Power Density Measurement Report

for Comparison with PD Simulation in NETGEAR 5G MHS Travel Router

RF Exposure Compliance Test Report – Part 0

FCC ID   **: PY319400469**

Equipment   **: 5G MHS Travel Router**

Brand Name   **: NETGEAR**

Model Name   **: MR5100**

Applicant   **: Netgear, Inc.**
                 350 E. Plumeria Drive, San Jose CA
                 95134, 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 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.

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Approved by: Cona Huang / Deputy Manager

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History of this test report

Report No.	Version	Description	Issued Date
FA9N2723	01	Initial issue of report	May 22, 2020

1. *Summary*

The maximum measured average power density found during testing for Netgear, Inc., 5G MHS Travel Router, are as follows.

Standalone transmission	
RF Transmitter	Measured PD (mW/cm^2)
5G FR2	0.579
Test Date	2020/5/15

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	5G MHS Travel Router
Brand Name	NETGEAR
Model Name	MR5100
FCC ID	PY319400469
Wireless Technology and Frequency Range	WCDMA Band II: 1852.4 MHz ~ 1907.6 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 14: 790.5 MHz ~ 795.5 MHz LTE Band 30: 2307.5 MHz ~ 2312.5 MHz LTE Band 66: 1710.7 MHz ~ 1779.3 MHz LTE Band 48: 3552.5 MHz ~ 3697.5 MHz 5G NR n2: 1852.5MHz ~ 1907.5MHz 5G NR n5: 826.5MHz ~ 846.5MHz 5G NR n66: 1712.5MHz ~ 1777.5MHz 5G NR n260: 37.6GHz~40GHz 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
Mode	RMC12.2Kbps HSDPA HSUPA DC-HSDPA LTE: QPSK, 16QAM, 64QAM WLAN: 802.11a/b/g/n/ac/ax 5GNR: DFT-s-OFDM/CP-OFDM, QPSK / 16QAM / 64QAM

Reviewed by: Jason Wang
Report Producer: Daisy Peng

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
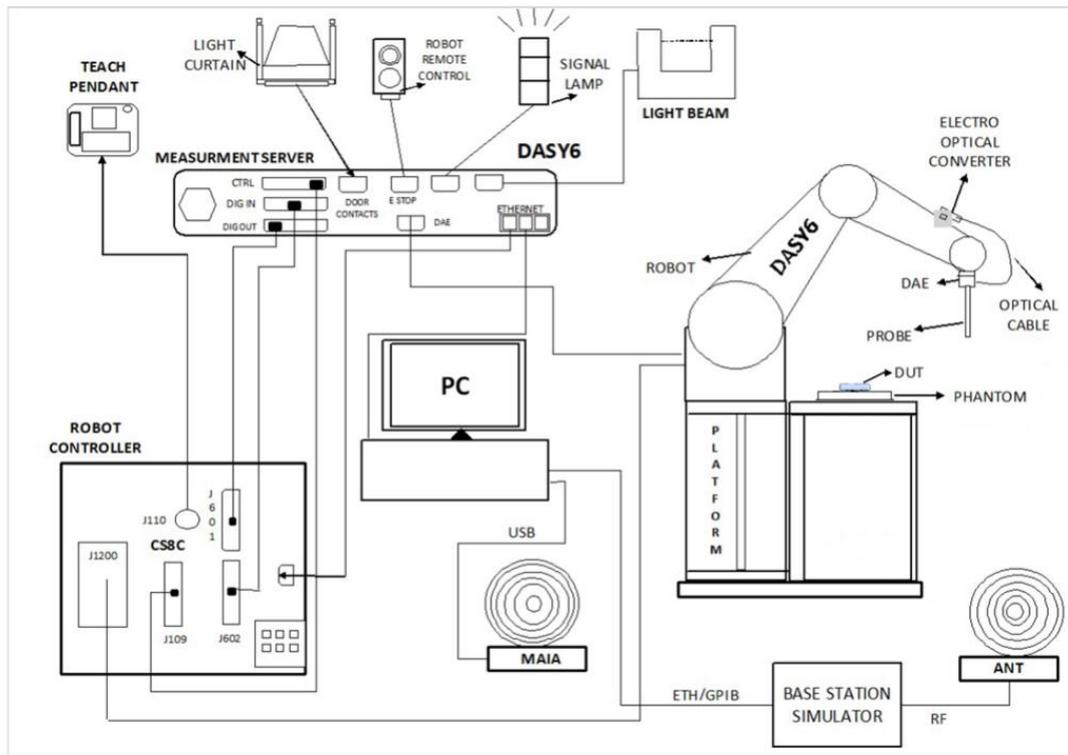
5.1 *EUmmWave Probe / E-Field 5G Probe*

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
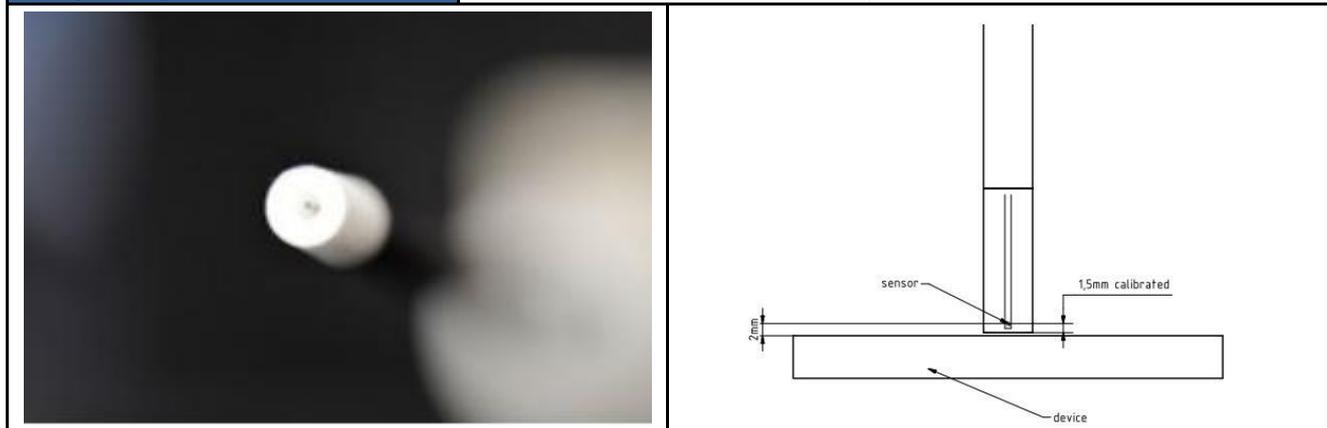
5.2 *Data Acquisition Electronics (DAE)*

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	EUmmWV4	9461	Nov. 05, 2019	Nov. 04, 2020
SPEAG	Data Acquisition Electronics	DAE4	854	May. 21, 2019	May. 20, 2020
TESTO	Hygro meter	608-H1	34893240	Nov. 07, 2019	Nov. 06, 2020
Aglient	Spectrum Analyzer	E4408B	MY44211028	Aug. 27, 2019	Aug. 26, 2020
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
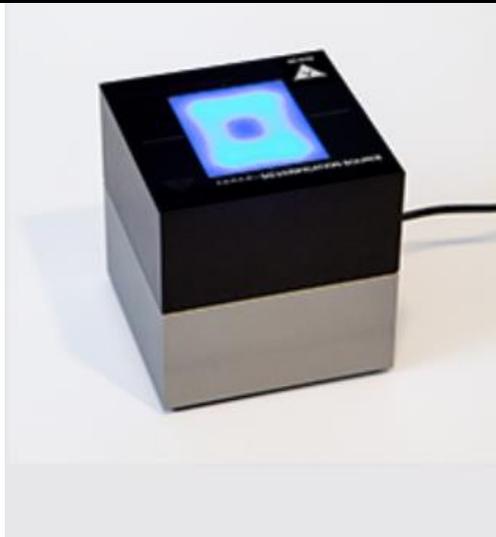
8. *Power Density System Verification*

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 0.66dB 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
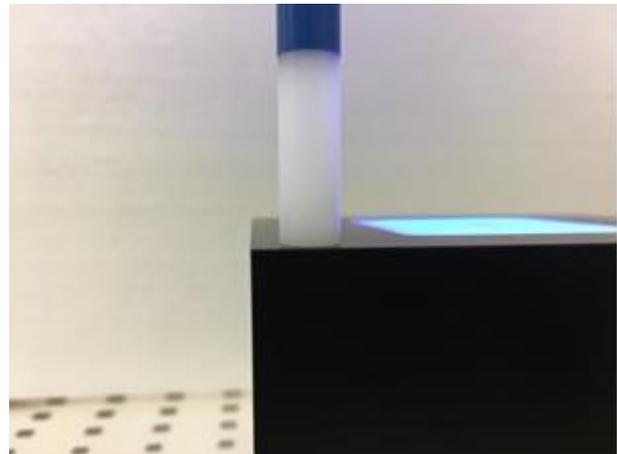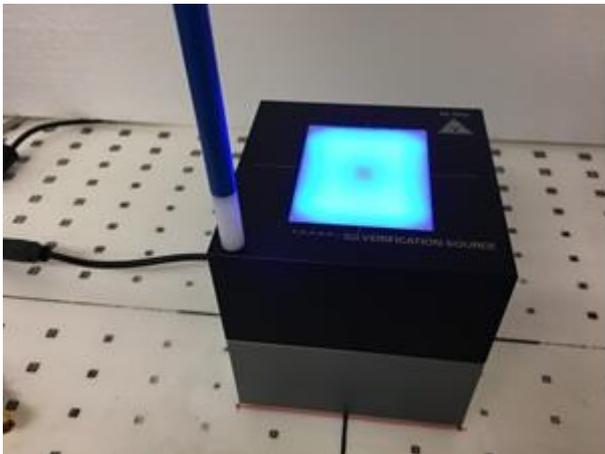
Verification Setup photo

9. *System Verification Results*

Date	Frequency (GHz)	5G Verification Source	Probe S/N	DAE S/N	Distance (mm)	Measured 4 cm^2 (mW/cm^2)	Targeted 4 cm^2 (mW/cm^2)	Deviation (dB)
2020/5/15	30G	30GHz_1007	9461	854	10mm	31.2	34.1	-8.50%

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9.1 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.
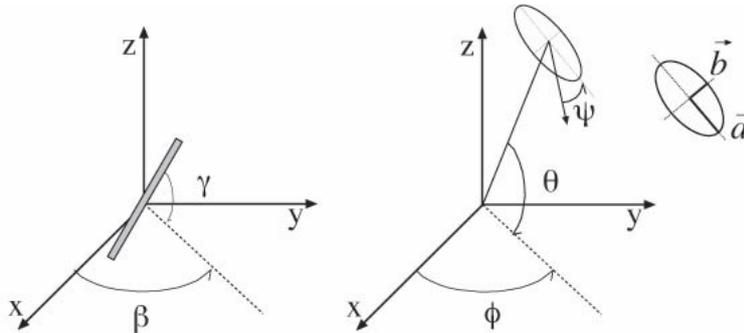

Illustration of the angles used for the numerical description of the sensor and the orientation of an ellipse in 3-D space.

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.

9.2 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

- $n \cdot Re\{S\}$ 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.

9.3 Test Positions

Exposure Position	Measurement Position					
	Front 10mm	Back 10mm	Left Side 10mm	Right Side 10mm	Top Side 10mm	Bottom Side 10mm
Antenna Module 0	Yes	Yes	No	No	No	Yes
Antenna Module 1	Yes	Yes	Yes	No	No	No
Antenna Module 2	Yes	Yes	No	Yes	No	No

10. RF Exposure Evaluation Results

1. The PD test was performed of a 10mm separation between sensor and EUT surface (the probe tip is 1.5mm to the EUT surface).
2. According to TCBC Workshop in October 2018, 4 cm^2 averaging area are used.
3. The test duty cycle was 100 % and it was confirmed by the manufacturer that the device was driven at this test duty cycle. The power density results were use this duty cycle of 100 % to evaluate the final production.

antenna module	Beam ID 1	Beam ID 2	Frequency (GHz)	Exposure Surface	Input limit(dB)	Test separation	modulation	Measured results Savg tot 4cm^2 (W/m2)	Measured results Savg tot 4cm^2 (mW/cm2)
0	39	-	38850MHz	Front	6	10mm	CW	1.29	0.129
0	39	-	38850MHz	Back	6	10mm	CW	2.45	0.245
0	39	-	38850MHz	Bottom Side	6	10mm	CW	5.79	0.579
0	-	166	38850MHz	Front	6	10mm	CW	1.72	0.172
0	-	166	38850MHz	Back	6	10mm	CW	1.83	0.183
0	-	166	38850MHz	Bottom Side	6	10mm	CW	4.23	0.423
1	20	-	38850MHz	Front	6	10mm	CW	1.04	0.104
1	20	-	38850MHz	Back	6	10mm	CW	2.12	0.212
1	20	-	38850MHz	Left Side	6	10mm	CW	5.24	0.524
1	-	148	38850MHz	Front	6	10mm	CW	1.37	0.137
1	-	148	38850MHz	Back	6	10mm	CW	2.21	0.221
1	-	148	38850MHz	Left Side	6	10mm	CW	5.15	0.515
2	30	-	38850MHz	Front	6	10mm	CW	1.25	0.125
2	30	-	38850MHz	Back	6	10mm	CW	1.75	0.175
2	30	-	38850MHz	Right Side	6	10mm	CW	4.86	0.486
2	-	158	38850MHz	Front	6	10mm	CW	1.25	0.125
2	-	158	38850MHz	Back	6	10mm	CW	1.93	0.193
2	-	158	38850MHz	Right Side	6	10mm	CW	4.97	0.497

Test Engineer：Steven Chang and Tom Jiang

11. *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	

12. *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.

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.