TESTING CERT #3478.01

TEST REPORT

EUT Description	**Wireless Gigabit radio installed in a Lenovo ThinkPad X1 Tablet**
Brand	**Intel® Wireless Gigabit 11000**
Model	**Platform Lenovo TP00082A / Intel module 11000D2W**
Serial Number	**Host Laptop: 1S48104W010020000064** (see section 4)
FCC/IC ID	**FCC ID: PD911000D2**
Hardware/Software Version	**Test SW: DRTU version 1.8.4-02270** **Driver ver.: 2.2.0.15**
Date of Sample Receipt	**2015-12-17**
Date of start/end of Tests	**Start : 2015-12-18 End: 2016-01-15**
Date of issue	**2016-01-28**
Features	**Module: WiGig** **Host: Lenovo TP00082A** (see section 5)

Applicant	**Intel Mobile Communications**
Address	**100 Center Point Circle, Suite 200** **Columbia, South Carolina 29210** **USA**
Contact Person	**Steven Hackett**
Telephone/Fax/ Email	**steven.c.hackett@intel.com**

Reference Standards	**FCC CFR Title 47 Part 15.255** (see section 1)

Test Report number	**15121701.TR01**
Revision Control	**Rev. 01**

The test results relate only to the samples tested.
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Table of Contents

1. Standards, reference documents and applicable test methods

1. FCC 47 CFR part 2 – Subpart C – §15.255 Operation within the band 57-64 GHz.

2. General conditions, competences and guarantees

- ✓ Intel Mobile Communications Wireless RF Lab (Intel WRF Lab) is a testing laboratory accredited by the American Association for Laboratory Accreditation (A2LA).
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3. Environmental Conditions

- ✓ At the site where the measurements were performed the following limits were not exceeded during the tests:

Temperature	24ºC ± 2ºC
Humidity	54% ± 5%

4. Test samples

Sample	Control #	Description	Model	Serial #	Date of reception
#01	15121701.S03	Laptop	Lenovo TP00082A	1S48104W010020000064	2015-12-17
	15121701.S02	AC/DC Adapter	ADLX45ULCU2A	8SPA145027ULL1CZ5A500CF	2015-12-17

5. EUT features

These are the detailed bands and modes supported by the equipment under Test:

WiGig	60GHz (58.320 – 62.640 GHz)

6. Remarks and comments

1. This report documents the results of radiated measurements of the EIRP and the resulting power density of a radio device operating in the 60 GHz unlicensed band.

7. Test Verdicts summary

N/A

8. Document Revision History

Revision #	Date	Modified by	Details
Rev. 00	2016-01-28	W. El Hajj	First Issue
Rev. 01	2016-03-09	A. Dhouibi	• Modifications to address FCC comments. • Editorial changes.

Annex A. Test & System Description

A.1 Test Conditions

The EUT is an Intel Wireless Gigabit radio model 11000D2W, FCC ID PD911000D2, installed in a Lenovo TP00082A.

The antenna is an integral phased array antenna with a maximum gain of 15.3 dBi.

The DUT was set to transmit at the highest power (3 dBm) conducted setting on MCS1 using proprietary software (Intel DRTU version 1.8.4.02270). The software enables the transmitter to operate at an actual maximum duty cycle of around 96% (please refer to duty cycle measurements details in Section B.1 which describes the combination of the duty cycle within burst and duty cycle over burst). The maximum EIRP measured and reported in the following table is normalized to 100% duty cycle:

Channel	Maximum EIRP (dBm)
1	16.47
2	17.34
3	14.37

A.2 Measurement system

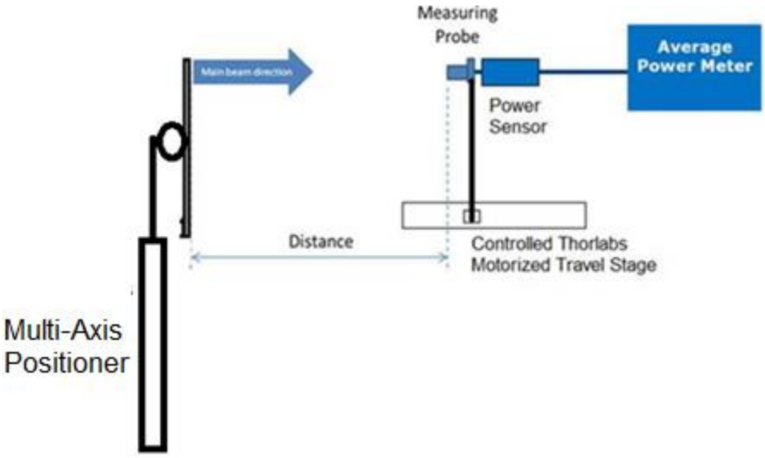
A Thorlabs Motorized Travel Stage controlled by software is used to maintain a consistent and accurate placement of the probe. A multi-axis Positioner is used for the Polarization / Elevation/ Azimuth scan.

Absorber material covering up to 110GHz is placed around the support structures and alignment fixture to reduce reflections, scattering and perturbations.

The Aperture Probe is aligned with the boresight of the EUT antenna. The probe is scanned over X / Y / Polarization / Elevation / Azimuth to maximize the emissions level.

The EIRP of each channel is measured and recorded, then P_t*G_t, Power density and EIRP are calculated as described below.

The measurement distance is varied from 4 to 20 cm in 1-cm steps and the power and results of subsequent calculations are recorded for each distance. The distance corresponds to the separation between the surface of the EUT and the aperture plane of the probe.



Test Setup schematics (Also refer to the photos in Annex D)

Before rotating the DUT, the antenna array was aligned to the measurement probe using a laser beam in order to optimize the positioning and have the probe to point exactly towards the antenna array location.

A.3 Test Equipment List

ID#	Device	Type/Model	Serial Number	Manufacturer	Cal. Date	Cal. Due Date
0014	Power Sensor (DC -67 GHz)	NRP-Z57	00152266	Rohde & Schwarz	2015-05-06	2017-05-06
0015	Spectrum analyzer	FSU67	100092	Rohde & Schwarz	2015-07-31	2017-07-31
0016	Signal Generator	SMF100A	102117	Rohde & Schwarz	2014-03-11	2016-03-11
0066	Standard Horn Antenna	FH-SG-075-25	20012	RPG	Calibration Not Required	
0331	Aperture Probe antenna	15EWG1.85	J215060133	A-Info	Characterized Internally	
0063	MULTIPLIER ASSEMBLY 40-220GHz	AFM-40-220	394	RPG	Calibration Not Required	
0328	Laser line pointer	GCL25	505000206	Bosch	Calibration Not Required	

Note: In order to normalize the EIRP data to 100% duty cycle, the actual Duty cycle is measured (see details in Section B.1) using the FSU 67 spectrum analyzer and a standard horn antenna. The FSU67 covers the 20Hz to 67GHz frequency range, therefore the measurement is performed directly without the need of an external mixer.

A.4 Measurement Uncertainty Evaluation

The Total Measurement Uncertainty is of **1.48 dB.** This value is obtained by calculating first the Aperture Probe Gain Measurement Uncertainty (see A.4.1) and then using this value with the other uncertainty sources to deduce the total Uncertainty (see A.4.2).

A.4.1 Aperture Probe Gain Characterization

3 Antennas Gain Method / Probe Characterization

Source of Uncertainty	Value [dB]	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty [dB]
Mismatch VSWR SG Block 1.1 - TR 1.5	0.08	U-shaped	1.414	1	0.06
Mismatch VSWR TR 1.5 - PM 1.35	0.26	U-shaped	1.414	1	0.18
Insertion Loss transition	0.40	rectangular	1.732	1	0.23
Mismatch VSWR SG Block 1.1 - Antenna Block 1.1	0.02	U-shaped	1.414	1	0.01
Mismatch VSWR Antenna Block 1.1 - TR 2	0.14	U-shaped	1.414	1	0.10
Mismatch VSWR TR 2 - PM 1.35	0.44	U-shaped	1.414	1	0.31
Position of the phase centre (Receiving Ant.)	0.13	rectangular	1.732	1	0.08
Linearity (included in Repeatability)	0.000	rectangular	1.732	1	0.00
Zero Offset	0.211	rectangular	1.732	1	0.12
Repeatability (Relative Power Meas.)	0.01	rectangular	1.732	1	0.01
Meas Noise	0.043	rectangular	1.732	1	0.02
				Combined Standard Uncertainty	0.47
				Expanded Uncertainty (k=2)*	**0.93**

A.4.2 EUT Measurement.

Source of Uncertainty	Value [dB]	Probability Distribution	Divisor	Sensitivity Coefficient	Standard Uncertainty [dB]
Meas. Antenna Gain Rx Aperture Probe	0.93	Normal k=2	2	1	0.47
Mismatch VSWR Block Antenna 2 - PM 1.35	0.26	U-shaped	1.414	1	0.31
Power Meter Accuracy	0.25	rectangular	1.732	1	0.14
Range Length (near/far field condition)	0.00	rectangular	1.732	1	0.00
Position of the phase center (Receiving Ant.)	0.13	rectangular	1.732	1	0.08
Ambient temperature impact	0.10	normal	1	1	0.10
Repeatability	0.50	normal	1	1	0.20
Zero Offset	0.144	rectangular	1.732	1	0.08
Meas Noise	0.019	rectangular	1.732	1	0.01
				Combined Standard Uncertainty	0.74
				Expanded Uncertainty (k=2)*	***1.48***

SG : Signal Generator TR : Transition PM : Power Meter

* The expanded Measurement Uncertainty with coverage factor (k=2) corresponds to a confidence level of 95%.

Annex B. Test Results

B.1 Duty Cycle

Test procedure

Duty cycle is calculated as *[(ON Time)/Period].*

The Duty cycle within the Burst is multiplied by the Duty cycle over the Burst Period to derive the Duty Cycle.

The duty cycle of the EUT modulation is measured, and used to provide the duty cycle correction factor.

*Duty Cycle Correction Factor = 10*Log(Duty Cycle)*

Where:
Duty Cycle Correction Factor is (dB)
Duty Cycle is (Linear)

The Duty cycle is measured using the FSU67 spectrum analyzer and a measurement antenna. The FSU67 covers the 20Hz to 67GHz frequency range. Therefore the measurement is performed directly without the need of an external mixer.

Results tables

Channel 1

Description	ON Time (ms)	Period (ms)	Duty Cycle Linear
Duty Cycle Within Burst	1.991506	2.046635	0.97306
Duty Cycle over Burst period	990.384615	1006.41	0.98408
Duty Cycle			0.95757

Duty Cycle Correction (dB)	0.1883

Channel 2

Description	ON Time (ms)	Period (ms)	Duty Cycle Linear
Duty Cycle Within Burst	1.97724	2.046635	0.96609
Duty Cycle over Burst period	990.384615	1003.205	0.98722
Duty Cycle			0.95375

Duty Cycle Correction (dB)	0.2057

Channel 3

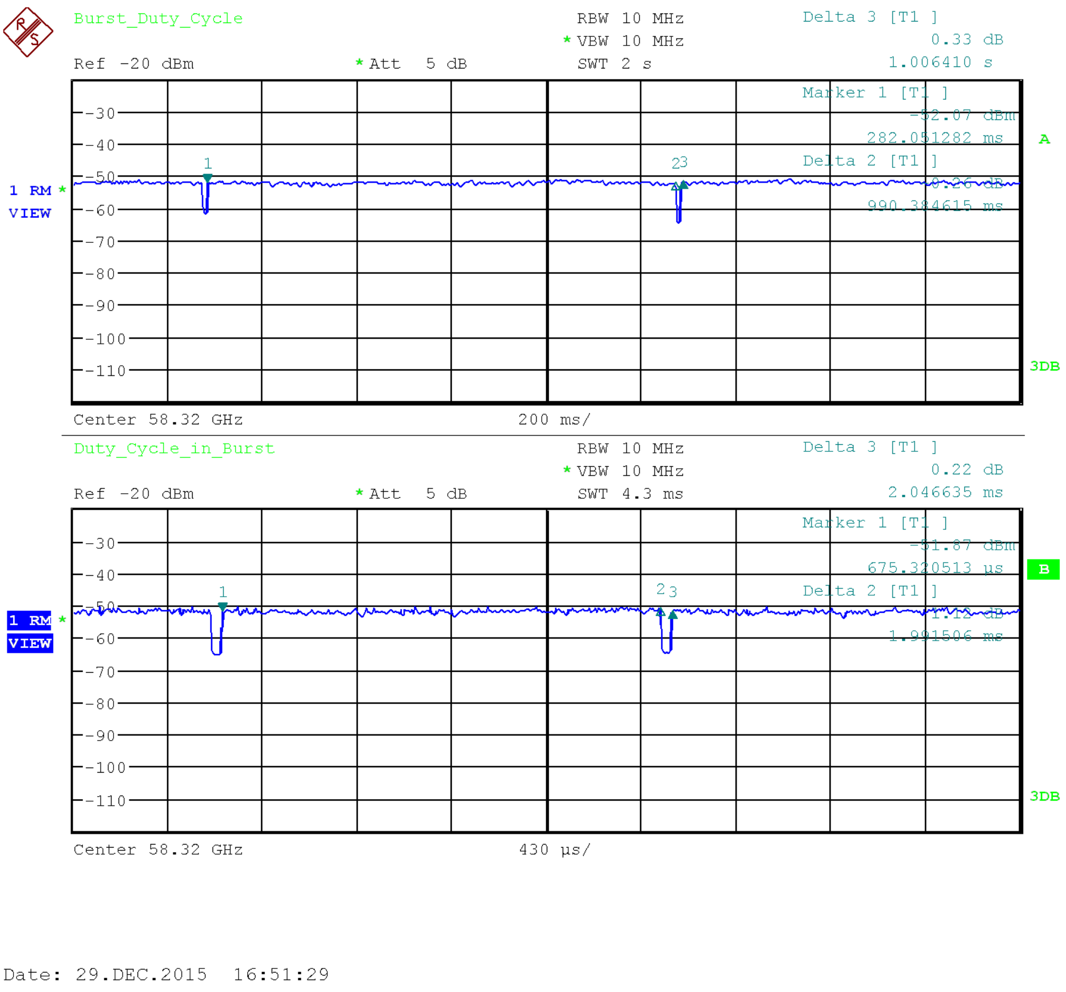
Description	ON Time (ms)	Period (ms)	Duty Cycle Linear
Duty Cycle Within Burst	1.998397	2.046635	0.97643
Duty Cycle over Burst period	990.384615	1003.205	0.98722
Duty Cycle			0.96395

Duty Cycle Correction (dB)	0.1594

Results screenshots

Duty Cycle

Channel 1

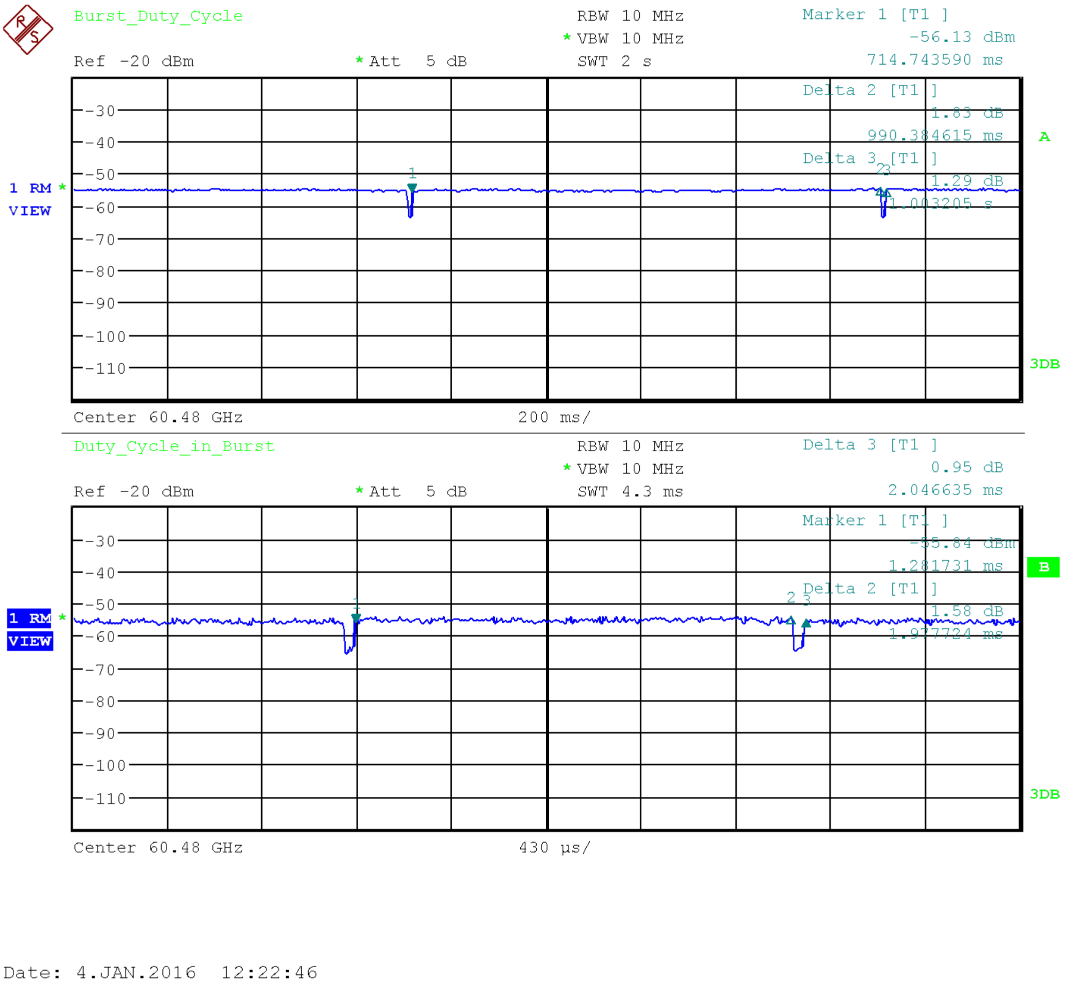


Burst_Duty_Cycle
RBW 10 MHz
* VBW 10 MHz
Ref -20 dBm
* Att 5 dB
SWT 2 s
Delta 3 [T1]
0.33 dB
1.006410 s
Marker 1 [T1]
-52.07 dBm
282.051282 ms
Delta 2 [T1]
0.26 dB
990.384615 ms
Center 58.32 GHz
200 ms/

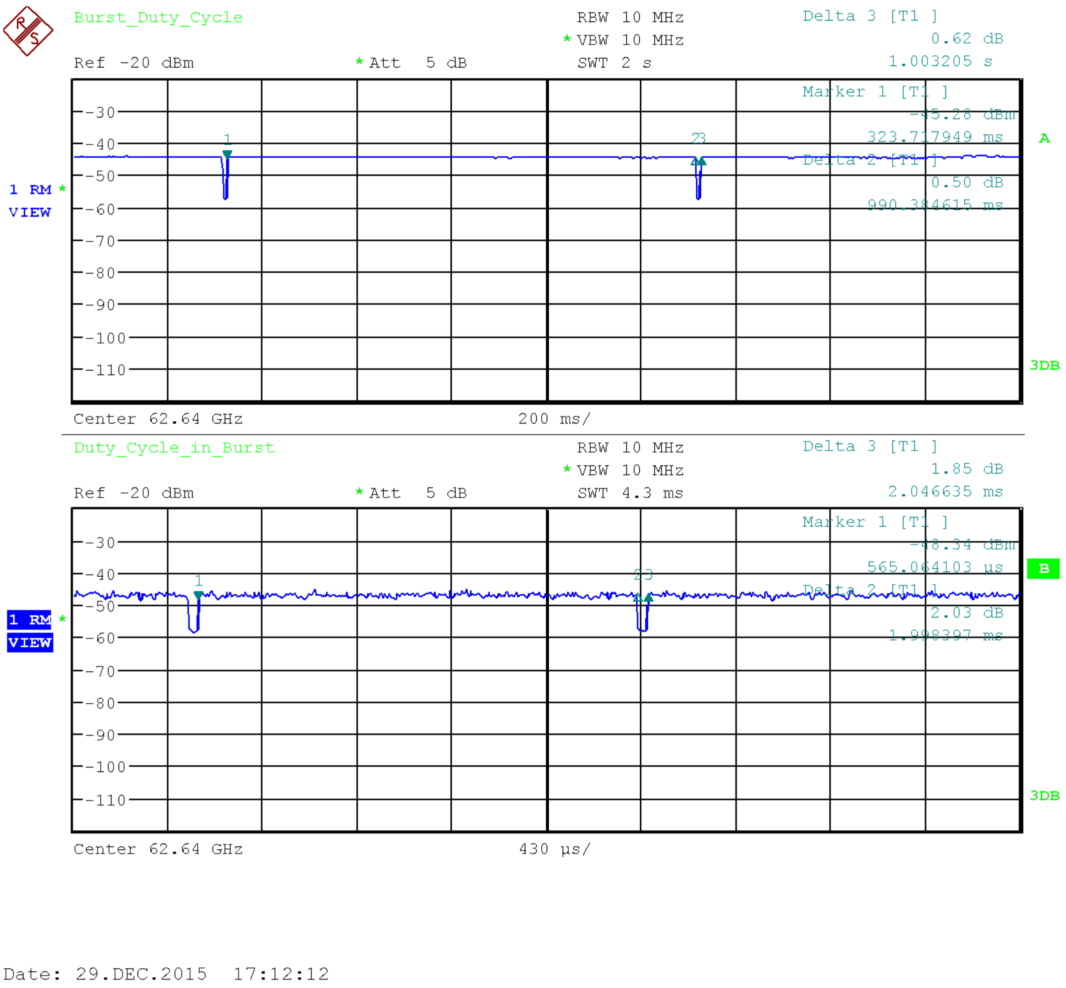
Duty_Cycle_in_Burst
RBW 10 MHz
* VBW 10 MHz
Ref -20 dBm
* Att 5 dB
SWT 4.3 ms
Delta 3 [T1]
0.22 dB
2.046635 ms
Marker 1 [T1]
-51.87 dBm
675.320513 µs
Delta 2 [T1]
1.12 dB
1.991506 ms
Center 58.32 GHz
430 µs/

Date: 29.DEC.2015 16:51:29

Channel 2


Burst_Duty_Cycle
RBW 10 MHz
VBW 10 MHz
SWT 2 s
Ref -20 dBm
Att 5 dB
Marker 1 [T1]
-56.13 dBm
714.743590 ms
Delta 2 [T1]
1.83 dB
990.384615 ms
Delta 3 [T1]
1.29 dB
1.003205 s
1 RM
VIEW
A
3DB
-30
-40
-50
-60
-70
-80
-90
-100
-110
Center 60.48 GHz
200 ms/
Duty_Cycle_in_Burst
RBW 10 MHz
VBW 10 MHz
SWT 4.3 ms
Ref -20 dBm
Att 5 dB
Delta 3 [T1]
0.95 dB
2.046635 ms
Marker 1 [T1]
-55.84 dBm
1.281731 ms
Delta 2 [T1]
1.58 dB
1.977724 ms
1 RM
VIEW
B
3DB
Center 60.48 GHz
430 µs/
Date: 4.JAN.2016 12:22:46

Channel 3



Burst_Duty_Cycle

RBW 10 MHz
* VBW 10 MHz
SWT 2 s
Ref -20 dBm
* Att 5 dB

Delta 3 [T1]
0.62 dB
1.003205 s

Marker 1 [T1]
-45.28 dBm
323.717949 ms

Delta 2 [T1]
0.50 dB
990.384615 ms

Center 62.64 GHz
200 ms/

Duty_Cycle_in_Burst

RBW 10 MHz
* VBW 10 MHz
SWT 4.3 ms
Ref -20 dBm
* Att 5 dB

Delta 3 [T1]
1.85 dB
2.046635 ms

Marker 1 [T1]
-48.34 dBm
565.064103 µs

Delta 2 [T1]
2.03 dB
1.998397 ms

Center 62.64 GHz
430 µs/

Date: 29.DEC.2015 17:12:12

B.2 EIRP & Power Density

Test procedure

The radiated emission level is measured with the aperture probe antenna connected to a power sensor.

Using the far-field Friis equation:

$$\frac{P_R}{P_T} = G_T \; G_R \left(\frac{\lambda}{4\pi D}\right)^2$$

the measured power P_R is converted to P_T*G_T using the same equation in logarithmic domain:

$$(P_T{*}G_T) = P_R - G_R + \mathit{Free\ Space\ Attenuation\ (dB)}$$

Where the:

$$\mathit{Free\ space\ Attenuation\ (dB)} = 20Log\left(\frac{4\pi D}{\lambda}\right)$$

and:

(P_T*G_T) is (dBm) (P_T is the transmitted power and G_T the emission antenna Gain)
D is in (m)
P_R is in (dBm)
G_R is the small aperture probe antenna Gain in (dBi)
λ is the wavelength in (m)

P_T*G_T is converted to power density using:

$$\mathit{Power\ Density} = \frac{P_T \; G_T}{4\pi D^2}$$

Where:
Power Density is in (mW/cm^2)
P_T*G_T is in (mW)
D is in (cm)

P_T*G_T is also converted to EIRP during the ON time of the burst using:

$$\mathit{EIRP} = (P_T{*}G_T) + \mathit{Duty\ Cycle\ Correction\ Factor}$$

Where:
EIRP is in (dBm)
P_T*G_T is in (dBm)
Duty Cycle Correction Factor is in (dB)

Results tables

Channel 1

EUT antenna gain = 15.30dBi

Freq (GHz)	Meas. Distance (cm)	Small Aperture Probe Gain G_R (dBi)	Free Space Attenuation (dB)	Meas Avg Power P_R (dBm)	P_T*G_T (dBm)	P_T*G_T (mW)	Power Density (mW/cm^2)	Duty Cycle Correction (dB)	EIRP (dBm)
58.32	4	5.37	39.80	-22.78	11.65	14.62	0.07271	0.1883	11.84
58.32	5	5.37	41.74	-22.00	14.37	27.34	0.08702	0.1883	14.56
58.32	6	5.37	43.32	-22.72	15.23	33.35	0.07372	0.1883	15.42
58.32	7	5.37	44.66	-23.27	16.02	40.00	0.06495	0.1883	16.21
58.32	8	5.37	45.82	-24.40	16.05	40.27	0.05007	0.1883	16.24
58.32	9	5.37	46.84	-25.20	16.27	42.39	0.04165	0.1883	16.46
58.32	10	5.37	47.76	-26.11	16.28	42.44	0.03378	0.1883	16.47
58.32	11	5.37	48.59	-27.00	16.22	41.84	0.02752	0.1883	16.40
58.32	12	5.37	49.34	-27.84	16.13	41.04	0.02268	0.1883	16.32
58.32	13	5.37	50.04	-28.54	16.13	40.99	0.01930	0.1883	16.32
58.32	14	5.37	50.68	-29.24	16.07	40.46	0.01643	0.1883	16.26
58.32	15	5.37	51.28	-30.04	15.87	38.64	0.01366	0.1883	16.06
58.32	16	5.37	51.84	-30.48	15.99	39.72	0.01235	0.1883	16.18
58.32	17	5.37	52.37	-31.11	15.89	38.79	0.01068	0.1883	16.08
58.32	18	5.37	52.86	-31.88	15.61	36.42	0.00895	0.1883	15.80
58.32	19	5.37	53.33	-32.05	15.91	39.02	0.00860	0.1883	16.10
58.32	20	5.37	53.78	-32.59	15.82	38.18	0.00760	0.1883	16.01

Note: For distances lower than 6-7 cm (in transition to near field) the numbers measured are expected to be invalid due to the potential coupling with the measuring device or other near objects.

Channel 2

EUT antenna gain = 15.20dBi

Freq (GHz)	Meas. Distance (cm)	Small Aperture Probe Gain G_R (dBi)	Free Space Attenuation (dB)	Meas Avg Power P_R (dBm)	P_T*G_T (dBm)	P_T*G_T (mW)	Power Density (mW/cm^2)	Duty Cycle Correction (dB)	EIRP (dBm)
60.48	4	5.86	40.12	-22.96	11.30	13.47	0.06702	0.2057	11.50
60.48	5	5.86	42.05	-23.09	13.10	20.43	0.06504	0.2057	13.31
60.48	6	5.86	43.64	-23.16	14.62	28.95	0.06400	0.2057	14.82
60.48	7	5.86	44.98	-23.48	15.64	36.61	0.05946	0.2057	15.84
60.48	8	5.86	46.14	-24.4	15.88	38.69	0.04811	0.2057	16.08
60.48	9	5.86	47.16	-25.55	15.75	37.57	0.03691	0.2057	15.95
60.48	10	5.86	48.07	-25.7	16.51	44.81	0.03566	0.2057	16.72
60.48	11	5.86	48.90	-26.34	16.70	46.79	0.03077	0.2057	16.91
60.48	12	5.86	49.66	-27.11	16.69	46.64	0.02577	0.2057	16.89
60.48	13	5.86	50.35	-27.58	16.91	49.12	0.02313	0.2057	17.12
60.48	14	5.86	51.00	-28.26	16.88	48.71	0.01978	0.2057	17.08
60.48	15	5.86	51.60	-28.74	17.00	50.07	0.01771	0.2057	17.20
60.48	16	5.86	52.16	-29.37	16.93	49.28	0.01532	0.2057	17.13
60.48	17	5.86	52.68	-29.88	16.94	49.47	0.01362	0.2057	17.15
60.48	18	5.86	53.18	-30.19	17.13	51.64	0.01268	0.2057	17.34
60.48	19	5.86	53.65	-30.74	17.05	50.69	0.01117	0.2057	17.25
60.48	20	5.86	54.09	-31.27	16.96	49.71	0.00989	0.2057	17.17

Note: For distances lower than 6-7 cm (in transition to near field) the numbers measured are expected to be invalid due to the potential coupling with the measuring device or other near objects.

Channel 3

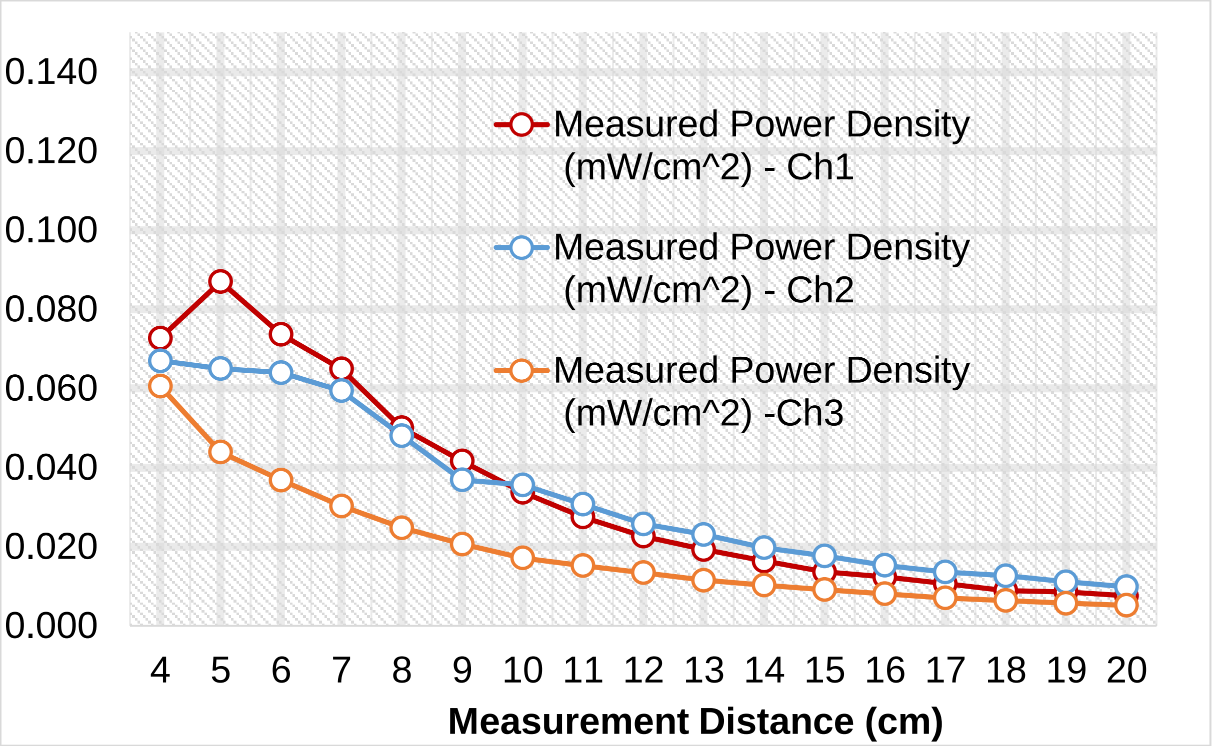
EUT antenna gain = 14.80dBi

Freq (GHz)	Meas. Distance (cm)	Small Aperture Probe Gain G_R (dBi)	Free Space Attenuation (dB)	Meas Avg Power P_R (dBm)	P_T*G_T (dBm)	P_T*G_T (mW)	Power Density (mW/cm^2)	Duty Cycle Correction (dB)	EIRP (dBm)
62.64	4	7.56	40.42	-22.00	10.86	12.19	0.06063	0.1954	11.06
62.64	5	7.56	42.36	-23.40	11.40	13.80	0.04392	0.1954	11.59
62.64	6	7.56	43.94	-24.16	12.22	16.68	0.03687	0.1954	12.42
62.64	7	7.56	45.28	-25.01	12.71	18.67	0.03032	0.1954	12.91
62.64	8	7.56	46.44	-25.88	13.00	19.96	0.02481	0.1954	13.20
62.64	9	7.56	47.46	-26.67	13.23	21.06	0.02069	0.1954	13.43
62.64	10	7.56	48.38	-27.48	13.34	21.57	0.01717	0.1954	13.53
62.64	11	7.56	49.21	-28.00	13.65	23.16	0.01523	0.1954	13.84
62.64	12	7.56	49.96	-28.54	13.86	24.34	0.01345	0.1954	14.06
62.64	13	7.56	50.66	-29.19	13.91	24.59	0.01158	0.1954	14.10
62.64	14	7.56	51.30	-29.69	14.05	25.42	0.01032	0.1954	14.25
62.64	15	7.56	51.90	-30.21	14.13	25.89	0.00916	0.1954	14.33
62.64	16	7.56	52.46	-30.73	14.17	26.13	0.00812	0.1954	14.37
62.64	17	7.56	52.99	-31.32	14.11	25.75	0.00709	0.1954	14.30
62.64	18	7.56	53.48	-31.75	14.17	26.15	0.00642	0.1954	14.37
62.64	19	7.56	53.95	-32.24	14.15	26.02	0.00574	0.1954	14.35
62.64	20	7.56	54.40	-32.66	14.18	26.18	0.00521	0.1954	14.37

Note: For distances lower than 6-7 cm (in transition to near field) the numbers measured are expected to be invalid due to the potential coupling with the measuring device or other near objects.

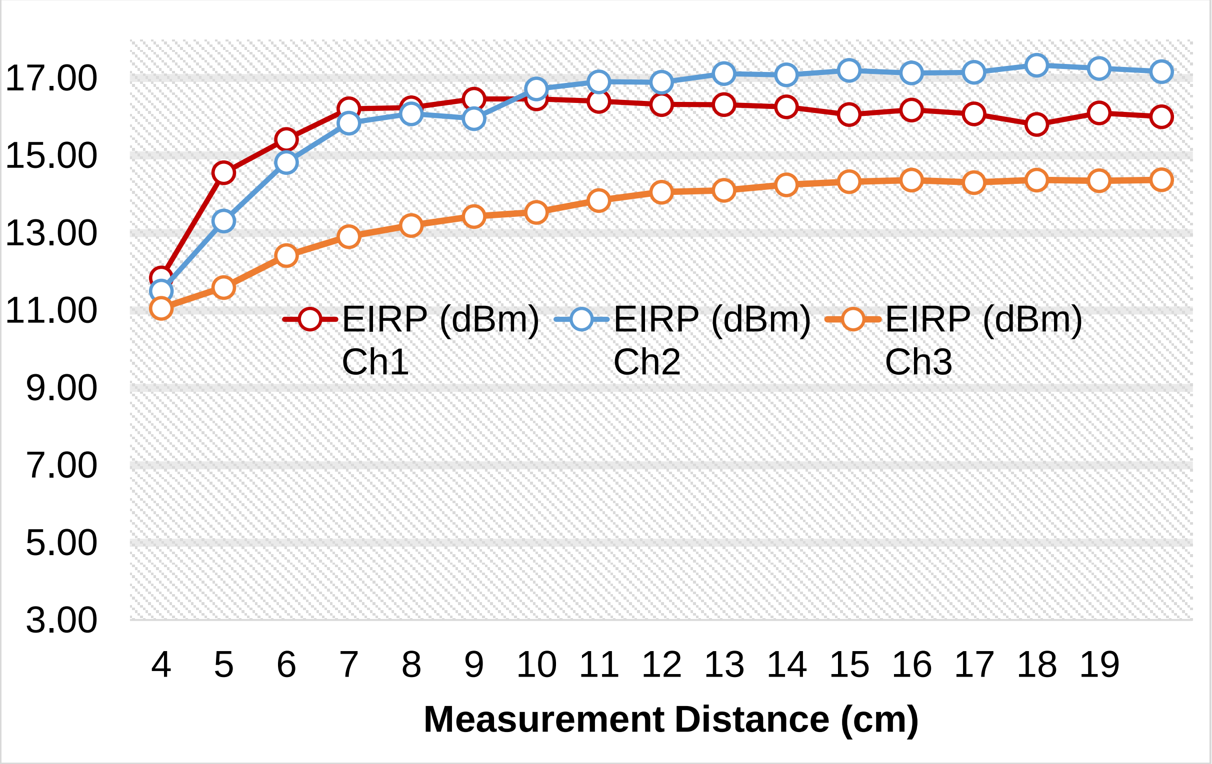
Results graph

Power Density



Power Density measured during the tests (i.e. with the ~ 96 % duty cycle measured in B.1)

EIRP



EIRP normalized for 100% duty cycle (after adding the Duty cycle correction factor measured in B.1)

Annex C. Aperture Probe Antenna Characterization

C.1 Description of the Antenna

The measuring antenna is an open-ended waveguide as specified in IEEE Std C95.3-2002 Clause 5.5.1.1.3 Small apertures. The aperture probe antenna consists of a 19 cm straight section of WR15 rectangular waveguide with a standard UG-385/U flange at one end. The aperture dimensions are 1.88 x 3.76 mm^2.

C.2 Derivation of characterization equations

Indeed, the ratio between the received power and the transmitted power between a pair of antennas is expressed in terms of their gains as follow:

$$G_T\ G_R = \frac{P_R}{P_T}\left(\frac{4\pi D}{\lambda}\right)^2$$

Converting from linear to logarithmic domain yields:

$$G_T + G_R = P_R - P_T + 20Log(\frac{4\pi D}{\lambda})$$

Converting from wavelength in meters to frequency in GHz yields:

$$G_T + G_R = P_R - P_T + 20Log(D) + 20Log(f) + 32.44 \qquad (1)$$

Where:

G_T is the gain of the transmit antenna (dBi)
G_R is the gain of the receive antenna (dBi)
P_R is the power received (dBm)
P_T is the power transmitted (dBm)
D is the distance between the antennas (m)
f is the frequency (GHz)

The individual far-field gain of each of three different antennas can be determined from three path loss measurements made under identical far-field conditions using the three different antennas taken in pairs. Three path loss measurements (P_{R12} - P_T), (P_{R13} - P_T) and (P_{R23} - P_T) are sufficient to simultaneously solve for three unknowns G_1, G_2 and G_3.

The Equation (1) is applied to each of the three path loss measurement as follows applied

$$A = G_1 + G_2 = P_{R12} - P_T + 20Log(D) + 20Log(f) + 32.44 \qquad (2)$$

$$B = G_1 + G_3 = P_{R13} - P_T + 20Log(D) + 20Log(f) + 32.44 \qquad (3)$$

$$C = G_2 + G_3 = P_{R23} - P_T + 20Log(D) + 20Log(f) + 32.44 \qquad (4)$$

Where:

$A = (G_1 + G_2)$ is the sum of the gains of Antennas 1 and 2
$B = (G_1 + G_3)$ is the sum of the gains of Antennas 1 and 3
$C = (G_2 + G_3)$ is the sum of the gains of Antennas 2 and 3
P_{R12} is the power received when measuring Antennas 1 and 2 (dBm)
P_{R13} is the power received when measuring Antennas 1 and 3 (dBm)
P_{R23} is the power received when measuring Antennas 2 and 3 (dBm)
P_T is the transmitted power (dBm)
D is the distance between the antennas (m)
f is the frequency (GHz)

The gain of each individual antenna is calculated as follows:

$$G_1 = 0.5\,(A + B - C) \tag{5}$$
$$G_2 = 0.5\,(A + C - B) \tag{6}$$
$$G_3 = 0.5\,(B + C - A) \tag{7}$$

Where:

G_1 is the gain of Antenna 1 (dBi)
G_2 is the gain of Antenna 2 (dBi)
G_3 is the gain of Antenna 3 (dBi)
A is the result of applying Equation (2)
B is the result of applying Equation (3)
C is the result of applying Equation (4)

C.3 Characterization Procedure

1. Allow the signal source, power sensor and power meter to warm up as specified by the manufacturer of the instruments.

2. Adjust the instruments to the applicable frequency. Connect the power sensor to the output of the source. Measure and record Power Transmitted.

3. Connect the first pair of antennas to their respective source (Tx antenna) and power sensor (Rx antenna). Place the antennas at the selected far-field separation distance in a bore-sight configuration using a laser level to align the antennas. Measure and record Power Received.

4. Repeat step 3 for each pair of antennas.

5. Calculate the antenna gains by applying Equations (2) through (7).

C.4 Characterization Results and Validation

C.4.1 Far-Field Distance

The gain reduction (relative to the far-field gain G∞) of an antenna is estimated as a function of normalized distance.
The normalized distance is given in terms of $n=d\lambda/a^2$ where d is distance, λ is wavelength and a is the largest aperture dimension. The far-field gain holds for distances greater than about $(8a^2)/\lambda$ (n > 8).

Note that for the verification we use three aperture antennas, the far field distance is therefore calculated using the largest aperture dimension among the three antennas (in our case it is the antenna 1) and $a= 5mm$.

The minimum far field distance is calculated for each channel as follow:

Frequency (GHz)	Wavelength λ (m)	Largest aperture dimension a (m)	Ratio (a^2/λ)	Minimum distance d (cm)
58.32	0.005144033	0.005	0.00486	**3.888**
60.48	0.004960317	0.005	0.00504	**4.032**
62.64	0.004789272	0.005	0.00522	**4.176**

We decide therefore to do the characterization at **15 cm**.

C.4.2 Probe Gain

The probe under verification is noted **Antenna 3** with Gain G_3. The antennas 1 and 2 are used to perform the characterization. The verification procedure (see § 12.3) is applied as follow:

1st Path Loss measurement → In Tx : Antenna 1 / In Rx : Antenna 2

Channel	PT (dBm)	PR12 (dBm)	D (m)	f (GHz)	G1+G2 (dBi)
1	5.01	-30.53	0.15	58.32	15.74
2	7.34	-29.41	0.15	60.48	14.84
3	7.04	-28.28	0.15	62.64	16.58

2nd Path Loss measurement → In Tx : Antenna 2 / In Rx : *Antenna 3*

Channel	PT (dBm)	PR23 (dBm)	D (m)	f (GHz)	G2+G3 (dBi)
1	5.01	-35.30	0.15	58.32	10.97
2	7.34	-32.93	0.15	60.48	11.32
3	7.04	-30.66	0.15	62.64	14.20

3rd Path Loss measurement → In Tx : Antenna 1 / In Rx : *Antenna 3*

Channel	PT (dBm)	PR13 (dBm)	D (m)	f (GHz)	G1+G3 (dBi)
1	5.01	-30.76	0.15	58.32	15.51
2	7.34	-29.01	0.15	60.48	15.24
3	7.04	-27.35	0.15	62.64	17.51

The measured gains are deduced and showed as follows:

Antenna	***Channel 1 Gain (dBi)***	***Channel 2 Gain (dBi)***	***Channel 3 Gain (dBi)***
Aperture Antenna 1	10.14	9.38	9.94
Aperture Antenna 2	5.60	5.46	6.63
Open Ended Waveguide Probe Antenna	5.37	5.86	7.56

C.4.3 Validation

The measured gain of the original probe antenna is compared to the realized gain from a theoretical model of common open-ended waveguide apertures with a two-to-one aspect ratio, i.e. a/b=2, provided by IEEE Std C95.3 Clause 5.5.1.1.3 equation (4)

Channel	**Frequency (GHz)**	**Dimension a (m)**	**Theoretical Gain (dBi)** $10\log(21.6 \cdot f[GHz] \cdot a)$	**Measured Gain (dBi)**	**Delta to Theoretical Gain (dB)**
1	58.32	0.00376	6.75	5.37	1.38
2	60.48	0.00376	6.91	5.86	1.05
3	62.64	0.00376	7.06	7.56	0.50

Annex D. Photographs

Test Setup