

FCC ID: A3LSMF966U

Power Density Simulation Report

Revision A

April 23rd, 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 modules, 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 final adaptive mesh of the device (cross-section of top view).

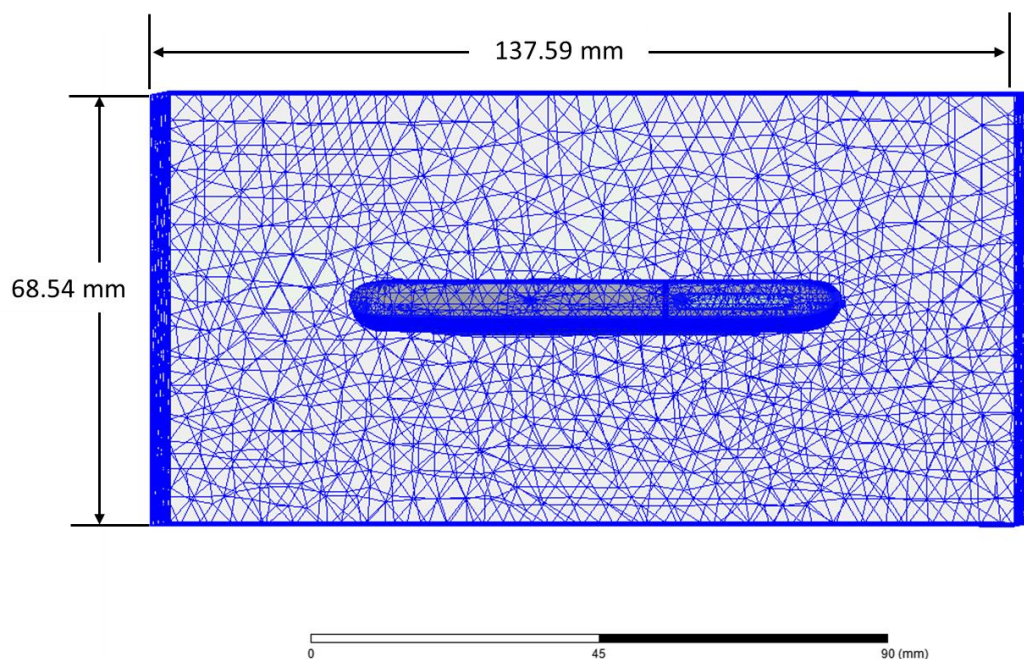


Figure 1 Example of the adaptive mesh technique (Top view)

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 2020.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:

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

, 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 a 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 a mmWave antenna module called as Ant J. For a folder open status (Fig. 2-1), Ant J is placed on the back side and antennas are facing the back side of the device. For a folder close status (Fig. 2-2), Ant J is placed same of the folder open status.

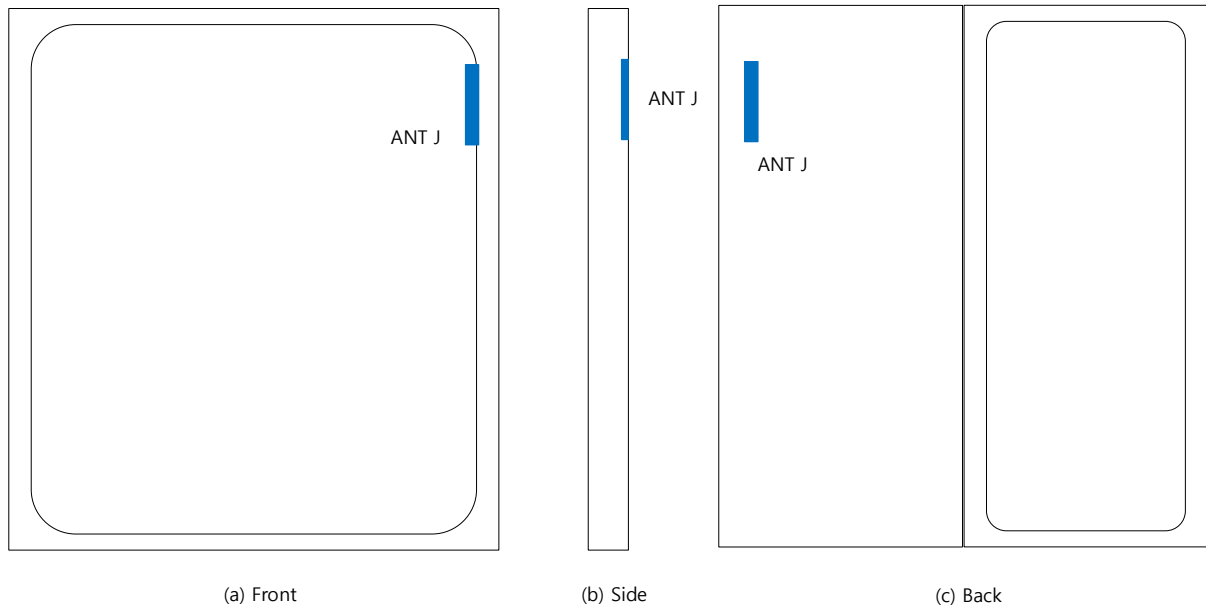


Figure 2-1. Simulation model which is mounted a mmWave antenna module (Folder Open Status)

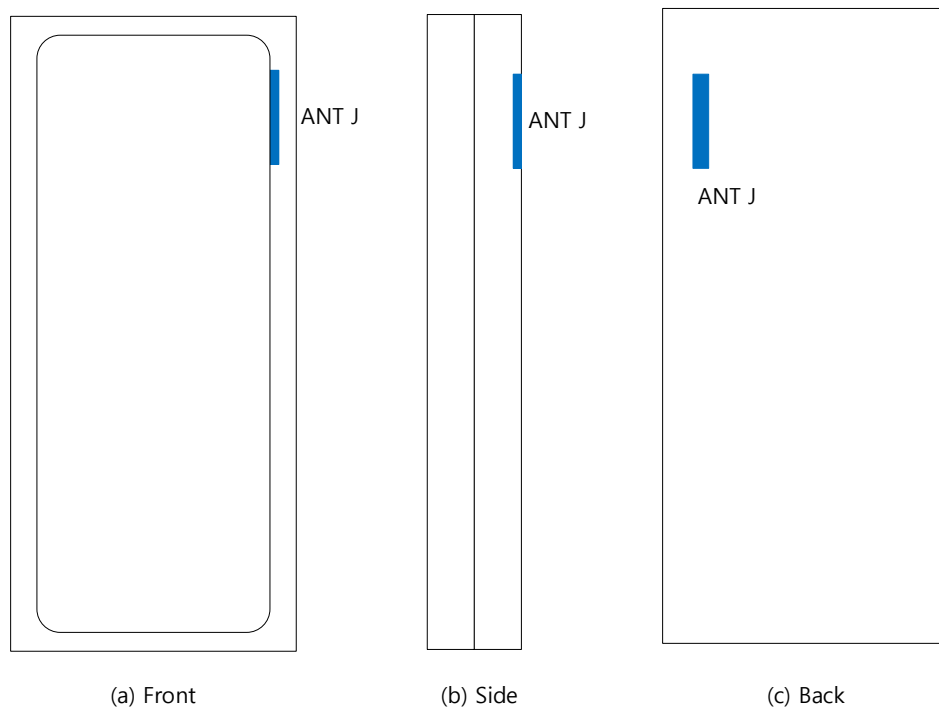


Figure 3-2. Simulation model which is mounted a mmWave antenna module (Folder Closed Status)

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 whole 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 J	O	O	O	O	O	O

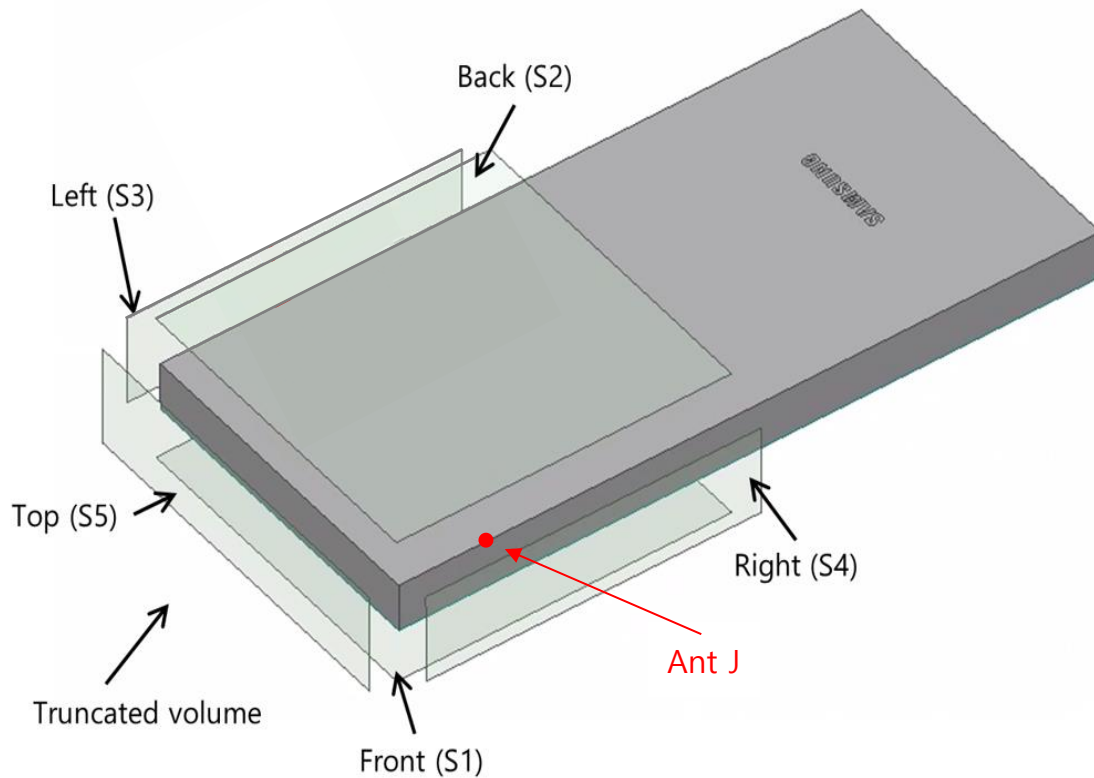


Figure 4. PD evaluation planes

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 module, 40 mm spacing from each surfaces of the device were adopted. This distance is

sufficiently large enough for “Qualcomm IPLG Script” to extract valid E-fields and H-fields from all adjacent exposure surfaces of the EUT.

1.2.4 Source excitation condition

The number of antenna ports of ANT J for source excitation are the same. The antenna port of ANT J is divided into 10 ports for n261 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 J module structure and surrounding structure. The ANT J module is encrypted in the ANSYS Electromagnetics suite (HFSS) and can only check the feeding position.

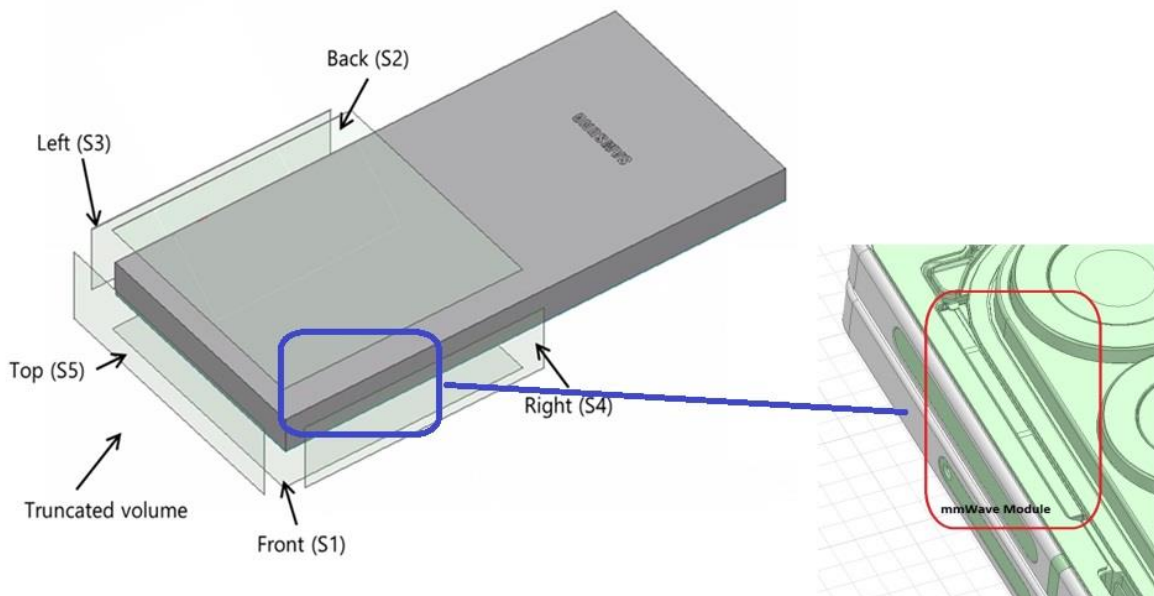


Figure 5. mmWave module (ANT J)

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.

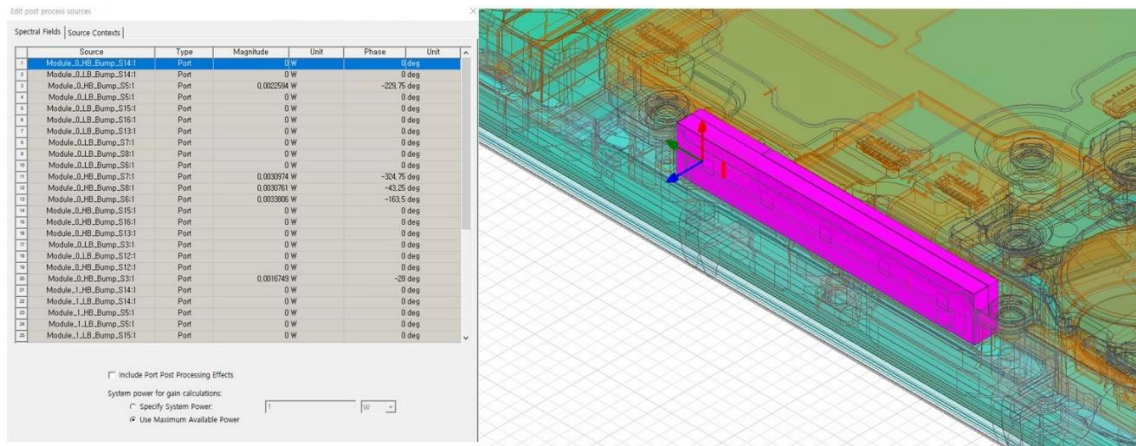


Figure 6. An example of port excitation (ANT J)

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

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.

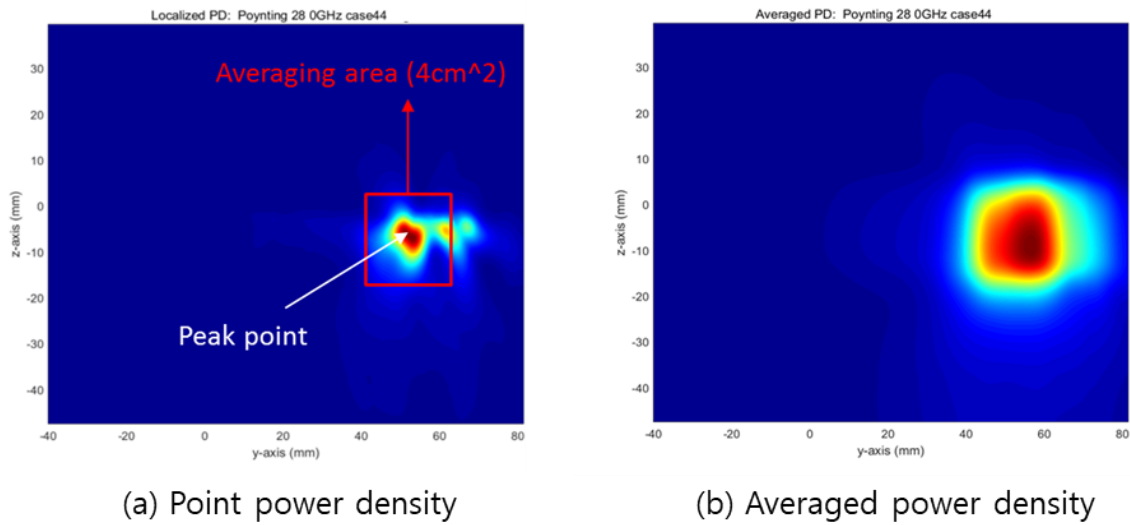


Figure 7. Power density distribution (Example)

For the Smart transmit GEN2, the “Qualcomm IPLG script” were used to extract E-fields 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 and 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, simulated power density and measured power density have a good correlation. The discrepancy in amplitude between simulated 4cm² averaged power density and measured 4cm² 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.

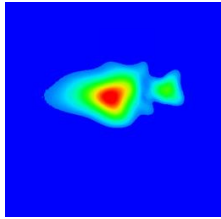
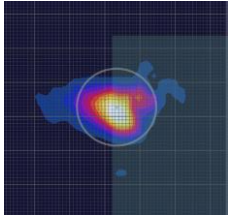
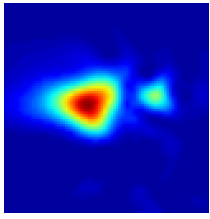
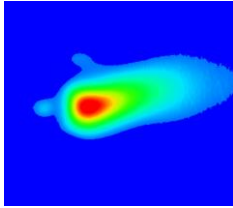
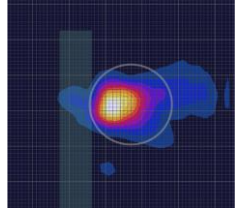
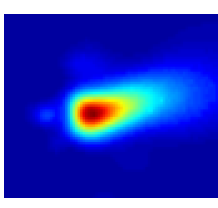
Mode/Band	Antenna	Input Power (dBm) SISO	Input Power (dBm) MIMO
5G NR n261	J Patch	6.0	6.0
5G NR n260	J Patch	6.0	6.0
5G NR n258	J Patch	6.0	6.0

* The below simulation and measurement result were performed at 2mm evaluation distance and 24.8GHz / 28GHz / 38.5GHz. The *input.power.limit* was determined based on below results in RF Exposure Part 0 Report.

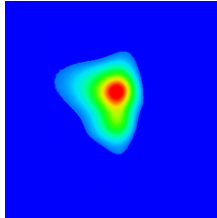
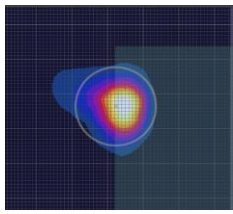
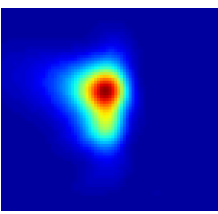
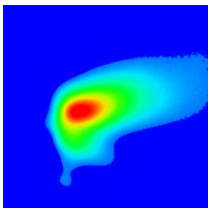
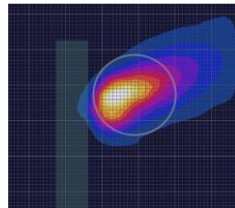
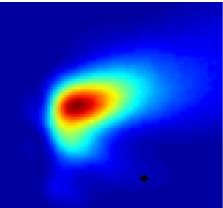
conditon	Band	Channel	Module	Type(P or D)	Side	Beam ID	PLS (10 dBm)	Sim. PD (mW/cm2)	Meas. PD (mW/cm2) * Circle Avg
Folder Closed	n261	Mid Ch. 2077915 (27924.96 MHz)	J	Patch	Right	19	60	1.18	0.49
						271		1.40	1.17
					Rear	19		1.61	0.64
						271		1.83	1.33
	n260	Mid Ch. 2254165 (38499.96 MHz)	J	Patch	Right	19	60	1.02	0.62
						270		1.03	0.67
					Rear	19		1.16	0.66
						270		1.26	0.80
	n258	Mid Ch. 2025833 (24800.04 MHz)	J	Patch	Right	12	60	0.58	0.31
						270		1.47	0.96
					Rear	12		0.72	0.40
						270		1.68	1.16
					Top	16		0.39	0.21
conditon	Band	Channel	Module	Type(P or D)	Side	Beam ID	PLS (10 dBm)	Sim. PD (mW/cm2)	Meas. PD (mW/cm2) * Circle Avg
Folder Open	n261	Mid Ch. 2077915 (27924.96 MHz)	J	Patch	Right	19	60	1.16	0.52
						269		1.68	1.12
					Rear	18		1.42	0.61
						271		1.84	1.33
	n260	Mid Ch. 2254165 (38499.96 MHz)	J	Patch	Right	19	60	1.03	0.62
						270		1.23	0.73
					Rear	19		1.04	0.66
						270		1.30	0.79
	n258	Mid Ch. 2025833 (24800.04 MHz)	J	Patch	Right	12	60	0.63	0.38
						270		1.46	1.01
					Rear	16		0.75	0.27
						270		1.67	1.17
					Front	12		0.64	0.32
					Top	16		0.53	0.24

[Folder Closed Status]

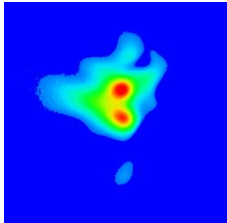
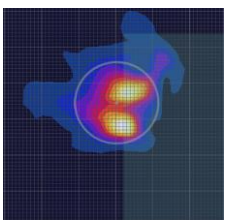
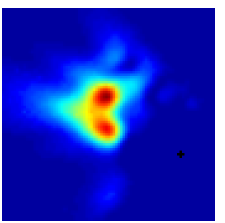
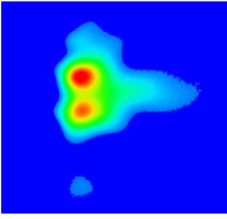
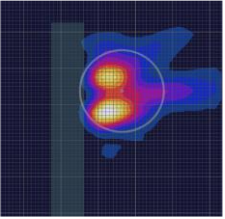
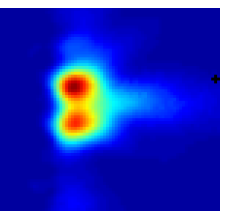
- Table 2-1, n261 ANT J-Patch: Mid Channel, Beam ID 19 for selected surfaces

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

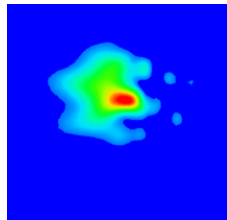
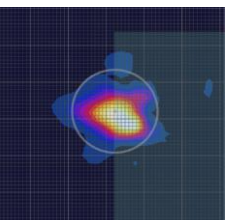
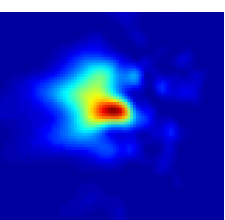
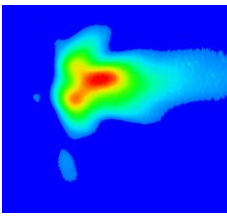
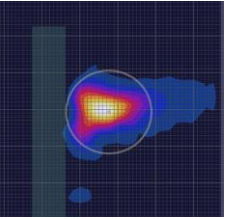
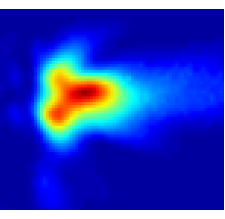
- Table 2-2, n261 ANT J-Patch: Mid Channel, Beam ID 271 for selected surfaces

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

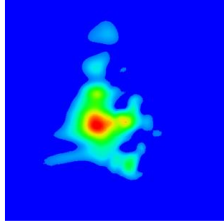
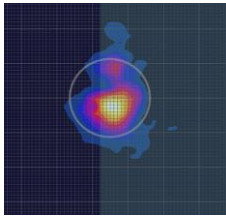
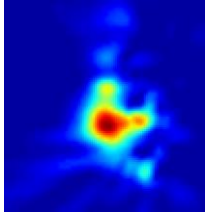
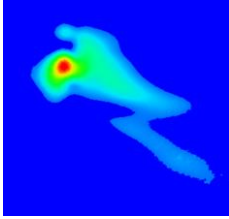
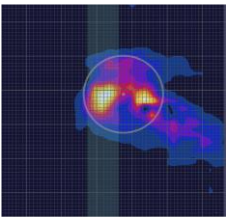
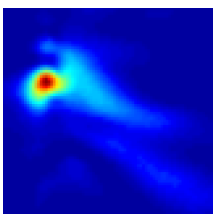
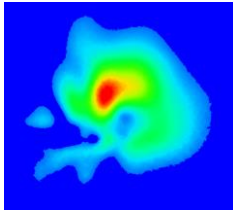
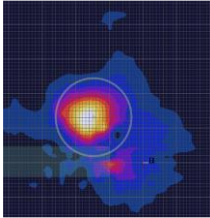
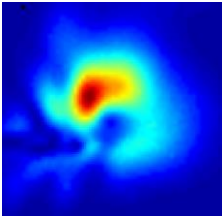
- Table 2-3, n260 ANT J-Patch: Mid Channel, Beam ID 19 for selected surfaces

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

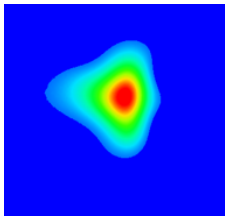
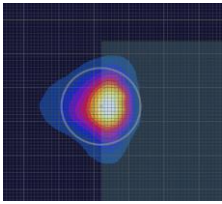
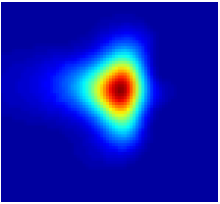
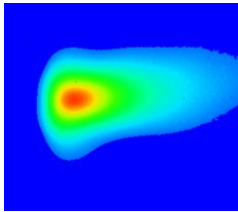
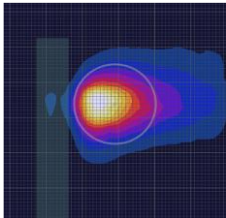
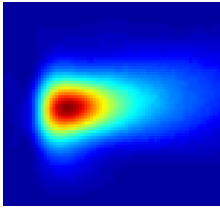
- Table 2-4, n260 ANT J-Patch: Mid Channel, Beam ID 270 for selected surfaces

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

- Table 2-5, n258 ANT J-Patch: Mid Channel, Beam ID 12, 16 for selected surfaces

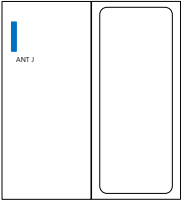
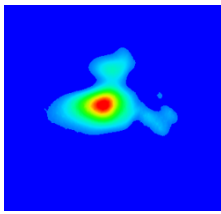
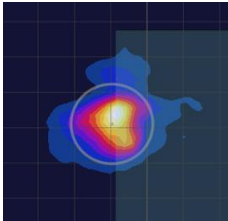
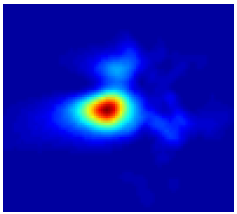
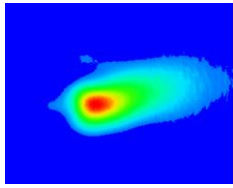
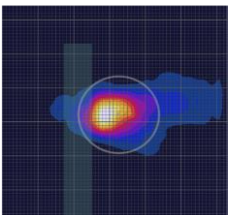
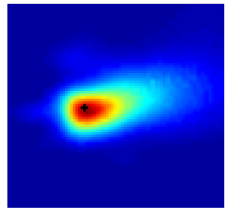
Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
12	S2 (Rear)				
	S4 (Right)				
16	S5 (Top)				

- Table 2-6, n258 ANT J-Patch: Mid Channel, Beam ID 270 for selected surfaces

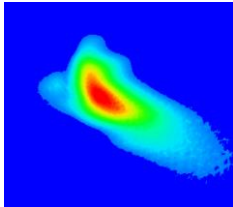
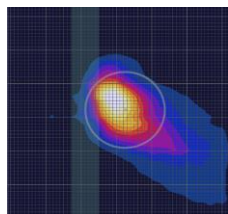
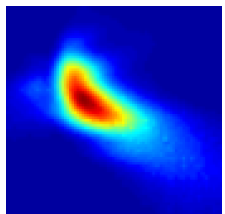
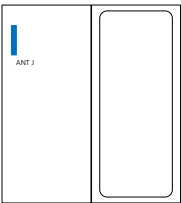
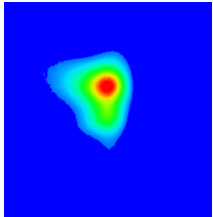
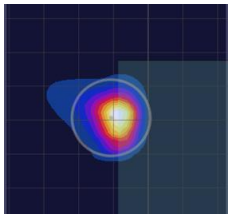
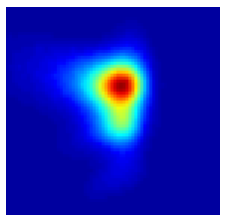
Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
270	S2 (Rear)				
	S4 (Right)				

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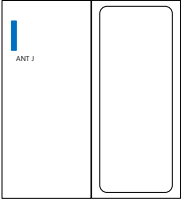
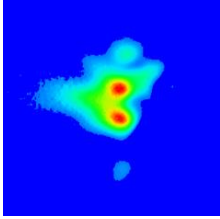
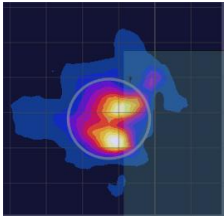
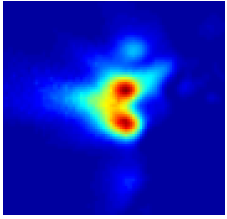
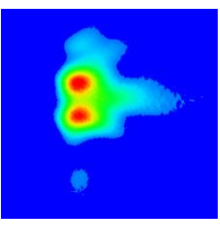
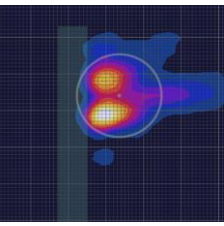
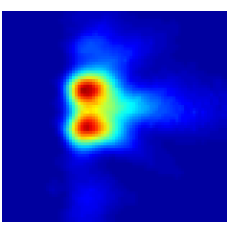
- Table 2-7, n261 ANT J-Patch: Mid Channel, Beam ID 18, 19 for selected surfaces

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

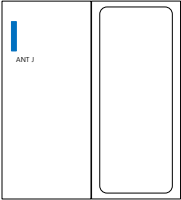
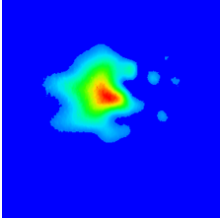
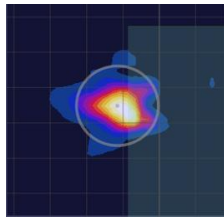
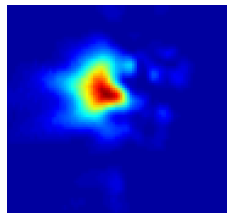
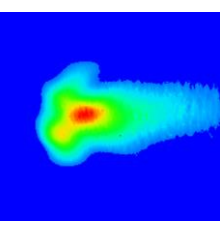
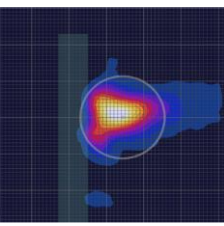
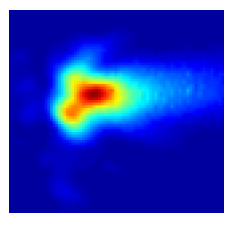
- Table 2-8, n261 ANT J-Patch: Mid Channel, Beam ID 269, 271 for selected surfaces

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

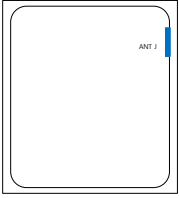
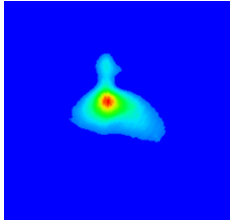
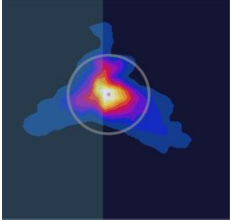
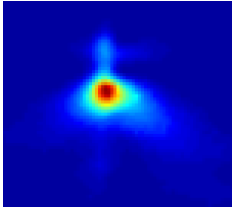
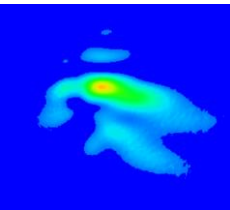
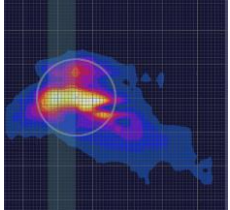
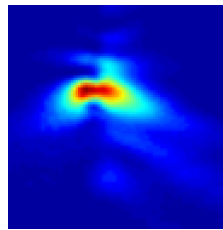
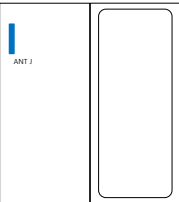
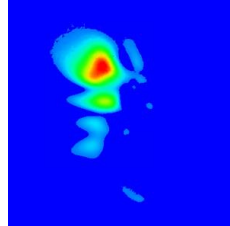
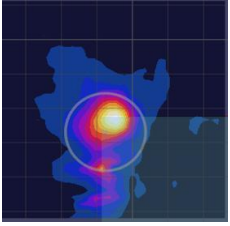
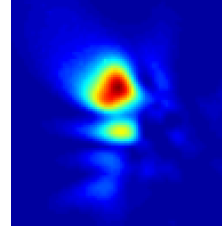
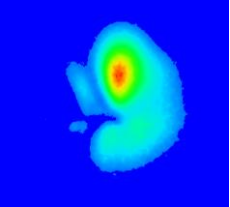
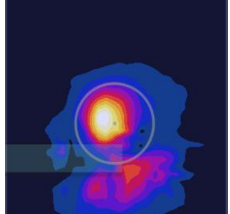
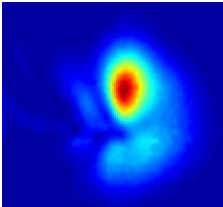
- Table 2-9, n260 ANT J-Patch: Mid Channel, Beam ID 19 for selected surfaces

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

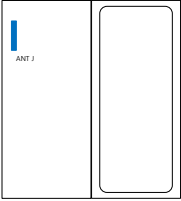
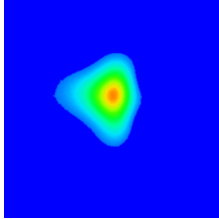
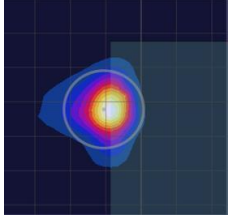
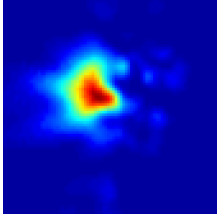
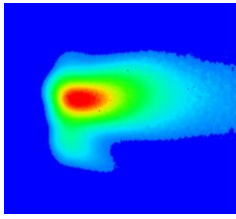
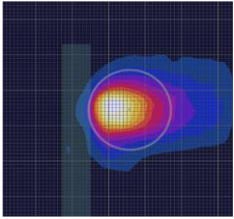
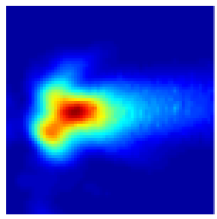
- Table 2-10, n260 ANT J-Patch: Mid Channel, Beam ID 270 for selected surfaces

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

● Table 2-11, n258 ANT J-Patch: Mid Channel, Beam ID 12, 16 for selected surfaces

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
12	S1 (Front)				
	S4 (Right)				
16	S2 (Rear)				
	S5 (Top)				

- Table 2-12, n258 ANT J-Patch: Mid Channel, Beam ID 270 for selected surfaces

Beam ID	Surface	View	Simulated PD	Measured PD	Print out from Qualcomm IPLG Script
270	S2 (Rear)				
	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 wer verified.

This model take “GEN2_SUB6” mode, thus, only verificatgion 1 is required.

3 Simulation results

This section shows the PD simulation results of Ant J at 24GHz, 28GHz and 39GHz for each evaluation plane specified in Table 3 at two separation distances of 2mm and 10mm for open condition and for closed conditions. The ratio of PD exposure from front surface to the worst surface at 2mm, and the ratio of PD exposure from 2mm to 10mm (open and closed) 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.

[illegible]

- High CH

No.	Model	Type	Basin 1, 1	Basin 2, 2	Basin 3, 3	Total	Area (Plan) (m ²)					max rates out of all basins										max rates out of all basins																																																																																																																																																																																																																																
							50mm	150mm	250mm	375mm	500mm	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput surface runoff	Left Throughput surface runoff	Right Throughput 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- Low CH

[illegible]

- Table 3-2, PD of Ant J – patch antenna (28GHz – n261)

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- Low CH

[illegible]

- Mid CH

[illegible]

- High CH

[illegible]

[Folder Closed Status]

- Low CH

[illegible]

- Mid CH

[illegible]

- High CH

[illegible]

- Low CH

No.	Module	Type	Exam ID-1	Exam ID-2	Find out	Aerial (Horizontal)										max rate out of all beams										max rate out of all beams										Aerial (Horizontal) or 3D view (vertical distance)										max rate out of all beams																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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deg	715deg	716deg	717deg	718deg	719deg	720deg	721deg	722deg	723deg	724deg	725deg	726deg	727deg	728deg	729deg	730deg	731deg	732deg	733deg	734deg	735deg	736deg	737deg	738deg	739deg	740deg	741deg	742deg	743deg	744deg	745deg	746deg	747deg	748deg	749deg	750deg	751deg	752deg	753deg	754deg	755deg	756deg	757deg	758deg	759deg	760deg	761deg	762deg	763deg	764deg	765deg	766deg	767deg	768deg	769deg	770deg	771deg	772deg	773deg	774deg	775deg	776deg	777deg	778deg	779deg	780deg	781deg	782deg	783deg	784deg	785deg	786deg	787deg	788deg	789deg	790deg	791deg	792deg	793deg	794deg	795deg	796deg	797deg	798deg	799deg	800deg	801deg	802deg	803deg	804deg	805deg	806deg	807deg	808deg	809deg	810deg	811deg	812deg	813deg	814deg	815deg	816deg	817deg	818deg	819deg	820deg	821deg	822deg	823deg	824deg	825deg	826deg	827deg	828deg	829deg	830deg	831deg	832deg	833deg	834deg	835deg	836deg	837deg	838deg	839deg	840deg	841deg	842deg	843deg	844deg	845deg	846deg	847deg	848deg	849deg	850deg	851deg	852deg	853deg	854deg	855deg	856deg	857deg	858deg	859deg	860deg	861deg	862deg	863deg	864deg	865deg	866deg	867deg	868deg	869deg	870deg	871deg	872deg	873deg	874deg	875deg	876deg	877deg	878deg	879deg	880deg	881deg	882deg	883deg	884deg	885deg	886deg	887deg	888deg	889deg	890deg	891deg	892deg	893deg	894deg	895deg	896deg	897deg	898deg	899deg	900deg	901deg	902deg	903deg	904deg	905deg	906deg	907deg	908deg	909deg	910deg	911deg	912deg	913deg	914deg	915deg	916deg	917deg	918deg	919deg	920deg	921deg	922deg	923deg	924deg	925deg	926deg	927deg	928deg	929deg	930deg	931deg	932deg	933deg	934deg	935deg	936deg	937deg	938deg	939deg	940deg	941deg	942deg	943deg	944deg	945deg	946deg	947deg	948deg	949deg	950deg	951deg	952deg	953deg	954deg	955deg	956deg	957deg	958deg	959deg	960deg	961deg	962deg	963deg	964deg	965deg	966deg	967deg	968deg	969deg	970deg	971deg	972deg	973deg	974deg	975deg	976deg	977deg	978deg	979deg	980deg	981deg	982deg	983deg	984deg	985deg	986deg	987deg	988deg	989deg	990deg	991deg	992deg	993deg	994deg

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