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Part 0 Power Density Report
Power Density Characterization

Revision A

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SAMSUNG ELECTRONICS

Power Density Characterization

1 Exposure Scenarios

At frequencies > 6 GHz, the total peak spatial averaged power density (psPD) is required to be assessed for all antenna configurations (beams) from all mmW antenna modules installed inside the device. This device has 2 patch antenna arrays (K Patch, L Patch).

As showed in Figure 1, the surfaces near-by each mmW antenna module for PD characterization are identified and listed in Table 1.

Table 1
Evaluation Surfaces for PD Characterization

Band/Mode	Antenna Module	Back	Front	Top	Bottom	Right	Left
NR n261	**K**	Yes	Yes	No	No	No	Yes
NR n261	**L**	Yes	Yes	No	No	Yes	No
NR n260	**K**	Yes	Yes	No	No	No	Yes
NR n260	**L**	Yes	Yes	No	No	Yes	No

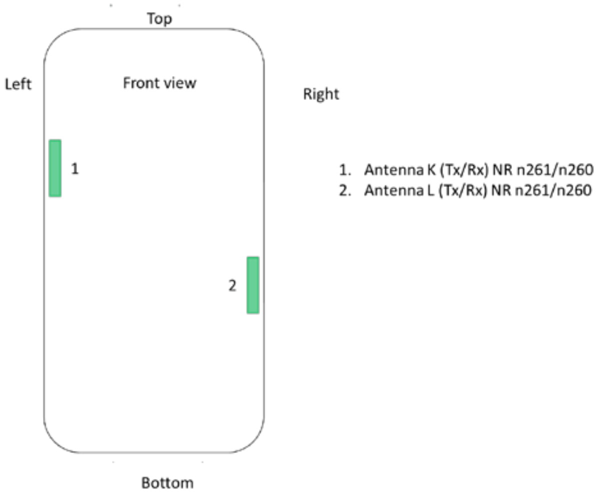

Figure 1: Location of mmW antenna modules looking from front of the DUT

2 Power Density Characterization Method

Simulation modeling and validation

- Correlate the simulated PD distributions with measured PD distribution for the selected beams to validate simulation model

↓

Uncertainty Budget

- Calculate the total device design uncertainty to include worst case RF tune-up accuracy and device-to-device variation

↓

PD_design_target

Specify a power density design target, which should be less than power density regulatory limit to account for the total device design uncertainties

↓

Worst-case housing material Influence Quantification

- Determine

Δ_{min} = *min{simulated PD@reference_power – measured PD@reference_power}*

to quantify the worst-case housing influence

↓

PD Char Generation

- Use validated simulation approach to determine input power limit for all the beams after accounting for the worst-case housing influence

3 Codebook for all supported beams

Table 2
5G mmW NR Band n261 Ant K Codebook

Band	Antenna Module	Antenna Type	Beam ID	Feed no.	Paired With
n261	K	Patch	2	1	130
n261	K	Patch	3	1	131
n261	K	Patch	4	1	132
n261	K	Patch	8	2	136
n261	K	Patch	9	2	137
n261	K	Patch	10	2	138
n261	K	Patch	13	2	141
n261	K	Patch	14	2	142
n261	K	Patch	20	5	148
n261	K	Patch	21	5	149
n261	K	Patch	22	5	150
n261	K	Patch	23	5	151
n261	K	Patch	24	5	152
n261	K	Patch	29	5	157
n261	K	Patch	30	5	158
n261	K	Patch	31	5	159
n261	K	Patch	32	5	160
n261	K	Patch	130	1	2
n261	K	Patch	131	1	3
n261	K	Patch	132	1	4
n261	K	Patch	136	2	8
n261	K	Patch	137	2	9
n261	K	Patch	138	2	10
n261	K	Patch	141	2	13
n261	K	Patch	142	2	14
n261	K	Patch	148	5	20
n261	K	Patch	149	5	21
n261	K	Patch	150	5	22
n261	K	Patch	151	5	23
n261	K	Patch	152	5	24
n261	K	Patch	157	5	29
n261	K	Patch	158	5	30
n261	K	Patch	159	5	31
n261	K	Patch	160	5	32

Table 3
5G mmW NR Band n261 Ant L Codebook

Band	Antenna Module	Antenna Type	Beam ID	Feed no.	Paired With
n261	L	Patch	0	1	128
n261	L	Patch	1	1	129
n261	L	Patch	5	2	133
n261	L	Patch	6	2	134
n261	L	Patch	7	2	135
n261	L	Patch	11	2	139
n261	L	Patch	12	2	140
n261	L	Patch	15	5	143
n261	L	Patch	16	5	144
n261	L	Patch	17	5	145
n261	L	Patch	18	5	146
n261	L	Patch	19	5	147
n261	L	Patch	25	5	153
n261	L	Patch	26	5	154
n261	L	Patch	27	5	155
n261	L	Patch	28	5	156
n261	L	Patch	128	1	0
n261	L	Patch	129	1	1
n261	L	Patch	133	2	5
n261	L	Patch	134	2	6
n261	L	Patch	135	2	7
n261	L	Patch	139	2	11
n261	L	Patch	140	2	12
n261	L	Patch	143	5	15
n261	L	Patch	144	5	16
n261	L	Patch	145	5	17
n261	L	Patch	146	5	18
n261	L	Patch	147	5	19
n261	L	Patch	153	5	25
n261	L	Patch	154	5	26
n261	L	Patch	155	5	27
n261	L	Patch	156	5	28

Table 4
5G mmW NR Band n260 Ant K Codebook

Band	Antenna Module	Antenna Type	Beam ID	Feed no.	Paired With
n260	K	Patch	3	1	131
n260	K	Patch	4	1	132
n260	K	Patch	5	1	133
n260	K	Patch	9	2	137
n260	K	Patch	10	2	138
n260	K	Patch	11	2	139
n260	K	Patch	14	2	142
n260	K	Patch	15	2	143
n260	K	Patch	21	5	149
n260	K	Patch	22	5	150
n260	K	Patch	23	5	151
n260	K	Patch	24	5	152
n260	K	Patch	25	5	153
n260	K	Patch	30	5	158
n260	K	Patch	31	5	159
n260	K	Patch	32	5	160
n260	K	Patch	33	5	161
n260	K	Patch	131	1	3
n260	K	Patch	132	1	4
n260	K	Patch	133	1	5
n260	K	Patch	137	2	9
n260	K	Patch	138	2	10
n260	K	Patch	139	2	11
n260	K	Patch	142	2	14
n260	K	Patch	143	2	15
n260	K	Patch	149	5	21
n260	K	Patch	150	5	22
n260	K	Patch	151	5	23
n260	K	Patch	152	5	24
n260	K	Patch	153	5	25
n260	K	Patch	158	5	30
n260	K	Patch	159	5	31
n260	K	Patch	160	5	32
n260	K	Patch	161	5	33

Table 5
5G mmW NR Band n260 Ant L Codebook

Band	Antenna Module	Antenna Type	Beam ID	Feed no.	Paired With
n260	L	Patch	0	1	128
n260	L	Patch	1	1	129
n260	L	Patch	2	1	130
n260	L	Patch	6	2	134
n260	L	Patch	7	2	135
n260	L	Patch	8	2	136
n260	L	Patch	12	2	140
n260	L	Patch	13	2	141
n260	L	Patch	16	5	144
n260	L	Patch	17	5	145
n260	L	Patch	18	5	146
n260	L	Patch	19	5	147
n260	L	Patch	20	5	148
n260	L	Patch	26	5	154
n260	L	Patch	27	5	155
n260	L	Patch	28	5	156
n260	L	Patch	29	5	157
n260	L	Patch	128	1	0
n260	L	Patch	129	1	1
n260	L	Patch	130	1	2
n260	L	Patch	134	2	6
n260	L	Patch	135	2	7
n260	L	Patch	136	2	8
n260	L	Patch	140	2	12
n260	L	Patch	141	2	13
n260	L	Patch	144	5	16
n260	L	Patch	145	5	17
n260	L	Patch	146	5	18
n260	L	Patch	147	5	19
n260	L	Patch	148	5	20
n260	L	Patch	154	5	26
n260	L	Patch	155	5	27
n260	L	Patch	156	5	28
n260	L	Patch	157	5	29

4 Simulation and Modeling Validation

Power density simulations of all beams and surfaces were performed. Details of these simulations and modeling validation can be found in the Power Density Simulation Report. Table below includes a summary of the validation results to support worst-case housing influence quantification in power density characterization for this model.

With an input power of 6 dBm for n261 band and 6 dBm for n260 band, PD measurements are conducted for at least one single beam per antenna module (K, L) on worst-surface(s). PD measurements are performed at mid channel of each mmW band and with CW modulation. All measured PD values are listed in table below along with corresponding simulated PD values for the same configuration.

PD value will be used to determine worst-case housing influence for conservative assessment.

Table 6

Band	Antenna	Beam ID	Surface	$4cm^2$ psPD		Delta = Simulated - Measured
				Measured	Simulated	
				(mW/cm2)		(dB)
n261	K (Patch)	21	Back	0.962	1.585	2.17
		21	Left	0.926	1.549	2.23
		150	Back	0.438	0.783	2.52
		159	Left	0.675	1.074	**2.02**
	L (Patch)	25	Back	0.889	1.649	2.68
		25	Right	0.859	1.497	2.41
		145	Back	0.423	0.762	2.56
		145	Right	0.750	1.120	**1.74**
n260	K (Patch)	31	Back	0.413	0.491	**0.75**
		33	Left	0.477	0.936	2.93
		159	Back	0.567	0.760	1.27
		159	Left	0.762	0.928	0.86
	L (Patch)	27	Back	0.516	0.800	1.90
		20	Right	0.685	1.174	2.34
		156	Back	0.723	1.136	1.96
		147	Right	0.853	1.074	**1.00**

5 *PD_design_target*

Table 7

PD_design_target	
$PD\_design\_target < PD\_regulatory\_limit \times 10^{\frac{-Total\ Uncertainty}{10}}$	
psPD over 4 cm^2 Averaging Area (mW/cm^2)	
Total Uncertainty	2.1 dB
PD_regulatory_limit	1.0 mW/cm^2
PD_design_target	0.6166 mW/cm^2

6 Δmin

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

Since the mmW antenna modules are placed at different locations, only surrounding material/housing has impact on EM field propagation, and in turn power density. Furthermore, depending on the type of antenna array, i.e., dipole antenna array or patch antenna array, the nature of EM field propagation in the near field is different. Therefore, the worst-case housing influence is determined per antenna module and per antenna type.

For this DUT, the below procedure was used to determine worst-case housing influence, Δmin:

1. Based on PD simulation, for each module and antenna type, determine one or more worst-surface(s) that has highest 4cm2 PD for all the single beams per antenna module and per antenna type in the mid channel of each band.
2. For identified worst surface(s) per antenna module and per antenna type group,
    a. First determine Δmin based on identified worst surface(s), and derive input.power.limit
    b. Then prove all other near-by surface(s), i.e., non-selected surface(s), is not required for housing material loss quantification (in other words, these

non-evaluated surfaces have no influence on the determined input.power.limit) by:

i. re-scale all simulated 4cm2 PD values to input.power.limit to identify the worst-PD beam per each non-evaluated surface

ii. Measure 4cm2 PD at input.power.limit on identified worst-PD beam per each non-evaluated surface

iii. Demonstrate all measured 4cm2 PD values are below PD_design_target

3. If any of the above surface(s) in Step (2.b.iii) have measured 4cm2 PD ≥ PD_design_target, then those surfaces must be included in the Δmin determination in Step (2.a), and re-evaluate input.power.limit with these added surfaces.

Following above procedure, based on Table 2 ~ Table 5 in Samsung PD simulation report, the worst-surface(s) having highest 4cm2 PD for all the single beams per each antenna type and each antenna module group in the mid channel of n261 and n260 bands are identified as:

a. for K patch: Back (S2) & Left (S3)

b. for L patch: Back (S2) & Right (S4)

Thus, when comparing a simulated 4cm2-averaged PD and measured 4 cm2-averaged PD for the identified worst surface(s), the worst error introduced for each antenna type and each antenna module group when using the estimated material property in the simulation is highlighted in bold numbers in Table 8. Thus, the worst-case housing influence, denoted as $\Delta_{min} = \mathrm{Sim.PD} - \mathrm{Meas.PD}$, is determined as

Table 8

Δ_{min} for Ant K, Ant L

Band	Antenna	Δmin (dB)
n261	K (Patch)	2.02
	L (Patch)	1.74
n260	K (Patch)	0.75
	L (Patch)	1.00

Δ_{min} represents the worst case where RF exposure is underestimated the most in simulation when using the estimated material property of the housing. For conservative assessment, the Δ_{min} is used as the worst-case factor and applied to all the beams in the corresponding antenna type and antenna module group to determine input power limits in PD char for compliance.

The detail input.power.limit derivation is described in Section 7.

Simulated 4cm2 PD values in Table 2 ~ Table 5 in Power Density Simulation Report are scaled to input.power.limit and are listed in Tables 9 – 12 for all single beams for all identified surfaces, when assuming the simulation is performed with correct housing influence.

Determine the worst beam for each of non-selected surface(s), i.e.,

a. for K patch: Front
b. for L patch: Front

Then perform PD measurement for all determined worst-case beams, highlighted in orange in Tables 9 – 12, on the corresponding surface. Measurement is performed in the mid channel of each band with CW modulation. The evaluation distance is at 2 mm.

The test results in Table 13 shows that the all measured 4cm2 PD values are less than PD_design_target of 0.6166 mW/cm2, thus, the non-selected surfaces have no influence on the determined Δ_{min} and input.power.limit in Section 7.

Table 9
n261/mid channel, K Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

Antenna	Beam ID_1	Simulated 4cm2 PD(mW/cm2) Corresponding to PD_design_target if the simulation was performed with correct No. Module Type housing material properties					
		S4(Right)	S3(Left)	S5(Top)	S6(Bottom)	S1(Front)	S2(Back)
K	2	0.003	0.527	0.022	0.002	0.022	0.603
K	3	0.002	0.582	0.039	0.000	0.035	0.617
K	4	0.003	0.569	0.038	0.000	0.035	0.617
K	8	0.004	0.577	0.060	0.001	0.047	0.600
K	9	0.002	0.593	0.013	0.001	0.032	0.616
K	10	0.003	0.535	0.004	0.003	0.062	0.591
K	13	0.003	0.550	0.025	0.002	0.091	0.530
K	14	0.002	0.555	0.008	0.002	0.034	0.617
K	20	0.003	0.570	0.103	0.002	0.066	0.617
K	21	0.003	0.586	0.056	0.000	0.057	0.600
K	22	0.003	0.572	0.014	0.000	0.055	0.587
K	23	0.002	0.546	0.012	0.001	0.055	0.582
K	24	0.004	0.526	0.019	0.002	0.066	0.604
K	29	0.003	0.590	0.084	0.001	0.067	0.617
K	30	0.002	0.599	0.006	0.001	0.055	0.591
K	31	0.003	0.562	0.014	0.000	0.058	0.583
K	32	0.004	0.529	0.017	0.002	0.065	0.596
K	130	0.013	0.601	0.044	0.006	0.257	0.326
K	131	0.005	0.617	0.061	0.000	0.169	0.412
K	132	0.005	0.559	0.057	0.000	0.149	0.358
K	136	0.015	0.544	0.036	0.003	0.232	0.339
K	137	0.014	0.589	0.021	0.005	0.185	0.482
K	138	0.014	0.603	0.094	0.005	0.214	0.366
K	141	0.020	0.614	0.026	0.006	0.170	0.494
K	142	0.010	0.588	0.022	0.004	0.198	0.472
K	148	0.010	0.604	0.055	0.002	0.221	0.428
K	149	0.008	0.556	0.029	0.003	0.183	0.407
K	150	0.007	0.545	0.009	0.001	0.174	0.405
K	151	0.010	0.617	0.021	0.002	0.192	0.446
K	152	0.011	0.608	0.068	0.004	0.196	0.419
K	157	0.008	0.577	0.038	0.001	0.200	0.414
K	158	0.011	0.545	0.009	0.002	0.169	0.411
K	159	0.005	0.596	0.014	0.001	0.180	0.425
K	160	0.013	0.617	0.035	0.003	0.210	0.441

Table 10

n261/mid channel, L Patch simulated 4cm2 PD at PD_Design_Target

(if simulation performed with correct housing material properties) (Δmin)

Antenna	Beam ID_1	Simulated 4cm2 PD(mW/cm2) Corresponding to PD_design_target if the simulation was performed with correct No. Module Type housing material properties					
		S4(Right)	S3(Left)	S5(Top)	S6(Bottom)	S1(Front)	S2(Back)
L	0	0.471	0.003	0.003	0.008	0.023	0.601
L	1	0.518	0.002	0.002	0.011	0.029	0.617
L	5	0.555	0.004	0.002	0.014	0.042	0.617
L	6	0.462	0.005	0.002	0.001	0.031	0.534
L	7	0.420	0.006	0.007	0.007	0.041	0.519
L	11	0.503	0.006	0.001	0.005	0.033	0.568
L	12	0.519	0.002	0.002	0.003	0.039	0.617
L	15	0.541	0.007	0.001	0.027	0.061	0.617
L	16	0.563	0.005	0.000	0.003	0.044	0.610
L	17	0.567	0.004	0.000	0.003	0.042	0.600
L	18	0.531	0.003	0.000	0.002	0.044	0.593
L	19	0.465	0.004	0.005	0.004	0.052	0.586
L	25	0.560	0.004	0.001	0.013	0.055	0.617
L	26	0.570	0.004	0.000	0.003	0.041	0.605
L	27	0.553	0.003	0.001	0.002	0.044	0.595
L	28	0.511	0.004	0.001	0.002	0.051	0.597
L	128	0.588	0.025	0.011	0.011	0.195	0.333
L	129	0.572	0.011	0.004	0.015	0.161	0.374
L	133	0.549	0.016	0.003	0.012	0.191	0.340
L	134	0.617	0.026	0.003	0.005	0.217	0.420
L	135	0.617	0.017	0.013	0.005	0.218	0.391
L	139	0.603	0.031	0.007	0.011	0.223	0.376
L	140	0.617	0.021	0.005	0.003	0.208	0.427
L	143	0.487	0.014	0.003	0.019	0.167	0.343
L	144	0.470	0.024	0.002	0.008	0.188	0.300
L	145	0.617	0.028	0.001	0.002	0.256	0.420
L	146	0.569	0.025	0.002	0.004	0.217	0.362
L	147	0.592	0.023	0.006	0.004	0.181	0.404
L	153	0.470	0.016	0.003	0.012	0.172	0.316
L	154	0.558	0.029	0.002	0.005	0.230	0.370
L	155	0.617	0.030	0.001	0.002	0.251	0.417
L	156	0.533	0.024	0.003	0.004	0.185	0.342

Table 11
n260/mid channel, K Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

Antenna	Beam ID_1	Simulated 4cm2 PD(mW/cm2) Corresponding to PD_design_target if the simulation was performed with correct No. Module Type housing material properties					
		S4(Right)	S3(Left)	S5(Top)	S6(Bottom)	S1(Front)	S2(Back)
K	3	0.010	0.597	0.019	0.005	0.191	0.354
K	4	0.008	0.577	0.032	0.003	0.222	0.333
K	5	0.005	0.568	0.024	0.003	0.178	0.304
K	9	0.007	0.547	0.037	0.004	0.258	0.324
K	10	0.009	0.617	0.024	0.000	0.263	0.400
K	11	0.008	0.617	0.048	0.005	0.230	0.320
K	14	0.021	0.617	0.021	0.003	0.269	0.403
K	15	0.004	0.494	0.024	0.005	0.158	0.253
K	21	0.011	0.616	0.089	0.006	0.297	0.372
K	22	0.008	0.585	0.024	0.003	0.276	0.346
K	23	0.006	0.527	0.015	0.001	0.219	0.330
K	24	0.003	0.564	0.054	0.003	0.258	0.287
K	25	0.004	0.524	0.062	0.009	0.152	0.266
K	30	0.015	0.617	0.051	0.003	0.281	0.405
K	31	0.007	0.515	0.019	0.001	0.217	0.352
K	32	0.007	0.510	0.016	0.001	0.239	0.296
K	33	0.003	0.568	0.060	0.008	0.183	0.286
K	131	0.005	0.573	0.024	0.002	0.089	0.468
K	132	0.004	0.609	0.055	0.004	0.105	0.500
K	133	0.004	0.606	0.026	0.000	0.109	0.478
K	137	0.004	0.597	0.052	0.002	0.094	0.409
K	138	0.006	0.544	0.021	0.001	0.090	0.463
K	139	0.004	0.617	0.029	0.007	0.113	0.444
K	142	0.005	0.576	0.028	0.002	0.112	0.478
K	143	0.003	0.617	0.024	0.005	0.135	0.379
K	149	0.005	0.528	0.062	0.005	0.076	0.458
K	150	0.004	0.560	0.025	0.001	0.090	0.480
K	151	0.004	0.588	0.029	0.002	0.131	0.478
K	152	0.004	0.601	0.062	0.003	0.138	0.452
K	153	0.004	0.611	0.090	0.007	0.112	0.462
K	158	0.005	0.542	0.046	0.004	0.079	0.474
K	159	0.004	0.581	0.013	0.001	0.116	0.476
K	160	0.004	0.617	0.047	0.004	0.152	0.493
K	161	0.004	0.617	0.088	0.003	0.125	0.432

Table 12
n260/mid channel, L Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

Antenna	Beam ID_1	Simulated 4cm2 PD(mW/cm2) Corresponding to PD_design_target if the simulation was performed with correct No. Module Type housing material properties					
		S4(Right)	S3(Left)	S5(Top)	S6(Bottom)	S1(Front)	S2(Back)
L	0	0.617	0.005	0.005	0.002	0.199	0.395
L	1	0.617	0.004	0.004	0.004	0.202	0.405
L	2	0.585	0.005	0.003	0.010	0.191	0.400
L	6	0.606	0.005	0.005	0.008	0.247	0.415
L	7	0.583	0.010	0.001	0.003	0.235	0.401
L	8	0.617	0.003	0.007	0.007	0.188	0.382
L	12	0.617	0.007	0.003	0.001	0.250	0.405
L	13	0.617	0.004	0.006	0.004	0.240	0.358
L	16	0.601	0.006	0.012	0.023	0.285	0.368
L	17	0.564	0.011	0.002	0.004	0.255	0.426
L	18	0.602	0.015	0.001	0.004	0.264	0.410
L	19	0.582	0.009	0.002	0.005	0.262	0.389
L	20	0.602	0.003	0.012	0.025	0.217	0.326
L	26	0.563	0.007	0.003	0.005	0.289	0.415
L	27	0.617	0.016	0.001	0.004	0.283	0.432
L	28	0.571	0.013	0.001	0.003	0.243	0.390
L	29	0.597	0.005	0.004	0.016	0.243	0.365
L	128	0.617	0.005	0.003	0.005	0.073	0.606
L	129	0.601	0.005	0.003	0.008	0.067	0.598
L	130	0.617	0.003	0.003	0.010	0.100	0.593
L	134	0.584	0.007	0.004	0.009	0.094	0.567
L	135	0.589	0.007	0.001	0.003	0.094	0.617
L	136	0.617	0.003	0.005	0.014	0.087	0.595
L	140	0.599	0.008	0.001	0.005	0.116	0.602
L	141	0.586	0.006	0.005	0.006	0.078	0.587
L	144	0.547	0.007	0.011	0.028	0.127	0.527
L	145	0.617	0.006	0.001	0.007	0.094	0.617
L	146	0.567	0.011	0.001	0.006	0.063	0.586
L	147	0.583	0.004	0.002	0.002	0.097	0.617
L	148	0.490	0.004	0.008	0.019	0.093	0.440
L	154	0.617	0.007	0.003	0.006	0.086	0.594
L	155	0.571	0.007	0.001	0.004	0.082	0.570

Table 13
4cm2 PD of the selected beams measured on the corresponding surfaces that are not selected for Δmin determination

Band	Antenna	Beam ID	Surface	Tested Power Level (dBm)	input.power.limit (dBm)	Meas. 4cm^2 PD (mW/cm^2)
n261	K (Patch)	130	Front	12.2	10.7	0.246
	L (Patch)	145	Front	4.5	4.0	0.293
n260	K (Patch)	21	Front	5.6	4.1	0.226
	L (Patch)	26	Front	4.2	3.7	0.244

7 PD Char

7.1 Single Beams

To determine the input power limit at each antenna port, simulation was performed at low, mid, and high channel for each mmW band supported, with 6 dBm input power per active port for n261 band and 6 dBm input power per active port for n260 band:

1. Obtained PDsurface value (the worst PD among all identified surfaces of the DUT) at all three channels for all single beams specified in the codebook.
2. Derived a scaling factor at low, mid and high channel, $s(i)_{low\_or\_mid\_or\_high}$, by:

$$s(i)_{low\_or\_mid\_or\_high} = \frac{PD\ design\ target}{sim.PD_{surface}(i)},\ i \in single\ beams \qquad (1)$$

3. Determined the worst-case scaling factor, $\boldsymbol{s(i)}$, among low, mid and high channels:

$$\boldsymbol{s(i)} = min\{s_{low}(i), s_{mid}(i), s_{high}(i)\},\ i \in single\ beams \qquad (2)$$

and this scaling factor applies to the input power at each antenna port.

For 2nd generation of Smart Transmit, "Qualcomm MG Script" prints the $sim.power_{limit}$ for all three channels, denoted as $sim.power_{limit\_}L$, $sim.power_{limit\_}M$, and $sim.power_{limit\_}H$. The $sim.power_{limit}$ is determined by:

$$sim.power_{limit} = min\{sim.power_{limit\_}L, sim.power_{limit\_}M, sim.power_{limit\_H}\}$$

7.2 Beam Pairs

Per the manufacturer, the relative phase between beam pair is not controlled in the chipset design and could vary from run to run. Therefore, for each beam pair, based on the simulation results, the worst-case scaling factor was determined mathematically to ensure the compliance. The worst-case PD for MIMO operations was found by sweeping the relative phase for all possible angles to ensure a conservative assessment. The power density simulation report contains the worst-case power density for each surface after sweeping through all relative phases between beams.

Once the power density was determined for the worst-case ∅, the scaling factor was obtained by the below equation for low, mid and high channels:

$$s(i)_{low\_or\_mid\_or\_high} = \frac{PD\ design\ target}{total\ PD\ (\emptyset(i)_{worstcase})}, i \in beam\ pairs \qquad (3)$$

The $total\ PD\ (\emptyset_{worstcase})$ varies with channel and beam pair, the lowest scaling factor among all three channels, $s(i)$, is determined for the beam pair i:

$$\boldsymbol{s(i)} = min\{s_{low}(i), s_{mid}(i), s_{high}(i)\},\ i \in beam\ pairs \qquad (4)$$

For 2nd generation of Smart Transmit, "Qualcomm MG Script" prints the $sim.power_{limit}$ for all three channels, denoted as $sim.power_{limit\_}L$, $sim.power_{limit\_}M$, and $sim.power_{limit\_}H$. The $sim.power_{limit}$ is determined by:

$$sim.power_{limit} = min\{sim.power_{limit\_}L, sim.power_{limit\_}M, sim.power_{limit\_H}\}$$

7.3 *Input.Power.Limit* Calculations

The PD Char specifies the limit of input power at antenna port that corresponds to PD_design_target for all the beams.

Ideally, if there is no uncertainty associated with hardware design, the input power limit, denoted as $input.power.limit(i)$, for beam i can be obtained after accounting for the housing influence (Δ_{min}) determined in Table 8, given by:

- For n260 and n261

$$input.power.limit(i) = sim.power_{limit} + 10 * \log\big(s(i)\big) + \Delta_{min},\ i \in all\ beams \quad (5)$$

where $6\ dBm$ is the input power used in simulation for n261 and n260, respectively; $s(i)$ is the scaling factor obtained from Eq. (2) or Eq. (4) for beam i; Δ_{min} is the worst-case housing influence factor (determined in Table 10) for beam i.

If simulation overestimates the housing influence, then Δ_{min} (= simulated PD – measured PD) is negative, which means that the measured PD would be higher than the simulated PD. The input power to antenna elements determined via simulation must be decreased for compliance.

Similarly, if simulation underestimates the loss, then Δ_{min} is positive (measured PD would be lower than the simulated value). Input power to antenna elements determined via simulation can be increased and still be PD compliant.

In reality the hardware design has uncertainty which must be properly considered. The device design related uncertainty is embedded in the process of Δ_{min} determination. Since the device uncertainty is already accounted for in PD_design_target, it needs to be removed to avoid double counting this uncertainty.

Thus, Equation 5 is modified to:

If -TxAGC uncertainty < Δmin < TxAGC uncertainty,

$$input.power.limit(i) = sim.power_{limit}(\mathrm{i}),\ i \in all\ beams, \text{ for n260 and n261} \quad (6)$$

else if Δmin < -TxAGC uncertainty,

$$input.power.limit(i) = sim.power_{limit}(\mathrm{i}) + (\Delta_{min} + \mathrm{TxAGC\ uncertainty}),$$
$$i \in all\ beams, \text{ for n260 and n261} \quad (7)$$

else if Δmin > TxAGC uncertainty,

$$input.power.limit(i) = sim.power_{limit}(\mathrm{i}) + (\Delta_{min} - \mathrm{TxAGC\ uncertainty}),$$
$$i \in all\ beams, \text{ for n260 and n261} \quad (8)$$

Following above logic, the input.power.limit for this DUT can be calculated using Equations (6), (7), and (8), i.e.,

Table 14
***input.power.limit* Calculation**

Band	Antenna	Δmin (dB)	TxAGC Uncertainty (dB)	*input.power.limit* (dBm)	Notes
n261	K (Patch)	2.02	0.5	*input.power.limit(i) = sim.power_limit + 1.52*	Using Eq.8
	L (Patch)	1.74	0.5	*input.power.limit(i) = sim.power_limit + 1.24*	Using Eq.8
n260	K (Patch)	0.75	0.5	*input.power.limit(i) = sim.power_limit + 0.25*	Using Eq.8
	L (Patch)	1.00	0.5	*input.power.limit(i) = sim.power_limit + 0.5*	Using Eq.8

Table 15
Permanent backoff applied to calculated input.power.limit

Band	Antenna	backoff (dB)
n261	K	1.5
n260	K	1.5
n261	L	0.5
n260	L	0.5

Note: The above backoff values have been permanently applied to the input.power.limits calculated from the equations from table 14. The final input.power.limits implemented in the EFS are in the tables below.

Table 16

5G NR n261 K Patch *input.power.limit*

Band	Beam ID 1	Beam ID 2	input.power.limit
n261	2	-	8.1
n261	3	-	8.6
n261	4	-	9.7
n261	8	-	5.7
n261	9	-	4.7
n261	10	-	5.7
n261	13	-	7.7
n261	14	-	4.9
n261	20	-	2.4
n261	21	-	1.5
n261	22	-	2.3
n261	23	-	1.7
n261	24	-	2.5
n261	29	-	1.8
n261	30	-	2.0
n261	31	-	2.1
n261	32	-	2.3
n261	-	130	10.7
n261	-	131	9.8
n261	-	132	9.9
n261	-	136	7.9
n261	-	137	9.4
n261	-	138	8.2
n261	-	141	10.3
n261	-	142	8.9
n261	-	148	4.6
n261	-	149	3.8
n261	-	150	2.9
n261	-	151	3.6
n261	-	152	5.1
n261	-	157	4.0
n261	-	158	3.0
n261	-	159	3.2
n261	-	160	4.3
n261	2	130	6.5
n261	3	131	5.5
n261	4	132	6.8
n261	8	136	3.5
n261	9	137	3.8
n261	10	138	3.6
n261	13	141	5.4
n261	14	142	3.7
n261	20	148	-0.3
n261	21	149	-0.6
n261	22	150	-0.4
n261	23	151	-0.2
n261	24	152	0.5
n261	29	157	-0.6
n261	30	158	-0.4
n261	31	159	-0.4
n261	32	160	-0.1

Table 17

5G NR n261 L Patch *input.power.limit*

Band	Beam ID 1	Beam ID 2	input.power.limit
n261	0	-	10.7
n261	1	-	9.2
n261	5	-	6.2
n261	6	-	7.3
n261	7	-	8.2
n261	11	-	7.1
n261	12	-	5.9
n261	15	-	2.7
n261	16	-	2.4
n261	17	-	2.8
n261	18	-	2.5
n261	19	-	2.7
n261	25	-	2.3
n261	26	-	2.6
n261	27	-	2.7
n261	28	-	2.5
n261	-	128	12.1
n261	-	129	12.3
n261	-	133	8.8
n261	-	134	8.9
n261	-	135	8.6
n261	-	139	10.0
n261	-	140	8.4
n261	-	143	5.5
n261	-	144	4.7
n261	-	145	4.0
n261	-	146	4.7
n261	-	147	4.8
n261	-	153	5.2
n261	-	154	4.6
n261	-	155	4.3
n261	-	156	4.6
n261	0	128	8.7
n261	1	129	7.6
n261	5	133	4.1
n261	6	134	5.4
n261	7	135	5.9
n261	11	139	5.4
n261	12	140	4.3
n261	15	143	0.5
n261	16	144	0.2
n261	17	145	0.4
n261	18	146	0.7
n261	19	147	0.5
n261	25	153	0.2
n261	26	154	0.4
n261	27	155	0.5
n261	28	156	0.5

Table 18

5G NR n260 K Patch *input.power.limit*

Band	Beam ID 1	Beam ID 2	input.power.limit
n260	3	-	11.5
n260	4	-	8.9
n260	5	-	9.0
n260	9	-	7.2
n260	10	-	9.6
n260	11	-	6.9
n260	14	-	10.1
n260	15	-	5.4
n260	21	-	4.1
n260	22	-	3.7
n260	23	-	3.4
n260	24	-	3.1
n260	25	-	2.4
n260	30	-	4.2
n260	31	-	3.3
n260	32	-	3.4
n260	33	-	2.5
n260	-	131	8.5
n260	-	132	10.6
n260	-	133	10.3
n260	-	137	7.3
n260	-	138	6.2
n260	-	139	6.0
n260	-	142	6.7
n260	-	143	5.0
n260	-	149	3.7
n260	-	150	3.3
n260	-	151	3.4
n260	-	152	3.5
n260	-	153	4.2
n260	-	158	3.7
n260	-	159	2.7
n260	-	160	3.2
n260	-	161	3.9
n260	3	131	4.9
n260	4	132	5.4
n260	5	133	5.8
n260	9	137	3.4
n260	10	138	3.7
n260	11	139	2.1
n260	14	142	4.2
n260	15	143	2.1
n260	21	149	0.2
n260	22	150	-0.1
n260	23	151	-0.5
n260	24	152	-1.5
n260	25	153	-1.8
n260	30	158	0.7
n260	31	159	-0.5
n260	32	160	-1.1
n260	33	161	-1.9

Table 19

5G NR n260 L Patch *input.power.limit*

Band	Beam ID 1	Beam ID 2	input.power.limit
n260	0	-	9.6
n260	1	-	8.9
n260	2	-	10.1
n260	6	-	6.8
n260	7	-	7.4
n260	8	-	6.5
n260	12	-	7.6
n260	13	-	6.1
n260	16	-	4.2
n260	17	-	3.8
n260	18	-	3.2
n260	19	-	3.1
n260	20	-	3.1
n260	26	-	3.7
n260	27	-	3.3
n260	28	-	3.2
n260	29	-	3.1
n260	-	128	10.0
n260	-	129	10.2
n260	-	130	11.2
n260	-	134	7.5
n260	-	135	6.4
n260	-	136	7.9
n260	-	140	7.1
n260	-	141	6.5
n260	-	144	5.9
n260	-	145	4.1
n260	-	146	3.5
n260	-	147	3.3
n260	-	148	4.0
n260	-	154	4.5
n260	-	155	3.9
n260	-	156	3.3
n260	-	157	3.5
n260	0	128	6.1
n260	1	129	5.5
n260	2	130	7.4
n260	6	134	4.4
n260	7	135	3.3
n260	8	136	3.0
n260	12	140	3.8
n260	13	141	2.2
n260	16	144	1.3
n260	17	145	0.7
n260	18	146	-0.2
n260	19	147	-1.0
n260	20	148	-1.3
n260	26	154	0.5
n260	27	155	0.5
n260	28	156	-0.4
n260	29	157	-1.1