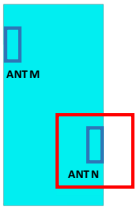
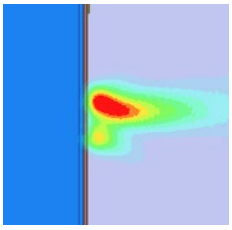
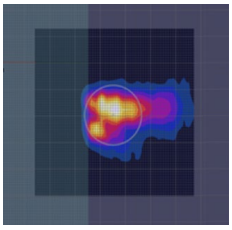
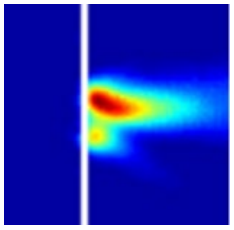
- Table 2-1, n261 ANT M-Patch

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

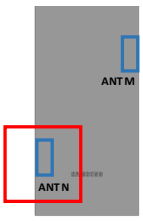
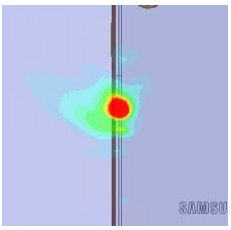
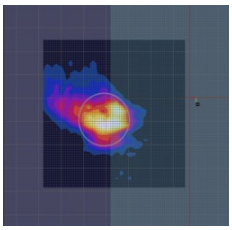
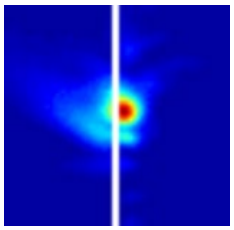
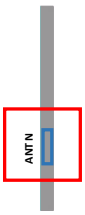
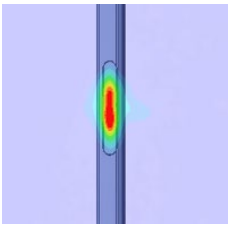
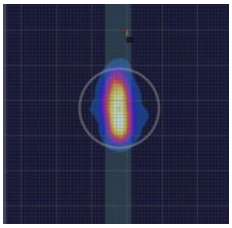
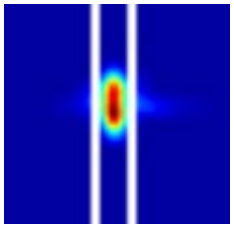
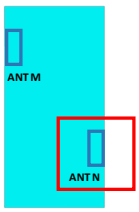
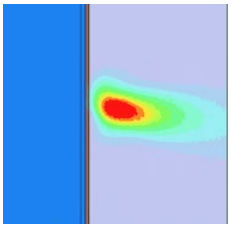
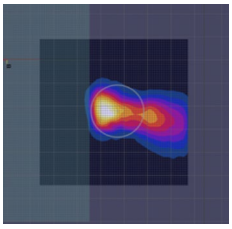
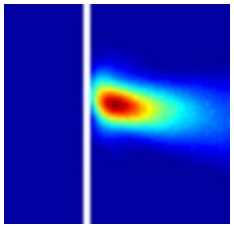
- Table 2-2, n261 ANT M-Patch

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

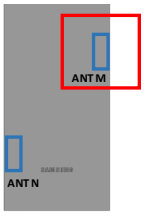
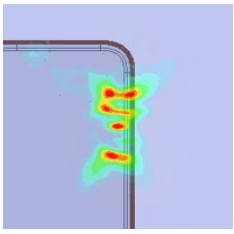
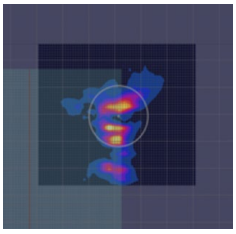
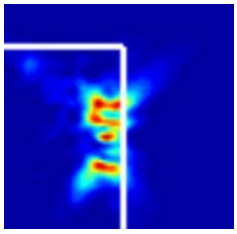
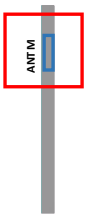
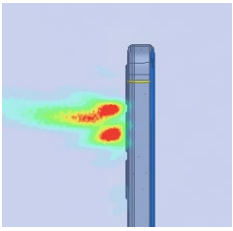
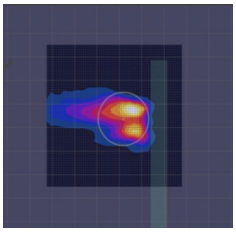
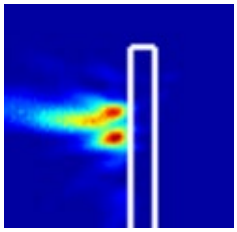
- Table 2-3, n261 ANT N-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
39	S2 (Rear)				
	S4 (Right)				
31	S1 (Front)				

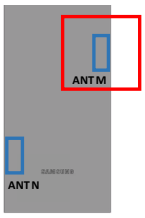
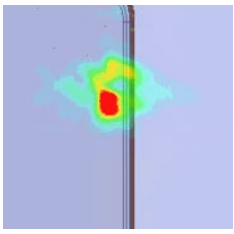
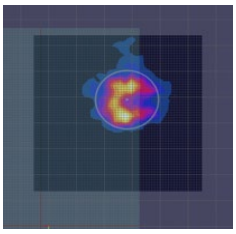
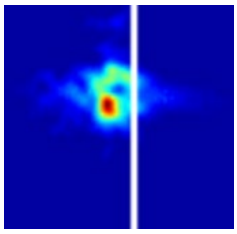
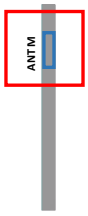
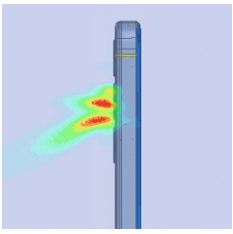
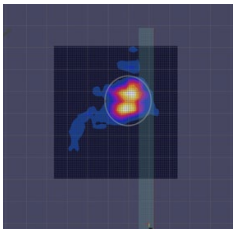
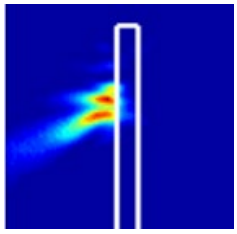
- Table 2-4, n261 ANT N-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
289	S2 (Rear)				
295	S4 (Right)				
	S1 (Front)				

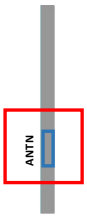
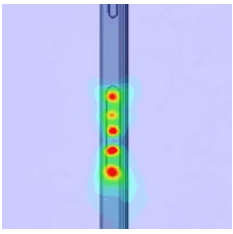
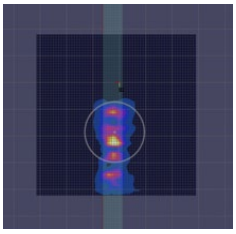
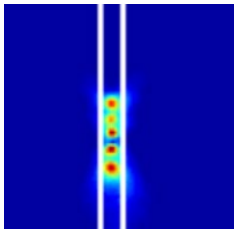
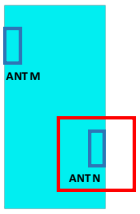
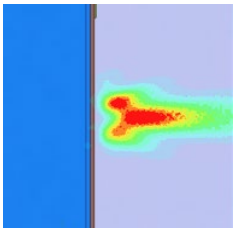
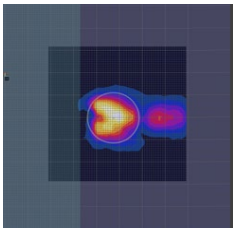
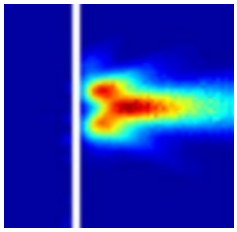
- Table 2-5, n260 ANT M-Patch

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

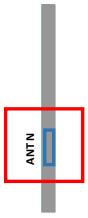
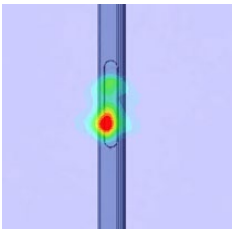
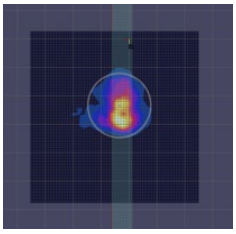
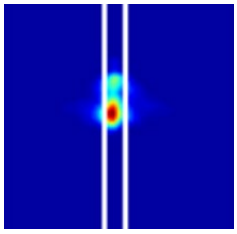
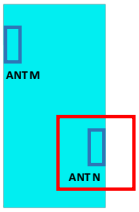
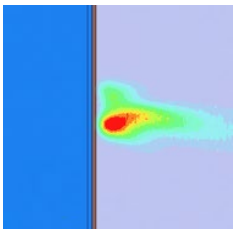
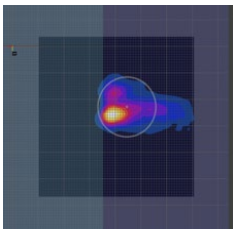
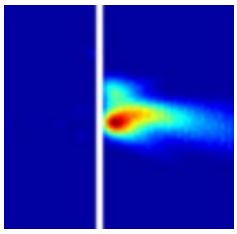
- Table 2-6, n260 ANT M-Patch

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

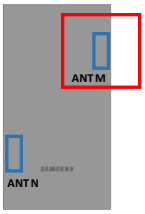
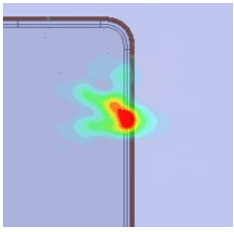
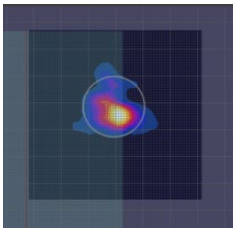
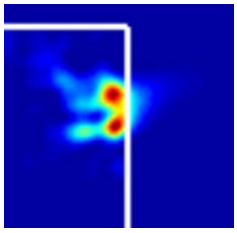
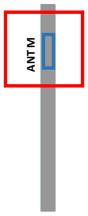
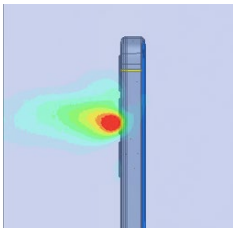
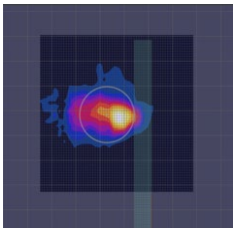
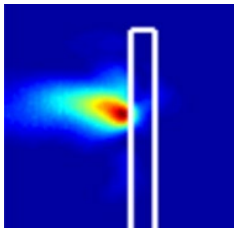
- Table 2-7, n260 ANT N-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
33	S4 (Right)				
31	S1 (Front)				

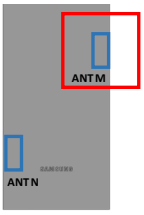
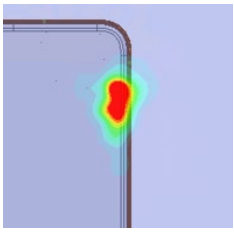
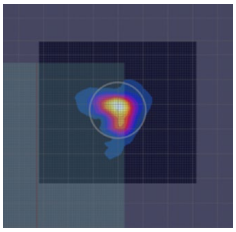
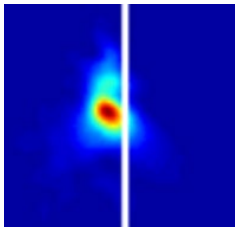
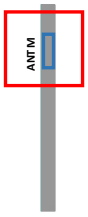
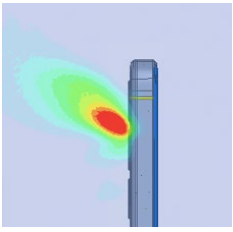
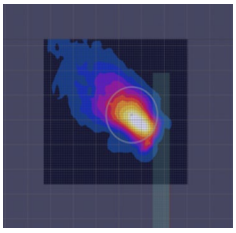
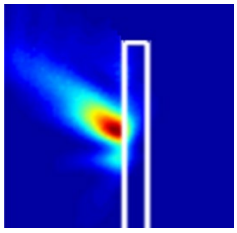
- Table 2-8, n260 ANT N-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
295	S4 (Right)				
	S1 (Front)				

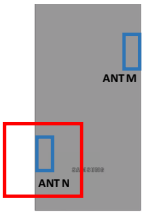
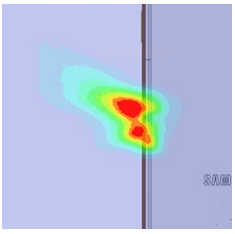
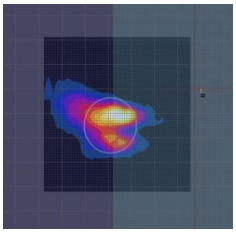
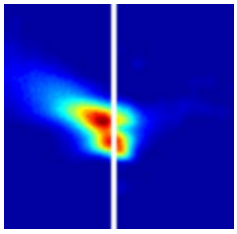
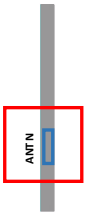
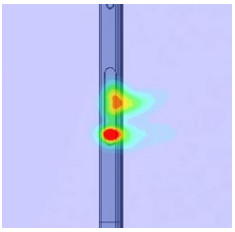
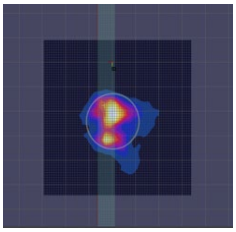
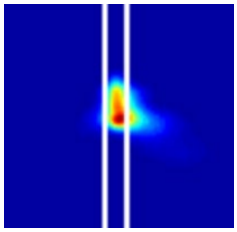
- Table 2-9, n258 ANT M-Patch

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

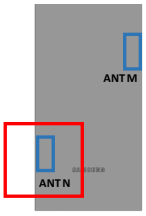
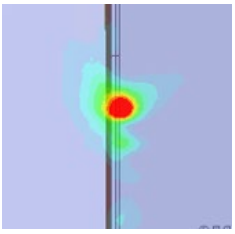
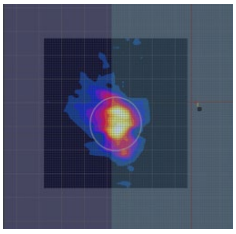
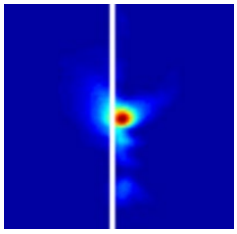
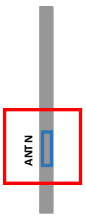
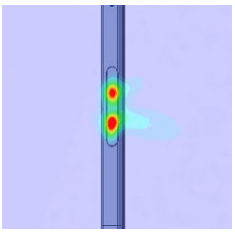
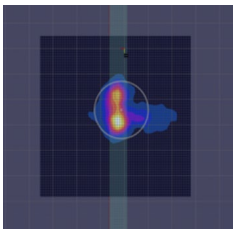
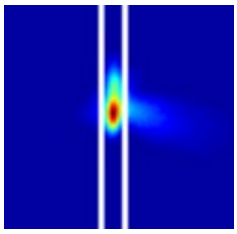
- Table 2-10, n258 ANT M-Patch

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

- Table 2-11, n258 ANT N-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
32	S2 (Rear)				
38	S4 (Right)				

- Table 2-12, n258 ANT N-Patch

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
289	S2 (Rear)				
286	S4 (Right)				

The Smart transmit GEN2 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 2-12), the model validation including IPLG script were verified.

VERIFICATION 2: Contribution factors from Qualcomm IPLG script and from HFSS for selected beams, and normalized combined PD verification, for device with 2 QTMs. The printed contribution factor from Qualcomm IPLG Script was within 2% numerical tolerance of the simulated contribution factor. Additionally, the normalized combined PD is < 1.0.

VERIFICATION3: Measured 4cm^2 PD on worst surface and combined PD at worst-case location for device with 2 QTMS. The device should be measured at the reference power level and scaled to the input.power.limit. The combined PD should be less than or equal to the *PD_Design_Target* within the uncertainty at the reference power level.

This model take "GEN2_UNIFIED" mode, thus, only verification 1 is required.

3. DSI_PD_ratios for mmW Antenna

This section shows the DSI_PD_ratios of Ant M and Ant N 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 2mm to 10mm evaluation distance for each beam are reported in this section to support RF exposure analysis for simultaneous transmission scenarios performed in the Part 1 Near Field PD report.

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.

- Table 2-13, DSI_PD_ratios for each plane combination

Band	Ref Plane	Evl Plane	Module	Ratio	Ref Surf	Eval Surf
n261	2	10	0	0.696	FBLRTb	FBLRTBt
			1	0.647	FBLRTb	FBLRTBt
n260			0	0.622	FBLRTb	FBLRTBt
			1	0.746	FBLRTb	FBLRTBt
n258			0	0.657	FBLRTb	FBLRTBt
			1	0.653	FBLRTb	FBLRTBt