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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 3 patch antenna arrays (J Patch, K Patch, L Patch) and 1 dipole antenna array (J Dipole).

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	Back (S2)	Front (S1)	Top (S5)	Bottom (S6)	Right (S4)	Left (S3)
5G NR Band n261	J Dipole	Yes	Yes	Yes	No	No	Yes
	J Patch	Yes	No	Yes	No	No	Yes
	K Patch	Yes	Yes	No	No	No	Yes
	L Patch	Yes	Yes	No	No	Yes	No
5G NR Band n260	J Dipole	Yes	Yes	Yes	No	No	Yes
	J Patch	Yes	No	Yes	No	No	Yes
	K Patch	Yes	Yes	No	No	No	Yes
	L Patch	Yes	Yes	No	No	Yes	No

Note: The J Patch antenna, located on the back surface, is constructed with its dedicated ground plane behind the entire patch array and can only propagate outward. Therefore, the front surface (S1) is excluded in Table 1 for the J Patch antenna.

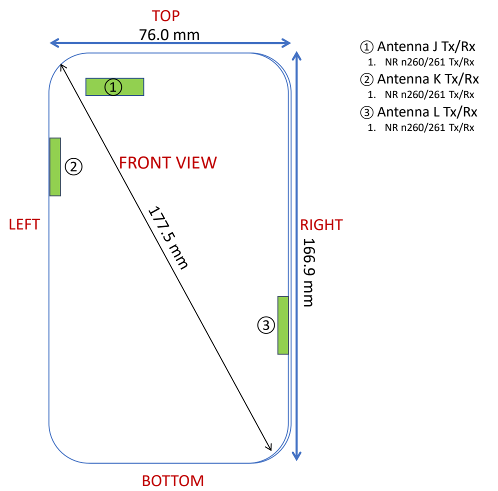

Figure 1: Location of mmW antenna modules looking from front of the DUT

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 J Codebook

Band	Beam ID	Antenna	Ant_Type	# of Antenna Feed	Paired_With
261	0	J	PATCH	1	128
261	1	J	DIPOLE	2	129
261	4	J	PATCH	2	134
261	5	J	PATCH	2	133
261	6	J	PATCH	2	132
261	7	J	DIPOLE	4	136
261	8	J	DIPOLE	4	135
261	9	J	DIPOLE	4	137
261	16	J	PATCH	2	145
261	17	J	PATCH	2	144
261	18	J	DIPOLE	4	146
261	19	J	DIPOLE	4	147
261	24	J	PATCH	4	156
261	25	J	PATCH	4	154
261	26	J	PATCH	4	153
261	27	J	PATCH	4	152
261	28	J	PATCH	4	155
261	39	J	PATCH	4	170
261	40	J	PATCH	4	169
261	41	J	PATCH	4	168
261	42	J	PATCH	4	167
261	128	J	PATCH	1	0
261	129	J	DIPOLE	2	1
261	132	J	PATCH	2	6
261	133	J	PATCH	2	5
261	134	J	PATCH	2	4
261	135	J	DIPOLE	4	8
261	136	J	DIPOLE	4	7
261	137	J	DIPOLE	4	9
261	144	J	PATCH	2	17
261	145	J	PATCH	2	16
261	146	J	DIPOLE	4	18
261	147	J	DIPOLE	4	19
261	152	J	PATCH	4	27
261	153	J	PATCH	4	26
261	154	J	PATCH	4	25
261	155	J	PATCH	4	28
261	156	J	PATCH	4	24
261	167	J	PATCH	4	42
261	168	J	PATCH	4	41
261	169	J	PATCH	4	40
261	170	J	PATCH	4	39

Table 3
5G mmW NR Band n260 Ant J Codebook

Band	Beam ID	Antenna	Ant_Type	# of Antenna Feed	Paired_With
260	0	J	PATCH	1	128
260	1	J	DIPOLE	2	129
260	4	J	PATCH	2	132
260	5	J	PATCH	2	133
260	6	J	PATCH	2	134
260	7	J	DIPOLE	4	136
260	8	J	DIPOLE	4	135
260	9	J	DIPOLE	4	137
260	16	J	PATCH	2	144
260	17	J	PATCH	2	145
260	18	J	DIPOLE	4	146
260	19	J	DIPOLE	4	147
260	24	J	PATCH	4	153
260	25	J	PATCH	4	154
260	26	J	PATCH	4	152
260	27	J	PATCH	4	155
260	28	J	PATCH	4	156
260	39	J	PATCH	4	168
260	40	J	PATCH	4	167
260	41	J	PATCH	4	169
260	42	J	PATCH	4	170
260	128	J	PATCH	1	0
260	129	J	DIPOLE	2	1
260	132	J	PATCH	2	4
260	133	J	PATCH	2	5
260	134	J	PATCH	2	6
260	135	J	DIPOLE	4	8
260	136	J	DIPOLE	4	7
260	137	J	DIPOLE	4	9
260	144	J	PATCH	2	16
260	145	J	PATCH	2	17
260	146	J	DIPOLE	4	18
260	147	J	DIPOLE	4	19
260	152	J	PATCH	4	26
260	153	J	PATCH	4	24
260	154	J	PATCH	4	25
260	155	J	PATCH	4	27
260	156	J	PATCH	4	28
260	167	J	PATCH	4	40
260	168	J	PATCH	4	39
260	169	J	PATCH	4	41
260	170	J	PATCH	4	42

Table 4
5G mmW NR Band n261 Ant K Codebook

Band	Beam ID	Antenna	Ant_Type	# of Antenna Feed	Paired_With
261	3	K	PATCH	1	131
261	13	K	PATCH	2	143
261	14	K	PATCH	2	142
261	15	K	PATCH	2	141
261	22	K	PATCH	2	151
261	23	K	PATCH	2	150
261	34	K	PATCH	4	165
261	35	K	PATCH	4	164
261	36	K	PATCH	4	163
261	37	K	PATCH	4	162
261	38	K	PATCH	4	166
261	47	K	PATCH	4	177
261	48	K	PATCH	4	176
261	49	K	PATCH	4	175
261	50	K	PATCH	4	178
261	131	K	PATCH	1	3
261	141	K	PATCH	2	15
261	142	K	PATCH	2	14
261	143	K	PATCH	2	13
261	150	K	PATCH	2	23
261	151	K	PATCH	2	22
261	162	K	PATCH	4	37
261	163	K	PATCH	4	36
261	164	K	PATCH	4	35
261	165	K	PATCH	4	34
261	166	K	PATCH	4	38
261	175	K	PATCH	4	49
261	176	K	PATCH	4	48
261	177	K	PATCH	4	47
261	178	K	PATCH	4	50

Table 5
5G mmW NR Band n260 Ant K Codebook

Band	Beam ID	Antenna	Ant_Type	# of Antenna Feed	Paired_With
260	3	K	PATCH	1	131
260	13	K	PATCH	2	141
260	14	K	PATCH	2	143
260	15	K	PATCH	2	142
260	22	K	PATCH	2	150
260	23	K	PATCH	2	151
260	34	K	PATCH	4	162
260	35	K	PATCH	4	163
260	36	K	PATCH	4	166
260	37	K	PATCH	4	165
260	38	K	PATCH	4	164
260	47	K	PATCH	4	176
260	48	K	PATCH	4	175
260	49	K	PATCH	4	178
260	50	K	PATCH	4	177
260	131	K	PATCH	1	3
260	141	K	PATCH	2	13
260	142	K	PATCH	2	15
260	143	K	PATCH	2	14
260	150	K	PATCH	2	22
260	151	K	PATCH	2	23
260	162	K	PATCH	4	34
260	163	K	PATCH	4	35
260	164	K	PATCH	4	38
260	165	K	PATCH	4	37
260	166	K	PATCH	4	36
260	175	K	PATCH	4	48
260	176	K	PATCH	4	47
260	177	K	PATCH	4	50
260	178	K	PATCH	4	49

Table 6
5G mmW NR Band n261 Ant L Codebook

Band	Beam ID	Antenna	Ant_Type	# of Antenna Feed	Paired_With
261	2	L	PATCH	1	130
261	10	L	PATCH	2	138
261	11	L	PATCH	2	139
261	12	L	PATCH	2	140
261	20	L	PATCH	2	148
261	21	L	PATCH	2	149
261	29	L	PATCH	4	157
261	30	L	PATCH	4	158
261	31	L	PATCH	4	159
261	32	L	PATCH	4	160
261	33	L	PATCH	4	161
261	43	L	PATCH	4	171
261	44	L	PATCH	4	172
261	45	L	PATCH	4	173
261	46	L	PATCH	4	174
261	130	L	PATCH	1	2
261	138	L	PATCH	2	10
261	139	L	PATCH	2	11
261	140	L	PATCH	2	12
261	148	L	PATCH	2	20
261	149	L	PATCH	2	21
261	157	L	PATCH	4	29
261	158	L	PATCH	4	30
261	159	L	PATCH	4	31
261	160	L	PATCH	4	32
261	161	L	PATCH	4	33
261	171	L	PATCH	4	43
261	172	L	PATCH	4	44
261	173	L	PATCH	4	45
261	174	L	PATCH	4	46

Table 7
5G mmW NR Band n260 Ant L Codebook

Band	Beam ID	Antenna	Ant_Type	# of Antenna Feed	Paired_With
260	2	L	PATCH	1	130
260	10	L	PATCH	2	139
260	11	L	PATCH	2	140
260	12	L	PATCH	2	138
260	20	L	PATCH	2	148
260	21	L	PATCH	2	149
260	29	L	PATCH	4	159
260	30	L	PATCH	4	158
260	31	L	PATCH	4	161
260	32	L	PATCH	4	160
260	33	L	PATCH	4	157
260	43	L	PATCH	4	172
260	44	L	PATCH	4	171
260	45	L	PATCH	4	174
260	46	L	PATCH	4	173
260	130	L	PATCH	1	2
260	138	L	PATCH	2	12
260	139	L	PATCH	2	10
260	140	L	PATCH	2	11
260	148	L	PATCH	2	20
260	149	L	PATCH	2	21
260	157	L	PATCH	4	33
260	158	L	PATCH	4	30
260	159	L	PATCH	4	29
260	160	L	PATCH	4	32
260	161	L	PATCH	4	31
260	171	L	PATCH	4	44
260	172	L	PATCH	4	43
260	173	L	PATCH	4	46
260	174	L	PATCH	4	45

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 type (dipole vs. patch) and per antenna module (J, 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 8

Band	Antenna	Beam ID	Surface	$4cm^2$ psPD		Delta = Simulated - Measured
				Measured	Simulated	
				(mW/cm2)		(dB)
n261	J (Dipole)	18	Back	0.781	1.33	**2.30**
		146	Back	0.423	1.00	3.74
	J (Patch)	25	Back	0.736	1.82	**3.93**
		156	Back	0.603	1.62	4.28
	K (Patch)	36	Back	0.542	1.30	3.81
			Left	0.669	1.26	2.73
		176	Back	0.415	1.40	5.29
			Left	0.813	1.50	**2.67**
	L (Patch)	45	Back	0.457	1.42	4.94
			Right	0.527	1.28	**3.86**
		171	Back	0.359	1.42	5.97
			Right	0.418	1.13	4.31
n260	J (Dipole)	18	Back	0.201	0.704	5.44
		136	Back	0.294	0.932	**5.01**
	J (Patch)	26	Back	0.594	1.55	**4.16**
		153	Back	0.588	1.54	4.19
	K (Patch)	49	Back	0.511	0.984	2.84
			Left	0.825	1.62	2.92
		165	Back	0.493	0.921	2.72
			Left	1.01	1.64	**2.10**
	L (Patch)	33	Back	0.432	0.871	3.05
			Right	0.659	1.52	3.62
		160	Back	0.614	1.02	2.18
			Right	1.11	1.65	**1.73**

5 *PD_design_target*

Table 9

PD_design_target	
$PD\_design\_target < PD\_regulatory\_limit \times 10^{\frac{-Total\ Uncertainty}{10}}$	
psPD over 4 cm² Averaging Area (mW/cm²)	
Total Uncertainty	2.1 dB
PD_regulatory_limit	1.0 mW/cm²
PD_design_target	0.6166 mW/cm²

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 7 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 J dipole: Back (S2)

b. for J patch: Back (S2)

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

d. 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 10
Δ_{min} for Ant J, Ant K and Ant L

Band	Antenna	Δmin (dB)
n261	J (Dipole)	2.30
	J (Patch)	3.93
	K (Patch)	2.67
	L (Patch)	3.86
n260	J (Dipole)	5.01
	J (Patch)	4.16
	K (Patch)	2.10
	L (Patch)	1.73

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 7 in Power Density Simulation Report are scaled to input.power.limit and are listed in Tables 11 – 18 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 J dipole: Left (S3), Top (S5), Front (S1)

b. for J patch: Left (S3), Top (S5)

c. for K patch: Front (S1)

d. for L patch: Front (S1)

Then perform PD measurement for all determined worst-case beams, highlighted in orange in Tables 11 – 18, 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 19 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 11
n261/mid channel, J Dipole simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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			
			S3(Left)	S5(Top)	S1(Front)	S2(Back)
1	J-D	1	0.090	0.190	0.032	0.617
2		7	0.108	0.234	0.017	0.617
3		8	0.130	0.226	0.036	0.617
4		9	0.147	0.279	0.072	0.617
5		18	0.093	0.238	0.012	0.614
6		19	0.142	0.216	0.052	0.617
7		129	0.036	0.034	0.007	0.452
8		135	0.077	0.288	0.046	0.518
9		136	0.033	0.359	0.012	0.584
10		137	0.092	0.354	0.041	0.550
11		146	0.030	0.328	0.018	0.570
12		147	0.171	0.338	0.037	0.528

Please note the above scaled simulation values correspond to PD_design_target if the simulation was performed with correct housing material properties.

Table 12
n261/mid channel J Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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		
			S3(Left)	S5(Top)	S2(Back)
19	J-P	0	0.129	0.070	0.566
20		4	0.086	0.055	0.596
21		5	0.010	0.049	0.596
22		6	0.066	0.052	0.616
23		16	0.100	0.053	0.617
24		17	0.034	0.052	0.609
25		24	0.199	0.085	0.599
26		25	0.031	0.050	0.594
27		26	0.014	0.067	0.600
28		27	0.045	0.037	0.600
29		28	0.070	0.043	0.607
30		39	0.135	0.089	0.595
31		40	0.015	0.067	0.592
32		41	0.019	0.051	0.589
33		42	0.049	0.040	0.605
34		128	0.049	0.046	0.617
35		132	0.055	0.084	0.605
36		133	0.016	0.046	0.595
37		134	0.059	0.033	0.595
38		144	0.021	0.031	0.603
39		145	0.042	0.043	0.588
40		152	0.043	0.021	0.567
41		153	0.027	0.041	0.595
42		154	0.062	0.054	0.588
43		155	0.064	0.041	0.590
44		156	0.165	0.049	0.617
45		167	0.041	0.043	0.582
46		168	0.024	0.041	0.599
47		169	0.045	0.049	0.574
48		170	0.106	0.042	0.610

Table 13
n261/mid channel, L Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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)	S1(Front)	S2(Back)
64	L	2	0.484	0.032	0.588
65		10	0.617	0.084	0.605
66		11	0.605	0.065	0.589
67		12	0.611	0.052	0.617
68		20	0.565	0.066	0.504
69		21	0.585	0.050	0.617
70		29	0.617	0.099	0.602
71		30	0.602	0.091	0.581
72		31	0.569	0.039	0.595
73		32	0.506	0.027	0.617
74		33	0.484	0.047	0.606
75		43	0.617	0.101	0.587
76		44	0.617	0.064	0.601
77		45	0.555	0.043	0.617
78		46	0.477	0.023	0.612
79		130	0.617	0.063	0.572
80		138	0.464	0.041	0.613
81		139	0.617	0.060	0.603
82		140	0.617	0.079	0.594
83		148	0.540	0.041	0.617
84		149	0.617	0.062	0.578
85		157	0.388	0.030	0.617
86		158	0.570	0.037	0.614
87		159	0.616	0.049	0.617
88		160	0.617	0.079	0.602
89		161	0.415	0.076	0.565
90		171	0.488	0.022	0.613
91		172	0.612	0.042	0.612
92		173	0.616	0.067	0.617
93		174	0.607	0.051	0.600

Table 14
n261/mid channel, K Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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		
			S3(Left)	S1(Front)	S2(Back)
109	K	3	0.533	0.079	0.429
110		13	0.552	0.068	0.467
111		14	0.558	0.038	0.570
112		15	0.530	0.089	0.486
113		22	0.617	0.054	0.566
114		23	0.544	0.035	0.617
115		34	0.604	0.098	0.539
116		35	0.584	0.054	0.550
117		36	0.558	0.027	0.579
118		37	0.486	0.060	0.573
119		38	0.470	0.092	0.572
120		47	0.587	0.068	0.601
121		48	0.572	0.028	0.572
122		49	0.581	0.043	0.595
123		50	0.464	0.079	0.569
124		131	0.580	0.042	0.519
125		141	0.584	0.077	0.522
126		142	0.609	0.063	0.569
127		143	0.514	0.050	0.617
128		150	0.617	0.072	0.568
129		151	0.615	0.033	0.617
130		162	0.617	0.091	0.592
131		163	0.612	0.069	0.587
132		164	0.571	0.034	0.556
133		165	0.581	0.042	0.603
134		166	0.511	0.049	0.617
135		175	0.617	0.080	0.597
136		176	0.612	0.056	0.572
137		177	0.575	0.037	0.562
138		178	0.537	0.038	0.604

Table 15
n260/mid channel, J Dipole simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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			
			S3(Left)	S5(Top)	S1(Front)	S2(Back)
1	J-D	1	0.157	0.195	0.032	0.460
2		7	0.079	0.193	0.022	0.431
3		8	0.199	0.137	0.034	0.518
4		9	0.241	0.133	0.024	0.462
5		18	0.180	0.141	0.030	0.524
6		19	0.249	0.157	0.041	0.553
7		129	0.078	0.194	0.020	0.488
8		135	0.110	0.144	0.038	0.549
9		136	0.043	0.244	0.019	0.586
10		137	0.097	0.150	0.026	0.539
11		146	0.060	0.215	0.027	0.572
12		147	0.035	0.179	0.017	0.523

Table 16
n260/mid channel J Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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		
			S3(Left)	S5(Top)	S2(Back)
19	J-P	0	0.077	0.038	0.588
20		4	0.027	0.051	0.617
21		5	0.019	0.145	0.617
22		6	0.146	0.071	0.577
23		16	0.024	0.093	0.617
24		17	0.072	0.155	0.617
25		24	0.037	0.063	0.617
26		25	0.051	0.081	0.578
27		26	0.106	0.123	0.617
28		27	0.143	0.107	0.617
29		28	0.131	0.170	0.617
30		39	0.055	0.088	0.617
31		40	0.098	0.117	0.617
32		41	0.128	0.112	0.617
33		42	0.184	0.180	0.617
34		128	0.028	0.056	0.573
35		132	0.028	0.033	0.617
36		133	0.033	0.093	0.566
37		134	0.250	0.088	0.617
38		144	0.050	0.168	0.617
39		145	0.056	0.043	0.540
40		152	0.041	0.094	0.588
41		153	0.031	0.123	0.617
42		154	0.096	0.089	0.617
43		155	0.094	0.072	0.617
44		156	0.120	0.107	0.539
45		167	0.029	0.111	0.617
46		168	0.055	0.144	0.617
47		169	0.102	0.057	0.617
48		170	0.058	0.081	0.486

Table 17
n260/mid channel, L Patch simulated 4cm2 PD at PD_Design_Target
(if simulation performed with correct housing material properties) (Δmin)

No.	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)	S1(Front)	S2(Back)
64	L	2	0.614	0.069	0.416
65		10	0.617	0.092	0.388
66		11	0.611	0.075	0.461
67		12	0.607	0.095	0.453
68		20	0.604	0.092	0.430
69		21	0.617	0.083	0.483
70		29	0.617	0.051	0.414
71		30	0.617	0.084	0.473
72		31	0.574	0.079	0.405
73		32	0.603	0.133	0.394
74		33	0.617	0.114	0.354
75		43	0.617	0.014	0.389
76		44	0.519	0.069	0.388
77		45	0.617	0.113	0.386
78		46	0.617	0.124	0.363
79		130	0.617	0.087	0.396
80		138	0.617	0.099	0.374
81		139	0.566	0.077	0.430
82		140	0.601	0.073	0.435
83		148	0.604	0.099	0.460
84		149	0.576	0.077	0.427
85		157	0.599	0.114	0.369
86		158	0.461	0.098	0.444
87		159	0.596	0.069	0.439
88		160	0.617	0.081	0.378
89		161	0.578	0.105	0.367
90		171	0.556	0.088	0.421
91		172	0.484	0.068	0.408
92		173	0.617	0.105	0.394
93		174	0.617	0.112	0.377

Table 18

n260/mid channel, K Patch simulated 4cm2 PD at PD_Design_Target

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

No.	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		
			S3(Left)	S1(Front)	S2(Back)
109	K	3	0.612	0.057	0.384
110		13	0.617	0.079	0.372
111		14	0.591	0.048	0.465
112		15	0.561	0.048	0.345
113		22	0.552	0.025	0.406
114		23	0.617	0.047	0.432
115		34	0.570	0.082	0.365
116		35	0.617	0.055	0.420
117		36	0.589	0.064	0.422
118		37	0.617	0.097	0.333
119		38	0.572	0.082	0.365
120		47	0.596	0.058	0.417
121		48	0.617	0.047	0.412
122		49	0.617	0.089	0.375
123		50	0.608	0.089	0.320
124		131	0.589	0.056	0.417
125		141	0.617	0.059	0.326
126		142	0.505	0.036	0.359
127		143	0.597	0.057	0.393
128		150	0.571	0.020	0.409
129		151	0.556	0.067	0.362
130		162	0.539	0.083	0.320
131		163	0.604	0.041	0.439
132		164	0.589	0.056	0.414
133		165	0.617	0.098	0.347
134		166	0.570	0.078	0.324
135		175	0.554	0.053	0.333
136		176	0.532	0.062	0.435
137		177	0.596	0.085	0.373
138		178	0.617	0.092	0.350

Table 19
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	J (Dipole)	9	Front	5.8	5.8	0.0892
		136	Top	4.5	4.5	0.182
		147	Left	5.2	5.2	0.143
	J (Patch)	39	Top	4	2.8	0.064
		24	Left	4.3	3.1	0.293
	L (Patch)	43	Front	5.9	4.7	0.149
	K (Patch)	34	Front	4.2	4.2	0.086
n260	J (Dipole)	19	Front	8.8	8.8	0.075
		136	Top	8.3	7.3	0.244
		19	Left	8.8	8.8	0.170
	J (Patch)	42	Top	6.6	5.6	0.132
		134	Left	8.3	8.3	0.223
	L (Patch)	32	Front	2.4	2.4	0.160
	K (Patch)	165	Front	3.4	3.4	0.0625

Some of the test cases above were tested at a higher power level than input.power.limit representing a more conservative evaluation.

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:

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

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

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

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

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:

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

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 10, given by:

- For n260 and n261

$$input.power.limit(i) = 6\ dBm + 10 * \log\big(s(i)\big) + \Delta_{min},\ i \in all\ beams \qquad (5)$$

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,

$$input.power.limit(i) = 6\ dBm + 10 * \log\big(s(i)\big),\ i \in all\ beams, \text{ for n260 and n261} \quad (6)$$

else if Δmin < -TxAGC uncertainty,

$$input.power.limit(i) = 6\ dBm + 10 * \log\big(s(i)\big) + \ (\Delta_{min} + \text{TxAGC uncertainty}),$$
$$i \in all\ beams, \text{ for n260 and n261} \quad (7)$$

else if Δmin > TxAGC uncertainty,

$$input.power.limit(i) = 6\ dBm + 10 * \log\big(s(i)\big) + (\Delta_{min} - \text{TxAGC uncertainty}),$$
$$i \in all\ beams, \text{ for n260 and n261} \quad (8)$$

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

Table 20
***input.power.limit* Calculation**

Band	Antenna	Δmin	TxAGC Uncertainty	*input.power.limit*	Notes
		(dB)	(dB)	(dBm)	
n261	J (Dipole Beam)	2.30	0.7	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 1.6*	Using Eq.8
	J (Patch Beam)	3.93	0.5	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 3.43*	Using Eq.8
	K (Patch Beam)	2.67	0.5	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 2.17*	Using Eq.8
	L (Patch Beam)	3.86	0.5	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 3.36*	Using Eq.8
n260	J (Dipole Beam)	5.01	0.7	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 4.31*	Using Eq.8
	J (Patch Beam)	4.16	0.5	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 3.66*	Using Eq.8
	K (Patch Beam)	2.10	0.5	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 1.6*	Using Eq.8
	L (Patch Beam)	1.73	0.5	*input.power.limit(i) = 6 dBm + 10 x log(s(i)) + 1.23*	Using Eq.8

For some bands/antennas, *input.power.limit* was reduced to implement a lower time-averaged power.

Table 21

5G NR n261 J Dipole *input.power.limit*

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
J-D	1		6.5
	7		3.7
	8		4.4
	9		5.8
	18		3.5
	19		5.1
	129		7.1
	135		5.6
	136		4.5
	137		5.4
	146		4.4
	147		5.2
	1	129	4.7
	7	136	1.7
	8	135	3.8
	9	137	4.0
	18	146	2.6
	19	147	3.6

Table 22

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

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
J-P	0		9.0
	4		6.1
	5		5.4
	6		6.5
	16		6.3
	17		6.0
	24		3.1
	25		2.6
	26		3.1
	27		2.7
	28		3.1
	39		2.8
	40		3.1
	41		2.8
	42		2.8
	128		9.1
	132		6.2
	133		4.9
	134		5.3
	144		5.3
	145		5.0
	152		3.1
	153		3.5
	154		3.6
	155		3.3
	156		3.2
	167		3.1
	168		3.5
	169		3.4
	170		3.2
	0	128	7.4
	4	134	2.7
	5	133	2.1
	6	132	3.2
	16	145	2.8
	17	144	2.5
	24	156	-0.1
	25	154	0.0
	26	153	0.0
	27	152	-0.2
	28	155	0.7
	39	170	-0.2
	40	169	0.3
	41	168	0.2
	42	167	-0.1

Table 23

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

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
K	3		10.2
	13		6.8
	14		7.4
	15		7.8
	22		6.4
	23		6.8
	34		4.2
	35		4.0
	36		3.9
	37		4.0
	38		4.4
	47		4.4
	48		4.1
	49		4.0
	50		4.2
	131		10.8
	141		6.5
	142		5.7
	143		6.4
	150		5.8
	151		7.8
	162		4.3
	163		3.5
	164		3.6
	165		3.8
	166		4.1
	175		3.7
	176		3.5
	177		3.7
	178		3.8
	3	131	9.1
	13	143	3.1
	14	142	2.4
	15	141	3.5
	22	151	3.2
	23	150	3.2
	34	165	-0.2
	35	164	-0.3
	36	163	-0.4
	37	162	0.3
	38	166	1.3
	47	177	-0.3
	48	176	-0.4
	49	175	-0.1
	50	178	1.1

Table 24

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

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
L	2		9.1
	10		7.9
	11		7.4
	12		8.4
	20		7.1
	21		7.6
	29		5.7
	30		4.8
	31		4.0
	32		4.2
	33		5.0
	43		4.7
	44		4.7
	45		3.7
	46		4.5
	130		10.2
	138		6.5
	139		6.1
	140		7.6
	148		6.1
	149		6.4
	157		3.9
	158		4.0
	159		4.3
	160		4.5
	161		5.3
	171		3.7
	172		4.3
	173		4.0
	174		5.4
	2	130	6.9
	10	138	4.0
	11	139	2.8
	12	140	4.3
	20	148	3.0
	21	149	3.3
	29	157	0.7
	30	158	0.2
	31	159	0.1
	32	160	0.6
	33	161	1.8
	43	171	0.3
	44	172	0.3
	45	173	0.1
	46	174	1.1

Table 25

5G NR n260 J Dipole *input.power.limit*

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
J-D	1		10.1
	7		7.5
	8		8.2
	9		8.6
	18		8.0
	19		8.8
	129		11.4
	135		8.3
	136		7.3
	137		7.8
	146		7.6
	147		7.2
	1	129	7.8
	7	136	4.8
	8	135	5.6
	9	137	5.2
	18	146	5.0
	19	147	5.1

Table 26

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

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
J-P	0		9.5
	4		7.5
	5		7.5
	6		7.4
	16		7.5
	17		7.9
	24		4.9
	25		5.0
	26		4.7
	27		4.8
	28		5.5
	39		5.1
	40		4.7
	41		4.7
	42		5.6
	128		10.2
	132		7.4
	133		7.3
	134		8.3
	144		8.0
	145		7.5
	152		4.8
	153		4.7
	154		4.8
	155		5.3
	156		5.3
	167		4.7
	168		5.7
	169		5.1
	170		5.0
	0	128	7.1
	4	132	3.8
	5	133	4.5
	6	134	4.6
	16	144	4.9
	17	145	4.5
	24	153	1.2
	25	154	1.6
	26	152	1.3
	27	155	1.8
	28	156	2.4
	39	168	1.8
	40	167	1.3
	41	169	1.5
	42	170	1.7

Table 27

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

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
K	3		8.8
	13		6.4
	14		6.2
	15		6.9
	22		6.9
	23		6.3
	34		4.3
	35		4.8
	36		3.6
	37		3.6
	38		4.4
	47		5.3
	48		3.9
	49		3.4
	50		3.9
	131		9.7
	141		7.0
	142		6.0
	143		6.0
	150		6.2
	151		5.7
	162		3.5
	163		4.8
	164		3.7
	165		3.4
	166		3.6
	175		4.8
	176		4.4
	177		3.5
	178		3.5
	3	131	6.5
	13	141	3.1
	14	143	2.1
	15	142	2.2
	22	150	2.4
	23	151	2.2
	34	162	1.2
	35	163	0.0
	36	166	0.2
	37	165	0.2
	38	164	0.0
	47	176	-0.6
	48	175	-0.3
	49	178	0.3
	50	177	0.0

Table 28

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

Antenna	Beam ID_1	Beam ID_2	Input.Power.Limit [dBm]
L	2		7.4
	10		6.2
	11		5.3
	12		5.9
	20		6.0
	21		5.6
	29		3.7
	30		3.2
	31		2.3
	32		2.4
	33		2.2
	43		3.5
	44		2.2
	45		2.4
	46		2.6
	130		8.6
	138		5.4
	139		4.9
	140		5.0
	148		6.0
	149		4.7
	157		2.2
	158		3.3
	159		2.4
	160		1.8
	161		2.4
	171		3.6
	172		3.0
	173		2.2
	174		2.0
	2	130	4.7
	10	139	1.2
	11	140	1.2
	12	138	2.8
	20	148	1.1
	21	149	1.2
	29	159	-0.7
	30	158	-2.1
	31	161	-0.7
	32	160	-0.7
	33	157	-0.2
	43	172	-1.6
	44	171	-1.4
	45	174	-0.8
	46	173	-0.9