RF EXPOSURE EVALUATION REPORT

FCC ID	**: IHDT56XL1**
Equipment	**: Mobile 5G MOD**
Brand Name	**: Motorola**
Applicant	**: Motorola Mobility LLC 222 W,Merchandise Mart Plaza, Chicago IL 60654 USA**
Manufacturer	**: Motorola Mobility LLC 222 W,Merchandise Mart Plaza, Chicago IL 60654 USA**
Standard	**: FCC 47 CFR Part 2 (2.1093)**

We, SPORTON INTERNATIONAL INC have been evaluated in accordance with 47 CFR Part 2.1093 for the device and pass the limit.

The test results in this variant report apply exclusively to the tested model / sample. Without written approval of SPORTON INTERNATIONAL INC. EMC & Wireless Communications Laboratory, the test report shall not be reproduced except in full.

Approved by: Cona Huang / Deputy Manager

SPORTON INTERNATIONAL INC. EMC & Wireless Communications Laboratory

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Table of Contents

History of this test report

Report No.	Version	Description	Issued Date
FA890514-05B	01	Initial issue of report	Jul. 09, 2019

1. Summary

The maximum measured average power density found during testing for Motorola Mobility LLC, Mobile 5G MOD, are as follows.

Standalone transmission			Simultaneous transmission with other transmitters
Wireless mode	Highest Total Power Density, averaging over $4cm^2$ (mW/cm^2)	Limit (FCC part 1.310) (mW/cm^2)	Summation of Exposure Ratio
5GNR n261	0.339	1	0.999

2. Guidance Applied

The Power Density testing specification, method, and procedure for this device is in accordance with the following standards:

- FCC 47 CFR Part 2.1091
- FCC 47 CFR Part 2.1093
- FCC KDB 865664 D02 SAR Reporting v01r02
- FCC KDB 447498 D01 General RF Exposure Guidance v06
- FCC KDB 648474 D04 SAR Evaluation Considerations for Wireless Handsets v01r03
- TCBC workshop notes
- IEC Draft TR 63170

3. Equipment Under Test (EUT) Information

3.1 General Information

Product Feature & Specification	
Equipment Name	Mobile 5G MOD
Brand Name	Motorola
FCC ID	IHDT56XL1
HW Version	DVT2
SW Version	PPZ29.67
EUT Stage	Identical Prototype
LTE	
Wireless Technology and Frequency Range	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 13: 779.5 MHz ~ 784.5 MHz LTE Band 66: 1710.7 MHz ~ 1779.3 MHz LTE Band 48: 3552.5 MHz ~ 3697.5 MHz
Modulation	LTE: QPSK, 16QAM, 64QAM
5GNR	
Wireless Technology and Frequency Range	5G NR n260: 37GHz~40GHz 5G NR n261: 27.5GHz~28.35GHz
Modulation	QPSK, 16QAM, and 64QAM for CP-OFDM
Supported Channel Bandwidth	50MHz/100MHz
Maximum Number of contiguous CC	4CC
Maximum Aggregated Bandwidth	400MHz
Max. Uplink Transmission Duty Cycle	100%
Antenna Information	Supports dual-polarization MIMO (2 × 2 uplink (UL) and 2 × 2 downlink (DL)) This device has 4 antenna array modules, only one module can be turned on and transmits at a time.
5GNR Operation	Non-Standalone (NSA) Mode
EN-DC combination	DC_2_n260, DC_4_n260, DC_5_n260, DC_13_n260, DC_66_n260 DC_2_n261, DC_4_n261, DC_5_n261, DC_13_n261, DC_66_n261

Remark:
1. The MOD is snapped onto the smartphone IHDT56WB1, and supports multiple antenna transmission, therefore need to consider simultaneous transmission analysis for SAR and PD, the WWAN and WLAN SAR test results were referring to the report of FCC ID: IHDT56WB1 (Sporton SAR Report No. FA733129-02). Power density is evaluated with the MOD attached on the phone.
2. The 5G NR n260 and n261 power density of Mobile 5G MOD has full evaluation in original filing, FCC ID: IHDT56XL1 Sporton Report No.: FA890514B for 5G NR n261, Sporton Report No.: FA890514-01 for 5G NR n260, in this report only spot check each worst case array module to show compliance.
3. For 5G n261/n260 operation, the device has 4 array modules and only one will transmit at a time. The device has implements the sensor to detect the human proximity, once the sensor detects and is triggered, the associated antenna array module will disable the transmission and switch to one of the other 3 array module. Detailed illustration of the sensor implementation is in the operation description.
4. For front facing array module (Array Module 2), when earpiece signal from phone indicates operation at head, this array module would be disabled, therefore head exposure condition evaluation is not required.

Reviewed by: Eric Huang
Report Producer: Wan Liu

4. RF Exposure Limits

4.1 Uncontrolled Environment

Uncontrolled Environments are defined as locations where there is the exposure of individuals who have no knowledge or control of their exposure. The general population/uncontrolled exposure limits are applicable to situations in which the general public may be exposed or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure or cannot exercise control over their exposure. Members of the general public would come under this category when exposure is not employment-related; for example, in the case of a wireless transmitter that exposes persons in its vicinity.

4.2 Controlled Environment

Controlled Environments are defined as locations where there is exposure that may be incurred by persons who are aware of the potential for exposure, (i.e. as a result of employment or occupation). In general, occupational/controlled exposure limits are applicable to situations in which persons are exposed as a consequence of their employment, who have been made fully aware of the potential for exposure and can exercise control over their exposure. The exposure category is also applicable when the exposure is of a transient nature due to incidental passage through a location where the exposure levels may be higher than the general population/uncontrolled limits, but the exposed person is fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area or by some other appropriate means.

The criteria listed in Table 1 shall be used to evaluate the environmental impact of human exposure above 6GHz to radio frequency (RF) radiation as specified in §1.1310.

General Population Basic restriction for power density for frequencies between 1.5GHz and 100 GHz is 1.0 mW/cm^2 = 10 W/m^2

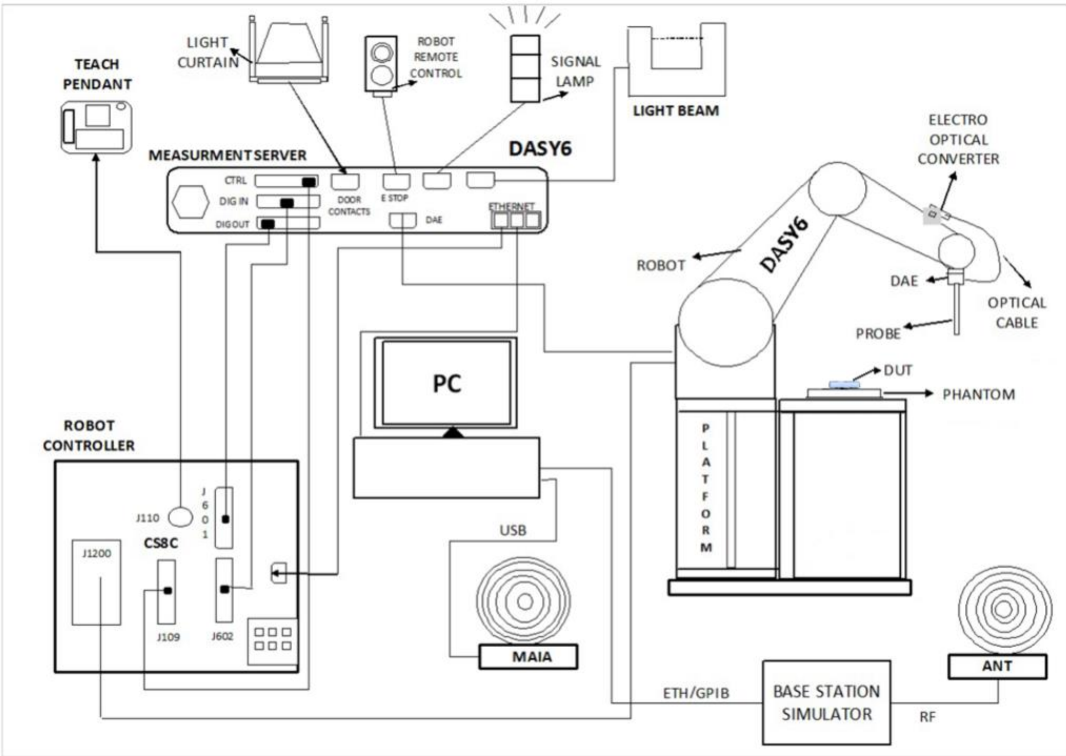
Frequency range (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (mW/cm^2)	Averaging time (minutes)
(A) Limits for Occupational/Controlled Exposures				
0.3-3.0	614	1.63	*(100)	6
3.0-30	1842/f	4.89/f	*(900/f2)	6
30-300	61.4	0.163	1.0	6
300-1500			f/300	6
1500-100,000			5	6
(B) Limits for General Population/Uncontrolled Exposure				
0.3-1.34	614	1.63	*(100)	30
1.34-30	824/f	2.19/f	*(180/f2)	30
30-300	27.5	0.073	0.2	30
300-1500			f/1500	30
1500-100,000			1.0	30

Table 1

5. System Description and Setup

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

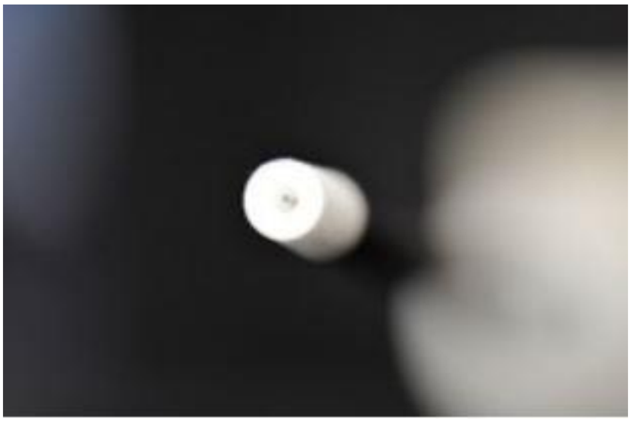
- SPEAG DASY6 system
- SPEAG cDASY6 5G module software
- EUmmWVx probe
- 5G Phantom cover

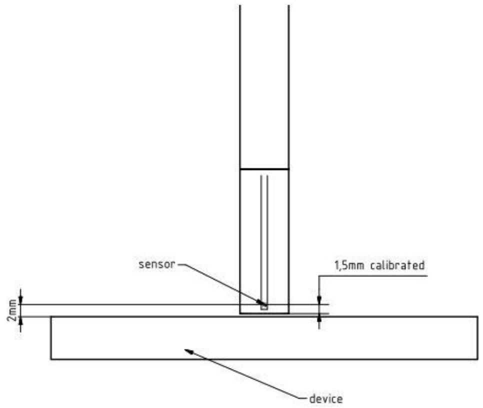


5.1 EUmmWave Probe / E-Field 5G Probe

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

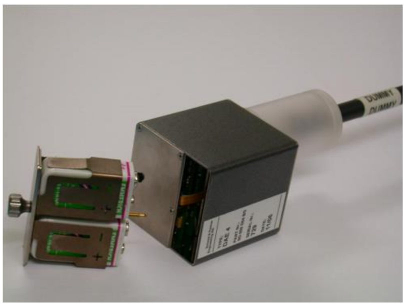




5.2 Data Acquisition Electronics (DAE)

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.



5.3 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.

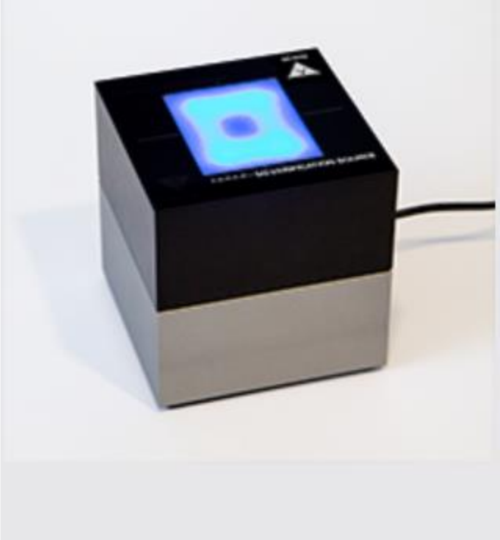
6. Test Equipment List

Manufacturer	Name of Equipment	Type/Model	Serial Number	Calibration	
				Last Cal.	Due Date
SPEAG	5G Verification Source	30 GHz	1007	Apr. 24, 2019	Apr. 23, 2020
SPEAG	EUmmWV Probe Tip Protection	EUmmWV3	9413	Feb. 13, 2019	Feb. 12, 2020
SPEAG	Data Acquisition Electronics	DAE4	853	Jul. 24, 2018	Jul. 23, 2019
TESTO	Hygro meter	608-H1	34913631	Aug. 27, 2018	Aug. 26, 2019
Rohde & Schwarz	Spectrum Analyzer	FSV40	101408	Jul. 30, 2018	Jul. 29, 2019
Custom Microwave	Standard Horn antenna	M15RH	V91113-A	NCR	NCR

7. 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



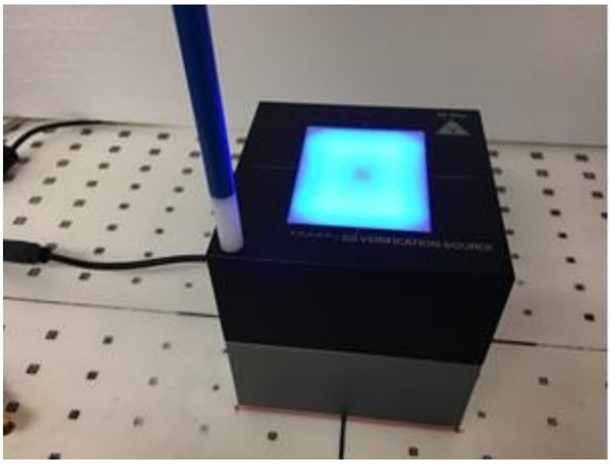
8. Power Density System Verification

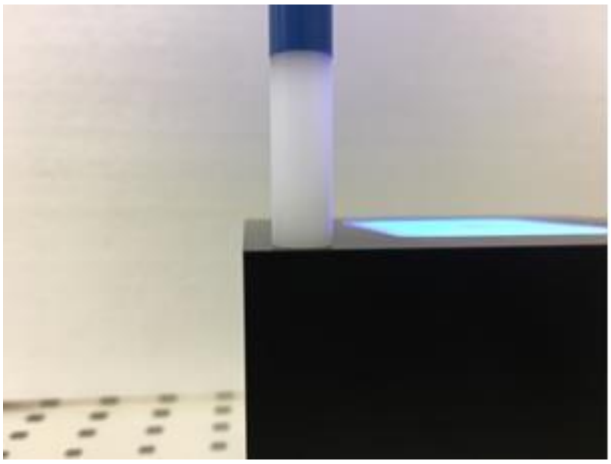
The system performance check verifies that the system operates within its specifications.

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 10% 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

9. System Verification Results

Date	Frequency (GHz)	5G Verification Source	Probe S/N	DAE S/N	Distance (mm)	Measured 4 cm² (W/m²)	Targeted 4 cm² (W/m²)	Deviation (%)
2019/6/5	30GHz	30GHz-1007	9413	853	10	38.1	37.9	0.53

10. Power Density Measurement Evaluation

1. The 5G NR n260 / n261 signal under testing was configured by test Qualcomm software, and the test tool can be used and set the relevant 5G radio parameters (e.g. TX carrier, polarization, band, channel, bandwidth and output power etc.)
2. The device was configured to transmit maximum power and at 100% duty cycle, for each RB configuration/modulation/bandwidth/channel to be tested
3. Since the device Supports dual-polarization MIMO (2 × 2 uplink (UL) and 2 × 2 downlink (DL)), therefore the device under test was configured beam pair testing at a time.
4. According to manufacturer simulation test results for different antenna modules and exposure planes, limited worst cases were selected for power density measurement.
5. According to TCBC Workshop in October 2018, 4 cm2 averaging area may now be considered.
6. The power density test separation distance and test conditions were confirmed by FCC in the lab KDB inquiry. The device implements the sensor detection, so that for some device orientations the PD test at default test separation was skipped and PD was tested at larger distance which represents the sensor detection range
7. Above 6 GHz, Maximum Permissible Exposure (MPE) limits apply to portable exposure conditions according to 47 CFR §2.1093.

10.1 Computation of the Electric Field Polarization Ellipse

For the numerical description of an arbitrarily oriented ellipse in three-dimensional space, five parameters are needed: the semi-major axis (a), the semi-minor axis (b), two angles describing the orientation of the normal vector of the ellipse (∅, θ), and one angle describing the tilt of the semi-major axis (ψ). For the two extreme cases, i.e., circular and linear polarizations, three parameters only (a, ∅ and θ) are sufficient for the description of the incident field.

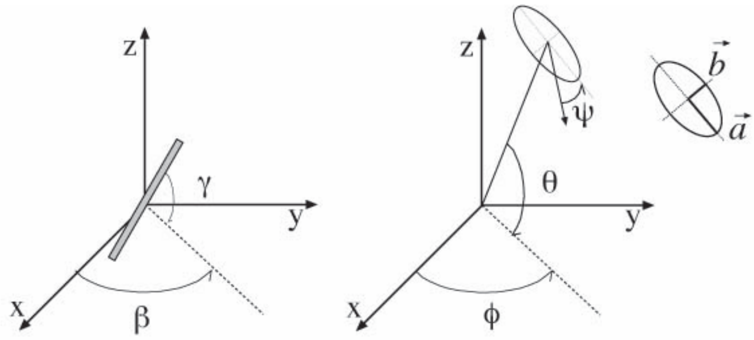


Illustration of the angles used for the numerical description of the sensor and the orientation of an ellipse in 3-D space.

For the reconstruction of the ellipse parameters from measured data, the problem can be reformulated as a nonlinear search problem. The semi-major and semi-minor axes of an elliptical field can be expressed as functions of the three angles (∅, θ and ψ). The parameters can be uniquely determined towards minimizing the error based on least-squares for the given set of angles and the measured data. In this way, the number of free parameters is reduced from five to three, which means that at least three sensor readings are necessary to gain sufficient information for the reconstruction of the ellipse parameters. However, to suppress the noise and increase the reconstruction accuracy, it is desirable that the system of equations be over determined. The solution to use a probe consisting of two sensors angled by r_1 and r_2 toward the probe axis and to perform measurements at three angular positions of the probe, i.e., at β_1, β_2 and β_3, results in over-determinations by a factor of two. If there is a need for more information or increased accuracy, more rotation angles can be added. The reconstruction of the ellipse parameters can be separated into linear and non-linear parts that are best solved by the Givens algorithm combined with a downhill simplex algorithm. To minimize the mutual coupling, sensor angles are set with a shift of 90 degree ($r_2 = r_1 + 90$ degree), and to simplify, the first rotation angle of the probe (β_1) can be set to 0 degree

10.2 Total Field and Power Flux Density Reconstruction

Computation of the power density in general requires knowledge of the electric and magnetic field amplitudes and phases in the plane of incidence. Reconstruction of these quantities from pseudo-vector E-field measurements is feasible, as they are constrained by Maxwell's equations. SPEAG have developed a reconstruction approach based on the Gerchberg-Saxton algorithm, which benefits from the availability of the E-field polarization ellipse information obtained with the EUmmWV2 probe.
The average of the reconstructed power density is evaluated over a circular area in each measurement plane. Two average power density values can be computed, the average total power density and the average incident power density, and the average total power density is used to determine compliance.

- $|Re\{S\}|$ is the total Poynting vector
- $\mathrm{n} \cdot Re\{S\}$ is the normal Poything vector

The software post-processing reports to values, "S avg tot" and "S avg inc". "S avg tot" represents average total power density (all three xyz components included), and "S avg inc" represents average normal power density. The average total power density "S avg tot" is reported to determine the device compliance.

11. RF Exposure Evaluation Results

1. The 5G NR n260 and n261 power density of Mobile 5G MOD has full evaluation in original filing, FCC ID: IHDT56XL1 Sporton Report No.: FA890514B for 5G NR n261, Sporton Report No.: FA890514-01 for 5G NR n260, in this report only spot check each worst case array module to show compliance.
2. 2 mm “Test separation” means 0.5 mm between probe-housing tip and DUT, with 1.5 mm from probe-housing tip to center of sensing elements.

<5G NR n261>

Plot No.	bandwidth	carrier aggregation	antenna module	Frequency	Exposure Conditions	Test separation	RB allocation	modulation	Measured E peak (V/m)	Measured H peak (V/m)	Measured 4cm^2 Average Normal PD (W/m^2)	Measured 4cm^2 Average Total PD (W/m^2)
1	100 MHz	1cc	Module 2	27.55	Top Side	5 mm	32RB_0 offset	QPSK, CP-OFDM	106	0.22	2.37	2.79
	50 MHz	1cc	Module 3	27.925	Top Side	5 mm	16RB_0 offset	QPSK, CP-OFDM	44.1	0.109	2.27	2.4
	100 MHz	1cc	Module 0	27.925	Left Side	70 mm	66RB_0 offset	QPSK, CP-OFDM	27.5	0.072	1.62	1.65
	100 MHz	1cc	Module 1	27.55	Right Side	70 mm	32RB_0 offset	QPSK, CP-OFDM	24.2	0.067	1.01	1.07

<5G NR n260>

Plot No.	bandwidth	carrier aggregation	antenna module	Frequency	Exposure Conditions	Test separation	RB allocation	modulation	Measured E peak (V/m)	Measured H peak (V/m)	Measured 4cm^2 Average Normal PD (W/m^2)	Measured 4cm^2 Average Total PD (W/m^2)
	100 MHz	1cc	Module 0	38.5	Back Surface	5 mm	32RB_0 offset	QPSK, CP-OFDM	69.4	0.168	1.62	1.89
	100 MHz	1cc	Module 1	38.5	Back Surface	5 mm	66RB_0 offset	QPSK, CP-OFDM	93.5	0.228	1.29	1.57
2	100 MHz	1cc	Module 2	38.5	Top Side	5 mm	32RB_0 offset	QPSK, CP-OFDM	84.7	0.172	3.05	3.39
	100 MHz	1cc	Module 3	37.05	Top Side	5 mm	1RB_0 offset	QPSK, CP-OFDM	25.2	0.066	0.874	0.9

12. Simultaneous Transmission Analysis

Simultaneous configuration	Supported
Mod WWAN LTE Bands+5GNR n261	yes
Phone WLAN 2.4GHz/5GHz+Mod LTE Bands + 5GNR n261	yes
Phone WWAN LTE bands+ phone WLAN 2.4GHz/5GHz+ Mod LTE Bands + 5GNR n261	yes
Phone WWAN CDMA bands+ phone WLAN 2.4GHz/5GHz+ Mod LTE Bands + 5GNR n261	yes
Mod WWAN LTE Bands+5GNR n260	yes
Phone WLAN 2.4GHz/5GHz+Mod LTE Bands + 5GNR n260	yes
Phone WWAN LTE bands+ phone WLAN 2.4GHz/5GHz+ Mod LTE Bands + 5GNR n260	yes
Phone WWAN CDMA bands+ phone WLAN 2.4GHz/5GHz+ Mod LTE Bands + 5GNR n260	yes

General Note:

1. The WWAN / WLAN and Bluetooth SAR test results of Mobile phone and Mobile 5G MOD were referring the report of FCC ID: IHDT56XL1 (Sporton SAR Report No. FA890514A) for Mobile 5G MOD, and Mobile phone report of FCC ID: IHDT56WB1 (Sporton SAR Report No. FA733129-02) to be used for simultaneous transmission analysis.
2. The Power density results of n260 and n261 were referring the report of FCC ID: IHDT56XL1 (Sporton SAR Report No. FA890514B for n261 and FA890514-01 for n260) to be used for simultaneous transmission analysis.
3. Considering 5G NR n261 / n260 with WWAN / WLAN and Bluetooth can transmit simultaneously, the basic restrictions are on SAR and power density, and summation of these quantities should follow below formula and the simultaneous transmission analysis was following below step and the detail analysis refer to appendix D:
   i) Use the standalone SAR according original report to collocate with 5G NR n261 power density at each exposure positions, if the result < 1, additional analysis is not necessary.
   ii) If this ratio is larger than 1, use surface single point SAR measurements and treat as 1-gram measurements with 1.6 W/kg as the limit. Use these measurement for the point by point summation and confirm the ratio summation does not exceed 1

The [∑ of (the highest measured or estimated SAR for each standalone antenna configuration, adjusted for maximum tune-up tolerance) / 1.6 W/kg] + [∑ of MPE ratios] is ≤ 1.0.

Test Engineer： Aaron Chen, Tom Jiang, Thomas Wang, Kurt Liu and Nick Yu

13. 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	

14. References

[1] FCC 47 CFR Part 2 “Frequency Allocations and Radio Treaty Matters; General Rules and Regulations”

[2] FCC KDB 447498 D01 v06, “Mobile and Portable Device RF Exposure Procedures and Equipment Authorization Policies”, Oct 2015

[3] FCC KDB 865664 D02 v01r02, “RF Exposure Compliance Reporting and Documentation Considerations” Oct 2015.

[4] FCC KDB 648474 D04 v01r03, “SAR Evaluation Considerations for Wireless Handsets”, Oct 2015.