RF Exposure Report

(Part 0: SAR and PD Char Evaluation)

FCC ID	**: IHDT56AA6**
Equipment	**: Wearable Cellular Device**
Brand Name	**: Motorola**
Model Name	**: XT2209-1**
Applicant	**: Motorola Mobility, LLC 222 W Merchandise Mart Plaza, Suite 1800, Chicago, IL 60654, United States**
Standard	**: FCC 47 CFR Part 2 (2.1093)**

We, SPORTON INTERNATIONAL INC., would like to declare that the tested sample has been evaluated in accordance with the test procedures and has been in compliance with the applicable technical standards.

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Approved by: Cona Huang / Deputy Manager

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History of this test report

Report No.	Version	Description	Issued Date
FA1O2008A	01	Initial issue of report	Dec. 03, 2021

1. Introduction

The FCC RF exposure limit is defined based on time-averaged RF exposure. The product implements Qualcomm Smart Transmit feature which controls the instantaneous transmitting power for WWAN transmitter sto ensure the product in compliance with FCC RF exposure limit over a defined time window, for SAR (transmit frequency ≤ 6GHz) and power density (transmit frequency > 6GHz). to control and manage transmitting power in real time and to ensure at all times the time-averaged RF exposure is compliant to the regulation requirement. Cannot operat without SAR and PD characterization at the device level, beforehand.

This report describes the procedures for the SAR char and PD char generation, and the parameters obtained from SAR and PD characterization (reffered to as SAR char and PD char, respectively) will be used as input for Smart Transmit. Both SAR char and PD char will be entered via the Embedded File System (EFS) to enable the Smart Transmit Feature.

Terminologies in this report

P_{limit}	The time-averaged RF power which corresponds to SAR_design_target.
P_{max}	Maximum target power level
SAR_design_target:	The design target for SAR compliance. It should be less than regulatory power density limit to account for all device design related uncertainties.
SAR char	P_{limit} for all the technologies/bands for all applicable DSI
PD_design_target:	The design target for PD compliance. It should be less than regulatory power density limit to account for all device design related uncertainties.
input.power.limit	For a PD characterized wireless device, the input power level at antenna port(s) for each beam corresponding to PD_design_target.
PD char	The table that contains input.power.limit fed to antenna port(s) for all supported beams.

2. Product Description

Product Feature & Specification	
Equipment Name	Wearable Cellular Device
FCC ID	IHDT56AA6
Wireless Technology and Frequency Range	LTE Band 2: 1850 MHz ~ 1910 MHz LTE Band 4: 1710 MHz ~ 1755 MHz LTE Band 5: 824 MHz ~ 849 MHz LTE Band 13: 777 MHz ~ 787 MHz LTE Band 48: 3550 MHz ~ 3700 MHz LTE Band 66: 1710 MHz ~ 1780 MHz 5G NR n2 : 1850 MHz ~ 1910 MHz 5G NR n5 : 824 MHz ~ 849 MHz 5G NR n66 : 1710 MHz ~ 1780 MHz 5G NR n77: 3700 MHz ~ 3980 MHz 5G NR n260: 37GHz ~ 40GHz 5G NR n261: 27.5GHz ~ 28.35GHz WLAN 2.4 GHz Band: 2400 MHz ~ 2483.5 MHz WLAN 5.2 GHz Band: 5150 MHz ~ 5250 MHz WLAN 5.3 GHz Band: 5250 MHz ~ 5350 MHz WLAN 5.6 GHz Band: 5470 MHz ~ 5725 MHz WLAN 5.8 GHz Band: 5725 MHz ~ 5850 MHz WLAN 6 GHz: 5925 MHz ~ 6425 MHz, 6425 MHz ~ 6525 MHz, 6525 MHz ~ 6875 MHz, 6875 MHz ~ 7125 MHz Bluetooth: 2400 MHz ~ 2483.5 MHz
Mode	LTE: QPSK, 16QAM, 64QAM, 256QAM 5G NR: DFT-s-OFDM/CP-OFDM, Pi/2 BPSK/QPSK/16QAM/64QAM/256QAM WLAN: 802.11a/b/g/n/ac/ax HT20/HT40/VHT20/VHT40/VHT80/VHT160/HE20/HE40/HE80/HE160 Bluetooth BR/EDR/LE

3. SAR Characterization

SAR char must be generated to cover all radio configurations and usage scenarios that the wireless device supports for operating at 6 GHz or below. It will then be used as input for Smart Transmit to control and manage RF exposure for f < 6 GHz.

3.1 SAR design target and uncertainty

Trigger condition

Exposure conditions	Trigger Conditions	DSI
Body	Proximity Sensor off	2
	Body Sensor detected (Frontpod not detected, RearPod detected)	3
	Sensor detected (Frontpod detected, RearPod not detected)	4
	Body Sensor detected (Frontpod detected, RearPod detected)	5

SAR design target

SAR design target	
WWAN Ant 0_1g SAR design Target (W/kg)	1.07
WWAN Ant 1_1g SAR design Target (W/kg)	1.13

	Uncertainty dB (k=2)
Device to device uncertainty	1.2
TXAGC uncertainty	1.0
Total uncertainty	1.5

To account for total uncertainty, SAR_design_target should be determined as:

$$SAR\_design\_target < SAR_{regulatory\_limit} \times 10^{\frac{-total\ uncertainty}{10}}$$

3.2 SAR Char Table

SAR char must be generated to cover all radio configurations and usage scenarios that the wireless device supports for operating at 6 GHz or below. It will then be used as input for Smart Transmit to control and manage RF exposure for f < 6 GHz

Plimit Table

Band	Antenna	Duty Cycle (%)	Body Sensor not detected	Body Sensor detected (Frontpod not detected, RearPod detected)	Body Sensor detected (Frontpod detected, RearPod not detected)		Body Sensor detected (Frontpod detected, RearPod detected)		Pmax
			(DSI2)	(DSI3)	(DSI4)		(DSI5)		
					WIFI OFF	WIFI On_Back Off level(dB)	WIFI OFF	WIFI On_Back Off level(dB)	
LTE Band 2	Ant 0	100%	31	31	31	-	31	-	23
LTE Band 4	Ant 0	100%	37	37	37	-	37	-	23
LTE Band 5	Ant 0	100%	30	21.8	30	-	21.8	-	23
LTE Band 13	Ant 0	100%	29	25	29	-	25	-	23
LTE Band 48	Ant 0	63.3%	31	20.5	31	-	20.5	-	21
FR1 n2	Ant 0	100%	31	25	31	-	25	-	23
FR1 n5	Ant 0	100%	32	25	32	-	25	-	23
FR1 N77 PC3	Ant 0	100%	31	19.5	31	-	19.5	-	23
FR1 N77 PC2	Ant 0	50%	31	19.5	31	-	19.5	-	23
LTE Band 2	Ant 1	100%	28	28	15.5	13	15.5	13	23
LTE Band 66	Ant 1	100%	30	30	15.5	13	15.5	13	23
LTE Band 48	Ant 1	100%	28	30	14.5	13	14.5	13	21
FR1 n2	Ant 1	100%	28	28	14.5	13	14.5	13	23
FR1 n66	Ant 1	100%	32	32	16.5	13	16.5	13	23
FR1 N77 PC3	Ant 1	100%	26	26	14.5	13	14.5	13	23
FR1 N77 PC2	Ant 1	50%	26	26	14.5	13	14.5	13	23
FR1 N77 PC3	Ant 2 (SRS)	100%	26	26	17	13	17	13	23
FR1 N77 PC2	Ant 2 (SRS)	50%	26	26	17	13	17	13	23
FR1 N77 PC3	Ant 3 (SRS)	100%	28	28	16	13	16	13	23
FR1 N77 PC2	Ant 3 (SRS)	50%	28	28	16	13	16	13	23

1. Pmax is used for RF tune up procedure. The maximum allowed output power is equal to Pmax + TXAGC uncertainty.
2. All Plimit / Pmax power levels entered in the Table correspond to average power levels after accounting for duty cycle in the case TDD modulation schemes (for e.g., GSM & LTE TDD & NR TDD).
3. The Plimit values, corresponding to SAR_design_target.
4. Maximum target power, P_{max}, is configured in NV settings in EUT to limit maximum transmitting power. This power is converted into peak power in NV settings for TDD schemes. The EUT maximum allowed output power is equal to P_{max} + 1.0dB TXAGC uncertainty.
5. Ant 2 and Ant 3 are used as SRS dedicated antennas, i.e., the antenna(s) are used for receive and Sound Reference Signal transmission (SRS) only (not traffic transmission).

4. Power Density Characterization

The device with 5G mmW NR typically supports many beams and contains multiple mmW antenna arrays installed at different locations to achieve good coverage in the field. The power density (PD) measurement is a time-consuming test, and it is not practical to measure the power density for all the beams on all the surfaces of the device, thus a hybrid approach using electromagnetic (EM) simulation in combination with measurement is recommended for PD char generation

4.1 PD Char Table

The mmW device supports total N beams, where M out of N are single beams and the rest of (N-M) are beam pairs (where 2 single beams are excited at the same time).

The following figure outlines the PD char process.

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

$$\Delta_{min} = \min\{\textit{simulated PD@8dBm} - \textit{measured PD@8dBm}\}$$

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

4.2 Codebook for all beams

All the beams that the device supports are specified in the pre-defined codebook, and the codebook is device design specific and generated after evaluating radiation coverage from this particular device. In the field, a smartphone manages the beam selection and utilization based on this pre-defined codebook that is loaded and stored in the device.

Band	Antenna Module	Beam ID 1	Beam ID 2	Antenna feed Number	Antenna Type
n260	0	1		1	Patch
n260	0	3		1	Patch
n260	0	5		1	Patch
n260	0	7		1	Patch
n260	0	9		1	Patch
n260	0	14		2	Patch
n260	0	15		2	Patch
n260	0	16		2	Patch
n260	0	17		2	Patch
n260	0	21		2	Patch
n260	0	22		2	Patch
n260	0	23		2	Patch
n260	0	29		5	Patch
n260	0	30		5	Patch
n260	0	31		5	Patch
n260	0	32		5	Patch
n260	0	33		5	Patch
n260	0	38		5	Patch
n260	0	39		5	Patch
n260	0	40		5	Patch
n260	0	41		5	Patch
n260	0		129	1	Patch
n260	0		131	1	Patch
n260	0		133	1	Patch
n260	0		135	1	Patch
n260	0		137	1	Patch
n260	0		142	2	Patch
n260	0		143	2	Patch
n260	0		144	2	Patch
n260	0		145	2	Patch
n260	0		149	2	Patch
n260	0		150	2	Patch
n260	0		151	2	Patch
n260	0		157	5	Patch
n260	0		158	5	Patch
n260	0		159	5	Patch
n260	0		160	5	Patch
n260	0		161	5	Patch
n260	0		166	5	Patch
n260	0		167	5	Patch
n260	0		168	5	Patch
n260	0		169	5	Patch

n260	0	1	129	2	Patch
n260	0	3	131	2	Patch
n260	0	5	133	2	Patch
n260	0	7	135	2	Patch
n260	0	9	137	2	Patch
n260	0	14	142	4	Patch
n260	0	15	143	4	Patch
n260	0	16	144	4	Patch
n260	0	17	145	4	Patch
n260	0	21	149	4	Patch
n260	0	22	150	4	Patch
n260	0	23	151	4	Patch
n260	0	29	157	10	Patch
n260	0	30	158	10	Patch
n260	0	31	159	10	Patch
n260	0	32	160	10	Patch
n260	0	33	161	10	Patch
n260	0	38	166	10	Patch
n260	0	39	167	10	Patch
n260	0	40	168	10	Patch
n260	0	41	169	10	Patch
n260	1	0		1	Patch
n260	1	2		1	Patch
n260	1	4		1	Patch
n260	1	6		1	Patch
n260	1	8		1	Patch
n260	1	10		2	Patch
n260	1	11		2	Patch
n260	1	12		2	Patch
n260	1	13		2	Patch
n260	1	18		2	Patch
n260	1	19		2	Patch
n260	1	20		2	Patch
n260	1	24		5	Patch
n260	1	25		5	Patch
n260	1	26		5	Patch
n260	1	27		5	Patch
n260	1	28		5	Patch
n260	1	34		5	Patch
n260	1	35		5	Patch
n260	1	36		5	Patch
n260	1	37		5	Patch
n260	1		128	1	Patch
n260	1		130	1	Patch
n260	1		132	1	Patch
n260	1		134	1	Patch
n260	1		136	1	Patch
n260	1		138	2	Patch
n260	1		139	2	Patch

n260	1		140	2	Patch
n260	1		141	2	Patch
n260	1		146	2	Patch
n260	1		147	2	Patch
n260	1		148	2	Patch
n260	1		152	5	Patch
n260	1		153	5	Patch
n260	1		154	5	Patch
n260	1		155	5	Patch
n260	1		156	5	Patch
n260	1		162	5	Patch
n260	1		163	5	Patch
n260	1		164	5	Patch
n260	1		165	5	Patch
n260	1	0	128	2	Patch
n260	1	2	130	2	Patch
n260	1	4	132	2	Patch
n260	1	6	134	2	Patch
n260	1	8	136	2	Patch
n260	1	10	138	4	Patch
n260	1	11	139	4	Patch
n260	1	12	140	4	Patch
n260	1	13	141	4	Patch
n260	1	18	146	4	Patch
n260	1	19	147	4	Patch
n260	1	20	148	4	Patch
n260	1	24	152	10	Patch
n260	1	25	153	10	Patch
n260	1	26	154	10	Patch
n260	1	27	155	10	Patch
n260	1	28	156	10	Patch
n260	1	34	162	10	Patch
n260	1	35	163	10	Patch
n260	1	36	164	10	Patch
n260	1	37	165	10	Patch
n261	0	1		1	Patch
n261	0	3		1	Patch
n261	0	5		1	Patch
n261	0	7		1	Patch
n261	0	9		1	Patch
n261	0	14		2	Patch
n261	0	15		2	Patch
n261	0	16		2	Patch
n261	0	17		2	Patch
n261	0	21		2	Patch
n261	0	22		2	Patch
n261	0	23		2	Patch
n261	0	29		5	Patch
n261	0	30		5	Patch

n261	0	31		5	Patch
n261	0	32		5	Patch
n261	0	33		5	Patch
n261	0	38		5	Patch
n261	0	39		5	Patch
n261	0	40		5	Patch
n261	0	41		5	Patch
n261	0		129	1	Patch
n261	0		131	1	Patch
n261	0		133	1	Patch
n261	0		135	1	Patch
n261	0		137	1	Patch
n261	0		142	2	Patch
n261	0		143	2	Patch
n261	0		144	2	Patch
n261	0		145	2	Patch
n261	0		149	2	Patch
n261	0		150	2	Patch
n261	0		151	2	Patch
n261	0		157	5	Patch
n261	0		158	5	Patch
n261	0		159	5	Patch
n261	0		160	5	Patch
n261	0		161	5	Patch
n261	0		166	5	Patch
n261	0		167	5	Patch
n261	0		168	5	Patch
n261	0		169	5	Patch
n261	0	1	129	2	Patch
n261	0	3	131	2	Patch
n261	0	5	133	2	Patch
n261	0	7	135	2	Patch
n261	0	9	137	2	Patch
n261	0	14	142	4	Patch
n261	0	15	143	4	Patch
n261	0	16	144	4	Patch
n261	0	17	145	4	Patch
n261	0	21	149	4	Patch
n261	0	22	150	4	Patch
n261	0	23	151	4	Patch
n261	0	29	157	10	Patch
n261	0	30	158	10	Patch
n261	0	31	159	10	Patch
n261	0	32	160	10	Patch
n261	0	33	161	10	Patch
n261	0	38	166	10	Patch
n261	0	39	167	10	Patch
n261	0	40	168	10	Patch
n261	0	41	169	10	Patch

n261	1	0		1	Patch
n261	1	2		1	Patch
n261	1	4		1	Patch
n261	1	6		1	Patch
n261	1	8		1	Patch
n261	1	10		2	Patch
n261	1	11		2	Patch
n261	1	12		2	Patch
n261	1	13		2	Patch
n261	1	18		2	Patch
n261	1	19		2	Patch
n261	1	20		2	Patch
n261	1	24		5	Patch
n261	1	25		5	Patch
n261	1	26		5	Patch
n261	1	27		5	Patch
n261	1	28		5	Patch
n261	1	34		5	Patch
n261	1	35		5	Patch
n261	1	36		5	Patch
n261	1	37		5	Patch
n261	1		128	1	Patch
n261	1		130	1	Patch
n261	1		132	1	Patch
n261	1		134	1	Patch
n261	1		136	1	Patch
n261	1		138	2	Patch
n261	1		139	2	Patch
n261	1		140	2	Patch
n261	1		141	2	Patch
n261	1		146	2	Patch
n261	1		147	2	Patch
n261	1		148	2	Patch
n261	1		152	5	Patch
n261	1		153	5	Patch
n261	1		154	5	Patch
n261	1		155	5	Patch
n261	1		156	5	Patch
n261	1		162	5	Patch
n261	1		163	5	Patch
n261	1		164	5	Patch
n261	1		165	5	Patch
n261	1	0	128	2	Patch
n261	1	2	130	2	Patch
n261	1	4	132	2	Patch
n261	1	6	134	2	Patch
n261	1	8	136	2	Patch
n261	1	10	138	4	Patch
n261	1	11	139	4	Patch

n261	1	12	140	4	Patch
n261	1	13	141	4	Patch
n261	1	18	146	4	Patch
n261	1	19	147	4	Patch
n261	1	20	148	4	Patch
n261	1	24	152	10	Patch
n261	1	25	153	10	Patch
n261	1	26	154	10	Patch
n261	1	27	155	10	Patch
n261	1	28	156	10	Patch
n261	1	34	162	10	Patch
n261	1	35	163	10	Patch
n261	1	36	164	10	Patch
n261	1	37	165	10	Patch

4.3 PD_design_target determination

To account for total uncertainty, PD_design_target should meet the criteria:

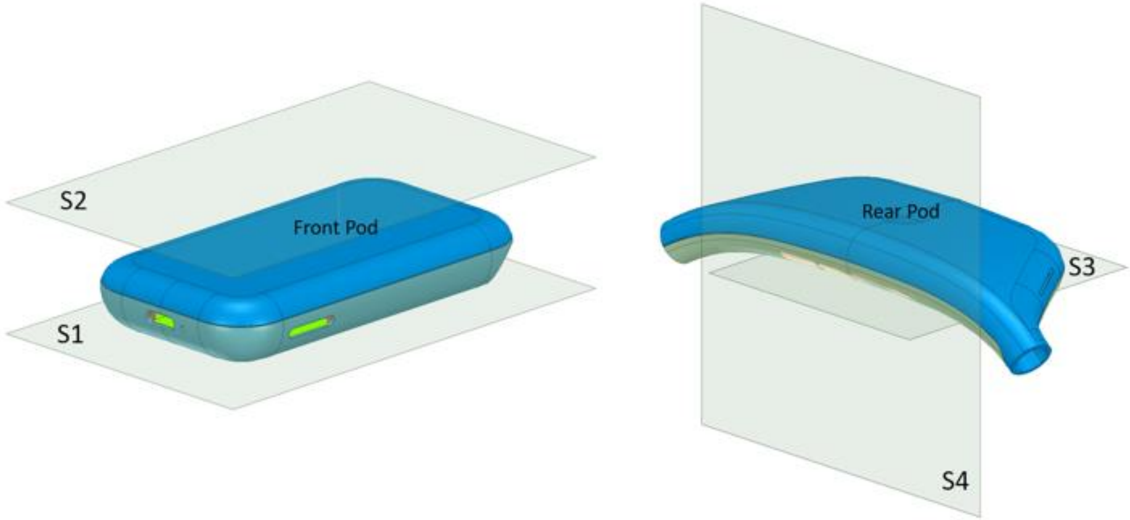
$$PD\_design\_target < PD_{regulatory\_limit} \times 10^{\frac{-totaluncertainty}{10}}$$

For this EUT, the PD design target and the uncertainty value are listed below

n260/261	PD design target	Antenna Module	W/m²
		Antenna Module 0/1	5.7

Item	Uncertainty dB (k=2)
Total uncertainty	2.0

4.4 Exposure positions for PD evaluation



a. Front pod b. Rear pod

Evaluation positions

(O for included X for not-included)	Back 2mm	Front 14 mm	Inner surface 2mm	Long edge 2mm
	S1	S2	S3	S4
FrontPod Antenna module 0	O	O	X	X
RearPod Antenna module 1	X	X	O	O

Remark:
1. Referring to the Part 0 PD simulation report for the reason of selecting surfaces/edges.

4.5 Simulation and modeling validation

Power density simulations of all beams and surfaces were performed by the manufacturer. Details of these simulations and modeling validation can be found in the Power Density Simulation Report. Following Table 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 and n260 band, PD measurements are conducted for at least one single beam per antenna type and per antenna module (0,1) on worst-surface(s) . PD measurements are performed at mid channel of each mmW band and with CW modulation.
PD value will be used to determine worst-case housing influence for conservative assessment

Band	Antenna	Beam ID	Surface	Test distance	Channel	Measured results Savg tot 4cm^2 (W/m2)	Simulated Pd (W/m^2), averaged over 4 cm2	Delta= Sim. – Meas. (dB)
n261	Front Pod module 0	40	Front	14 mm	Mid	7.89	13.96	2.5
		168	Front	14 mm	Mid	6.65	13.93	3.2
	Rear Pod module 1	36	Long edge	2 mm	Mid	2.54	5.27	3.2
		164	Long edge	2 mm	Mid	2.53	4.81	2.8
n260	Front Pod module 0	30	Front	14 mm	Mid	4.76	10.11	3.3
		158	Front	14 mm	Mid	5.32	11.39	3.3
	Rear Pod module 1	36	Long edge	2 mm	Mid	1.84	2.93	2.0
		164	Long edge	2 mm	Mid	1.24	4.58	5.7

4.6 PD Char

4.6.1 Simulated input power limit for single beams

Perform simulation at low, mid and high channel for each mmW band supported, with a given input power per active port, *sim.input.power.per.active.port* (6 dBm for this product):

1. Obtain $PD_{surface}$ value (the worst PD among all identified surfaces of the device) at all three channels for all single beams (1~M) specified in *codebook_sim*.
2. Adjust input power to determine a scaling factor at all three channels by:

   $$s(i)_{low\_or\_mid\_high} = \frac{PD\ design\ target}{sim.PD_{surface}(i)},\ i = 1,2,\ldots M \qquad (4)$$

3. Determine the worst-case scaling factor among low, mid and high channels:

   $$s(i) = \min\{s_{low}(i), s_{mid}(i), s_{high}(i)\},\ i = 1,2,\ldots M \qquad (5)$$

   Note: This scaling factor applies to the input power at each antenna port
4. Determine the simulated input power limit, sim.powerlimit, for single beam i by:

   $$sim.\ power_{limit}.(i)dBm = 10 \ast \log(s(i)) + sim.input.power.per.active.port$$
   $$,\ i = 1,2,\ldots M \qquad (6)$$

4.6.2 Simulated input power limit for beam pairs

The relative phase between single beams of a beam pair is sweeped to find the worst case PD for beam-pairs operation, and PD simulation data has taken this into considerationfor beam-pair operations take consideration of the variation relative phase was reported
For beam pair, extract the E-fields and H-fields from the corresponding single beams at and high channel for each supported band and for all identified surfaces of the device.
For a given beam pair containing *beam_a* and *beam_b with relative phase* $\emptyset$ and for a given channel, determine the worst-case $\emptyset_{worstcase}$ which results in the highest $\text{total}\ PD$ ($\emptyset$) among all identified surfaces for this beam pair at this channel. When $\emptyset_{worstcase}$ is determined for all three channels, obtain the scaling factor given by the below equation for low, mid and high channels:

$$s(i)_{low\_or\_mid\_high} = \frac{PD\ design\ target}{total.PD(\emptyset(\mathrm{i})_{worstcase})},\ i = M+1,\ M+2, \ldots N \qquad (8)$$

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

$$s(i) = min\{s_{low}(i), s_{mid}(i), s_{high}(i)\},\ i = M+1,\ M+2, \ldots N \qquad (9)$$

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

$$sim.power_{limit}(i)dBm = 10*\log(\mathrm{s(i)}) + sim.input.power.per.active.port, i=M+1,\ M+2,\ \ldots N \qquad (10)$$

4.6.3 Worst-case housing influence determination

Referring to the PD simulation report for PD simulation data for all beams . For non-metal material, the material property cannot be accurately characterized at mmW frequencies. The estimated material property for the device housing is used in the simulation model, which could impact 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.

Referring to the PD simulation report for PD simulation data for all beams, and the worst beams are selected to be tested Power density simulation for all

The mmW antenna modules are placed at different locations and only surrounding material/housing has impact on EM field propagation and in turn power density, and depending on the type of 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 procedure to determine worst-case housing influence, denoted as $\Delta_{\min}$:

1. Based on PD simulation, determine one or more worst-surface(s) that contains all the highest 4cm^2-averaged PD for each of the 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 Δ_{min} based on identified worst surface(s) in Step 1, and then follow the procedures described in Section 4.6 to derive *input.power.limit* corresponding to *PD_design_target* for all the beams
   b. Then prove all other surface(s) near-by the mmW module, i.e., surface(s) not selected in Step 1, is not required for housing material loss quantification (in other words, these nonevaluated surfaces have no influence on the determined *input.power.limit*) by:
      i. Scale the simulated 4cm^2-averaged PD values for all single beams to correspond to their *sim.power$_{limit}$*, and identify the worst-PD beam per each non-selected surface.
      ii. Measure 4cm^2-averaged PD at *input.power.limit* for the identified worst-PD beam at each non-selected surface
      iii. Demonstrate all measured 4cm^2-averaged PD values are below *PD_design_target*.
3. If any of the above surface(s) in Step (2.b.iii) have measured 4cm^2-averaged PD ≥ *PD_design_target*, then those surfaces must be included in the Δ_{min} determination in Step (2.a), and follow the procedures in Section 4.6 to re-evaluate *input.power.limit* with these added surfaces.

Therefore, when comparing a simulated 4cm^2-avgeraged PD and measured 4cm^2-avgeraged PD for the above identified surfaces, the worst errors introduced when using the estimated material property in the simulation per module and per antenna type (worst out of both polarizations) is highlighted in bolded numbers in section 4.5. Thus, the worst-case housing influence, denoted as Δ_{min} (= minimum of (sim.PD – meas.PD) for the same antenna type of each module), is determined as:

Band	Antenna		Delta_min (dB)
n261	Front pod	Beam ID 1	2.4
		Beam ID 2	3.2
	Rear pod	Beam ID 1	3.2
		Beam ID 2	1.3
n260	Front pod	Beam ID 1	3.3
		Beam ID 2	3.3
	Rear pod	Beam ID 1	2.0
		Beam ID 2	2.0

Δ_{min} represents the worst case where RF exposure is underestimated the most by simulation upon using the estimated material property for glass/plastics of the housing. For conservative assessment, the Δ_{min} is used as the worst case correction and applied to each corresponding beam group to determine power limits in PD char for compliance. To ensure that condition described in Step (2.b.iii) is met, apply the correct input.power.limit to derive the PD simulated results for all beams, and select the worst beams (yellow highlighted in the PD table) for each of non-selected applicable surface(s).
The PD test results for non-selected surfaces are less than PD_design_target, and meets condition in Step (2.b.iii), thus performing Step (3) is not needed

Simulated 4cm^2-averaged PD at input.power.limit
Determine the worst beam for each of non-selected surface(s)

Front pod n260:

Band	Beam ID 1	Beam ID 2	Antenna Module	HFSS Simulated 4cm2 Average Total PD (W/m^2)	
				Back (S1)	Front (S2)
n260	1		0	0.2	5.7
n260	3		0	0.2	5.3
n260	5		0	0.2	5.4
n260	7		0	0.2	5.7
n260	9		0	0.3	5.1
n260	14		0	0.3	5.6
n260	15		0	0.2	5.5
n260	16		0	0.3	5.6
n260	17		0	0.3	5.7
n260	21		0	0.2	5.7
n260	22		0	0.2	5.7
n260	23		0	0.3	5.7
n260	29		0	0.2	5.6
n260	30		0	0.1	5.4
n260	31		0	0.2	5.2
n260	32		0	0.3	5.6
n260	33		0	0.2	5.7
n260	38		0	0.2	5.7
n260	39		0	0.1	5.0
n260	40		0	0.2	5.6
n260	41		0	0.3	5.3
n260		129	0	0.2	5.7
n260		131	0	0.2	5.3
n260		133	0	0.2	5.0
n260		135	0	0.2	5.5
n260		137	0	0.2	5.5
n260		142	0	0.1	5.5
n260		143	0	0.1	5.5
n260		144	0	0.4	5.7
n260		145	0	0.2	5.4
n260		149	0	0.2	5.2
n260		150	0	0.1	5.7
n260		151	0	0.4	5.7
n260		157	0	0.2	5.7
n260		158	0	0.1	5.6
n260		159	0	0.1	4.9
n260		160	0	0.3	5.6
n260		161	0	0.2	5.4
n260		166	0	0.1	5.7
n260		167	0	0.1	4.8
n260		168	0	0.2	5.7
n260		169	0	0.4	5.2

Rear pod n260:

Band	Beam ID 1	Beam ID 2	Antenna Module	HFSS Simulated 4cm2 Average Total PD (W/m^2)	
				Inner (S3)	Long edge (S4)
n260	0		1	1.2	4.7
n260	2		1	1.4	5.4
n260	4		1	1.0	5.7
n260	6		1	2.1	5.7
n260	8		1	1.9	5.6
n260	10		1	1.1	4.3
n260	11		1	1.1	5.2
n260	12		1	1.2	4.3
n260	13		1	1.6	5.0
n260	18		1	1.4	4.5
n260	19		1	1.5	5.7
n260	20		1	1.2	4.6
n260	24		1	1.9	5.0
n260	25		1	1.8	4.7
n260	26		1	1.5	5.7
n260	27		1	0.9	4.4
n260	28		1	0.8	3.8
n260	34		1	2.2	5.3
n260	35		1	1.7	5.2
n260	36		1	1.0	5.7
n260	37		1	1.1	5.7
n260		128	1	1.3	4.4
n260		130	1	1.3	4.1
n260		132	1	1.5	4.4
n260		134	1	1.0	3.2
n260		136	1	0.8	1.8
n260		138	1	0.7	3.3
n260		139	1	0.9	3.9
n260		140	1	1.4	4.3
n260		141	1	0.7	2.1
n260		146	1	1.8	2.7
n260		147	1	0.7	3.5
n260		148	1	1.2	3.5
n260		152	1	0.8	3.8
n260		153	1	1.0	3.9
n260		154	1	1.1	4.7
n260		155	1	1.7	4.5
n260		156	1	2.0	4.3
n260		162	1	0.7	4.1
n260		163	1	0.8	3.9
n260		164	1	1.7	5.1
n260		165	1	2.1	4.5

Front pod n261:

Band	Beam ID 1	Beam ID 2	Antenna Module	HFSS Simulated 4cm2 Average Total PD (W/m^2)	
				Back (S1)	Front (S2)
n261	1		0	0.2	5.7
n261	3		0	0.2	5.6
n261	5		0	0.2	5.5
n261	7		0	0.3	5.4
n261	9		0	0.2	5.3
n261	14		0	0.2	5.5
n261	15		0	0.1	5.6
n261	16		0	0.1	5.5
n261	17		0	0.3	5.7
n261	21		0	0.3	5.5
n261	22		0	0.1	5.6
n261	23		0	0.1	5.7
n261	29		0	0.5	5.7
n261	30		0	0.3	5.7
n261	31		0	0.1	5.5
n261	32		0	0.1	5.6
n261	33		0	0.2	5.6
n261	38		0	0.4	5.6
n261	39		0	0.1	5.5
n261	40		0	0.1	5.6
n261	41		0	0.2	5.7
n261		129	0	0.4	5.5
n261		131	0	0.2	5.7
n261		133	0	0.1	5.6
n261		135	0	0.1	5.4
n261		137	0	0.1	5.4
n261		142	0	0.1	5.6
n261		143	0	0.1	5.6
n261		144	0	0.1	5.7
n261		145	0	0.2	5.4
n261		149	0	0.3	5.4
n261		150	0	0.0	5.6
n261		151	0	0.2	5.7
n261		157	0	0.2	5.4
n261		158	0	0.1	5.6
n261		159	0	0.1	5.6
n261		160	0	0.1	5.6
n261		161	0	0.2	5.6
n261		166	0	0.1	5.6
n261		167	0	0.1	5.6
n261		168	0	0.1	5.7
n261		169	0	0.2	5.6

Rear pod n261:

Band	Beam ID 1	Beam ID 2	Antenna Module	HFSS Simulated 4cm2 Average Total PD (W/m^2)	
				Inner (S3)	Long edge (S4)
n261	0		1	0.9	5.7
n261	2		1	0.5	5.0
n261	4		1	0.6	5.6
n261	6		1	0.6	5.3
n261	8		1	0.6	5.5
n261	10		1	0.5	5.1
n261	11		1	0.3	5.2
n261	12		1	0.5	5.1
n261	13		1	0.7	4.9
n261	18		1	0.8	5.4
n261	19		1	0.5	5.7
n261	20		1	1.0	5.4
n261	24		1	0.7	5.4
n261	25		1	1.0	5.7
n261	26		1	0.3	5.7
n261	27		1	0.9	5.5
n261	28		1	1.1	5.1
n261	34		1	0.7	5.7
n261	35		1	0.9	5.6
n261	36		1	0.4	5.7
n261	37		1	1.2	5.4
n261		128	1	0.7	4.6
n261		130	1	0.6	5.3
n261		132	1	0.5	5.5
n261		134	1	0.5	4.9
n261		136	1	0.4	4.7
n261		138	1	0.9	5.2
n261		139	1	0.9	4.9
n261		140	1	0.3	5.5
n261		141	1	0.5	5.3
n261		146	1	0.8	5.6
n261		147	1	0.5	5.6
n261		148	1	0.5	4.7
n261		152	1	0.6	4.6
n261		153	1	1.1	5.2
n261		154	1	0.5	5.7
n261		155	1	0.3	5.5
n261		156	1	0.5	5.7
n261		162	1	0.7	4.7
n261		163	1	0.8	5.6
n261		164	1	0.3	5.5
n261		165	1	0.5	5.5

4cm²-averaged PD for the selected beams on non-selected surfaces for Δ_{min} determination

and	Antenna		Beam ID	Surface	Input.power.limit (dBm)	Meas. 4 cm² avg. PD (W/m²)
n260	Front pod	Beam ID 1	23	Back 2mm	12.5	0.078
		Beam ID 2	169	Back 2mm	8.5	0.081
	Rear pod	Beam ID 1	34	Inner 2mm	8.8	0.133
		Beam ID 2	165	Inner 2mm	7.8	0.044
n261	Front pod	Beam ID 1	29	Back 2mm	6.6	0.12
		Beam ID 2	129	Back 2mm	13.5	0.075
	Rear pod	Beam ID 1	37	Inner 2mm	9.5	0.137
		Beam ID 2	153	Inner 2mm	7.5	0.099

4.7 PD Char

This section describes the PD char generation that complies with the *PD_design_target* and is in compliance with the regulatory power density limit.

4.7.1 PD char generation

Ideally, if there is no uncertainty associated with hardware as described in Section 4.4, after accounting for the housing influence (***Δ**min*), *input.power.limit(i)*, for beam *i* can be obtained:

$$input.power.limit(i) = 6\,dBm + 10 * \log(s(i)) + \Delta_{min},\ i \in all\ beams \quad (11)$$

If simulation overestimates the housing influence, then Δ_{min} (= minimum {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 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 in equation (11). In Section 4.7, the TxAGC uncertainty at reference power level (6dBm in report) is embedded in the process of Δ_{min} determination and should be removed to avoid double counting this uncertainty.

If -TxAGC uncertainty at reference power level < *Δmin* < TxAGC uncertainty at reference power level,

$$Input.power.limit(i) = sim.power_{limit}(i), i = 1,2,..,N \quad (12)$$

else if Δmin < -TxAGC uncertainty at reference power level,

$$Input.power.limit(i) = sim.power_{limit}(i) + (\Delta min + TxAGC\ uncertainty), i = 1,2,..,N \quad (13)$$

else if Δmin > TxAGC uncertainty at reference power level,

$$Input.power.limit(i) = sim.power_{limit}(i) + (\Delta min - TxAGC\ uncertainty), i = 1,2,..,N \quad (14)$$

The input power limit is derived and listed in the table below

Band	Antenna		Delta_min (dB)	TxAGC uncertainty (dB)	Input.power.limit (dBm)=
n261	Front pod	Beam ID 1	2.4	0.63	6 + 10* log(s(i)) + 1.77
		Beam ID 2	3.2	0.63	6 + 10* log(s(i)) + 2.57
	Rear pod	Beam ID 1	3.2	0.63	6 + 10* log(s(i)) + 2.57
		Beam ID 2	1.3	0.63	6 + 10* log(s(i)) + 0.67
n260	Front pod	Beam ID 1	3.3	0.63	6 + 10* log(s(i)) + 2.67
		Beam ID 2	3.3	0.63	6 + 10* log(s(i)) + 2.67
	Rear pod	Beam ID 1	2.0	0.63	6 + 10* log(s(i)) + 1.37
		Beam ID 2	2.0	0.63	6 + 10* log(s(i)) + 1.37

4.7.2 PD char Table

Combining the information in previous sections, PD char is derived and listed below

n260 Antenna module 0/1

Beam ID 1	Beam ID 2	Input Power Limit (dBm)
0		12.5
1		12.5
2		12.5
3		12.5
4		12.5
5		12.5
6		12.5
7		12.5
8		12.5
9		12.5
10		12.5
11		12.5
12		12.5
13		12.5
14		11.8
15		9.5
16		11.5
17		12.5
18		12.5
19		12.5
20		12.5
21		9.5
22		10.2
23		12.5
24		8.3
25		8.2
26		9.2
27		10.5
28		8.7
29		6.7
30		6
31		5.9
32		7.1
33		7.6
34		8.8
35		9.1
36		10.2
37		11
38		6.4
39		5.8
40		6.6
41		8.5
	128	12.5
	129	12.5
	130	12.5
	131	12.5
	132	12.5

	133	12.5
	134	12.5
	135	12.5
	136	12.5
	137	12.5
	138	11.4
	139	11.2
	140	12.1
	141	10.1
	142	9.9
	143	9.9
	144	12
	145	11.7
	146	12.3
	147	11.4
	148	11.1
	149	11.1
	150	10
	151	12.5
	152	7.4
	153	8
	154	8.9
	155	7
	156	8.2
	157	7.1
	158	5.5
	159	6.1
	160	7.7
	161	6.7
	162	7.6
	163	8.4
	164	7.9
	165	7.8
	166	6.2
	167	5.8
	168	7.2
	169	8.5
0	128	12.5
1	129	11.1
2	130	12.5
3	131	11.5
4	132	12.5
5	133	9.8
6	134	12.5
7	135	10.6
8	136	12.5
9	137	10.4
10	138	10.1
11	139	9.6
12	140	10.6
13	141	9.7
14	142	7.4
15	143	8.1
16	144	8.4

17	145	8.4
18	146	10.8
19	147	11.5
20	148	10.4
21	149	8.3
22	150	7.9
23	151	10.2
24	152	7
25	153	8.1
26	154	7.3
27	155	7
28	156	7
29	157	3.8
30	158	2.2
31	159	2.7
32	160	5.1
33	161	4
34	162	7.6
35	163	7.7
36	164	7.2
37	165	7.5
38	166	3.2
39	167	2
40	168	4.9
41	169	5.5

n261 Antenna module 0/1

Beam ID 1	Beam ID 2	Input Power Limit (dBm)
0		13.5
1		13
2		13.5
3		13.3
4		13.5
5		13.5
6		13.5
7		13.1
8		13.5
9		13
10		13.5
11		13.5
12		13.5
13		13.5
14		9.7
15		8.1
16		8.6
17		9.4
18		13.5
19		13.5
20		13.5
21		9.3
22		8.1
23		8.9
24		12.7
25		11.7
26		9.4
27		10.3
28		9.8
29		6.6
30		4.6
31		4
32		3.8
33		4.6
34		12.4
35		11
36		8.9
37		9.5
38		5.7
39		4.1
40		3.7
41		3.7
	128	13.5
	129	13.5
	130	13.5
	131	13.5
	132	13.5
	133	13.5
	134	13.5
	135	13.5
	136	13.5

	137	13.5
	138	12.8
	139	12.9
	140	11.3
	141	13.5
	142	10.1
	143	9
	144	9.1
	145	10.3
	146	13.5
	147	13.1
	148	13.5
	149	10.2
	150	8.6
	151	9.9
	152	9.4
	153	7.5
	154	7.4
	155	8.1
	156	10.9
	157	5.9
	158	4.3
	159	4.5
	160	4.7
	161	6.2
	162	9.2
	163	7.1
	164	7.2
	165	9.8
	166	4.5
	167	4.5
	168	4.6
	169	5
0	128	13.5
1	129	10.3
2	130	12.8
3	131	9.6
4	132	12.8
5	133	9.8
6	134	13.5
7	135	9.4
8	136	10.1
9	137	10.2
10	138	11.2
11	139	10
12	140	9.4
13	141	12.4
14	142	6.9
15	143	4.8
16	144	5.8
17	145	7.3
18	146	10.4
19	147	9.4
20	148	10.4

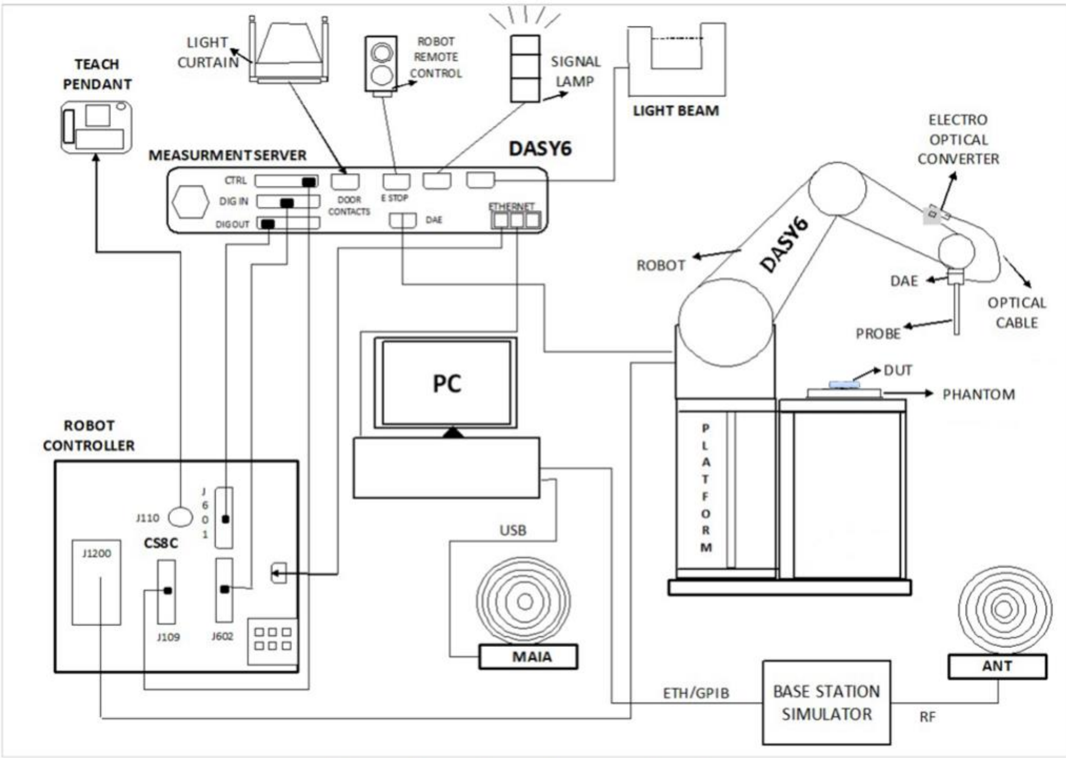
21	149	6.6
22	150	5.5
23	151	6.2
24	152	8.1
25	153	7
26	154	3.9
27	155	5.9
28	156	8
29	157	2.4
30	158	0.5
31	159	0.4
32	160	0.4
33	161	1.2
34	162	7.4
35	163	5.1
36	164	3.5
37	165	7.7
38	166	0.8
39	167	0.6
40	168	0.3
41	169	0.5

5. PD Test Setup

5.1 PD Test – System Setup

The system to be used for the near field power density measurement

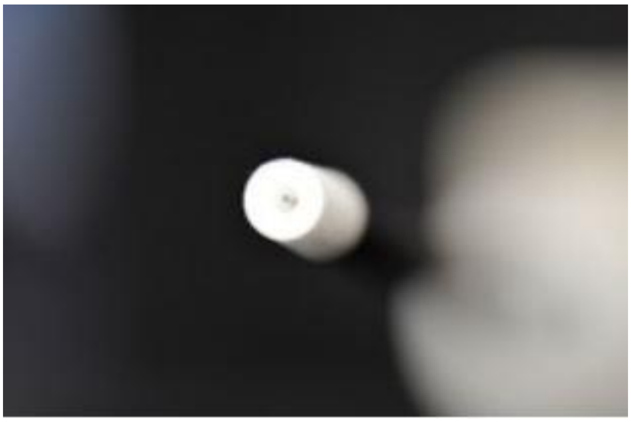
- SPEAG DASY6 system
  - SPEAG cDASY6 5G module software
  - EUmmWVx probe
- 5G Phantom cover

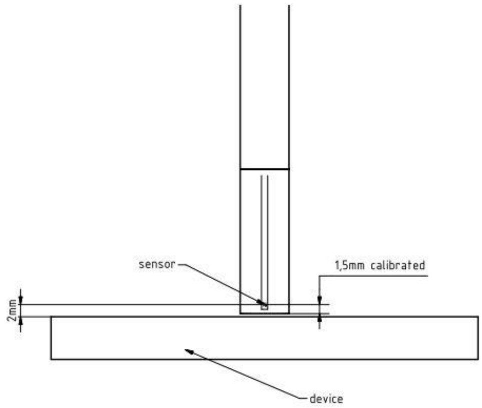


5.2 EUmmWave Probe / E-Field 5G Probe

The probe design allows measurements at distances as small as 2 mm from the sensors to the surface of the device under test (DUT). The typical sensor to probe tip distance is 1.5 mm.

Frequency	750 MHz – 110 GHz
Probe Overall Length	320 mm
Probe Body Diameter	8.0 mm
Tip Length	23.0 mm
Tip Diameter	8.0 mm
Probe's two dipoles length	0.9 mm – Diode loaded
Dynamic Range	< 20 V/m - 10000 V/m with PRE-10 (min < 50 V/m - 3000 V/m)
Position Precision	< 0.2 mm
Distance between diode sensors and probe's tip	1.5 mm
Minimum Mechanical separation between probe tip and a Surface	0.5 mm
Applications	E-field measurements of 5G devices and other mm-wave transmitters operating above 10GHz in < 2 mm distance from device (free-space) Power density, H-field and far-field analysis using total field reconstruction.
Compatibility	cDASY6 + 5G-Module SW1.0 and higher





5.3 Data Acquisition Electronics (DAE)

The data acquisition electronics (DAE) consists of a highly sensitive electrometer-grade preamplifier with auto-zeroing, a channel and gain-switching multiplexer, a fast 16 bit AD-converter and a command decoder and control logic unit. Transmission to the measurement server is accomplished through an optical downlink for data and status information as well as an optical uplink for commands and the clock.
The input impedance of the DAE is 200 MOhm; the inputs are symmetrical and floating. Common mode rejection is above 80 dB.

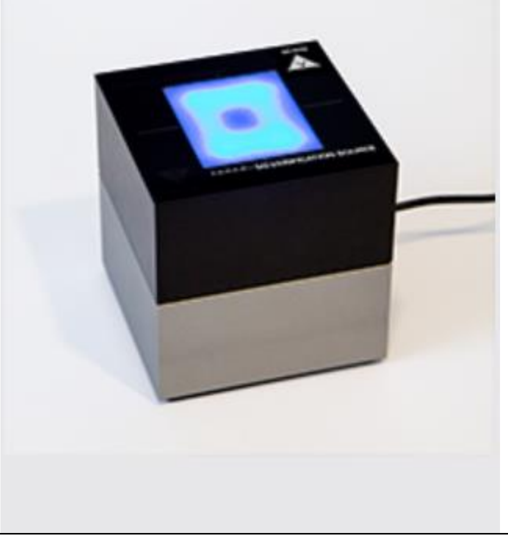
5.4 Scan configuration

Fine-resolution scans on 2 different planes are performed to reconstruct the E- and H-fields as well as the power density; the z-distance between the 2 planes is set to λ/4.
The (x, y) grid step is also set λ/4, the grid extent is set to sufficiently large to identify the field pattern and the peak.

5.5 System Verification Source

The System Verification sources at 30 GHz and above comprise horn-antennas and very stable signal generators.

Model	Ka-band horn antenna
Calibrated frequency:	30 GHz at 10mm from the case surface
Frequency accuracy	± 100 MHz
E-field polarization	linear
Harmonics	-20 dBc
Total radiated power	14 dBm
Power stability	0.05 dB
Power consumption	5 W
Size	00 x 100 x 100 mm
Weight	1 kg

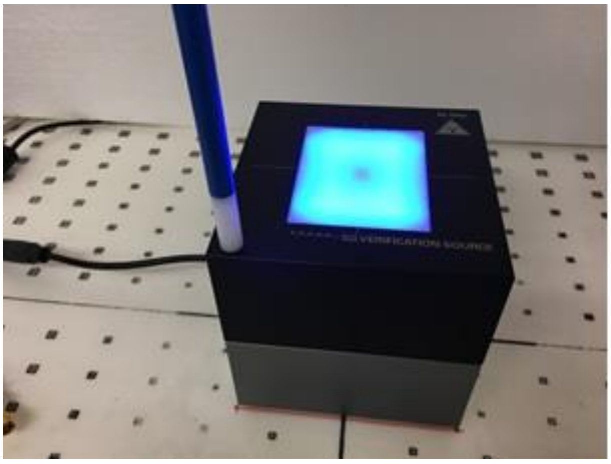


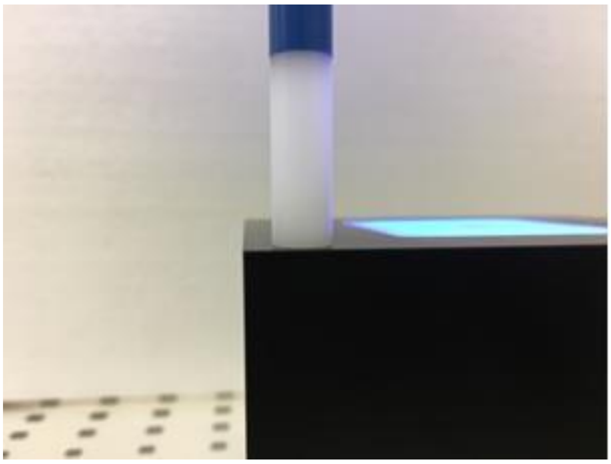
5.6 Power Density System Verification

The system performance check verifies that the system operates within its specifications.
The EUT is replaced by a calibrated source, the same spatial resolution, measurement region and the test separation used in the calibration was applied to system check. Through visual inspection into the measured power density distribution, both spatially (shape) and numerically (level) have no noticeable difference. The measured results should be within 0.66B of the calibrated targets.

Frequency [GHz]	Grid step	Grid extent X/Y [mm]	Measurement points
10	0.25 ($\frac{\lambda}{4}$)	120/120	16×16
30	0.25 ($\frac{\lambda}{4}$)	60/60	24×24
60	0.25 ($\frac{\lambda}{4}$)	32.5/32.5	26×26
90	0.25 ($\frac{\lambda}{4}$)	30/30	36×36

Settings for measurement of verification sources





Verification Setup photo

5.7 System Verification Results

Frequency (GHz)	5G Verification Source	Probe S/N	DAE S/N	Distance (mm)	Measured 4 cm^2 (W/m^2)	Targeted 4 cm^2 (W/m^2)	Deviation (dB)	Date
30G	30GHz_1007	9441	577	10mm	32.3	36.3	-0.51	2020/12/12
30G	30GHz_1007	9441	376	10mm	38.8	36.3	0.29	2021/1/4
30G	30GHz_1007	9441	376	10mm	32.5	36.3	-0.48	2021/1/12

6. Uncertainty Assessment

The budget is valid for evaluation distances > λ/2π. For specific tests and configurations, the Uncertainty could be considerably smaller.

Preliminary Module mmWave Uncertainty Budget Evaluation Distances to the Antennas > λ / 2π						
Error Description	**Uncertainty Value (± dB)**	**Probability**	**Divisor**	**(Ci)**	**Standard Uncertainty (±dB)**	**(Vi) Veff**
Measurement System						
Probe Calibration	0.49	N	1	1	0.49	∞
Hemispherical Isotropy	0.50	R	1.732	1	0.29	∞
Linearity	0.20	R	1.732	0	0.12	∞
System Detection Limits	0.04	R	1.732	1	0.02	∞
Modulation Response	0.40	R	1.732	1	0.23	∞
Readout Electronics	0.03	N	1	1	0.03	∞
Response Time	0.00	R	1.732	1	0.00	∞
Integration Time	0.00	R	1.732	1	0.00	∞
RF Ambient Noise	0.2	R	1.732	1	0.12	∞
RF Ambient Reflections	0.21	R	1.732	1	0.12	∞
Probe Positioner	0.04	R	1.732	1	0.02	∞
Probe Positioning	0.30	R	1.732	1	0.17	∞
S_{avg} Reconstruction	0.60	R	1.732	1	0.35	∞
Test Sample Related						
Power Drift	0.2	R	1.732	1	0.12	∞
Input Power	0	N	1	0	0.00	∞
Combined Std. Uncertainty					0.76 dB	∞
Coverage Factor for 95 %					K=2	
Expanded STD Uncertainty					1.52 dB	