RF Exposure Report

(Part 0: SAR and PD Char Report)

FCC ID : **O57FLEX5G14X05**
Equipment : **Notebook Computer**
Brand Name : **Lenovo**
Applicant : **Lenovo (Shanghai) Electronics Technology Co., Ltd.**
Section 304-305, Building No. 4, # 222, Meiyue Road,
China (Shanghai) Pilot Free Trade Zone, Shanghai
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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Cona Huang

Approved by: Cona Huang / Deputy Manager

Sporton International Inc.
No. 52, Huaya 1st Rd., Guishan Dist., Taoyuan City, Taiwan

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History of this test report

Report No.	Version	Description	Issued Date
FA9N2705C	01	Initial issue of report	Feb. 19, 2020

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_targer.
P_{max}	Maximum tune-up 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	Notebook Computer
Brand Name	Lenovo
FCC ID	O57FLEX5G14X05
Wireless Technology and Frequency Range	WCDMA Band II: 1852.4 MHz ~ 1907.6 MHz WCDMA Band IV: 1712.4 MHz ~ 1752.6 MHz WCDMA Band V: 826.4 MHz ~ 846.6 MHz LTE Band 2: 1850.7 MHz ~ 1909.3 MHz LTE Band 4: 1710.7 MHz ~ 1754.3 MHz LTE Band 5: 824.7 MHz ~ 848.3 MHz LTE Band 7: 2502.5 MHz ~ 2567.5 MHz LTE Band 12: 699.7 MHz ~ 715.3 MHz LTE Band 13: 779.5 MHz ~ 784.5 MHz LTE Band 14: 790.5 MHz ~ 795.5 MHz LTE Band 17: 706.5 MHz ~ 713.5 MHz LTE Band 25: 1850.7 MHz ~ 1914.3 MHz LTE Band 26: 814.7 MHz ~ 848.3 MHz LTE Band 30: 2307.5 MHz ~ 2312.5 MHz LTE Band 38: 2572.5 MHz ~ 2617.5 MHz LTE Band 41: 2498.5 MHz ~ 2687.5 MHz LTE Band 48: 3552.5 MHz ~ 3697.5 MHz LTE Band 66: 1710.7 MHz ~ 1779.3 MHz LTE Band 71: 665.5 MHz ~ 695.5 MHz 5G NR n260: 37GHz~40GHz 5G NR n261: 27.5GHz~28.35GHz WLAN 2.4GHz Band: 2412 MHz ~ 2472 MHz WLAN 5.2GHz Band: 5180 MHz ~ 5240 MHz WLAN 5.3GHz Band: 5260 MHz ~ 5320 MHz WLAN 5.5GHz Band: 5500 MHz ~ 5720 MHz WLAN 5.8GHz Band: 5745 MHz ~ 5825 MHz Bluetooth: 2402 MHz ~ 2480 MHz
Mode	RMC 12.2Kbps HSDPA HSUPA DC-HSDPA HSPA+ LTE: QPSK, 16QAM, 64QAM 5GNR: DFT-s-OFDM/CP-OFDM, QPSK / 16QAM / 64QAM WLAN: 802.11a/b/g/n/ac HT20 / HT40 / VHT20 / VHT40 / VHT80 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

Sub6 radio antenna	1g SAR design target	0.95 W/kg

Sub6 radio	Uncertainty dB (k=2)
Sub6 radio	1.0

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

Tech/Band	Antenna	**DSI 0 Tablet Sensor off**	**DSI 1 Tablet Sensor on**	**DSI 2 NB Sensor on**	**DSI 3 NB Sensor off**	**PMAX***
WCDMA B2	Ant 1	26.6	13.5	18.5	26.6	23
WCDMA B4	Ant 1	24.7	13.5	18.8	24.7	23
WCDMA B5	Ant 1	24.4	15.4	19.6	24.4	23
LTE B25/2	Ant 1	25.8	12.9	18.8	25.8	23
LTE B66/4	Ant 1	24.9	13.8	19	24.9	23
LTE B26/5	Ant 1	25.4	15.5	20.5	25.4	23
LTE B7	Ant 1	23.1	11.4	17.6	23.1	23
LTE B12/17	Ant 1	26.8	18.4	21.7	26.8	23
LTE B13	Ant 1	27.7	17.3	21.6	27.7	23
LTE B14	Ant 1	26.3	15.7	21.4	26.3	23
LTE B30	Ant 1	23	13.6	18.6	23	22
LTE B41/38(**)	Ant 1	23.4	10.9	17	23.4	21
LTE B48(**)	Ant 1	22.1	11.2	15.1	22.1	20
LTE B42(**)	Ant 1	21.6	14.7	15.6	21.6	21
LTE B71	Ant 1	26.7	17.7	20.5	26.7	23

*Pmax is used for RF tune up procedure. The maximum allowed output power is equal to Pmax + device uncertainty.

**All Plimit 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).

The Plimit values, corresponding to 0.95 W/kg (1gSAR) of SAR_design_target for bottom antenna.

Maximum tune up 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 device uncertainty

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.

N260

Module	Type	Beam ID_1	Beam ID_2	Feed no.
L	Patch	0		1
		3		2
		4		2
		5		2
		12		2
		13		2
		18		4
		19		4
		20		4
		21		4
		22		4
		33		4
		34		4
		35		4
		36		4
		128		1
		131		2
		132		2
		133		2
		140		2
		141		2
		146		4
		147		4
		148		4
		149		4
		150		4
		161		4

		162		4
		163		4
		164		4
		0	128	2
		3	131	4
		4	132	4
		5	133	4
		12	140	4
		13	141	4
		18	146	8
		19	147	8
		20	148	8
		21	149	8
		22	150	8
		33	161	8
		34	162	8
		35	163	8
		36	164	8

Module	Type	Beam ID_1	Beam ID_2	Feed no.
J	Patch	1		1
		6		2
		7		2
		8		2
		14		2
		15		2
		23		4
		24		4
		25		4
		26		4
		27		4
		37		4
		38		4
		39		4
		40		4
		129		1
		134		2
		135		2
		136		2
		142		2
		143		2
		151		4
		152		4
		153		4
		154		4
		155		4
		165		4
		166		4
		167		4
		168		4
		1	129	2
		6	134	4
		7	135	4

		8	136	4
		14	143	4
		15	142	4
		23	155	8
		24	153	8
		25	152	8
		26	151	8
		27	154	8
		37	167	8
		38	166	8
		39	165	8
		40	168	8

Module	Type	Beam ID_1	Beam ID_2	Feed no.
K	Patch	2		1
		9		2
		10		2
		11		2
		16		2
		17		2
		28		4
		29		4
		30		4
		31		4
		32		4
		41		4
		42		4
		43		4
		44		4
		130		1
		137		2
		138		2
		139		2
		144		2
		145		2
		156		4
		157		4
		158		4
		159		4
		160		4
		169		4
		170		4
		171		4
		172		4
		2	130	2
		9	137	4
		10	138	4

		11	139	4
		16	144	4
		17	145	4
		28	156	8
		29	157	8
		30	158	8
		31	159	8
		32	160	8
		41	169	8
		42	170	8
		43	171	8
		44	172	8

N261

Module	Type	Beam ID_1	Beam ID_2	Feed no.
L	Patch	0		1
		3		2
		4		2
		5		2
		12		2
		13		2
		18		4
		19		4
		20		4
		21		4
		22		4
		33		4
		34		4
		35		4
		36		4
		128		1
		131		2
		132		2
		133		2
		140		2

		141		2
		146		4
		147		4
		148		4
		149		4
		150		4
		161		4
		162		4
		163		4
		164		4
		0	128	2
		3	131	4
		4	132	4
		5	133	4
		12	140	4
		13	141	4
		18	146	8
		19	147	8
		20	148	8
		21	149	8
		22	150	8
		33	161	8
		34	162	8
		35	163	8
		36	164	8

Module	Type	Beam ID_1	Beam ID_2	Feed no.
J	Patch	1		1
		6		2
		7		2
		8		2
		14		2
		15		2
		23		4
		24		4

		25		4
		26		4
		27		4
		37		4
		38		4
		39		4
		40		4
		129		1
		134		2
		135		2
		136		2
		142		2
		143		2
		151		4
		152		4
		153		4
		154		4
		155		4
		165		4
		166		4
		167		4
		168		4
		1	129	2
		6	134	4
		7	136	4
		8	135	4
		14	142	4
		15	143	4
		23	151	8
		24	152	8
		25	153	8
		26	155	8
		27	154	8
		37	165	8
		38	166	8
		39	168	8

		40	167	8

Module	Type	Beam ID_1	Beam ID_2	Feed no.
K	Patch	2		1
		9		2
		10		2
		11		2
		16		2
		17		2
		28		4
		29		4
		30		4
		31		4
		32		4
		41		4
		42		4
		43		4
		44		4
		130		1
		137		2
		138		2
		139		2
		144		2
		145		2
		156		4
		157		4
		158		4
		159		4
		160		4
		169		4
		170		4
		171		4
		172		4
		2	130	2
		9	137	4

		10	138	4
		11	139	4
		16	144	4
		17	145	4
		28	156	8
		29	157	8
		30	158	8
		31	159	8
		32	160	8
		41	169	8
		42	170	8
		43	171	8
		44	172	8

4.3 PD_design_target determination

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

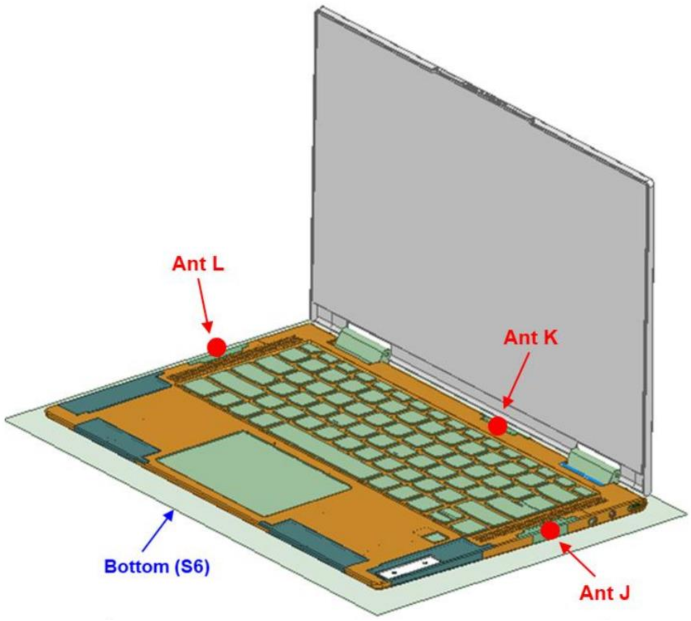
$$PD\_design\_target < PD_{regulatory\_limit} \times 10^{\frac{-totaluncertainty}{10}}$$

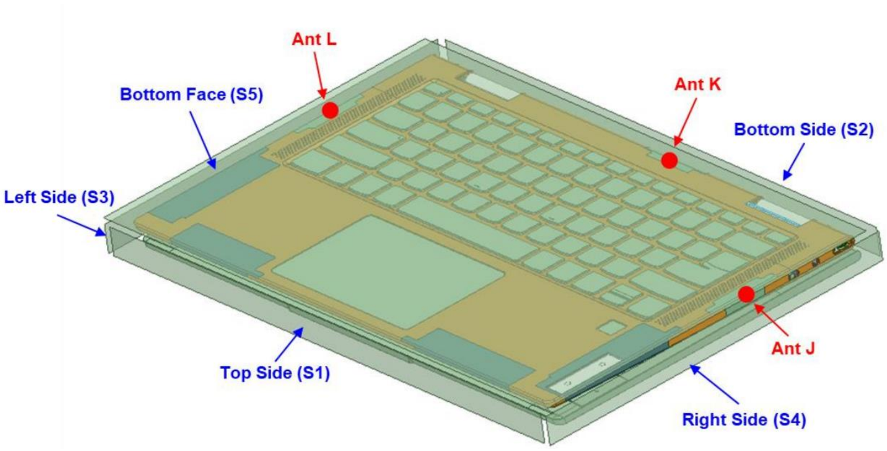
For this EUT, the PD design target and the uncertainty value are listed below

PD design target	6.165 W/m^2

Item	Uncertainty dB (k=2)
Total uncertainty	2.1

4.4 Exposure positions for PD evaluation





The six measurement planes are named as follows:

- ■ S1 = Top Side
- ■ S2 = Bottom Side
- ■ S3 = Left Side
- ■ S4 = Right Side
- ■ S5 = Bottom Face
- ■ S6 = Bottom

Evaluation positions

	Tablet Mode					Laptop
	Top Side (S1)	Bottom Side (S2)	Left Side (S3)	Right Side (S4)	Bottom Face (S5)	Bottom (S6)
Ant J	X	X	X	V	V	V
Ant K	X	V	X	X	V	V
Ant L	X	X	V	X	V	V

Remark:
Referring to the PD simulation report for the reason of selecting surfaces/edges

					Input power = 6dBm		
					4cm2 avg. PD (W/m2)		
Band	Antenna module	Beam ID	surface	channel	meas.	Sim.	Delta = Sim. - Meas (dB)
n260	L	22	Left Side	Mid	7.86	17.37	3.44
	L	150	Left Side	Mid	8.1	17.95	3.46
	L	21	Bottom Face	Mid	3.54	7.33	**3.16**
	L	150	Bottom Face	Mid	3.82	9.09	3.77
	J	37	Right Side	Mid	8.09	19.46	3.81
	J	155	Right Side	Mid	7.68	16.25	3.25
	J	37	Bottom Face	Mid	4.29	10.35	3.82
	J	165	Bottom Face	Mid	4.37	6.52	**1.74**
	K	43	Bottom Side	Mid	8.3	12.64	1.83
	K	169	Bottom Side	Mid	9.2	13.1	**1.53**
	K	28	Bottom Face	Mid	4.53	9.16	3.06
	K	159	Bottom Face	Mid	5.37	7.89	1.67
n261	L	20	Left Side	Mid	9.58	18.36	2.83
	L	162	Left Side	Mid	10.6	17.84	2.26
	L	34	Bottom Face	Mid	4.37	7.11	**2.11**
	L	148	Bottom Face	Mid	4.72	9.67	3.11
	J	38	Right Side	Mid	10.2	19.3	2.77
	J	152	Right Side	Mid	9.45	17.42	**2.66**
	J	24	Bottom Face	Mid	4.4	9.98	3.56
	J	152	Bottom Face	Mid	4.2	9.17	3.39
	K	30	Bottom Side	Mid	6.79	12.82	2.76
	K	170	Bottom Side	Mid	7.47	12.05	**2.08**
	K	30	Bottom Face	Mid	3.6	9.02	3.99
	K	158	Bottom Face	Mid	4.19	8.06	2.84

4.5 PD Char

4.5.1 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:
   $$sim.\ power_{limit}.(i)dBm = 10\ *log(s(i)) + sim.input.power.per.active.port\ ,\ i = 1,2,\ldots M \qquad (6)$$

4.5.2 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 Ø* and for a given channel, determine the worst-case $Ø_{worstcase}$ which results in the highest $total\ PD$ (∅) among all identified surfaces for this beam pair at this channel. When $Ø_{worstcase}$ 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 $Ø_{worstcase}$ 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

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

4.5.3 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 of middle channel 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 Table 4-3. 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	Δ_{min}**(dB)**
n260	L	3.16
	J	1.74
	K	1.53
n261	L	2.11
	J	2.66
	K	2.08

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 of 6.165 W/m2, and meets condition in Step (2.b.iii), thus performing Step (3) is not needed

Simulated 4cm^2-averaged PD at input.power.limi

Band	Module	Type	Beam ID	Feed no.	HFSS Simulated 4cm2 Average Total PD (W/m^2)		
					S3	S6	S5
					(Left Side)	(Bottom)	(Bottom Face)
N260	L	Patch	0	1	5.785	1.955	2.703
			3	2	5.811	1.868	2.069
			4	2	6.165	2.143	2.943
			5	2	4.951	2.000	1.719
			12	2	5.680	3.170	1.776
			13	2	5.576	1.654	2.659
			18	4	5.746	1.855	1.934
			19	4	5.658	2.737	2.142
			20	4	5.461	2.346	2.288
			21	4	6.165	2.811	2.751
			22	4	6.165	2.456	2.279
			33	4	5.742	2.683	2.107
			34	4	5.943	2.828	2.392
			35	4	5.759	2.347	2.571
			36	4	6.165	2.185	2.425
			128	1	6.030	1.524	3.845
			131	2	6.115	2.010	2.921
			132	2	5.400	2.081	2.767
			133	2	5.805	1.618	3.063
			140	2	6.165	1.877	3.906
			141	2	5.402	1.736	2.566
			146	4	6.056	1.986	3.238
			147	4	6.165	2.112	3.280
			148	4	5.159	2.108	2.433
			149	4	5.663	1.997	3.022
			150	4	6.165	1.610	3.120
			161	4	5.837	2.087	2.989
			162	4	5.111	2.136	2.691
			163	4	5.402	2.127	2.485
			164	4	6.165	1.550	3.022

Band	Module	Type	Beam ID_1	Feed no.	HFSS Simulated 4cm2 Average Total PD (W/m^2)		
					S6 (Bottom)	S4 (Right Side)	S5 (Bottom Face)
N260	J	Patch	1	1	1.983	6.165	3.043
			6	2	1.769	6.015	2.894
			7	2	2.053	6.061	2.618
			8	2	1.870	6.165	2.937
			14	2	1.848	6.165	3.326
			15	2	2.261	5.562	2.738
			23	4	1.777	6.165	2.913
			24	4	2.049	6.165	3.162
			25	4	2.375	5.933	2.885
			26	4	2.063	6.165	3.274
			27	4	2.099	6.165	3.072
			37	4	2.047	6.165	3.274
			38	4	2.154	6.165	3.095
			39	4	2.091	5.738	2.756
			40	4	2.146	6.165	3.343
			129	1	2.413	6.064	2.438
			134	2	2.017	5.743	2.142
			135	2	2.401	6.112	3.083
			136	2	2.016	5.742	2.184
			142	2	2.109	5.885	2.376
			143	2	2.207	5.965	2.703
			151	4	2.270	5.674	2.290
			152	4	2.785	6.165	2.586
			153	4	3.186	6.165	2.456
			154	4	2.774	6.165	2.340
			155	4	2.581	6.165	2.114
			165	4	2.755	6.165	2.626
			166	4	3.119	6.156	2.704
			167	4	3.235	6.165	2.362
			168	4	2.488	6.165	2.214

Band	Module	Type	Beam ID_1	Feed no.	HFSS Simulated 4cm2 Average Total PD (W/m^2)		
					S6 (Bottom)	S2 (Bottom Side)	S5 (Bottom Face)
N260	K	Patch	2	1	1.863	6.165	3.992
			9	2	1.973	6.165	3.279
			10	2	2.464	6.064	4.685
			11	2	1.961	5.787	3.166
			16	2	1.972	5.811	3.264
			17	2	2.386	6.066	4.485
			28	4	1.870	6.165	4.786
			29	4	1.939	6.035	4.441
			30	4	3.029	6.165	3.460
			31	4	3.034	5.978	3.702
			32	4	2.552	5.897	2.959
			41	4	2.055	6.165	4.208
			42	4	2.171	5.534	3.783
			43	4	2.946	6.165	3.273
			44	4	2.472	6.165	3.528
			130	1	2.909	5.703	2.286
			137	2	2.777	5.911	3.042
			138	2	2.770	5.357	3.328
			139	2	2.477	6.165	2.860
			144	2	3.379	6.165	3.130
			145	2	2.109	6.165	3.132
			156	4	2.990	6.165	2.702
			157	4	3.677	6.165	2.269
			158	4	2.668	6.165	3.917
			159	4	2.017	5.841	4.256
			160	4	2.212	6.165	3.896
			169	4	3.233	6.165	2.654
			170	4	2.976	6.064	3.244
			171	4	2.023	6.165	4.124
			172	4	2.005	5.587	4.000

Band	Module	Type	Beam ID_1	Feed no.	HFSS Simulated 4cm2 Average Total PD (W/m^2)		
					S3 (Left Side)	S6 (Bottom)	S5 (Bottom Face)
N261	L	Patch	0	1	5.98	1.84	2.82
			3	2	5.42	2.32	1.51
			4	2	5.95	2.56	2.90
			5	2	5.90	2.02	2.00
			12	2	6.01	2.05	2.88
			13	2	5.94	2.38	2.76
			18	4	5.24	2.13	2.33
			19	4	5.91	2.66	2.38
			20	4	6.17	2.93	2.34
			21	4	5.62	2.26	2.26
			22	4	5.51	2.26	2.48
			33	4	5.43	2.23	2.33
			34	4	6.10	2.85	2.39
			35	4	5.98	2.71	2.44
			36	4	5.58	2.13	2.49
			128	1	5.99	2.09	2.83
			131	2	5.67	1.74	2.16
			132	2	6.06	2.81	2.91
			133	2	6.02	2.13	1.97
			140	2	5.98	2.48	3.12
			141	2	6.10	2.62	2.30
			146	4	5.87	1.80	3.06
			147	4	6.17	2.44	3.38
			148	4	6.15	2.62	3.39
			149	4	5.43	2.91	2.24
			150	4	5.38	2.30	2.49
			161	4	6.06	1.91	2.92
			162	4	6.17	2.74	3.27
			163	4	5.65	2.67	3.07
			164	4	5.28	2.53	2.41

Band	Module	Type	Beam ID_1	Feed no.	HFSS Simulated 4cm2 Average Total PD (W/m^2)		
					S6 (Bottom)	S4 (Right Side)	S5 (Bottom Face)
N261	J	Patch	1	1	2.011	6.165	2.454
			6	2	1.283	6.165	2.924
			7	2	2.443	6.165	3.066
			8	2	2.424	6.077	2.166
			14	2	2.166	6.165	3.317
			15	2	2.518	5.971	2.447
			23	4	2.099	6.165	3.525
			24	4	2.564	6.165	3.252
			25	4	2.155	6.165	3.344
			26	4	2.311	4.834	2.155
			27	4	1.946	5.979	2.640
			37	4	2.283	6.165	3.488
			38	4	2.485	6.165	3.175
			39	4	2.138	5.216	2.333
			40	4	2.298	5.086	2.174
			129	1	2.096	6.165	2.677
			134	2	1.513	6.165	2.970
			135	2	2.795	6.165	2.801
			136	2	2.385	5.973	2.598
			142	2	2.506	6.165	3.096
			143	2	2.445	6.165	2.659
			151	4	2.093	6.120	2.763
			152	4	2.569	6.165	3.245
			153	4	2.643	6.113	3.037
			154	4	2.291	5.633	2.506
			155	4	2.131	6.000	2.507
			165	4	2.168	6.024	2.867
			166	4	2.504	6.165	3.005
			167	4	2.529	5.997	2.788
			168	4	2.343	5.767	2.550

Band	Module	Type	Beam ID_1	Feed no.	HFSS Simulated 4cm2 Average Total PD (W/m^2)		
					S6 (Bottom)	S2 (Bottom Side)	S5 (Bottom Face)
N261	K	Patch	2	1	1.437	6.082	4.457
			9	2	2.475	6.078	3.661
			10	2	2.678	5.953	3.355
			11	2	1.751	6.165	4.239
			16	2	2.403	5.959	3.228
			17	2	2.700	6.046	3.316
			28	4	3.712	6.165	4.350
			29	4	2.550	5.806	3.862
			30	4	2.501	6.165	4.338
			31	4	2.522	5.903	4.290
			32	4	2.251	6.165	3.364
			41	4	2.742	6.101	4.386
			42	4	2.333	5.964	4.190
			43	4	2.682	6.083	4.413
			44	4	2.405	6.165	3.392
			130	1	2.205	5.783	2.948
			137	2	1.877	6.165	5.370
			138	2	2.352	6.122	4.157
			139	2	2.509	6.165	4.244
			144	2	1.926	6.165	4.923
			145	2	2.562	5.936	3.786
			156	4	2.597	5.705	3.663
			157	4	2.622	5.984	3.951
			158	4	2.414	6.165	4.148
			159	4	2.466	5.704	3.683
			160	4	4.122	6.165	5.339
			169	4	2.418	5.621	3.927
			170	4	2.446	6.165	4.042
			171	4	2.427	5.811	3.942
			172	4	3.435	6.101	4.736

4cm^2-averaged PD for the selected beams on non-selected surfaces for Δ_{min}determination

Band	Beam ID	antenna module	Type	Surface	Exposure Surface	Input Power limit (dB)	Test separation	Measured results Savg tot 4cm^2 (W/m2)
N261	20	L	Patch	S6	Bottom of Laptop	1.3	2mm	1.02
N261	149	L	Patch	S6	Bottom of Laptop	2.8	2mm	1.56
N261	24	J	Patch	S6	Bottom of Laptop	1.7	2mm	0.935
N261	135	J	Patch	S6	Bottom of Laptop	4.6	2mm	0.738
N261	28	K	Patch	S6	Bottom of Laptop	5.1	2mm	0.694
N261	160	K	Patch	S6	Bottom of Laptop	5.6	2mm	0.474
N260	12	L	Patch	S6	Bottom of Laptop	4.8	2mm	0.981
N260	162	L	Patch	S6	Bottom of Laptop	3.1	2mm	0.648
N260	25	J	Patch	S6	Bottom of Laptop	1.8	2mm	0.166
N260	167	J	Patch	S6	Bottom of Laptop	2	2mm	0.939
N260	31	K	Patch	S6	Bottom of Laptop	3.5	2mm	0.855
N260	157	K	Patch	S6	Bottom of Laptop	3	2mm	1.41

4.6 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.

4.6.1 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:

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

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,

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

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

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

else if Δmin > TxAGC uncertainty at reference power level,

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

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

Band	Anenna Module	Δ_{min} (dB)	Uncertainty (dB)	Input.power.limit (dBm)
n260	L	3.16	2.1	6 +10* log(s(i))+1.06
	J	1.74	2.1	6 +10* log(s(i))
	K	1.53	2.1	6 +10* log(s(i))
n261	L	2.11	2.1	6 +10* log(s(i))+0.01
	J	2.66	2.1	6 +10* log(s(i))+0.56
	K	2.08	2.1	6 +10* log(s(i))

4.6.2 PD char Table

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

Band	Module	Type	Beam ID 1	Beam ID 2	Input Power limit (dBm)
N260	L	Patch	0		7.7
			3		4.9
			4		6.0
			5		4.7
			12		4.9
			13		5.3
			18		2.6
			19		2.5
			20		3.2
			21		2.8
			22		2.6
			33		2.6
			34		2.9
			35		3.1
			36		2.7
			128		9.3
			131		5.0
			132		4.9
			133		5.3
			140		6.1
			141		4.5
			146		2.6
			147		3.2
			148		2.9
			149		3.1
			150		2.4
			161		2.8
			162		3.1
			163		3.0
			164		2.6

			0	128	5.9
			3	131	2.2
			4	132	2.5
			5	133	2.1
			12	140	2.6
			13	141	2.0
			18	146	-0.1
			19	147	-0.3
			20	148	0.4
			21	149	0.4
			22	150	0.0
			33	161	-0.5
			34	162	-0.1
			35	163	0.5
			36	164	0.2

Band	Module	Type	Beam ID 1	Beam ID 2	Input Power limit (dBm)
N260	J	Patch	1		5.9
			6		3.4
			7		4.1
			8		3.3
			14		3.5
			15		4.2
			23		1.3
			24		1.2
			25		1.8
			26		2.3
			27		1.6
			37		1.0
			38		1.6
			39		1.8
			40		2.3
			129		7.0
			134		3.6
			135		4.8

			136		3.6
			142		3.9
			143		4.4
			151		1.9
			152		2.3
			153		2.0
			154		1.9
			155		1.8
			165		2.0
			166		2.4
			167		2.0
			168		1.9
			1	129	3.4
			6	134	1.2
			7	135	1.7
			8	136	0.7
			14	143	1.5
			15	142	0.9
			23	155	-1.4
			24	153	-1.2
			25	152	-1.1
			26	151	-0.6
			27	154	-0.8
			37	167	-1.1
			38	166	-1.4
			39	165	-1.0
			40	168	-0.7

Band	Module	Type	Beam ID 1	Beam ID 2	Input Power limit (dBm)
N260	K	Patch	2		9.5
			9		5.6
			10		6.1
			11		5.4
			16		5.5
			17		6.0

			28		3.2
			29		3.0
			30		2.9
			31		3.5
			32		3.1
			41		2.9
			42		2.8
			43		2.9
			44		3.4
			130		9.6
			137		6.1
			138		5.8
			139		5.5
			144		5.8
			145		5.5
			156		3.1
			157		3.0
			158		3.4
			159		3.3
			160		3.1
			169		2.7
			170		3.0
			171		3.8
			172		3.2
			2	130	6.7
			9	137	2.6
			10	138	2.2
			11	139	1.9
			16	144	3.3
			17	145	2.6
			28	156	0.5
			29	157	-0.5
			30	158	0.3
			31	159	0.3
			32	160	0.0
			41	169	-0.5

			42	170	-0.4
			43	171	0.0
			44	172	0.0

Band	Module	Type	Beam ID 1	Beam ID 2	Input Power limit (dBm)
N261	L	Patch	0		6.6
			3		4.3
			4		4.2
			5		4.2
			12		4.6
			13		4.3
			18		2.2
			19		1.5
			20		1.3
			21		2.5
			22		3.1
			33		2.3
			34		1.3
			35		1.8
			36		2.9
			128		7.6
			131		4.3
			132		4.1
			133		4.3
			140		4.4
			141		4.0
			146		2.9
			147		1.7
			148		1.5
			149		2.8
			150		2.6
			161		2.3
			162		1.4
			163		2.2
			164		2.7

			0	128	3.9
			3	131	1.4
			4	132	0.8
			5	133	1.2
			12	140	1.4
			13	141	1.0
			18	146	-0.1
			19	147	-1.3
			20	148	-1.6
			21	149	-0.4
			22	150	0.2
			33	161	-0.4
			34	162	-1.7
			35	163	-1.2
			36	164	0.0

Band	Module	Type	Beam ID 1	Beam ID 2	Input Power limit (dBm)
N261	J	Patch	1		8.3
			6		4.9
			7		4.8
			8		4.9
			14		4.8
			15		4.7
			23		3.1
			24		1.7
			25		1.9
			26		2.9
			27		3.3
			37		2.2
			38		1.6
			39		3.2
			40		2.9
			129		7.9
			134		5.0
			135		4.6

			136		5.1
			142		4.8
			143		4.8
			151		3.5
			152		2.0
			153		2.6
			154		3.4
			155		3.7
			165		3.0
			166		2.1
			167		3.4
			168		3.8
			1	129	5.1
			6	134	2.2
			7	136	2.0
			8	135	1.8
			14	142	1.6
			15	143	2.0
			23	151	0.7
			24	152	-1.4
			25	153	-1.0
			26	155	0.4
			27	154	1.0
			37	165	-0.6
			38	166	-1.3
			39	168	0.3
			40	167	1.2

Band	Module	Type	Beam ID 1	Beam ID 2	Input Power limit (dBm)
N261	K	Patch	2		9.2
			9		7.6
			10		6.0
			11		7.0
			16		6.8
			17		6.0

			28		5.1
			29		3.3
			30		2.8
			31		3.5
			32		4.1
			41		4.5
			42		2.9
			43		3.1
			44		3.9
			130		9.5
			137		7.2
			138		6.3
			139		7.6
			144		6.6
			145		6.6
			156		4.6
			157		3.1
			158		3.1
			159		5.0
			160		5.7
			169		3.9
			170		3.1
			171		3.6
			172		5.6
			2	130	6.2
			9	137	4.4
			10	138	2.8
			11	139	3.9
			16	144	3.5
			17	145	3.1
			28	156	2.4
			29	157	0.3
			30	158	-0.2
			31	159	0.7
			32	160	3.2
			41	169	1.7

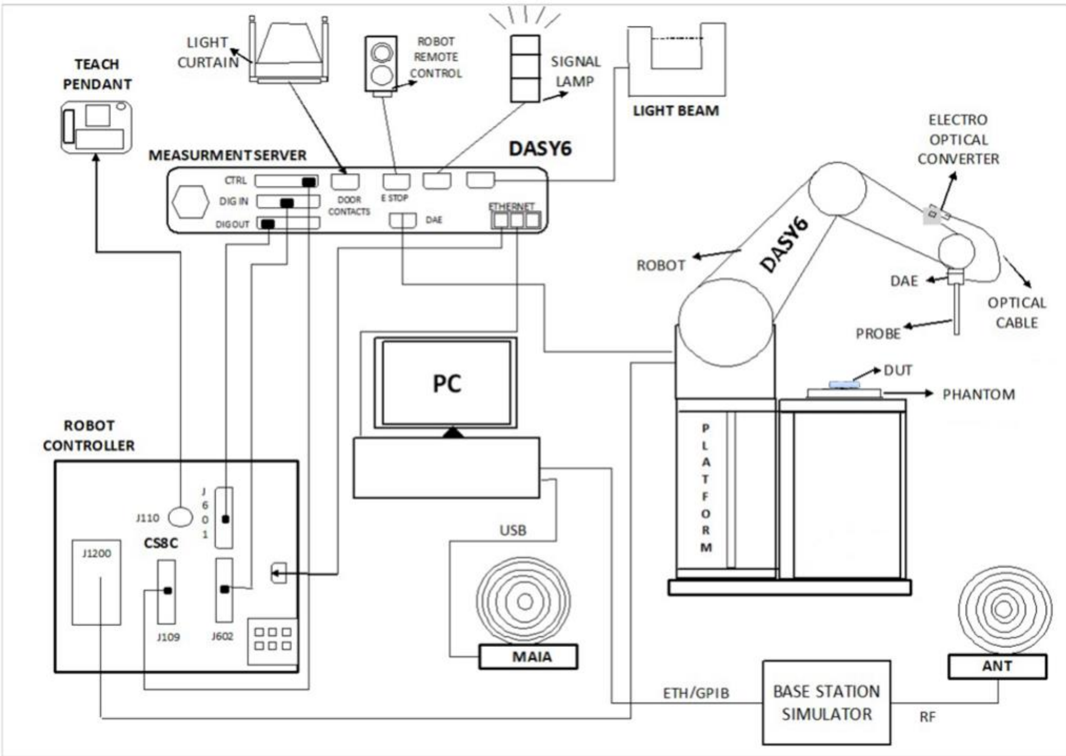
			42	170	-0.2
			43	171	0.1
			44	172	2.1

5. PD Test Setup

5.1 PD Test – System Setup

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

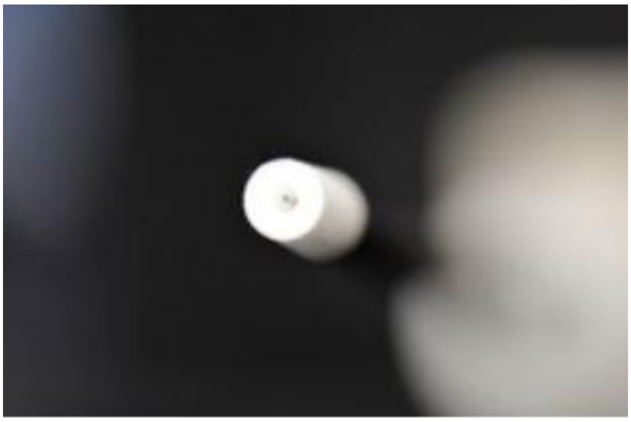
- SPEAG DASY6 system
  - SPEAG cDASY6 5G module software
  - EUmmWVx probe
- 5G Phantom cover

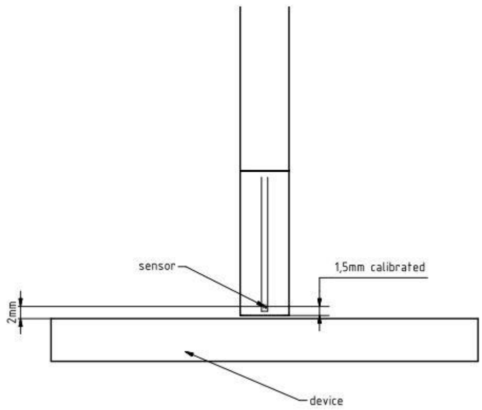


5.2 EUmmWave Probe / E-Field 5G Probe

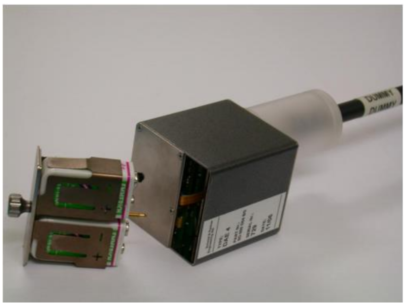
The probe design allows measurements at distances as small as 2 mm from the sensors to the surface of the device under test (DUT). The typical sensor to probe tip distance is 1.5 mm.

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.

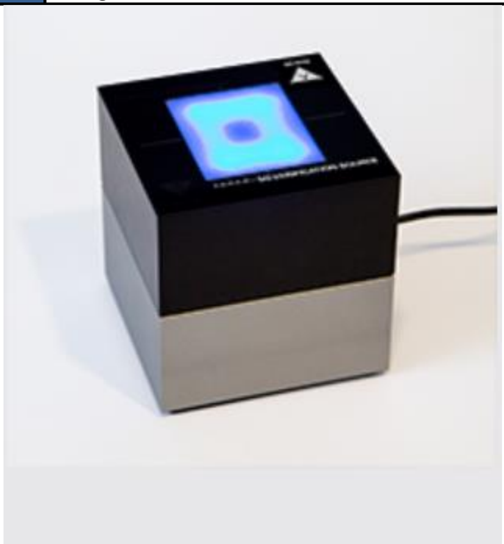
5.4 Scan configuration

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 $\lambda/4$.
The (x, y) grid step is also set $\lambda/4$, 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

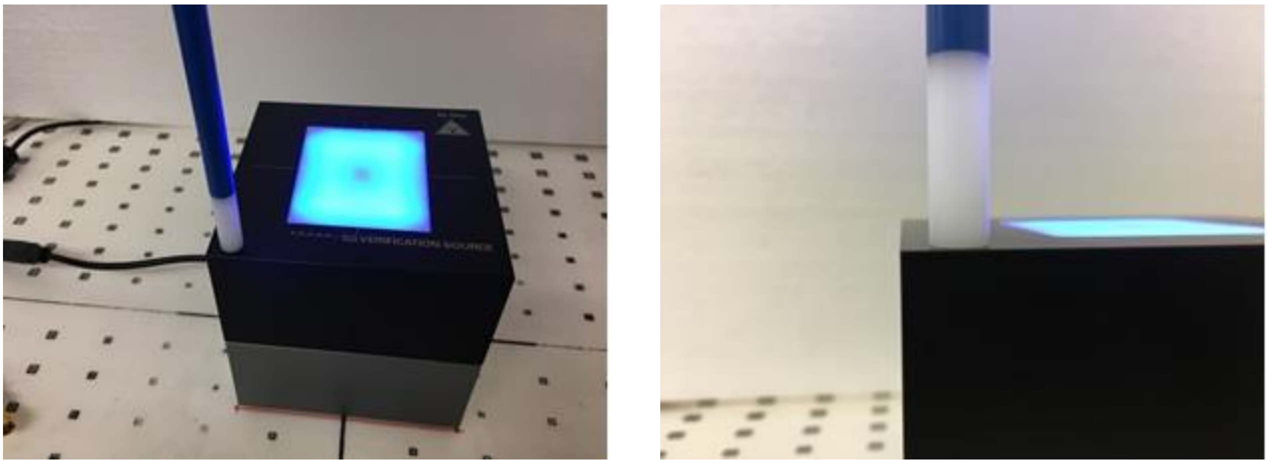


5.6 Power Density System Verification

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

Date	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)
2019/12/17	30	30GHz_1007	9461	854	10mm	31.5	34.1	-0.32
2019/12/26	30	30GHz_1007	9461	854	10mm	34.5	34.1	0.05
2020/1/23	30	30GHz_1007	9461	376	10mm	31.2	34.1	-0.35
2020/2/12	30	30GHz_1007	9441	778	10mm	30.9	34.1	-0.39

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	

Appendix A. Plots of System Performance Check

The plots are shown as follows.

Appendix B. Plots of Power Density Measurement

The plots are shown as follows.

Appendix C. DASY Calibration Certificate

The DASY calibration certificates are shown as follows.