RF Exposure Report

(Part 0: SAR and PD Char Evaluation)

FCC ID	: PKRISGM2100
Equipment	: Wireless Hotspot Modem
Brand Name	: Inseego
Model Name	: M2100
Applicant	: Inseego Corporation 9710 Scranton Road Suite 200, San Diego,, CA 92121
Manufacturer	: Inseego Corporation 9710 Scranton Road Suite 200, San Diego,, CA 92121
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

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History of this test report

Report No.	Version	Description	Issued Date
FA041648-02D	01	Initial issue of report	Jul. 28, 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_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	Wireless Hotspot Modem
FCC ID	PKRISGM2100
Wireless Technology and Frequency Range	WCDMA Band II: 1850 MHz ~ 1910 MHz WCDMA Band IV: 1710 MHz ~ 1755 MHz WCDMA Band V: 824 MHz ~ 849 MHz LTE Band 2: 1850 MHz ~ 1910 MHz LTE Band 4: 1710 MHz ~ 1755 MHz LTE Band 5: 824 MHz ~ 849 MHz LTE Band 7: 2500 MHz ~ 2570 MHz LTE Band 12: 699 MHz ~ 716 MHz LTE Band 13: 777 MHz ~ 787 MHz LTE Band 14: 788 MHz ~ 798 MHz LTE Band 17: 704 MHz ~ 716 MHz LTE Band 66: 1710 MHz ~ 1780 MHz LTE Band 48: 3550 MHz ~ 3700 MHz 5G NR n2 : 1850 MHz ~ 1910 MHz 5G NR n5 : 824 MHz ~ 849 MHz 5G NR n66 : 1710 MHz ~ 1780 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: 5150 MHz ~ 5250 MHz WLAN 5.3GHz Band: 5250 MHz ~ 5350 MHz WLAN 5.6GHz Band: 5470 MHz ~ 5725 MHz WLAN 5.8GHz Band: 5725 MHz ~ 5825 MHz
Mode	RMC/AMR 12.2Kbps HSDPA HSUPA DC-HSDPA 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
EUT Stage	Production Unit

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

Exposure conditions	SAR design target	W/kg
Body Exposure condition	1g SAR design target	0.79

	Uncertainty dB (k=2)
Total uncertainty	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

Exposure Scenario:		Body	Pmax(*)
Averaging volume:		1g	
Spacing:		10	
DSI		0	
Band	Antenna	Plimit corresponding to SAR design target	
WCDMA_B2	0	21.7	23.0
WCDMA_B4	0	20.6	23.0
WCDMA_B5	0	22.7	23.0
LTE_B2	0	21.6	23.0
LTE_B2	8	21.2	23.0
LTE_B4	0	21.3	23.0
LTE_B4	8	23.0	23.0
LTE_B5	0	21.8	23.0
LTE_B7	0	20.7	23.0
LTE_B12	0	23.4	23.0
LTE_B13	0	23.3	23.0
LTE_B14	0	23.3	23.0
LTE_B48**	4	16.5	16.5
LTE_B66	0	21.3	23.0
LTE_B66	8	23.0	23.0
5G FR1_n2	0	21.0	23.0
5G FR1_n2	8	20.6	23.0
5G FR1_n5	0	23.0	23.0
5G FR1_n66	0	21.6	23.0
5G FR1_n66	8	23.1	23.0

Remark: Ant 8 for transmission only for LTE Inter-Band ULCA, and LTE anchor band of 5GNR EN-DC combination.

*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 SAR_design_target.

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 device uncertainty

LTE inter-band uplink CA combinations

ULCA	PCC		SCC	
	Band	ANT port	Band	ANT port
2A-4A	2	8	4	0
4A-2A	4	0	2	8
2A-5A	2	8	5	0
5A-2A	5	0	2	8
2A-13A	2	8	13	0
13A-2A	13	0	2	8
2A-66A	2	8	66	0
66A-2A	66	0	2	8
4A-5A	4	8	5	0
5A-4A	5	0	4	8
4A-13A	4	8	13	0
13A-4A	13	0	4	8
5A-66A	5	0	66	8
66A-5A	66	8	5	0
13A-66A	13	0	66	8
66A-13A	66	8	13	0

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					
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	
0	Patch	Single Beam H-pol	1		1
			2		5
			2		6
			2		7
			2		10
			2		11
			4		17
			4		18
			4		19
			4		20
			4		21
			4		26
			4		27
			4		28
			4		29
		Single Beam V-pol	1		129
			2		133
			2		134
			2		135
			2		138
			2		139
			4		145
			4		146
			4		147
			4		148
			4		149
			4		154
			4		155
			4		156
			4		157
		Paired Beam	1	1	129
			2	5	133
			2	6	134
			2	7	135
			2	10	138
			2	11	139
			4	17	145
			4	18	146
			4	19	147
			4	20	148
			4	21	149
			4	26	154
			4	27	155
			4	28	156
			4	29	157

n260					
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	
1	Patch	Single Beam H-pol	1		0
			2		2
			2		3
			2		4
			2		8
			2		9
			4		12
			4		13
			4		14
			4		15
			4		16
			4		22
			4		23
			4		24
			4		25
		Single Beam V-pol	1		128
			2		130
			2		131
			2		132
			2		136
			2		137
			4		140
			4		141
			4		142
			4		143
			4		144
			4		150
			4		151
			4		152
			4		153
		Paired Beam	1	0	128
			2	2	132
			2	3	131
			2	4	130
			2	8	137
			2	9	136
			4	12	141
			4	13	142
			4	14	144
			4	15	140
			4	16	143
			4	22	152
			4	23	151
			4	24	150

			4	25	153
n261					
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	
0	Patch	Single Beam H-pol	1		1
			2		5
			2		6
			2		7
			2		10
			2		11
			4		17
			4		18
			4		19
			4		20
			4		21
			4		26
			4		27
			4		28
			4		29
		Single Beam V-pol	1		129
			2		133
			2		134
			2		135
			2		138
			2		139
			4		145
			4		146
			4		147
			4		148
			4		149
			4		154
			4		155
			4		156
			4		157
		Paired Beam	1	1	129
			2	5	134
			2	6	135
			2	7	133
			2	10	139
			2	11	138
			4	17	147
			4	18	149
			4	19	146
			4	20	148
			4	21	145
			4	26	156
			4	27	157
			4	28	154

Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	
			4	29	155
n261					
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	
1	Patch	Single Beam H-pol	1		0
			2		2
			2		3
			2		4
			2		8
			2		9
			4		12
			4		13
			4		14
			4		15
			4		16
			4		22
			4		23
			4		24
			4		25
		Single Beam V-pol	1		128
			2		130
			2		131
			2		132
			2		136
			2		137
			4		140
			4		141
			4		142
			4		143
			4		144
			4		150
			4		151
			4		152
			4		153
		Paired Beam	1	0	128
			2	2	131
			2	3	130
			2	4	132
			2	8	137
			2	9	136
			4	12	143
			4	13	142
			4	14	141
			4	15	140
			4	16	144
			4	22	152
			4	23	150
			4	24	151

			4	25	153

4.3 PD_design_target determination

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

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

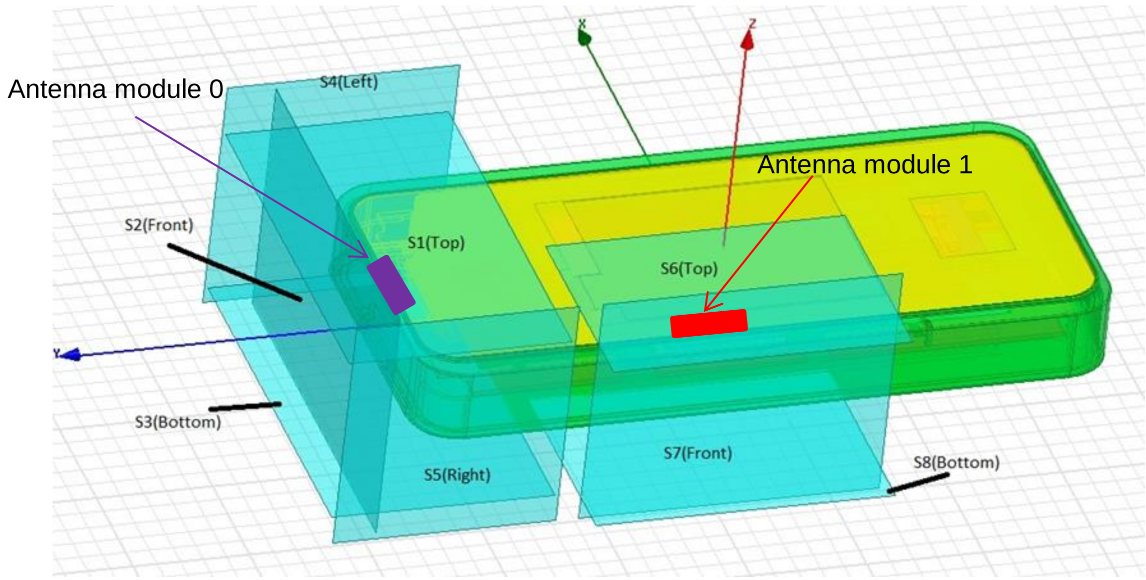
For this EUT, the PD design target and the uncertainty value are listed below

N260	PD design target	Antenna Module	W/m^2
		Antenna Module 0/1	3.8

N261	PD design target	Antenna Module	W/m^2
		Antenna Module 0/1	3.8

Item	Uncertainty dB (k=2)
Total uncertainty	2.1

4.4 Exposure positions for PD evaluation



Evaluation positions

Antenna module 0	Top Surface	Front Surface	Bottom Surface	Left Surface	Right Surface
	S1	S2	S3	S4	S5
	v	v	v	v	v
Antenna module 1	Top Surface	Front Surface	Bottom Surface		
	S6	S7	S8		
	v	v	v		

Remark:

1. Referring to the PD simulation report for the reason of selecting surfaces/edges.
2. The exposure positions selection is based on the all edges and surfaces of the device with a transmitting antenna located within 25 mm from that surface or edge.

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

PD Simulation vs Measured Verification 4cm2 Avg. PD (mW/cm2) @+6dBm Per Element											
Band	Surface Side	Surface ID	Polarization	Mid Channel	Antenna	Beam ID	Simulated W/m²	Measured W/m²	Delta = Sim. - Meas (dB)	H_Δ minimum (dB)	V_Δ minimum (dB)
n261	Top	S1	H	2077917	0	17	5.80	2.13	4.35	4.35	5.99
	Top	S1	V	2077917		145	6.80	0.87	8.93		
	Front	S2	H	2077917		20	7.24	1.06	8.34		
	Front	S2	V	2077917		145	6.16	1.55	5.99		
	Top	S6	H	2077917	1	22	10.72	2.26	6.76	3.69	6.46
	Top	S6	V	2077917		143	10.56	1.40	8.78		
	Front	S7	H	2077917		23	6.24	2.67	3.69		
	Front	S7	V	2077917		140	5.88	1.33	6.46		

PD Simulation vs Measured Verification 4cm2 Avg. PD (mW/cm2) @+6dBm Per Element											
Band	Surface Side	Surface ID	Polarization	Mid Channel	Antenna	Beam ID	Simulated W/m²	Measured W/m²	Delta = Sim. - Meas (dB)	H_Δ minimum (dB)	V_Δ minimum (dB)
n260	Top	S1	H	2254167	0	28	8.44	2.25	5.74	5.39	7.78
	Top	S1	V	2254167		149	6.84	1.14	7.78		
	Front	S2	H	2254167		29	6.68	1.93	5.39		
	Front	S2	V	2254167		154	8.04	1.31	7.88		
	Top	S6	H	2254167	1	22	9.92	2.02	6.91	4.76	7.25
	Top	S6	V	2254167		140	10.48	1.76	7.75		
	Front	S7	H	2254167		16	7.84	2.62	4.76		
	Front	S7	V	2254167		140	8.12	1.53	7.25		

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:

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

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 $total\ PD\ (\emptyset)$ 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:

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

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

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

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 module	H_Δ minimum (dB)	V_Δ minimum (dB)
n261	0	4.35	5.99
	1	3.69	6.46

Band	Antenna	H_Δ minimum (dB)	V_Δ minimum (dB)
n260	0	5.39	7.78
	1	4.76	7.25

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)

Simulated 4cm 2 SAPD (W/m 2) corresponding to PD_design_target									
n260 PD Simulation					Top	Bottom	Front	Left	Right
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	4cm2 avg. PD (mW/cm2) @ 10mm distance				
					Channel				
					Mid	Mid	Mid	Mid	Mid
0	Patch	Single Beam H-pol	1	1	0.35	0.06	0.37	0.02	0.03
			2	5	0.34	0.07	0.38	0.01	0.06
			2	6	0.38	0.07	0.21	0.03	0.01
			2	7	0.31	0.05	0.38	0.01	0.04
			2	10	0.36	0.09	0.26	0.04	0.07
			2	11	0.26	0.06	0.36	0.01	0.02
			4	17	0.32	0.08	0.26	0.01	0.05
			4	18	0.30	0.14	0.38	0.07	0.05
			4	19	0.38	0.06	0.23	0.02	0.03
			4	20	0.38	0.11	0.31	0.02	0.02
			4	21	0.38	0.09	0.28	0.02	0.03
			4	26	0.33	0.09	0.29	0.02	0.09
			4	27	0.28	0.13	0.32	0.06	0.05
			4	28	0.38	0.10	0.30	0.02	0.03
			4	29	0.38	0.11	0.31	0.02	0.04
		Single Beam V-pol	1	129	0.32	0.07	0.36	0.03	0.03
			2	133	0.34	0.08	0.29	0.03	0.03
			2	134	0.28	0.10	0.26	0.08	0.01
			2	135	0.33	0.05	0.21	0.03	0.02
			2	138	0.38	0.10	0.27	0.04	0.06
			2	139	0.28	0.04	0.21	0.05	0.02
			4	145	0.30	0.12	0.38	0.02	0.02
			4	146	0.31	0.11	0.38	0.04	0.03
			4	147	0.28	0.20	0.26	0.13	0.03
			4	148	0.32	0.07	0.23	0.04	0.02
			4	149	0.33	0.07	0.25	0.05	0.02
			4	154	0.28	0.12	0.38	0.02	0.02
			4	155	0.30	0.16	0.38	0.04	0.06
			4	156	0.28	0.10	0.23	0.09	0.01
			4	157	0.32	0.08	0.24	0.05	0.02

Simulated 4cm 2 SAPD (W/m 2) corresponding to PD_design_target							
n260 PD Simulation					Top	Bottom	Front
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	4cm2 avg. PD (mW/cm2) @ 10mm distance		
					Channel		
					Mid	Mid	Mid
1	Patch	Single Beam H-pol	1	0	0.38	0.01	0.23
			2	2	0.38	0.01	0.25
			2	3	0.36	0.03	0.31
			2	4	0.28	0.02	0.38
			2	8	0.37	0.02	0.33
			2	9	0.30	0.03	0.37
			4	12	0.38	0.03	0.29
			4	13	0.34	0.03	0.26
			4	14	0.36	0.02	0.26
			4	15	0.38	0.02	0.24
			4	16	0.37	0.03	0.36
			4	22	0.38	0.02	0.29
			4	23	0.38	0.02	0.30
			4	24	0.38	0.02	0.29
			4	25	0.38	0.03	0.33
		Single Beam V-pol	1	128	0.38	0.01	0.24
			2	130	0.38	0.02	0.22
			2	131	0.38	0.02	0.26
			2	132	0.32	0.04	0.31
			2	136	0.32	0.02	0.35
			2	137	0.38	0.02	0.35
			4	140	0.38	0.02	0.29
			4	141	0.38	0.02	0.31
			4	142	0.38	0.03	0.27
			4	143	0.31	0.03	0.24
			4	144	0.28	0.04	0.29
			4	150	0.38	0.02	0.30
			4	151	0.37	0.03	0.22
			4	152	0.31	0.03	0.27
			4	153	0.30	0.03	0.32

Simulated 4cm 2 SAPD (W/m 2) corresponding to PD_design_target									
n261 PD Simulation					Top	Bottom	Front	Left	Right
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	4cm2 avg. PD (mW/cm2) @ 10mm distance				
					Channel				
					Mid	Mid	Mid	Mid	Mid
0	Patch	Single Beam H-pol	1	1	0.25	0.03	0.18	0.04	0.03
			2	5	0.33	0.03	0.29	0.02	0.03
			2	6	0.31	0.14	0.38	0.08	0.10
			2	7	0.38	0.07	0.29	0.09	0.11
			2	10	0.35	0.03	0.38	0.06	0.03
			2	11	0.38	0.03	0.27	0.02	0.05
			4	17	0.36	0.11	0.17	0.04	0.09
			4	18	0.37	0.07	0.22	0.05	0.14
			4	19	0.26	0.06	0.38	0.01	0.01
			4	20	0.29	0.03	0.38	0.03	0.03
			4	21	0.21	0.09	0.38	0.10	0.12
			4	26	0.37	0.09	0.20	0.06	0.13
			4	27	0.20	0.07	0.38	0.01	0.02
			4	28	0.23	0.04	0.38	0.01	0.01
			4	29	0.16	0.06	0.38	0.07	0.05
		Single Beam V-pol	1	129	0.38	0.06	0.17	0.05	0.04
			2	133	0.38	0.05	0.22	0.02	0.04
			2	134	0.38	0.06	0.21	0.06	0.05
			2	135	0.36	0.04	0.24	0.03	0.04
			2	138	0.38	0.05	0.22	0.03	0.05
			2	139	0.34	0.10	0.37	0.08	0.09
			4	145	0.38	0.03	0.34	0.01	0.04
			4	146	0.37	0.09	0.34	0.09	0.10
			4	147	0.33	0.14	0.33	0.16	0.08
			4	148	0.35	0.07	0.30	0.06	0.03
			4	149	0.30	0.02	0.26	0.01	0.01
			4	154	0.38	0.05	0.35	0.04	0.09
			4	155	0.38	0.15	0.30	0.12	0.10
			4	156	0.36	0.09	0.34	0.14	0.07
			4	157	0.28	0.02	0.22	0.03	0.03

Simulated 4cm 2 SAPD (W/m 2) corresponding to PD_design_target							
n261 PD Simulation					Top	Bottom	Front
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID	4cm2 avg. PD (mW/cm2) @ 10mm distance		
					Channel		
					Mid	Mid	Mid
1	Patch	Single Beam H-pol	1	0	0.37	0.02	0.20
			2	2	0.37	0.02	0.18
			2	3	0.37	0.02	0.20
			2	4	0.36	0.05	0.28
			2	8	0.37	0.01	0.15
			2	9	0.34	0.02	0.14
			4	12	0.38	0.02	0.18
			4	13	0.36	0.01	0.19
			4	14	0.38	0.04	0.25
			4	15	0.38	0.04	0.18
			4	16	0.33	0.03	0.18
			4	22	0.37	0.01	0.20
			4	23	0.38	0.03	0.24
			4	24	0.38	0.05	0.29
			4	25	0.38	0.03	0.20
		Single Beam V-pol	1	128	0.37	0.02	0.16
			2	130	0.34	0.02	0.12
			2	131	0.37	0.02	0.17
			2	132	0.37	0.03	0.17
			2	136	0.34	0.03	0.23
			2	137	0.38	0.02	0.15
			4	140	0.35	0.03	0.23
			4	141	0.28	0.02	0.14
			4	142	0.36	0.02	0.14
			4	143	0.38	0.02	0.18
			4	144	0.38	0.02	0.17
			4	150	0.36	0.03	0.19
			4	151	0.32	0.02	0.17
			4	152	0.38	0.03	0.19
			4	153	0.38	0.01	0.19

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

Band	antenna module	Beam ID 1	Beam ID 2	Frequency (GHz)	Exposure Surface	Input power limit (dB)	Test separation	modulation	Measured results Savg tot 4cm^2 (W/m2)
n261	0	-	155	27.925	S3(Bottom)	10.4	10mm	CW	1.31
	0	-	147	27.925	S4(Left)	11.7	10mm	CW	0.209
	0	18	-	27.925	S5(Right)	8.6	10mm	CW	1.16
	1	24	-	27.925	S8(Bottom)	8.0	10mm	CW	0.807
n260	0	-	147	38.5	S3(Bottom)	11.4	10mm	CW	1.59
	0	-	147	38.5	S4(Left)	11.4	10mm	CW	0.555
	0	26	-	38.5	S5(Right)	9.2	10mm	CW	0.734
	1	-	132	38.5	S8(Bottom)	13.3	10mm	CW	0.618

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 ($\boldsymbol{\Delta_{min}}$), *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 $\boldsymbol{\Delta_{min}}$ (= 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 $\boldsymbol{\Delta_{min}}$ 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 $\boldsymbol{\Delta_{min}}$ 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	Anenna Module	Polarization	Δ_{min} (dB)	TxAGC uncertainty (dB)	Input.power.limit (dBm)
n260	0	H	5.39	0.5	6 +10* log(s(i))+4.89
		V	7.78	0.5	6 +10* log(s(i))+7.28
	1	H	4.76	0.5	6 +10* log(s(i))+4.26
		V	7.25	0.5	6 +10* log(s(i))+6.75
n261	0	H	4.35	0.5	6 +10* log(s(i))+3.85
		V	5.99	0.5	6 +10* log(s(i))+5.49
	1	H	3.69	0.5	6 +10* log(s(i))+3.19
		V	6.46	0.5	6 +10* log(s(i))+5.96

4.7.2 PD char Table

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

n260						
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID		Input power limit
0	Patch	Single Beam H-pol	1		1	14.54
			2		5	11.08
			2		6	10.22
			2		7	10.50
			2		10	11.78
			2		11	9.86
			4		17	8.19
			4		18	9.53
			4		19	8.24
			4		20	7.77
			4		21	7.70
			4		26	9.18
			4		27	9.00
			4		28	7.43
			4		29	7.53
		Single Beam V-pol	1		129	16.98
			2		133	13.26
			2		134	13.92
			2		135	12.70
			2		138	15.13
			2		139	12.59
			4		145	10.09
			4		146	10.91
			4		147	11.36
			4		148	10.05
			4		149	10.14
			4		154	10.03
			4		155	11.48
			4		156	10.46
			4		157	10.09
		Paired Beam	1	1	129	14.62
			2	5	133	10.78
			2	6	134	12.01
			2	7	135	8.14
			2	10	138	10.94
			2	11	139	11.27
			4	17	145	7.77
			4	18	146	8.44
			4	19	147	10.26
			4	20	148	6.90
			4	21	149	7.37
			4	26	154	7.51

			4	27	155	9.43
			4	28	156	8.85
			4	29	157	7.55

n260						
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID		Input power limit
1	Patch	Single Beam H-pol	1		0	11.56
			2		2	7.38
			2		3	9.17
			2		4	8.86
			2		8	9.14
			2		9	9.62
			4		12	6.16
			4		13	7.66
			4		14	7.01
			4		15	6.71
			4		16	6.88
			4		22	6.09
			4		23	6.82
			4		24	7.56
			4		25	6.98
		Single Beam V-pol	1		128	14.15
			2		130	10.05
			2		131	12.94
			2		132	13.34
			2		136	11.32
			2		137	11.34
			4		140	8.34
			4		141	9.60
			4		142	10.00
			4		143	8.12
			4		144	9.65
			4		150	8.65
			4		151	9.35
			4		152	8.18
			4		153	10.02
		Paired Beam	1	0	128	11.01
			2	2	132	8.62
			2	3	131	10.35
			2	4	130	9.14
			2	8	137	9.83
			2	9	136	9.93
			4	12	141	6.33
			4	13	142	8.51
			4	14	144	7.41
			4	15	140	5.80
			4	16	143	5.61

			4	22	152	5.11
			4	23	151	7.71
			4	24	150	7.09
			4	25	153	7.25

n261						
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID		Input power limit
0	Patch	Single Beam H-pol	1		1	12.98
			2		5	10.01
			2		6	13.34
			2		7	12.47
			2		10	10.65
			2		11	10.60
			4		17	7.81
			4		18	8.59
			4		19	8.23
			4		20	7.05
			4		21	7.95
			4		26	8.23
			4		27	8.23
			4		28	7.72
			4		29	7.43
		Single Beam V-pol	1		129	16.53
			2		133	12.00
			2		134	13.17
			2		135	12.03
			2		138	12.27
			2		139	13.95
			4		145	8.94
			4		146	9.90
			4		147	11.68
			4		148	9.57
			4		149	8.46
			4		154	9.51
			4		155	10.37
			4		156	10.94
			4		157	8.62
		Paired Beam	1	1	129	14.86
			2	5	134	11.21
			2	6	135	10.76
			2	7	133	9.46
			2	10	139	12.68
			2	11	138	11.63
			4	17	147	10.04
			4	18	149	9.99
			4	19	146	8.80
			4	20	148	10.82
			4	21	145	10.09
			4	26	156	11.05
			4	27	157	9.14
			4	28	154	8.46
			4	29	155	8.73

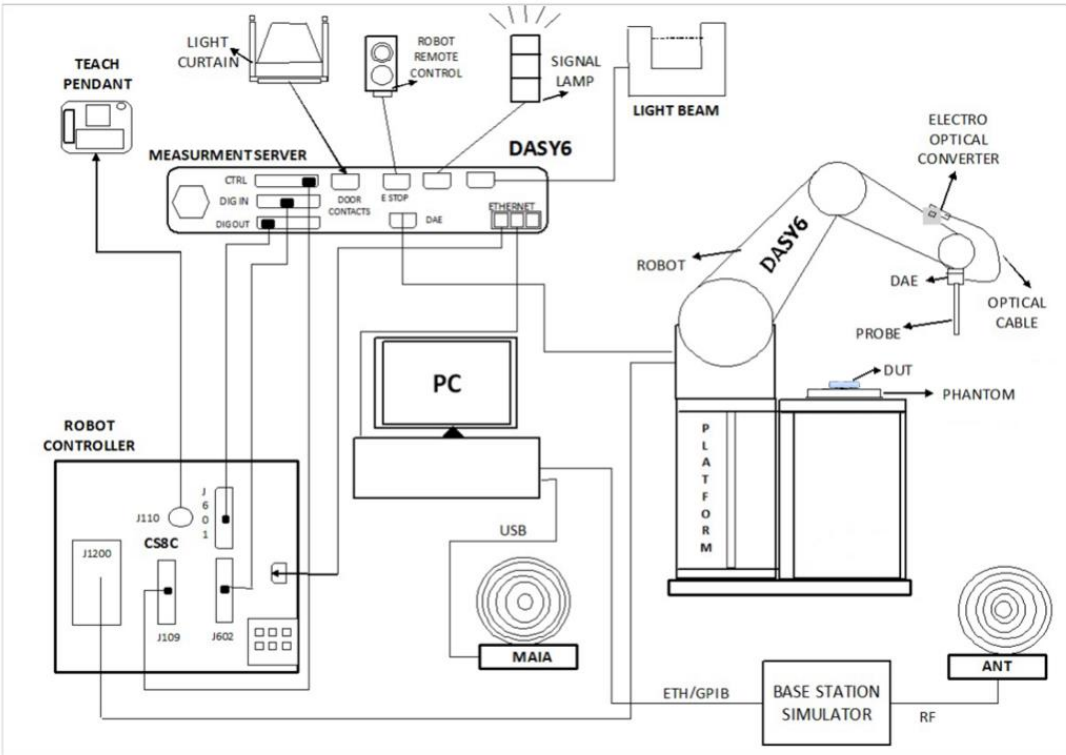
n261						
Ant Module	Ant. Type	SISO/MIMO & Polarization	Feed no.	Beam ID		Input power limit
1	Patch	Single Beam H-pol	1		0	13.11
			2		2	7.87
			2		3	8.28
			2		4	11.29
			2		8	8.12
			2		9	10.36
			4		12	4.95
			4		13	4.48
			4		14	5.37
			4		15	8.39
			4		16	8.25
			4		22	4.62
			4		23	4.98
			4		24	8.03
			4		25	8.96
		Single Beam V-pol	1		128	16.02
			2		130	10.56
			2		131	12.31
			2		132	10.51
			2		136	13.64
			2		137	11.93
			4		140	7.82
			4		141	9.69
			4		142	9.69
			4		143	7.50
			4		144	8.77
			4		150	9.43
			4		151	10.90
			4		152	7.65
			4		153	8.04
		Paired Beam	1	0	128	12.76
			2	2	131	8.28
			2	3	130	9.47
			2	4	132	10.27
			2	8	137	9.07
			2	9	136	11.56
			4	12	143	4.40
			4	13	142	5.33
			4	14	141	6.04
			4	15	140	7.66
			4	16	144	7.26
			4	22	152	4.30
			4	23	150	5.70
			4	24	151	6.79
			4	25	153	6.79

5. PD Test Setup

5.1 PD Test – System Setup

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

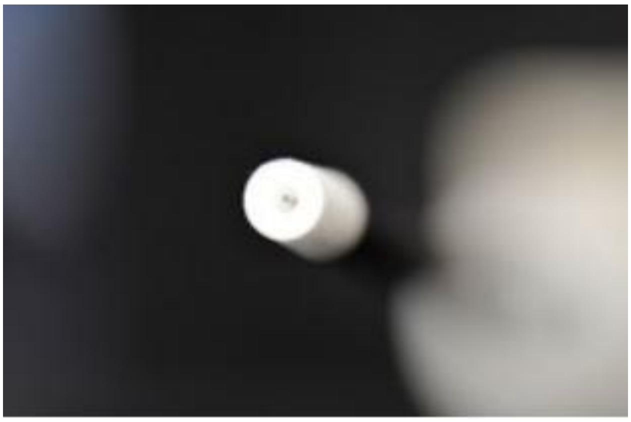
- SPEAG DASY6 system
    - SPEAG cDASY6 5G module software
    - EUmmWVx probe
- 5G Phantom cover

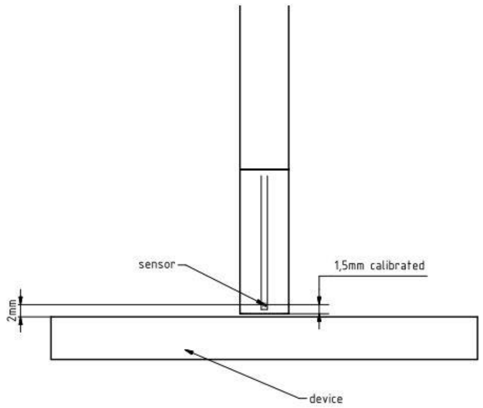


5.2 EUmmWave Probe / E-Field 5G Probe

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.

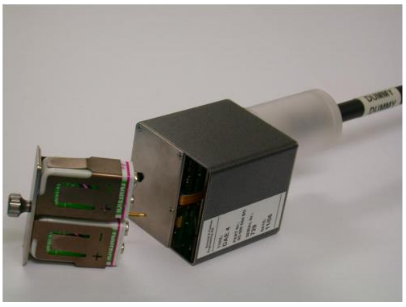
Frequency	750 MHz – 110 GHz
Probe Overall Length	320 mm
Probe Body Diameter	8.0 mm
Tip Length	23.0 mm
Tip Diameter	8.0 mm
Probe's two dipoles length	0.9 mm – Diode loaded
Dynamic Range	< 20 V/m - 10000 V/m with PRE-10 (min < 50 V/m - 3000 V/m)
Position Precision	< 0.2 mm
Distance between diode sensors 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

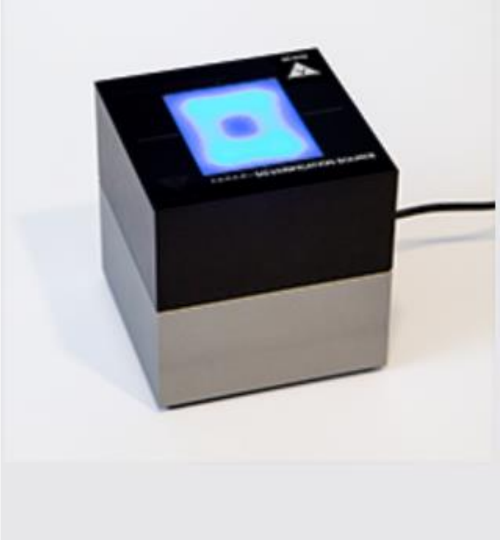
Fine-resolution scans on 2 different planes are performed to reconstruct the E- and H-fields as well as the power density; the z-distance between the 2 planes is set to λ/4.

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

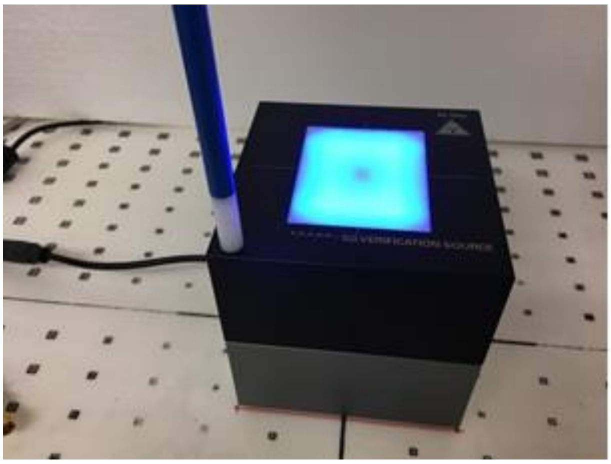


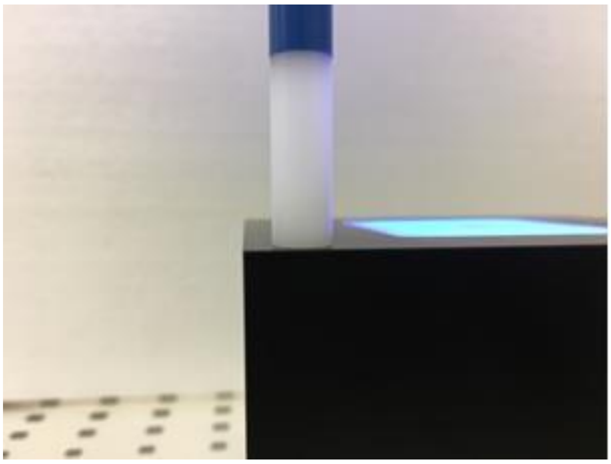
5.6 Power Density System Verification

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

System Verification									
Plot	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 (%)	Date
1	30	30GHz_1007	9461	854	10	31.2	34.1	-8.50%	2020/5/31
2	30	30GHz_1007	9461	1424	10	33.1	34.1	-2.93%	2020/6/13
6	30	30GHz_1007	9461	1424	10	31.8	34.1	-6.74%	2020/7/16

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	