Part 0: SAR and Power Density Characterization
EUT RF Exposure Compliance Test Report

For
SMARTPHONE

FCC ID: BCG-E8688A
Model Name: A3081

Report Number: 14982484-S5V1
Issue Date: 7/30/2024

Prepared for
APPLE INC.
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Prepared by
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Revision History

Rev.	Date	Revisions	Revised By
V1	7/30/2024	Initial Issue	--

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Tables

1. Attestation of Test Results

Applicant Name	APPLE INC.
FCC ID	BCG-E8688A
Model Name	A3081
Reference SAR Report	14982484-S1

Exposure Category	SAR Limits (W/Kg)		PD Limits (W/m^2)
	Peak spatial-average (1g of tissue)	Extremities (hands, wrists, ankles, etc.) (10g of tissue)	
General Population (Uncontrolled Exposure)	1.6	4	10

RF Exposure Conditions		Equipment Class - Highest Reported SAR (W/kg)								Highest Reported PD (W/m^2)
		TNE	PCE	CBE	DTS	NII	6CD	DSS	DXX	
Head		0.858	0.959	0.916	1.082	0.798	0.031	1.001	N/A	3.900
Body-worn (Dist.= 5 mm)		0.944	0.955	0.927	0.855	1.167	0.397	0.625	N/A	
Hotspot (Dist.= 5 mm)		0.944	0.957	0.927	1.113	1.167	N/A	0.625	N/A	
Extremities (Dist.= 0 mm)		2.388	N/A	N/A	N/A	N/A	0.397	N/A	0.000	
Simultaneous TX	Head	1.409	1.493	1.391	1.493	1.493	1.493	1.477	N/A	
	Body-worn	1.510	1.522	1.493	1.522	1.537	1.537	1.537	N/A	
	Hotspot	1.510	1.522	1.493	1.522	1.537	1.537	1.537	N/A	
	Extremities	2.501	N/A	N/A	N/A	N/A	2.501	N/A	2.501	

Date Tested	5/15/2024 to 7/11/2024

UL Verification Services Inc. tested the above equipment in accordance with the requirements set forth in the above standards. The test results show that the equipment tested is capable of demonstrating compliance with the requirements as documented in this report.
This report contains data provided by the customer which can impact the validity of results. UL Verification Services Inc. is only responsible for the validity of results after the integration of the data provided by the customer.
The results documented in this report apply only to the tested sample, under the conditions and modes of operation as described herein. It is the manufacturer's responsibility to assure that additional production units of this model are manufactured with identical electrical and mechanical components. All samples tested were in good operating condition throughout the entire test program. Measurement Uncertainties are published for informational purposes only and were not taken into account unless noted otherwise.
This document may not be altered or revised in any way unless done so by UL Verification Services Inc. and all revisions are duly noted in the revisions section. Any alteration of this document not carried out by UL Verification Services Inc. will constitute fraud and shall nullify the document. This report must not be used by the client to claim product certification, approval, or endorsement by A2LA, NIST, or any agency of the U.S. Government, or any agency of the U.S. government.

Approved & Released By:	Prepared By:
Michael Heckrotte Principal Engineer UL Verification Services Inc.	Nathan Sousa Senior Laboratory Engineer UL Verification Services Inc.

2. Facilities and Accreditation

The test sites and measurement facilities used to collect data are located at:

47173 Benicia Street	47266 Benicia Street
SAR Labs A to I	SAR Labs 1 to 19

UL Verification Services Inc. is accredited by A2LA, Certificate Number 0751.05

The Test Lab Conformity Assessment Body Identifier (CABID)

Location	CABID	Company Number
47173 Benicia Street, Fremont, CA, 94538 UNITED STATES	US0104	2324A
47266 Benicia Street, Fremont, CA, 94538 UNITED STATES		

3. Introduction

The equipment under test (EUT) is a smart phone. It contains the Qualcomm modem supporting 2G/3G/4G/5G WWAN technologies and millimeter wave 5G NR bands. These WWAN modems enable Qualcomm's Smart Transmit feature to control and manage transmitting power, in real time, and to ensure the time-averaged RF exposure is always in compliance with the FCC requirement.

In this report, Part 0, the EUT SAR and power density (PD) are characterized for WWAN radios (2G/3G/4G/5G/ millimeter wave 5G NR) to determine the power limit that corresponds to the exposure design target after accounting for all device design related uncertainties, i.e., $SAR_{Design\ Target}$ (< FCC SAR limit) for Sub-6 GHz radio and $PD_{Design\ Target}$ (< FCC PD limit) for millimeter wave radio. The SAR Characterization and PD Characterization are denoted as *SAR Char* and *PD Char*.

SAR Char and *PD Char* will be used as input for Qualcomm Smart Transmit to operate. Both *SAR Char* and *PD Char* will be loaded and stored in the EUT via the *Embedded File System* (EFS).

The EUT supports WLAN/BT/MSS radio(s) as well, but the WLAN/BT/MSS modem is not enabled with Qualcomm's Smart Transmit feature.

4. SAR Characterization

SAR Char is generated to cover all radio configurations and usage scenarios that are reported in the initial FCC submission.

4.1. Worst-case SAR Determination

Based on FCC KDBs, in general, for a smartphone, the SAR evaluation is required for the exposure scenarios shown in Figure 4-1.

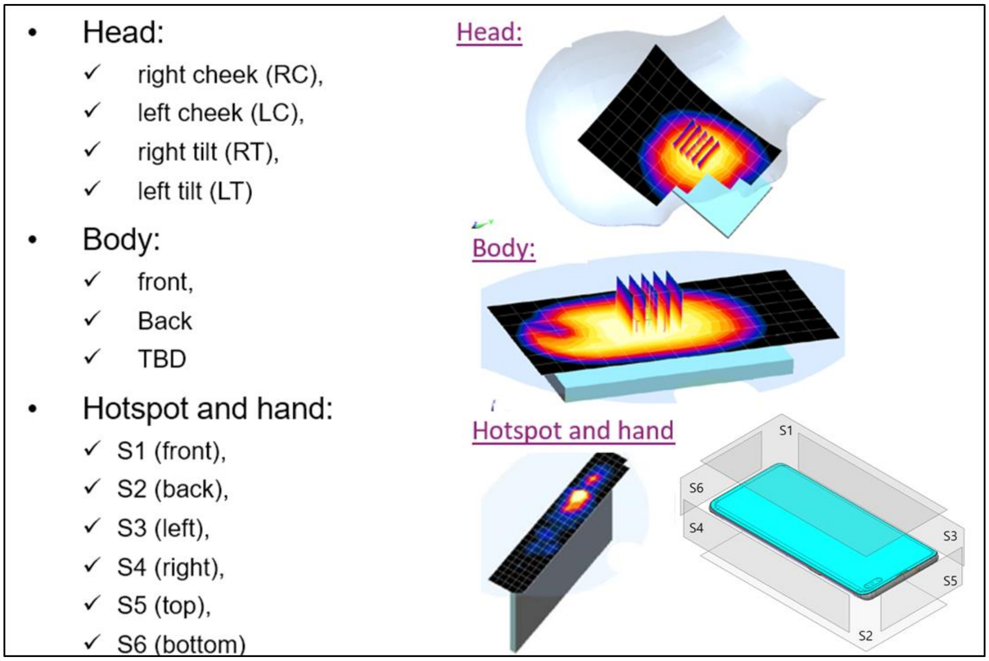
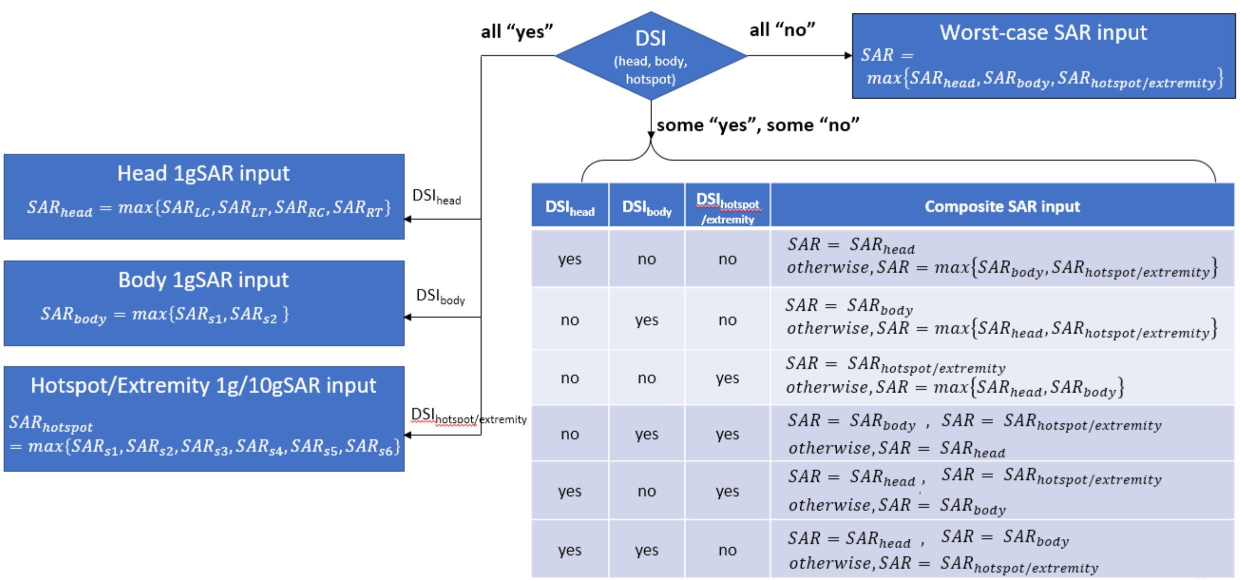


Figure 4-1: SAR evaluation for smartphone application

The *Device State Index* (DSI) used in Figure 4-2 represents each exposure scenario. Depending on the detection scheme implemented in the smartphone, the worst-case SAR is further grouped and determined for each or combined exposure scenario(s). Note, for the 1-g SAR versus 10-g SAR exposure scenario, the worst-case is determined in term of exposure ratio (i.e., exposure level relative to the corresponding 1-g or 10-g SAR limit).

- If the device does not have any detection mechanism (**all "no"** in Figure 4-2), then the worst-case SAR is determined by taking the maximum SAR value among all exposure scenarios, i.e., worst-case SAR = *max* {SAR_{head}, SAR_{body}, $SAR_{hotspot/extremity}$}
- If the device can distinguish each of the above scenarios (**all "yes"** in Figure 4-2), then the worst-case SAR for each individual exposure scenario is given by corresponding SAR_{head}, SAR_{body}, and $SAR_{hotspot/extremity}$
- If the device can only distinguish a subset of the scenarios (**some "yes", some "no"** in Figure 4-2), then the worst-case SAR is given by:
  - Corresponding SAR for each exposure scenario that can be distinguished (DSI=yes)
  - Worst-case SAR among all other exposure scenario(s) that cannot be distinguished (DSI=no)



DSI_{head}	DSI_{body}	$DSI_{hotspot/extremity}$	Composite SAR input
yes	no	no	$SAR = SAR_{head}$ $otherwise, SAR = max\{SAR_{body}, SAR_{hotspot/extremity}\}$
no	yes	no	$SAR = SAR_{body}$ $otherwise, SAR = max\{SAR_{head}, SAR_{hotspot/extremity}\}$
no	no	yes	$SAR = SAR_{hotspot/extremity}$ $otherwise, SAR = max\{SAR_{head}, SAR_{body}\}$
no	yes	yes	$SAR = SAR_{body}$, $SAR = SAR_{hotspot/extremity}$ $otherwise, SAR = SAR_{head}$
yes	no	yes	$SAR = SAR_{head}$, $SAR = SAR_{hotspot/extremity}$ $otherwise, SAR = SAR_{body}$
yes	yes	no	$SAR = SAR_{head}$, $SAR = SAR_{body}$ $otherwise, SAR = SAR_{hotspot/extremity}$

Figure 4-2: Worst-case SAR determination based on DSI

4.2. Usage Scenarios in SAR Evaluation

The EUT has a detection mechanism to distinguish Head, Body-worn, Hotspot, and Extremity exposure conditions, which is represented using *DSI 0* and *1*. These *DSI* states were used to determine the power limit for Smart Transmit to operate; where the exposure scenario is managed as the same DSI state, all other exposures which cannot be distinguished, in this particular instance and based on the worst-case SAR determination criteria described in §4.1, the maximum SAR (or the minimum P_{limit}) among all remaining exposure scenarios (i.e., Body-worn 1-g SAR evaluation at a specified test separation distance, phablet extremity 10-g SAR evaluation at a specified test separation distance, and maximum RF tune-up power (P_{max})) supported by the device if SAR measurement is not performed for this tech/band/antenna because of meeting SAR test exclusion criteria) is used to determine the power limit for Smart Transmit to operate.

The corresponding usage scenarios supported by EUT are summarized in Table 4-1:

Table 4-1: Usage/Exposure Scenario

Scenario	DSI State	Description	SAR Definition	Worst-case SAR
Head	0	▪ Device positioned next to head ▪ 1-g SAR evaluated in four positions (left/right cheek/tilt)	SAR_{head} = max {SAR_{LC}, SAR_{LT}, SAR_{RC}, SAR_{RT}}	SAR_{head}
Body-worn Hotspot Extremity	1	▪ Device transmits in Hotspot mode and assumed to be located next to human body ▪ 1-g/10-g SAR is evaluated for all six surfaces of the EUT (S1-S6 as shown in Figure 4-1) at 0/5 mm test separation distance relative to the flat phantom	$SAR_{hotspot}$ = max {SAR_{s1}, SAR_{s2}, SAR_{s3}, SAR_{s4}, SAR_{s5}, SAR_{s6}}	SAR_{body}

4.3. $SAR_{Design\ Target}$

The total device design and related uncertainties of the EUT, including TxAGC and device to device variation, are accounted for in the SAR design Target ($SAR_{Design\ Target}$) per the following equation:

$$SAR_{Design\ Target} < SAR_{regulatory_{limit}} \times 10^{\frac{-total\ uncertainty}{10}}$$

For the FCC SAR requirement of 1.6 W/kg and 4.0 W/kg, 1-g and 10-g SAR respectively, the $SAR_{Design\ Target}$ for the EUT is determined as:

$SAR_{Design\ Target}$ (1-g W/kg)	$SAR_{Design\ Target}$ (10-g W/kg)	$SAR_{Design\ Limit}$ (1-g W/kg)	$SAR_{Design\ Limit}$ (10-g W/kg)
0.8	2.0	1.0	2.5

4.4. SAR Characterization

Per the reference SAR report mentioned in §1, the worst-case *reported* SAR for each antenna/technology/band/DSI is summarized in Table 4-2:

Table 4-2: Worst-case *reported* SAR

Tech/Band	Antenna				Worst-case SAR (W/kg)				P_{limit} (dBm) + Uncertainty (dBm)			
	Head	Body & Hotspot	Hotspot	Extremity	Head	Body & Hotspot	Hotspot	Extremity	Head	Body & Hotspot	Hotspot	Extremity
	DSI: 0	DSI: 1	DSI: 1	DSI: 1	DSI: 0	DSI: 1	DSI: 1	DSI: 1	DSI: 0	DSI: 1	DSI: 1	DSI: 1
GSM 850 2 slots	ANT 2	ANT 2	ANT 2	N/A	0.647	0.604	0.604	N/A	29.50	31.50	31.50	N/A
GSM 1900 2 slots	ANT 4	ANT 4	ANT 1	N/A	0.666	0.695	0.862	N/A	22.80	24.50	25.60	N/A
W-CDMA B2	ANT 4	ANT 2	ANT 2	N/A	0.931	0.908	0.938	N/A	16.80	19.60	19.60	N/A
W-CDMA B4	ANT 2	ANT 3	ANT 4	N/A	0.919	0.849	0.883	N/A	18.10	22.10	20.00	N/A
W-CDMA B5	ANT 2	ANT 2	ANT 2	N/A	0.911	0.700	0.711	N/A	23.50	25.20	25.20	N/A
LTE Band 5	ANT 2	ANT 2	ANT 2	N/A	0.916	0.688	0.688	N/A	23.50	25.20	25.20	N/A
LTE Band 7	ANT 4	ANT 4	ANT 4	N/A	0.939	0.955	0.955	N/A	18.60	19.20	19.20	N/A
LTE Band 12/17	ANT 2	ANT 1	ANT 2	N/A	0.618	0.432	0.615	N/A	25.20	25.70	25.20	N/A
LTE Band 13	ANT 2	ANT 1	ANT 1	N/A	0.813	0.619	0.775	N/A	24.70	25.70	25.70	N/A
LTE Band 14	ANT 2	ANT 1	ANT 2	N/A	0.942	0.565	0.605	N/A	24.70	25.70	25.20	N/A
LTE Band 25/2	ANT 4	ANT 4	ANT 3	N/A	0.914	0.919	0.950	N/A	16.80	18.50	21.80	N/A
LTE Band 26	ANT 2	ANT 2	ANT 2	N/A	0.792	0.531	0.536	N/A	23.50	25.20	25.20	N/A
LTE Band 30	ANT 2	ANT 2	ANT 3	N/A	0.912	0.904	0.938	N/A	19.30	19.80	23.10	N/A
LTE Band 41	ANT 4	ANT 4	ANT 4	N/A	0.690	0.941	0.941	N/A	19.40	20.70	20.70	N/A
LTE Band 41 (PC2)	ANT 1	N/A	N/A	N/A	0.310	N/A	N/A	N/A	28.00	N/A	N/A	N/A
LTE Band 48	ANT 4	ANT 9	ANT 9	N/A	0.916	0.794	0.942	N/A	22.30	21.20	21.20	N/A
LTE Band 53	ANT 2	ANT 2	ANT 2	N/A	0.812	0.676	0.779	N/A	20.40	20.70	20.70	N/A
LTE Band 66/4	ANT 4	ANT 4	ANT 1	N/A	0.940	0.919	0.957	N/A	18.20	20.00	20.00	N/A
LTE Band 71	ANT 2	ANT 1	ANT 1	N/A	0.866	0.414	0.614	N/A	25.20	25.70	25.70	N/A
MSS	N/A	N/A	N/A	ANT 1	N/A	N/A	N/A	2.388	N/A	N/A	N/A	25.80
NR n5	ANT 2	ANT 2	ANT 2	N/A	0.707	0.498	0.635	N/A	23.50	25.20	25.20	N/A
NR n7	ANT 4	ANT 2	ANT 4	N/A	0.914	0.904	0.908	N/A	18.60	19.00	19.20	N/A
NR n12	ANT 2	ANT 1	ANT 1	N/A	0.694	0.610	0.742	N/A	25.20	25.70	25.70	N/A
NR n14	ANT 2	ANT 1	ANT 1	N/A	0.754	0.608	0.821	N/A	24.70	25.70	25.70	N/A
NR n25/2	ANT 2	ANT 4	ANT 3	N/A	0.931	0.881	0.944	N/A	19.80	18.50	21.80	N/A
NR n26	ANT 2	ANT 2	ANT 1	N/A	0.860	0.644	0.662	N/A	23.50	25.20	25.70	N/A
NR n30	ANT 4	ANT 3	ANT 1	N/A	0.959	0.916	0.925	N/A	17.80	23.10	19.40	N/A
NR n41	ANT 2	ANT 4	ANT 4	N/A	0.814	0.934	0.934	N/A	18.00	18.70	18.70	N/A
NR n48	ANT 4	ANT 4	ANT 9	N/A	0.908	0.927	0.933	N/A	20.30	21.10	19.20	N/A
NR n53	ANT 2	ANT 2	ANT 2	N/A	0.858	0.944	0.944	N/A	18.40	19.40	19.40	N/A
NR n66	ANT 2	ANT 4	ANT 2	N/A	0.909	0.889	0.920	N/A	18.10	20.00	18.30	N/A
NR n70	ANT 2	ANT 4	ANT 2	N/A	0.935	0.752	0.902	N/A	18.10	20.00	18.30	N/A
NR n71	ANT 2	ANT 1	ANT 1	N/A	0.658	0.566	0.717	N/A	25.20	25.70	25.70	N/A
NR n77	ANT 8	ANT 8	ANT 8	N/A	0.885	0.928	0.928	N/A	19.10	17.80	17.80	N/A

Using the reported SAR listed in Table 4-2, and following the procedure described in §4.1, the *SAR Char* of this EUT, i.e., P_{limit} corresponding to $SAR_{Design\ Target}$, is determined for each supported antenna/technology/band/DSI as:

1. For DSI = 0, P_{limit} is calculated based on 1-g SAR head evaluation.
2. For DSI = 1, P_{limit} is calculated based on 1-g SAR body-worn/hotspot exposure evaluation at 5 mm spacing.

$$P_{limit} = \min\{\, \mathrm{P}_{limit} \text{ corresponding to body worn 1gSAR evaluation at 15mm spacing,} \\ P_{limit} \text{ corresponding to 10-g SAR extremity evaluation at 0mm spacing,} \\ P_{max} \text{maximum RF tuneup power for the case that the SAR test is excluded}\}$$

The SAR Char is listed in Table 4-3.

Table 4-3: SAR Characterization

Exposure Scenario		Duty Cycle	Head				Body & Hotspot				Hotspot				Extremity				P_{max} (dBm)	
Spatial-average			1-g				1-g				1-g				10-g					
Test Distance			0 mm				5 mm				5 mm				0 mm					
Power Mode (DSI)			DSI: 0				DSI: 1				DSI: 1				DSI: 1					
Antenna	Tech/Band		P_{design} (dBm)	P_{limit} + Uncertainty (dBm)	P_{design} (dBm)	P_{limit} + Uncertainty (dBm)	P_{design} (dBm)	P_{limit} + Uncertainty (dBm)	P_{design} (dBm)	P_{limit} + Uncertainty (dBm)	P_{design} (dBm)	P_{limit} + Uncertainty (dBm)	P_{design} (dBm)	P_{limit} + Uncertainty (dBm)	P_{design} (dBm)	P_{limit} (dBm)	P_{design} (dBm)	P_{limit} (dBm)		
			Burst Average		Frame Average		Burst Average		Frame Average		Burst Average		Frame Average		Burst Average		Frame Average		Burst Average	Frame Average
ANT 1	GSM 850 2 slots	25.0%	38.25	32.50	32.23	26.48	36.39	32.50	30.37	26.48	35.25	32.50	29.23	26.48	N/A	N/A	N/A	N/A	32.50	26.48
	GSM 1900 2 slots	25.0%	36.10	30.50	30.08	24.48	28.15	25.60	22.13	19.58	26.02	25.60	20.00	19.58	N/A	N/A	N/A	N/A	31.00	24.98
	W-CDMA B2	100.0%	29.68	24.50	29.68	24.50	22.08	19.60	22.08	19.60	19.79	19.60	19.79	19.60	N/A	N/A	N/A	N/A	25.70	25.70
	W-CDMA B4	100.0%	33.25	24.20	33.25	24.20	22.63	20.00	22.63	20.00	20.76	20.00	20.76	20.00	N/A	N/A	N/A	N/A	25.70	25.70
	W-CDMA B5	100.0%	30.12	25.70	30.12	25.70	28.47	25.70	28.47	25.70	28.33	25.70	28.33	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 5	100.0%	31.46	25.70	31.46	25.70	29.53	25.70	29.53	25.70	28.33	25.70	28.33	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 7	100.0%	27.42	24.70	27.42	24.70	22.85	20.80	22.85	20.80	21.03	20.80	21.03	20.80	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 12/17	100.0%	32.26	25.70	32.26	25.70	29.12	25.70	29.12	25.70	29.12	25.70	29.12	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 13	100.0%	31.63	25.70	31.63	25.70	27.56	25.70	27.56	25.70	26.58	25.70	26.58	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 14	100.0%	31.66	25.70	31.66	25.70	27.96	25.70	27.96	25.70	27.88	25.70	27.88	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 25/2	100.0%	31.38	24.50	31.38	24.50	21.61	19.60	21.61	19.60	19.70	19.60	19.70	19.60	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 26	100.0%	31.27	25.70	31.27	25.70	29.27	25.70	29.27	25.70	28.33	25.70	28.33	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 30	100.0%	31.70	25.00	31.70	25.00	20.52	19.40	20.52	19.40	20.52	19.40	20.52	19.40	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 41	63.3%	30.12	25.70	28.13	23.71	25.03	22.60	23.05	20.61	24.32	22.60	22.34	20.61	N/A	N/A	N/A	N/A	25.70	23.71
	LTE Band 41 (PC2)	43.3%	32.86	28.00	29.23	24.36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	28.70	25.06
	LTE Band 53	63.3%	30.15	20.70	28.17	18.71	24.91	20.70	22.93	18.71	23.30	20.70	21.32	18.71	N/A	N/A	N/A	N/A	20.70	18.71
	LTE Band 66/4	100.0%	33.49	24.20	33.49	24.20	21.99	20.00	21.99	20.00	19.97	20.00	19.97	20.00	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 71	100.0%	32.84	25.70	32.84	25.70	29.30	25.70	29.30	25.70	27.59	25.70	27.59	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	MSS	100.0%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	26.00	25.80	26.00	25.80	28.00	28.00
	NR n5	100.0%	30.96	25.70	30.96	25.70	28.86	25.70	28.86	25.70	28.66	25.70	28.66	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	NR n7	100.0%	28.40	24.70	28.40	24.70	23.01	20.80	23.01	20.80	21.48	20.80	21.48	20.80	N/A	N/A	N/A	N/A	25.70	25.70
	NR n12	100.0%	31.30	25.70	31.30	25.70	27.63	25.70	27.63	25.70	26.77	25.70	26.77	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	NR n14	100.0%	31.81	25.70	31.81	25.70	27.64	25.70	27.64	25.70	26.33	25.70	26.33	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	NR n25/2	100.0%	31.53	24.50	31.53	24.50	21.94	19.60	21.94	19.60	19.83	19.60	19.83	19.60	N/A	N/A	N/A	N/A	25.70	25.70
	NR n26	100.0%	30.72	25.70	30.72	25.70	28.09	25.70	28.09	25.70	27.27	25.70	27.27	25.70	N/A	N/A	N/A	N/A	25.70	25.70
	NR n30	100.0%	30.63	25.00	30.63	25.00	21.57	19.40	21.57	19.40	19.52	19.40	19.52	19.40	N/A	N/A	N/A	N/A	25.20	25.20
	NR n41	100.0%	27.86	24.40	27.86	24.40	22.23	20.60	22.23	20.60	20.93	20.60	20.93	20.60	N/A	N/A	N/A	N/A	25.70	25.70
	NR n53	100.0%	27.12	20.70	27.12	20.70	22.70	20.70	22.70	20.70	21.49	20.70	21.49	20.70	N/A	N/A	N/A	N/A	20.70	20.70
	NR n66	100.0%	33.03	24.20	33.03	24.20	22.27	20.00	22.27	20.00	20.32	20.00	20.32	20.00	N/A	N/A	N/A	N/A	25.70	25.70
	NR n70	100.0%	35.97	24.20	35.97	24.20	22.59	20.00	22.59	20.00	20.45	20.00	20.45	20.00	N/A	N/A	N/A	N/A	25.70	25.70
	NR n71	100.0%	31.89	25.70	31.89	25.70	27.95	25.70	27.95	25.70	26.92	25.70	26.92	25.70	N/A	N/A	N/A	N/A	25.70	25.70
ANT 2	GSM 850 2 slots	25.0%	31.17	29.50	25.15	23.48	33.47	31.50	27.45	25.48	33.47	31.50	27.45	25.48	N/A	N/A	N/A	N/A	31.50	25.48
	GSM 1900 2 slots	25.0%	27.41	25.80	21.39	19.78	27.37	25.60	21.34	19.58	27.12	25.60	21.10	19.58	N/A	N/A	N/A	N/A	28.50	22.48
	W-CDMA B2	100.0%	20.69	19.80	20.69	19.80	19.80	19.60	19.80	19.60	19.66	19.60	19.66	19.60	N/A	N/A	N/A	N/A	23.40	23.40
	W-CDMA B4	100.0%	18.24	18.10	18.24	18.10	19.07	18.30	19.07	18.30	18.64	18.30	18.64	18.30	N/A	N/A	N/A	N/A	23.40	23.40
	W-CDMA B5	100.0%	23.68	23.50	23.68	23.50	26.53	25.20	26.53	25.20	26.46	25.20	26.46	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	LTE Band 5	100.0%	23.66	23.50	23.66	23.50	26.60	25.20	26.60	25.20	26.60	25.20	26.60	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	LTE Band 7	100.0%	18.45	17.70	18.45	17.70	19.09	19.00	19.09	19.00	19.09	19.00	19.09	19.00	N/A	N/A	N/A	N/A	23.70	23.70
	LTE Band 12/17	100.0%	27.07	25.20	27.07	25.20	28.71	25.20	28.71	25.20	27.09	25.20	27.09	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	LTE Band 13	100.0%	25.38	24.70	25.38	24.70	28.15	25.20	28.15	25.20	27.04	25.20	27.04	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	LTE Band 14	100.0%	24.74	24.70	24.74	24.70	28.00	25.20	28.00	25.20	27.16	25.20	27.16	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	LTE Band 25/2	100.0%	20.25	19.80	20.25	19.80	20.70	19.60	20.70	19.60	19.71	19.60	19.71	19.60	N/A	N/A	N/A	N/A	23.40	23.40
	LTE Band 26	100.0%	24.29	23.50	24.29	23.50	27.72	25.20	27.72	25.20	27.68	25.20	27.68	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	LTE Band 30	100.0%	19.48	19.30	19.48	19.30	20.02	19.80	20.02	19.80	20.02	19.80	20.02	19.80	N/A	N/A	N/A	N/A	23.70	23.70
	LTE Band 41	63.3%	21.86	20.00	19.87	18.01	21.48	20.70	19.50	18.71	21.48	20.70	19.50	18.71	N/A	N/A	N/A	N/A	25.70	23.71
	LTE Band 53	63.3%	21.08	20.40	19.10	18.41	22.18	20.70	20.19	18.71	21.56	20.70	19.57	18.71	N/A	N/A	N/A	N/A	20.70	18.71
	LTE Band 66/4	100.0%	18.24	18.10	18.24	18.10	19.33	18.30	19.33	18.30	18.35	18.30	18.35	18.30	N/A	N/A	N/A	N/A	25.70	25.70
	LTE Band 71	100.0%	25.60	25.20	25.60	25.20	29.03	25.20	29.03	25.20	27.35	25.20	27.35	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	NR n5	100.0%	24.78	23.50	24.78	23.50	28.00	25.20	28.00	25.20	26.95	25.20	26.95	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	NR n7	100.0%	18.10	17.70	18.10	17.70	19.22	19.00	19.22	19.00	19.22	19.00	19.22	19.00	N/A	N/A	N/A	N/A	23.70	23.70
	NR n12	100.0%	26.56	25.20	26.56	25.20	28.23	25.20	28.23	25.20	27.74	25.20	27.74	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	NR n14	100.0%	25.70	24.70	25.70	24.70	27.72	25.20	27.72	25.20	26.24	25.20	26.24	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	NR n25/2	100.0%	19.89	19.80	19.89	19.80	20.12	19.60	20.12	19.60	20.12	19.60	20.12	19.60	N/A	N/A	N/A	N/A	23.40	23.40
	NR n26	100.0%	23.93	23.50	23.93	23.50	26.89	25.20	26.89	25.20	26.89	25.20	26.89	25.20	N/A	N/A	N/A	N/A	25.20	25.20
	NR n30	100.0%	19.52	19.30	19.52	19.30	20.11	19.80	20.11	19.80	20.11	19.80	20.11	19.80	N/A	N/A	N/A	N/A	23.20	23.20
	NR n41	100.0%	18.67	18.00	18.67	18.00	19.47	18.70	19.47	18.70	19.47	18.70	19.47	18.70	N/A	N/A	N/A	N/A	25.70	25.70
	NR n53	100.0%	18.84	18.40	18.84	18.40	19.43	19.40	19.43	19.40	19.43	19.40	19.43	19.40	N/A	N/A	N/A	N/A	20.70	20.70
	NR n66	100.0%	18.29	18.10	18.29	18.10	19.62	18.30	19.62	18.30	18.44	18.30	18.44	18.30	N/A	N/A	N/A	N/A	25.70	25.70
	NR n70	100.0%	18.17	18.10	18.17	18.10	20.27	18.30	20.27	18.30	18.52	18.30	18.52	18.30	N/A	N/A	N/A	N/A	25.70	25.70
	NR n71	100.0%	26.79	25.20	26.79	25.20	28.65	25.20	28.65	25.20	28.65	25.20	28.65	25.20	N/A	N/A	N/A	N/A	25.20	25.20
ANT 3	GSM 1900 2 slots	25.0%	43.00	28.30	36.98	22.28	30.30	27.80	24.28	21.78	29.01	27.80	22.99	21.78	N/A	N/A	N/A	N/A	30.50	24.48
	W-CDMA B2	100.0%	28.50	22.30	28.50	22.30	23.26	21.80	23.26	21.80	21.94	21.80	21.94	21.80	N/A	N/A	N/A	N/A	25.50	25.50
	W-CDMA B4	100.0%	27.05	21.60	27.05	21.60	22.59	22.10	22.59	22.10	22.59	22.10	22.59	22.10	N/A	N/A	N/A	N/A	25.50	25.50
	LTE Band 7	100.0%	26.67	23.30	26.67	23.30	22.55	20.50	22.55	20.50	20.85	20.50	20.85	20.50	N/A	N/A	N/A	N/A	25.00	25.00
	LTE Band 25/2	100.0%	27.77	22.30	27.77	22.30	22.78	21.80	22.78	21.80	21.80	21.80	21.80	21.80	N/A	N/A	N/A	N/A	25.50	25.50
	LTE Band 30	100.0%	33.44	23.00	33.44	23.00	23.65	23.10	23.65	23.10	23.16	23.10	23.16	23.10	N/A	N/A	N/A	N/A	25.00	25.00
	LTE Band 41	63.3%	31.03	23.90	29.05	21.91	23.87	22.10	21.88	20.11	23.81	22.10	21.82	20.11	N/A	N/A	N/A	N/A	25.70	23.71
	LTE Band 66/4	100.0%	28.86	21.60	28.86	21.60	23.65	22.10	23.65	22.10	23.49	22.10	23.49	22.10	N/A	N/A	N/A	N/A	25.50	25.50
	NR n7	100.0%	26.52	23.30	26.52	23.30	21.84	20.50	21.84	20.50	20.97	20.50	20.97	20.50	N/A	N/A	N/A	N/A	25.00	25.00
	NR n25/2	100.0%	26.48	22.30	26.48	22.30	22.42	21.80	22.42	21.80	21.83	21.80	21.83	21.80	N/A	N/A	N/A	N/A	25.50	25.50
	NR n30	100.0%	33.46	23.00	33.46	23.00	23.26	23.10	23.26	23.10	23.26	23.10	23.26	23.10	N/A	N/A	N/A	N/A	24.50	24.50
	NR n41	100.0%	31.94	21.90	31.94	21.90	21.00	20.10	21.00	20.10	20.28	20.10	20.28	20.10	N/A	N/A	N/A	N/A	25.70	25.70
	NR n66	100.0%	28.11	21.60	28.11	21.60	23.35	22.10	23.35	22.10	22.92	22.10	22.92	22.10	N/A	N/A	N/A	N/A	25.50	25.50
	NR n70	100.0%	28.82	21.60	28.82	21.60	24.15	22.10	24.15	22.10	23.11	22.10	23.11	22.10	N/A	N/A	N/A	N/A	25.50	25.50
ANT 4	GSM 1900 2 slots	25.0%	24.34	22.80	18.32	16.78	25.86	24.50	19.84	18.48	25.86	24.50	19.84	18.48	N/A	N/A	N/A	N/A	28.00	21.98
	W-CDMA B2	100.0%	16.89	16.80	16.89	16.80	19.46	18.50	19.46	18.50	19.34	18.50	19.34	18.50	N/A	N/A	N/A	N/A	22.90	22.90
	W-CDMA B4	100.0%	19.21	18.20	19.21	18.20	21.69	20.00	21.69	20.00	20.32	20.00	20.32	20.00	N/A	N/A	N/A	N/A	22.90	22.90
	LTE Band 7	100.0%	18.65	18.60	18.65	18.60	19.18	19.20	19.18	19.20	19.18	19.20	19.18	19.20	N/A	N/A	N/A	N/A	22.70	22.70
	LTE Band 25/2	100.0%	16.97	16.80	16.97	16.80	18.64	18.50	18.64	18.50	18.64	18.50	18.64	18.50	N/A	N/A	N/A	N/A	22.90	22.90
	LTE Band 30	100.0%	18.02	17.80	18.02	17.80	19.62	19.30	19.62	19.30	19.62	19.30	19.62	19.30	N/A	N/A	N/A	N/A	22.70	22.70
	LTE Band 41	63.3%	20.79	19.40	18.80	17.41	20.74	20.70	18.76	18.71	20.74	20.70	18.76	18.71	N/A	N/A	N/A	N/A	25.70	23.71
	LTE Band 48	63.3%	22.46	22.30	20.47	20.31	23.95	23.10	21.97	21.11	23.95	23.10	21.97	21.11	N/A	N/A	N/A	N/A	24.70	22.71
	LTE Band 66/4	100.0%	18.25	18.20	18.25	18.20	20.15	20.00	20.15	20.00	20.15	20.00	20.15	20.00	N/A	N/A	N/A	N/A	25.20	25.20
	MSS	100.0%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	24.06	23.50	24.06	23.50	25.80	25.80
	NR n7	100.0%	18.77	18.60	18.77	18.60	19.66	19.20	19.66	19.20	19.40	19.20	19.40	19.20	N/A	N/A	N/A	N/A	22.70	22.70
	NR n25/2	100.0%	16.99	16.80	16.99	16.80	18.83	18.50	18.83	18.50	18.83	18.50	18.83	18.50	N/A	N/A	N/A	N/A	22.90	22.90
	NR n30	100.0%	17.76	17.80	17.76	17.80	20.36	19.30	20.36	19.30	20.36	19.30	20.36	19.30	N/A	N/A	N/A	N/A	22.20	22.20
	NR n41	100.0%	18.18	17.40	18.18	17.40	18.78	18.70	18.78	18.70	18.78	18.70	18.78	18.70	N/A	N/A	N/A	N/A	25.70	25.70
	NR n48	100.0%	20.50	20.30	20.50	20.30	21.21	21.10	21.21	21.10	21.21	21.10	21.21	21.10	N/A	N/A	N/A	N/A	24.70	24.70
	NR n66	100.0%	18.54	18.20	18.54	18.20	20.29	20.00	20.29	20.00	20.29	20.00	20.29	20.00	N/A	N/A	N/A	N/A	25.20	25.20
	NR n70	100.0%	18.78	18.20	18.78	18.20	21.02	20.00	21.02	20.00	21.02	20.00	21.02	20.00	N/A	N/A	N/A	N/A	25.20	25.20
	NR n77	100.0%	20.61	18.50	20.61	18.50	20.88	19.50	20.88	19.50	20.88	19.50	20.88	19.50	N/A	N/A	N/A	N/A	24.70	24.70
ANT 7	LTE Band 48	63.3%	33.43	23.70	31.45	21.71	24.69	21.50	22.70	19.51	23.03	21.50	21.04	19.51	N/A	N/A	N/A	N/A	25.60	23.61
	NR n48	100.0%	31.68	21.70	31.68	21.70	20.81	19.50	20.81	19.50	19.79	19.50	19.79	19.50	N/A	N/A	N/A	N/A	25.60	25.60
	NR n77	100.0%	31.18	21.70	31.18	21.70	20.82	18.60	20.82	18.60	20.50	18.60	20.50	18.60	N/A	N/A	N/A	N/A	26.00	26.00
ANT 8	LTE Band 48	63.3%	22.98	21.50	20.99	19.51	22.47	20.70	20.48	18.71	22.47	20.70	20.48	18.71	N/A	N/A	N/A	N/A	24.70	22.71
	NR n48	100.0%	20.33	19.50	20.33	19.50	19.24	18.70	19.24	18.70	19.24	18.70	19.24	18.70	N/A	N/A	N/A	N/A	24.70	24.70
	NR n77	100.0%	19.41	19.10	19.41	19.10	17.90	17.80	17.90	17.80	17.90	17.80	17.90	17.80	N/A	N/A	N/A	N/A	25.70	25.70
ANT 9	LTE Band 48	63.3%	29.56	22.10	27.58	20.11	21.98	21.20	20.00	19.21	21.24	21.20	19.25	19.21	N/A	N/A	N/A	N/A	25.00	23.01
	NR n48	100.0%	28.15	20.10	28.15	20.10	19.82	19.20	19.82	19.20	19.28	19.20	19.28	19.20	N/A	N/A	N/A	N/A	25.00	25.00
	NR n77	100.0%	29.12	19.30	29.12	19.30	20.96	17.70	20.96	17.70	19.13	17.70	19.13	17.70	N/A	N/A	N/A	N/A	26.00	26.00

5. Power Density Characterization

The EUT's 5G millimeter wave NR contains one Qualcomm millimeter wave antenna modules (module 1), denoted as ANT M1 (module 1), which is installed at one location as shown in the operational description. There is a total of 63 antenna array configurations per band. In this chapter, a hybrid approach of using electromagnetic (EM) simulation and actual measurements to efficiently, and conservatively, characterize the power density profile for the EUT.

5.1. Exposure Scenarios in PD Evaluation

In general, for a smartphone operating at frequencies > 6 GHz, the PD is required to be assessed for all antenna configurations (beams) from all millimeter wave antenna modules installed inside the device. Furthermore, this PD evaluation should be performed at low, mid, and high channels for each supported millimeter wave band.

For this EUT, the 4cm^2 spatially-averaged PD is evaluated along the surfaces (*S1=front, S2=back, S3=left, S4=right, S5=top,* and *S6=bottom* as shown in Figure 5-1) and the worst-case PD is determined by taking the maximum PD among all the evaluated surfaces for each beam/band.

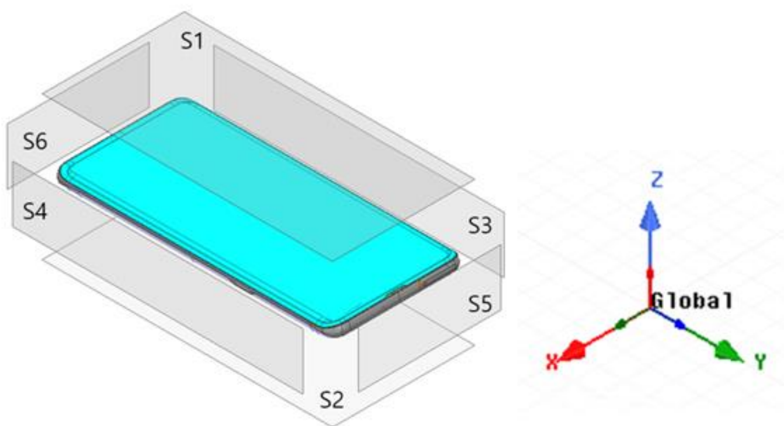


Figure 5-1: EUT surface definition

5.2. PD Characterization Overview

Parameters used in PD Characterization:

- The EUT supports a total of 63 beams per band, where 42 beams are single beams (SISO) and 21 are beam pairs (MIMO) where 2 single beams are excited at the same time.
- ***PD**$_{Design\ Target}$*: The design target for PD compliance as defined in the summary report. It should be less than the FCC PD limit to account for all device design related uncertainties.
- ***P**$_{limit}$*: For a PD characterized wireless device, the input power level at antenna port(s) for each beam corresponding to *PD_design_target*.
- **PD Characterization**: The table that contains the P_{limit} fed to antenna port(s) for all supported beams.

Figure 5-2 outlines the PD Char process.

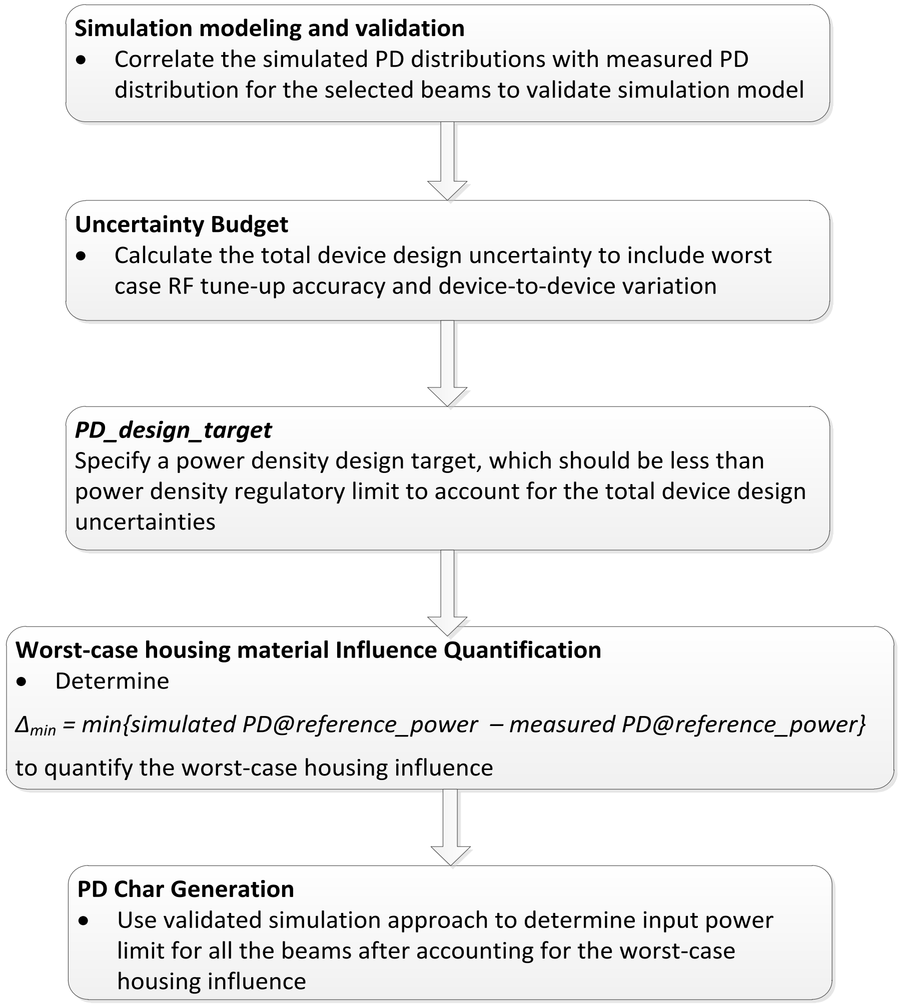


Figure 5-2 High level flow chart for power density characterization

5.3. EUT Codebook

In general, all the beams that the smartphone supports are specified in the pre-defined codebook. The codebook is device design specific and generated after evaluating radiation coverage from this specific device.

Table 5-1 shows all the beams and their relevant information. Note that Module ID 1 correspond to Antenna M1, respectively, in Figure 5-1.

The PD evaluation needs to be performed for all the beams listed in Table 5-1.

Table 5-1: EUT Codebook

n258				
Beam ID	Paired With	Module	Ant Type	# of Elements
0	128	M1	PATCH	1
1	129	M1	PATCH	1
2	130	M1	PATCH	1
3	131	M1	PATCH	1
4	132	M1	PATCH	1
5	133	M1	PATCH	2
6	134	M1	PATCH	2
7	135	M1	PATCH	2
8	136	M1	PATCH	2
9	137	M1	PATCH	2
10	138	M1	PATCH	2
11	139	M1	PATCH	2
12	140	M1	PATCH	5
13	141	M1	PATCH	5
14	142	M1	PATCH	5
15	143	M1	PATCH	5

n260				
Beam ID	Paired With	Module	Ant Type	# of Elements
0	128	M1	PATCH	1
1	129	M1	PATCH	1
2	130	M1	PATCH	1
3	131	M1	PATCH	1
4	132	M1	PATCH	1
5	133	M1	PATCH	2
6	134	M1	PATCH	2
7	135	M1	PATCH	2
8	136	M1	PATCH	2
9	137	M1	PATCH	2
10	138	M1	PATCH	2
11	139	M1	PATCH	2
12	140	M1	PATCH	5
13	141	M1	PATCH	5
14	142	M1	PATCH	5
15	143	M1	PATCH	5

n261				
Beam ID	Paired With	Module	Ant Type	# of Elements
0	128	M1	PATCH	1
1	129	M1	PATCH	1
2	130	M1	PATCH	1
3	131	M1	PATCH	1
4	132	M1	PATCH	1
5	133	M1	PATCH	2
6	134	M1	PATCH	2
7	135	M1	PATCH	2
8	136	M1	PATCH	2
9	137	M1	PATCH	2
10	138	M1	PATCH	2
11	139	M1	PATCH	2
12	140	M1	PATCH	5
13	141	M1	PATCH	5
14	142	M1	PATCH	5
15	143	M1	PATCH	5

n258				
Beam ID	Paired With	Module	Ant Type	# of Elements
16	144	M1	PATCH	5
17	145	M1	PATCH	5
18	146	M1	PATCH	5
19	147	M1	PATCH	5
20	148	M1	PATCH	5
128	0	M1	PATCH	1
129	1	M1	PATCH	1
130	2	M1	PATCH	1
131	3	M1	PATCH	1
132	4	M1	PATCH	1
133	5	M1	PATCH	2
134	6	M1	PATCH	2
135	7	M1	PATCH	2
136	8	M1	PATCH	2
137	9	M1	PATCH	2
138	10	M1	PATCH	2
139	11	M1	PATCH	2
140	12	M1	PATCH	5
141	13	M1	PATCH	5
142	14	M1	PATCH	5
143	15	M1	PATCH	5
144	16	M1	PATCH	5
145	17	M1	PATCH	5
146	18	M1	PATCH	5
147	19	M1	PATCH	5
148	20	M1	PATCH	5

n260				
Beam ID	Paired With	Module	Ant Type	# of Elements
16	144	M1	PATCH	5
17	145	M1	PATCH	5
18	146	M1	PATCH	5
19	147	M1	PATCH	5
20	148	M1	PATCH	5
128	0	M1	PATCH	1
129	1	M1	PATCH	1
130	2	M1	PATCH	1
131	3	M1	PATCH	1
132	4	M1	PATCH	1
133	5	M1	PATCH	2
134	6	M1	PATCH	2
135	7	M1	PATCH	2
136	8	M1	PATCH	2
137	9	M1	PATCH	2
138	10	M1	PATCH	2
139	11	M1	PATCH	2
140	12	M1	PATCH	5
141	13	M1	PATCH	5
142	14	M1	PATCH	5
143	15	M1	PATCH	5
144	16	M1	PATCH	5
145	17	M1	PATCH	5
146	18	M1	PATCH	5
147	19	M1	PATCH	5
148	20	M1	PATCH	5

n261				
Beam ID	Paired With	Module	Ant Type	# of Elements
16	144	M1	PATCH	5
17	145	M1	PATCH	5
18	146	M1	PATCH	5
19	147	M1	PATCH	5
20	148	M1	PATCH	5
128	0	M1	PATCH	1
129	1	M1	PATCH	1
130	2	M1	PATCH	1
131	3	M1	PATCH	1
132	4	M1	PATCH	1
133	5	M1	PATCH	2
134	6	M1	PATCH	2
135	7	M1	PATCH	2
136	8	M1	PATCH	2
137	9	M1	PATCH	2
138	10	M1	PATCH	2
139	11	M1	PATCH	2
140	12	M1	PATCH	5
141	13	M1	PATCH	5
142	14	M1	PATCH	5
143	15	M1	PATCH	5
144	16	M1	PATCH	5
145	17	M1	PATCH	5
146	18	M1	PATCH	5
147	19	M1	PATCH	5
148	20	M1	PATCH	5

5.4. Simulation and modeling validation

5.4.1. Modeling for Simulation

Device modeling is described in the *5G Product mmWave MPE Simulation Report* exhibit.

5.4.2. Modeling Validation

To validate modeling and simulation:

1. Select one beam (i.e., antenna array configuration) per antenna type (dipole/patch) and per antenna module. All three antennas contain only patch arrays. Therefore, the beam selection criteria for each millimeter wave antenna are:

   a) Two beams from each antenna module.

   Note: Since the relative phase between two single beams in a beam pair is uncontrolled and could vary from run to run, for the validation purpose, the selection is limited to the single beam antenna array configuration. Additionally, single beam containing a higher number of active antenna elements is selected. For example, a single beam with four active patches should be selected over beam with a single active patch antenna beam.

2. For a given input power, perform both PD simulation and PD measurement to obtain the simulated PD distributions and measured PD distributions on the surface in front of the antenna array as well as the surfaces that are adjacent to the antenna array as they could potentially have strong radiating energy when considering the orientation of antenna array and type of antenna array (i.e., patch array or dipole array).

3. Validate modeling and simulation by correlating the simulated PD distribution and measured PD distribution for all antenna array configurations selected in Step 1 and for all surfaces selected in Step 2.

The modeling validation is performed through correlating the simulated point PD distribution to measured point PD distribution.

The difference in 4cm^2-avg PD is not used for the purpose of validity of the modeling because the housing material property (for non-metal material) used in the simulation is an approximation (note the accurate material properties are not available at millimeter wave frequencies). This discrepancies in PD magnitude will be used to determine the worst-case housing influence (due to non-metal material property uncertainty) in §5.6. The worst-case housing influence will be accounted for in PD Characterization generation for conservative RF exposure assessment, see §5.7 for details.

Based on the selection criteria described in Step 1 and Step 2, the beams and surfaces selected for modeling validation of the EUT are listed in Table 5-2.

Table 5-2: Beams and surfaces selection for PD correlation

Band	Beam ID	Antenna	Pol	Surface
n258	14	M1	V	S2
	148		H	S2
n260	19	M1	V	S2
	146		H	S2
n261	20	M1	V	S2
	140		H	S2

With an input power of 6 dBm for n258, n260, and n261,PD measurement and PD simulation are conducted for all beams and surfaces listed in Table 5-2. Both PD measurement and PD simulation are performed at mid channel of each millimeter wave beam, PD measurement is conducted with CW modulation.

- PD distribution:

  Please refer to the operational description.

- 4cm^2-averaged PD value

  Table 5-3 lists the measured 4cm^2-averaged PD and simulated 4cm^2-averaged PD for all selected beams and surfaces for n258, n260, and n261 bands. The discrepancy between simulated and measured PD value will be used to determine worst-case housing influence for conservative assessment (see §5.6).

Table 5-3: Measured and simulated 4cm^2 averaged PD for selected beams with 6 dBm input power for n258, n260, and n261

Band	Beam ID	Antenna	Pol	Surface	4cm^2 avg. PD (W/m^2)		Delta[1]
					Meas.	Sim	
n258	14	M1	V	S2	16.70	20.78	**0.95**
	148		H	S2	17.70	20.48	**0.63**
n260	19	M1	V	S2	8.31	17.96	**3.35**
	146		H	S2	8.99	17.80	**2.97**
n261	20	M1	V	S2	11.80	19.34	**2.15**
	140		H	S2	12.50	25.01	**3.01**

[1]Delta = Sim - Meas (dB)

5.4.3. Simulation for power density

The model is validated in §5.4.3, the PD exposure of EUT can be reliably assessed using the validated simulation approach.

In general, all six surfaces of the EUT, as shown in Figure 4-2, should be assessed for RF exposure from the millimeter wave radio and the worst-case PD should be determined by:

$$\boldsymbol{PD_{worst\text{-}case}} = \max \{PD_{s1}, PD_{s2}, PD_{s3}, PD_{s4}, PD_{s5}, PD_{s6}\} \quad (1)$$

where PD_{s1}, PD_{s2}, PD_{s3}, PD_{s4}, PD_{s5}, PD_{s6} are the highest 4cm^2-avgeraged PD on surface S1, S2, S3, S4, S5 and S6 of the device. respectively.

However, depending on the location of the millimeter wave module and the antenna array orientation relative to the surface of the device, one or more surface(s) can be excluded for PD calculation as the PD value(s) on the excluded surface(s) will be undoubtedly lower when comparing to other surfaces; thus, the exclusion will have no impact for the worst-case PD determined using Equation 1.

For this EUT, based on the location of M1 (shown in the operational description) and the type of antenna array (containing in each millimeter wave Ant), the surface planes identified for PD evaluation to determine the worst-case PD are selected and listed in Table 5-4.

Table 5-4: PD evaluation plane

ANT	Front	Back	Left	Right	Top	Bottom
	S1	S2	S3	S4	S5	S6
M1	No	Yes	Yes	No	Yes	No

The EM simulation is performed to characterize PD at low, mid, and high channels for each supported band. The simulation setup (mesh, convergence criteria, and radiation boundary settings) as described in the operational description, ensures the accurate and reliable result for PD simulation on the planes identified. Both point PD and 4cm^2-averaged PD distributions on the worst surface plane (i.e., the surface having highest PD value for the beam tested) are plotted and provided in the operational description to show that the PD hotspots are captured in this analysis.

5.5. $PD_{Design\ Target}$

The manufacturer has their own internal controls for managing uncertainty for use in determining the $PD_{Design\ Target}$ using Qualcomm's modules.
To account for the total design related uncertainty, $PD_{Design\ Target}$ needs to be:

$$PD_{Design\ Target} < PD_{regulatory\_limit} \times 10^{\frac{-total\ uncertainty}{10}}$$

With FCC's 4cm^2-averaged PD requirement of 10 W/m^2, the $PD_{Design\ Target}$ is determined as:

$PD_{Design\ Target}$ (W/m^2)	$PD_{Design\ Limit}$ (W/m^2)
3.9	6.3

5.6. Worst-case Housing Influence Determination

For non-metal material, the material property cannot be accurately characterized at millimeter wave 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 millimeter wave antenna modules are placed at different locations, as shown in the operational description, only material/housing have an impact on EM field propagation, and, in turn, impact on 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 EUT, when comparing a simulated 4cm^2-avgeraged PD and measured 4 cm^2-avgerated PD, the worst error introduced for each type of antenna array and antenna module when using the estimated material property in the simulation is accented in bold numbers in Table 5-5. Thus, the worst-case housing influence, denoted as $\Delta_{min} = \text{Sim. PD} - \text{Meas. PD}$, is determined as:

Table 5-5: Δ_{min} for M1

Band	Ant	Pol	Δ_{min} (dB)
n258	M1	V	**0.95**
		H	**0.63**
n260	M1	V	**3.35**
		H	**2.97**
n261	M1	V	**2.15**
		H	**3.01**

Δ_{min} represents the worst case where RF exposure is underestimated the most in simulation when using the estimated material property for glass/plastics 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 beam group to determine input power limits in PD char for compliance (see §5.7.3 for details).

5.7. PD Characterization

This section describes the PD Characterization generation that complies with the $PD_{Design\ Target}$ determined in §5.5 and complies the regulatory power density limit.

5.7.1. Scaling Factor for Single Beams

To determine the P_{limit} at each antenna port, perform the simulation at low, mid, and high channel for each mmW band supported, with a given input power per active port:

1. Obtain $PD_{surface}$ value (the worst PD among all identified surfaces of the EUT) at all three channels for all single beams specified in the codebook of Table 5-1.

2. Derive a scaling factor at low, mid and high channel, $s(i)_{low\_or\_mid\_or\_high}$, by:

$$s(i)_{low\_or\_mid\_or\_high} = \frac{PD\ design\ target}{sim.PD_{surface}(i)},\ i \in single\ beams \quad (2)$$

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

$$s(i) = min\left\{s_{low}(i), s_{mid}(i), s_{high}(i)\right\},\ i \in single\ beams \quad (3)$$

4. Determine the simulated P_{limit}, $sim.power_{limit}$, for single beam i by:

$$sim.power_{limit} = 10 * log_{10}\big(s(i)\big) + sim.input.power.at.active.port, i \in single\ beams \quad (4)$$

In the above equation, power is expressed in units of (dBm)

NOTE: $P_{ref}(i)$ = *sim.input.power.at.active.port(i)*

5.7.2. Scaling Factor for Beam Pairs

The relative phase between beam pair is not controlled in the modem's design and could vary from run to run. Therefore, for a beam pair, based on the simulation results, the worst-case scaling factor needs to be determined mathematically to ensure compliance.

For a beam pair, extract the E-fields and H-fields from the corresponding single beams at low, mid, and high channel for each supported band and for all identified surfaces of the EUT.

For a given beam pair containing $beam_a$ and $beam_b$, and for a given channel, let relative phase between $beam_a$ and $beam_b$ = ∅, and the total PD of the beam pair can be expressed as:

$$total\ PD\ (\emptyset) = \frac{1}{2}\sqrt{Re\{PD_x(\emptyset)\}^2 + Re\{PD_y(\emptyset)\}^2 + Re\{PD_z(\emptyset)\}^2}$$
$$= \tfrac{1}{2} Re\left\{\left(\overrightarrow{E_a} + \overrightarrow{E_b e^{j\omega\emptyset}}\right) \times \left(\overrightarrow{H_a} + \overrightarrow{H_b e^{j\omega\emptyset}}\right)^*\right\} \quad (5)$$

where, $PD_x(\emptyset)$, $PD_y(\emptyset)$, and $PD_z(\emptyset)$ are the three components of the $total\ PD\ (\emptyset)$; E_a and H_a are the extracted E-fields and H-fields of $beam_a$, while E_b and H_b are the extracted E-fields and H-fields of $beam_b$.

Sweep ∅ with a 5° step from 0° to 360° to determine the worst-case, $\emptyset_{worstcase}$, which results in the highest $total\ PD\ (\emptyset)$ among all identified surfaces for this beam pair at this channel. For details on the worst case $total\ PD\ (\emptyset)$ derivation, see Appendix A.

Follow the above procedure to determine $\emptyset_{worstcase}$ for all three channels to obtain the scaling factor given by the equation below for low, mid, and high channels:

$$s(i)_{low\_or\_mid\_or\_high} = \frac{PD\ design\ target}{total\ PD\ (\emptyset(i)_{worstcase})}, i \in beam\ pairs \quad (6)$$

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

$$s(i) = min\{s_{low}(i), s_{mid}(i), s_{high}(i)\},\ i \in beam\ pairs \quad (7)$$

The simulated P_{limit}, $sim.power_{limit}$, for beam pair i can be determined by:

$$sim.power_{limit} = 10 * log_{10}\big(s(i)\big) + sim.input.power.at.active.port, i \in beam\ pairs \quad (8)$$

In the above equation, power is expressed in units of (dBm)

NOTE: $P_{ref}(i)$ = *sim.input.power.at.active.port(i)*

5.7.3. Input Power Limit

The PD Characterization specifies the limit of input power at an antenna port that corresponds to $PD_{Design\ Target}$ for all beams.

Ideally, if there is no uncertainty associated with hardware design, P_{limit}, denoted as $P_{limit}\ (i)$, for beam *i* can be obtained after accounting for the housing influence (Δ_{min}) determined in Table 5-5 of §5.6, given by:

$$P_{limit}\ (i) = sim.power_{limit}(i) + \Delta_{min},\ i \in all\ beams \quad (8)$$

In the above equation, power is expressed in units of (dBm)

The term $sim.power_{limit}(i)$ includes the design uncertainty, the TxAGC uncertainty, and the scaling factor obtained from Eq. (4) or Eq. (8) for beam *i*; the term Δ_{min} is the worst-case housing influence factor (determined in Table 5-5) 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.

The hardware design has uncertainty which must be properly considered. In §5.6, the TxAGC uncertainty is embedded in the process of Δ_{min} determination. Since TxAGC uncertainty is already accounted for in $PD_{Design\ Target}$ (see §5.5), it needs to be removed to avoid double counting this uncertainty.

Thus, Equation 8 is modified to:

If -TxAGC uncertainty < Δ_{min} < TxAGC uncertainty,

$$input.power.limit(i) = sim.power_{limit}(i),\ i \in all\ beams \quad (9)$$

else if Δ_{min} < -TxAGC uncertainty,

$$input.power.limit(i) = sim.power_{limit}(i) + (\Delta_{min} + \text{TxAGC uncertainty}), i \in all\ beams \quad (10)$$

else if Δ_{min} > TxAGC uncertainty,

$$input.power.limit(i) = sim.power_{limit}(i) + (\Delta_{min} - \text{TxAGC uncertainty}), i \in all\ beams \quad (11)$$

In the above three equations, power is expressed in units of (dBm)

Following the logic above, P_{limit} for this EUT can be calculated using Equations (9), (10) and (11), i.e.,

Table 5-6: P_{limit} calculation

Band	Ant	Pol	Δ_{min} (dB)	Notes
n258	M1	V	**0.95**	Using Eq. 9
		H	**0.63**	Using Eq. 9
n260	M1	V	**3.35**	Using Eq. 11
		H	**2.97**	Using Eq. 11
n261	M1	V	**2.15**	Using Eq. 11
		H	**3.01**	Using Eq. 11

Thus, the EUT PD Char for n258, n260, and n261 bands are as shown in Table 5-7.

Table 5-7: PD Characterization

n258			n260			n261		
Paired ID (Beam Pair)	Beam ID	P_{Limit} (dBm)	Paired ID (Beam Pair)	Beam ID	P_{Limit} (dBm)	Paired ID (Beam Pair)	Beam ID	P_{Limit} (dBm)
N/A	0	7.7	N/A	0	7.3	N/A	0	6.7
	1	6.8		1	7.7		1	6.7
	2	8.7		2	7.5		2	6.1
	3	6.5		3	7.6		3	6.9
	4	7.7		4	6.8		4	6.3
	5	6.4		5	4.5		5	3.4
	6	3.1		6	3.9		6	3.0
	7	3.7		7	4.2		7	3.1
	8	3.4		8	5.0		8	3.7
	9	4.9		9	5.0		9	3.2
	10	2.9		10	4.0		10	2.6
	11	3.0		11	4.6		11	3.3
	12	1.8		12	1.8		12	-1.0
	13	-0.3		13	0.6		13	-0.9
	14	-1.2		14	0.3		14	-1.0
	15	-1.1		15	0.1		15	-1.1
	16	0.0		16	1.7		16	-0.8
	17	0.6		17	0.9		17	-0.9
	18	-0.9		18	0.7		18	-0.9
	19	-0.9		19	-0.1		19	-0.8
	20	-0.8		20	0.3		20	-1.1
	128	8.7		128	7.6		128	6.5
	129	7.0		129	7.8		129	6.5
	130	7.1		130	7.7		130	7.1
	131	6.0		131	7.4		131	5.9
	132	7.4		132	6.6		132	5.9
	133	4.0		133	4.1		133	3.2
	134	4.8		134	4.7		134	2.2
	135	2.9		135	4.7		135	2.0
	136	3.5		136	4.5		136	4.4
	137	5.2		137	4.6		137	2.7
	138	3.9		138	3.7		138	2.4
	139	2.2		139	4.4		139	3.4
	140	0.6		140	0.7		140	-2.0
	141	-0.8		141	0.3		141	-1.5
	142	-0.9		142	0.7		142	-1.8
	143	-1.2		143	1.1		143	-1.3
	144	-0.9		144	2.6		144	-0.9
	145	-0.7		145	0.4		145	-1.7
	146	-0.8		146	0.2		146	-1.7
	147	-1.0		147	1.0		147	-1.7
	148	-1.3		148	1.3		148	-1.3

n258			n260			n261		
Paired ID (Beam Pair)	Beam ID	P_{Limit} (dBm)	Paired ID (Beam Pair)	Beam ID	P_{Limit} (dBm)	Paired ID (Beam Pair)	Beam ID	P_{Limit} (dBm)
128	0	4.7	128	0	4.0	128	0	3.1
129	1	3.0	129	1	3.9	129	1	2.7
130	2	4.0	130	2	3.8	130	2	3.1
131	3	2.9	131	3	3.7	131	3	2.6
132	4	3.8	132	4	3.1	132	4	2.6
133	5	2.1	133	5	0.6	133	5	0.2
134	6	0.9	134	6	1.4	134	6	0.0
135	7	0.1	135	7	0.9	135	7	-0.9
136	8	-0.5	136	8	2.7	136	8	0.1
137	9	1.2	137	9	1.3	137	9	0.2
138	10	-0.1	138	10	0.5	138	10	-0.7
139	11	-1.0	139	11	2.2	139	11	0.8
140	12	-2.6	140	12	-2.8	140	12	-4.8
141	13	-4.3	141	13	-3.2	141	13	-4.5
142	14	-4.4	142	14	-2.8	142	14	-4.7
143	15	-4.6	143	15	-2.9	143	15	-4.8
144	16	-3.9	144	16	-1.6	144	16	-4.5
145	17	-4.0	145	17	-3.2	145	17	-4.6
146	18	-4.4	146	18	-3.0	146	18	-4.7
147	19	-4.4	147	19	-2.8	147	19	-4.5
148	20	-4.3	148	20	-2.9	148	20	-4.8

A Worst Phase Derivation for Beam Pair

For beam pairs, since the relative phase between two beams is unknown, finding the worst-case PD by sweeping the relative phase for all possible angles is required for conservative assessment.

Assuming E-field and H-field of $beam_a$ are {$Ex_{\_a}$, $Ey_{\_a}$, $Ez_{\_a}$} and {$Hx_{\_a}$, $Hy_{\_a}$, $Hz_{\_a}$}, respectively; E-field and H-field of $beam_b$ are {$Ex_{\_b}$, $Ey_{\_b}$, $Ez_{\_b}$} and {$Hx_{\_b}$, $Hy_{\_b}$, $Hz_{\_b}$}, respectively; and the relative phase is ∅, for beam pair consisting of $beam_a$ and $beam_b$, the combined E- and H-fields, {$Ex_{\_pair\_i}$, $Ey_{\_pair\_i}$, $Ez_{\_pair\_i}$} and {$Hx_{\_pair\_i}$, $Hy_{\_pair\_i}$, $Hz_{\_pair\_i}$}, can be expressed as:

$$Ex(\emptyset)_{\_pair\_i} = E_{x\_a} + E_{x\_b} \times e^{-j\omega\emptyset}$$
$$Ey(\emptyset)_{\_pair\_i} = E_{y\_a} + E_{y\_b} \times e^{-j\omega\emptyset}$$
$$Ez(\emptyset)_{\_pair\_i} = E_{z\_a} + E_{z\_b} \times e^{-j\omega\emptyset}$$

$$Hx(\emptyset)_{\_pair\_i} = H_{x\_a} + H_{x\_b} \times e^{-j\omega\emptyset}$$
$$Hy(\emptyset)_{\_pair\_i} = H_{y\_a} + H_{y\_b} \times e^{-j\omega\emptyset}$$
$$Hz(\emptyset)_{\_pair\_i} = H_{z\_a} + H_{z\_b} \times e^{-j\omega\emptyset}$$

The combined PD can then be calculated:

$$PDx(\emptyset)_{pair\_i} = Ey(\emptyset)_{\_pair\_i} \times Hz(\emptyset)^*_{pair\_i} - Ez(\emptyset)_{\_pair\_i} \times Hy(\emptyset)^*_{\_pair\_i}$$
$$PDy(\emptyset)_{\_pair\_i} = Ez(\emptyset)_{\_pair\_i} \times Hx(\emptyset)^*_{\_pair\_i} - Ex(\emptyset)_{\_pair\_i} \times Hz(\emptyset)^*_{\_pair\_i}$$
$$PDz(\emptyset)_{\_pair\_i} = Ex(\emptyset)_{\_pair\_i} \times Hy(\emptyset)^*_{\_pair\_i} - Ey(\emptyset)_{\_pair\_i} \times Hx(\emptyset)^*_{\_pair\_i}$$

$$PD(\emptyset) = \frac{1}{2}\sqrt{Re\{PDx(\emptyset)\}^2_{\_pair\_i} + Re\{PDy(\emptyset)\}^2_{\_pair\_i} + Re\{PDz(\emptyset)\}^2_{\_pair\_i}}$$

Sweep ∅ from 0 degree to 360 degree to find the highest PD (out of low, mid, and high channel) and its corresponding ∅, $\emptyset_{worstcase}$, for all the beam pairs specified in the *codebook_sim*. The worst-case scaling factor *s(i)* for beam pair should be determined with $\emptyset(i)_{worstcase}$.

B Simulated Input Power Limit

Table B-1 lists input power limit per channel per band for all the beams that EUT supports.

Table B-1: Simulated P_{limit} for n258, n260, and n261

n258					n260					n261				
Paired ID (Beam Pair)	Beam ID	Low	Mid	High	Paired ID (Beam Pair)	Beam ID	Low	Mid	High	Paired ID (Beam Pair)	Beam ID	Low	Mid	High
N/A	0	1.93	2.33	2.69	N/A	0	2.07	3.52	3.28	N/A	0	3.40	3.21	3.09
	1	3.29	3.17	2.83		1	1.77	3.20	3.22		1	3.38	3.42	3.42
	2	1.99	2.08	2.14		2	2.13	3.13	3.41		2	3.62	3.82	3.95
	3	2.70	3.27	3.55		3	1.91	3.33	3.32		3	3.08	3.11	3.22
	4	2.72	2.59	2.60		4	3.46	4.00	3.86		4	3.25	3.45	3.70
	5	3.37	3.46	3.66		5	5.69	6.73	6.14		5	7.26	6.65	6.44
	6	6.48	7.24	7.83		6	5.41	7.78	7.43		6	7.93	7.51	7.17
	7	6.73	6.68	6.35		7	4.13	6.69	7.14		7	6.88	7.29	7.77
	8	6.84	7.33	7.24		8	3.57	5.97	5.86		8	6.74	6.26	5.94
	9	4.78	4.93	5.20		9	3.20	6.03	5.91		9	7.63	7.36	7.13
	10	7.31	8.12	8.17		10	4.06	7.15	7.64		10	8.05	8.31	8.81
	11	7.03	7.46	8.02		11	3.91	6.52	6.49		11	7.47	6.83	6.43
	12	9.64	10.54	10.58		12	10.34	12.46	12.00		12	19.90	18.79	18.76
	13	15.59	16.72	16.98		13	10.14	16.35	15.79		13	19.54	19.26	19.33
	14	19.38	20.78	21.18		14	9.83	15.99	17.63		14	19.82	19.16	19.00
	15	17.41	19.32	20.56		15	10.93	17.84	18.69		15	20.03	20.04	20.53
	16	14.20	15.17	16.05		16	7.12	11.24	12.94		16	15.15	17.42	19.35
	17	12.53	13.56	13.84		17	10.94	15.41	15.42		17	19.52	18.56	18.62
	18	17.80	19.19	19.65		18	9.92	15.93	16.18		18	19.58	19.28	19.04
	19	17.58	19.02	19.73		19	10.14	17.96	19.29		19	19.29	19.02	19.24
	20	16.18	17.94	19.34		20	11.10	17.26	17.68		20	17.54	19.34	20.75
	128	1.94	1.95	2.16		128	2.44	3.57	3.27		128	3.65	3.61	3.67
	129	2.47	2.92	3.19		129	1.88	3.37	3.20		129	3.68	3.59	3.50
	130	3.06	3.12	3.03		130	1.99	3.40	3.46		130	3.23	3.20	3.21
	131	2.98	3.58	4.04		131	2.30	3.73	3.60		131	4.21	4.20	4.21
	132	2.85	2.79	2.92		132	2.76	4.43	4.32		132	4.17	4.23	4.10
	133	4.82	5.49	6.29		133	5.32	7.98	7.74		133	7.75	7.76	7.85
	134	5.13	5.21	5.22		134	4.23	6.92	6.78		134	9.83	9.81	9.65
	135	7.05	7.73	8.12		135	3.82	6.84	6.86		135	10.32	10.26	9.82
	136	5.53	6.30	7.06		136	5.03	7.29	6.51		136	5.67	5.79	5.98
	137	4.76	4.84	4.86		137	4.29	7.06	6.74		137	8.34	8.63	8.85
	138	6.19	6.40	6.51		138	4.46	8.28	8.75		138	9.41	8.97	8.16
	139	8.30	8.96	9.50		139	4.65	7.36	6.87		139	6.49	6.98	7.57
	140	10.15	12.35	14.00		140	11.31	17.48	16.05		140	26.12	25.01	23.75
	141	17.16	18.32	19.32		141	10.53	18.81	18.98		141	22.91	22.31	21.42
	142	16.84	18.24	19.43		142	8.94	16.19	17.32		142	24.69	23.71	22.02
	143	18.10	19.63	21.02		143	9.64	15.98	15.52		143	21.55	22.15	21.87
	144	18.11	19.32	19.80		144	7.23	10.23	11.20		144	13.92	17.05	20.05
	145	16.00	17.50	18.69		145	11.43	18.77	17.96		145	23.96	23.3	22.23
	146	16.84	18.09	19.18		146	9.68	17.80	19.35		146	24.02	22.07	20.51
	147	17.47	18.86	20.17		147	10.04	16.18	15.69		147	24.13	23.65	21.88
	148	18.95	20.48	21.25		148	9.36	14.47	15.08		148	21.11	22.13	22.29

n258			n260			n261		
Paired ID (Beam Pair)	Beam ID	Worst Case Sim Beam Pair	Paired ID (Beam Pair)	Beam ID	Worst Case Sim Beam Pair	Paired ID (Beam Pair)	Beam ID	Worst Case Sim Beam Pair
128	0	5.36	128	0	7.50	128	0	7.80
129	1	7.99	129	1	7.66	129	1	8.61
130	2	6.29	130	2	7.95	130	2	7.86
131	3	8.24	131	3	8.15	131	3	8.75
132	4	6.69	132	4	9.34	132	4	8.74
133	5	9.77	133	5	16.68	133	5	15.29
134	6	12.96	134	6	13.70	134	6	15.77
135	7	15.50	135	7	15.26	135	7	19.71
136	8	17.90	136	8	10.30	136	8	15.71
137	9	12.02	137	9	13.98	137	9	15.08
138	10	16.27	138	10	17.06	138	10	18.55
139	11	20.00	139	11	11.50	139	11	13.39
140	12	28.84	140	12	36.48	140	12	48.52
141	13	43.13	141	13	39.41	141	13	44.92
142	14	43.68	142	14	36.30	142	14	46.82
143	15	45.83	143	15	37.14	143	15	47.93
144	16	39.54	144	16	27.49	144	16	45.27
145	17	40.05	145	17	40.08	145	17	45.60
146	18	43.44	146	18	38.01	146	18	47.20
147	19	44.03	147	19	36.17	147	19	45.38
148	20	42.46	148	20	37.02	148	20	48.20

END OF REPORT