



TESTING CERT #3478.01



# TEST REPORT

|                            |                                                                                                                 |
|----------------------------|-----------------------------------------------------------------------------------------------------------------|
| EUT Description            | Wireless Gigabit radio installed in a Dell model P67G (CF)                                                      |
| Brand                      | Intel® Tri-Band Wireless-AC 18260                                                                               |
| Model                      | Platform Dell model P67G (CF)/ Intel module 18260NGW                                                            |
| Serial Number              | Host Laptop: 0158B1-12963-597-0003<br>(see section 4)                                                           |
| FCC/IC ID                  | FCC ID: PD918260NG                                                                                              |
| Hardware/Software Version  | Test SW: DRTU version 1.8.4-02763<br>Driver ver.: 2.2.20.18                                                     |
| Date of Sample Receipt     | 2016-04-19                                                                                                      |
| Date of start/end of Tests | Start : 2016-09-15 End: 2016-09-16                                                                              |
| Features                   | Module: WiGig + 802.11 a/b/g/n/ac WLAN + BDR/EDR 2.1 + BLE 4.0<br>Host: Dell model P67G (CF)<br>(see section 5) |
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| Reference Standards        | FCC CFR Title 47 Part 15.255<br>(see section 1)                                                                 |
| Test Report number         | 160205-05.TR01                                                                                                  |
| Revision Control           | Rev. 00                                                                                                         |

The test results relate only to the samples tested.

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## 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).
- ✓ Intel Mobile Communications Wireless RF Lab (Intel WRF Lab) is an Accredited Test Firm listed by the FCC, with Designation Number FR0011.
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- ✓ Intel WRF Lab is liable to the client for the maintenance of the confidentiality of all information related to the item under test and the results of the test.
- ✓ Intel WRF Lab has developed calibration and proficiency programs for its measurement equipment to ensure correlated and reliable results to its customers.
- ✓ This report is only referred to the item that has undergone the test.
- ✓ This report does not imply an approval of the product by the Certification Bodies or competent Authorities.
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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 | 22.5°C ± 2°C |
| Humidity    | 42% ± 5%     |

#### 4. Test samples

| Sample | Control #     | Description   | Model                | Serial #                     | Date of reception |
|--------|---------------|---------------|----------------------|------------------------------|-------------------|
| #01    | 160205-05.S01 | Laptop        | Dell model P67G (CF) | CN0158B1129635970003         | 2016-04-19        |
|        | 160205-05.S02 | AC/DC Adapter | LA45NM150            | CN-0HDCY5-72438-58H-008E-X05 | 2016-04-19        |

#### 5. EUT features

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

|                                   |                                                                                              |
|-----------------------------------|----------------------------------------------------------------------------------------------|
| WiGig                             | 60GHz (58.320 – 62.640 GHz)                                                                  |
| 802.11b/g/n                       | 2.4GHz (2400.0 – 2483.5 MHz)                                                                 |
| 802.11a/n/ac                      | 5.2GHz (5150.0 – 5350.0 MHz)<br>5.6GHz (5470.0 – 5725.0 MHz)<br>5.8GHz (5725.0 – 5850.0 MHz) |
| BDR/EDR v2.1<br>Bluetooth LE v4.0 | 2.4GHz (2400.0 – 2483.5 MHz)                                                                 |

#### 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    | 2016-09-19 | M.Lefebvre  | First Issue |

# Annex A. Test & System Description

## A.1 Test Conditions

The EUT is an Intel Wireless Gigabit radio model 18260NGW, FCC ID PD918260NG, installed in a Dell model P67G (CF).

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 (4.0 dBm) conducted setting on MCS1 using proprietary software (Intel DRTU version 1.8.4-02763). 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       | 18.48              |
| 2       | 18.10              |
| 3       | 17.11              |

## A.2 Measurement system

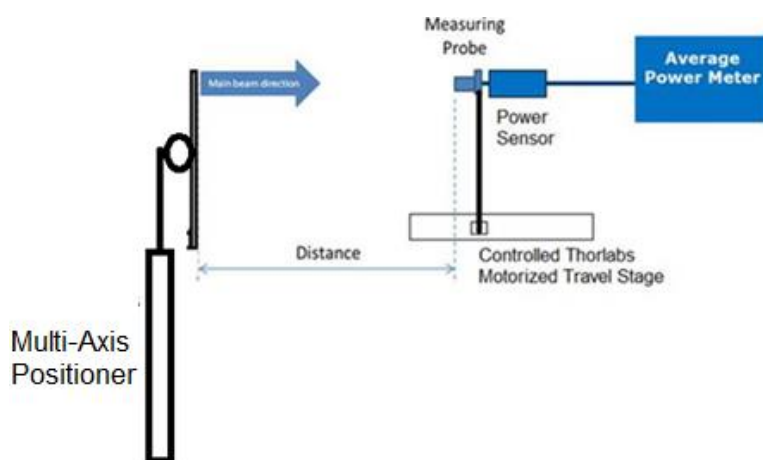
A Thorlabs Motorized Travel Stage controlled by software is used to maintain a consistent and accurate placement of the probe. A multi-axis Positioner is used for the Polarization / Elevation / Azimuth scan.

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 DUT's radiated power is measured using the average power meter connected to the power sensor and measuring probe, and recorded for all channels. The Power density and EIRP are then calculated according to the test procedure described in B.2.

The measurement distance is varied from 5 to 25 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**

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      | 101280        | 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 | 2016-03-24               | 2018-03-24    |
| 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:* The Duty cycle is measured using the FSU67 spectrum analyzer and a standard horn antenna. The FSU67 covers (20Hz-67GHz) frequency range, therefore the measurement is performed directly without a need to 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)*                    |            |                          |         |                         | <b>0.93</b>               |

### 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)*                   |            |                          |         |                         | <b>1.48</b>               |

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      | 990.380      | 1003.205    | 0.987             |
| Duty Cycle over Burst period | 1.992        | 2.047       | 0.973             |
| Duty Cycle                   |              |             | 0.96062           |
| Duty Cycle Correction (dB)   |              |             | 0.1745            |

#### Channel 2

| Description                  | ON Time (ms) | Period (ms) | Duty Cycle Linear |
|------------------------------|--------------|-------------|-------------------|
| Duty Cycle Within Burst      | 993.589      | 1003.205    | 0.990             |
| Duty Cycle over Burst period | 1.985        | 2.053       | 0.966             |
| Duty Cycle                   |              |             | 0.95718           |
| Duty Cycle Correction (dB)   |              |             | 0.1901            |

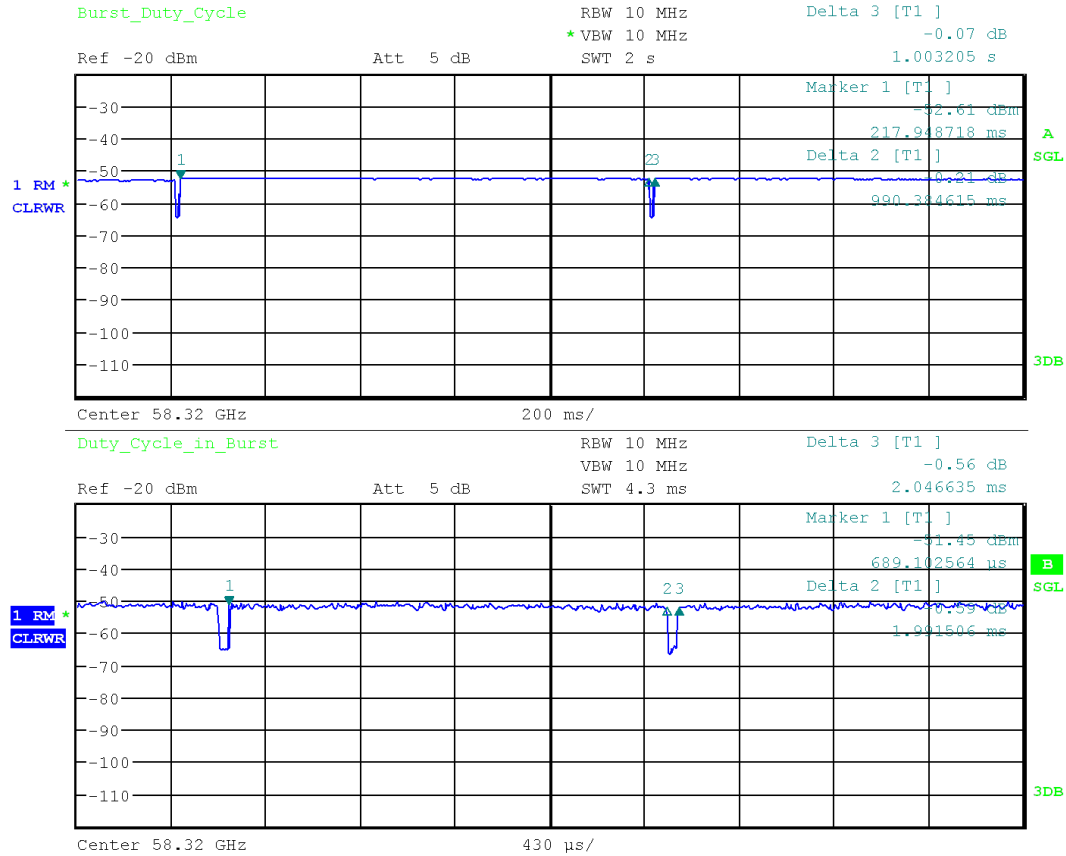
Channel 3

| Description                  | ON Time (ms) | Period (ms) | Duty Cycle Linear |
|------------------------------|--------------|-------------|-------------------|
| Duty Cycle Within Burst      | 983.974      | 996.795     | 0.987             |
| Duty Cycle over Burst period | 1.991        | 2.053       | 0.970             |
| Duty Cycle                   |              |             | 0.95734           |
| Duty Cycle Correction (dB)   |              |             | 0.1894            |

## Results screenshots

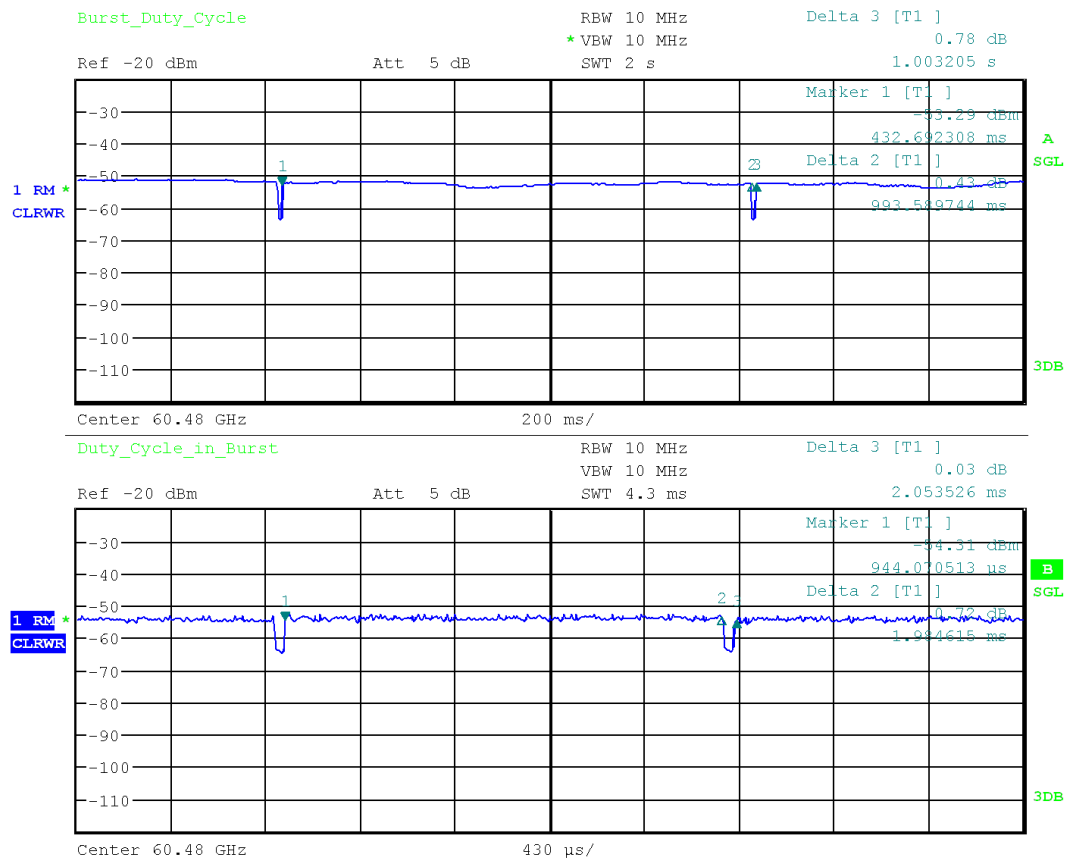
# Duty Cycle

## Channel 1



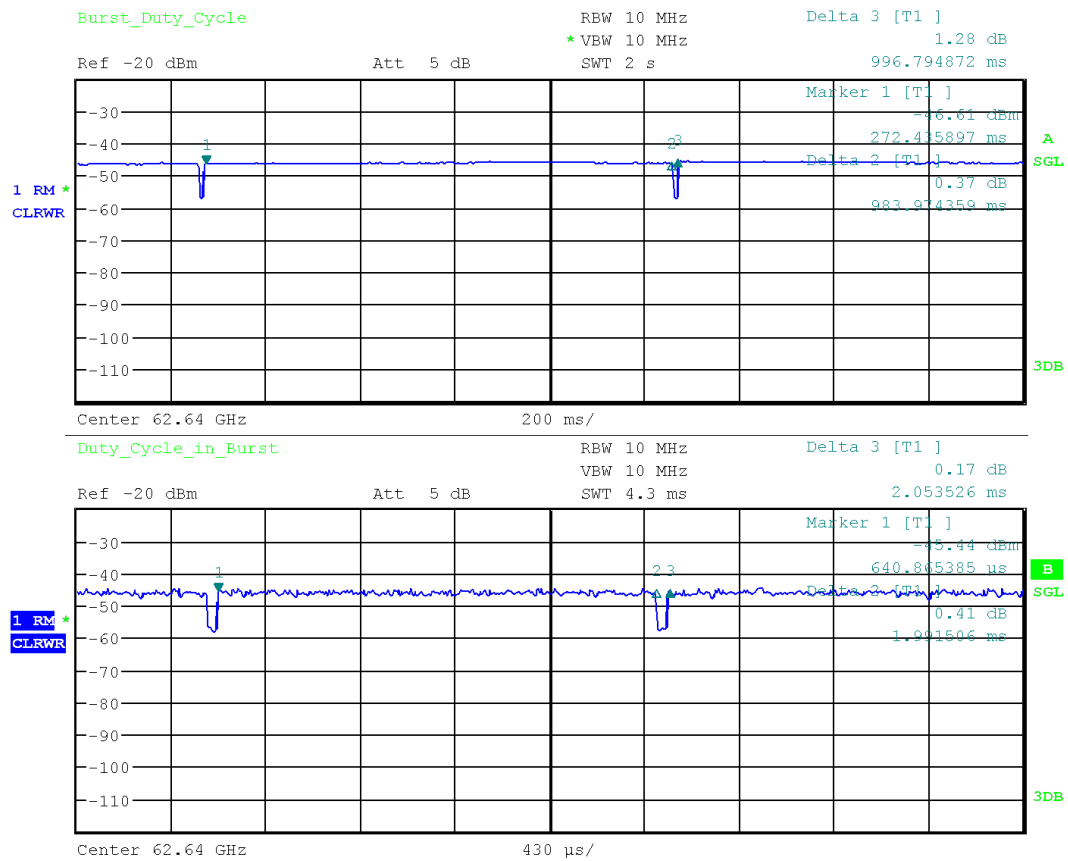
Date: 16.SEP.2016 18:52:18

## Channel 2



Date: 16.SEP.2016 18:58:07

### Channel 3



Date: 16.SEP.2016 19:01:07

## 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:

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

Where the:

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

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)

$\lambda$  is the wavelength in (m)

$P_T * G_T$  is converted to power density using:

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

Where:

**Power Density** is in (mW/cm<sup>2</sup>)

$P_T * G_T$  is in (mW)

$D$  is in (cm)

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

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

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 = 15.30 dBi

| 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 <sup>2</sup> ) | Duty Cycle Correction (dB) | EIRP (dBm) |
|------------|---------------------|---------------------------------------|-----------------------------|----------------------------|-------------------|------------------|-------------------------------------|----------------------------|------------|
| 58.32      | 5                   | 5.37                                  | 41.74                       | -21.02                     | 15.35             | 34.26            | 0.10904                             | 0.1745                     | 15.52      |
| 58.32      | 6                   | 5.37                                  | 43.32                       | -21.55                     | 16.40             | 43.66            | 0.09652                             | 0.1745                     | 16.58      |
| 58.32      | 7                   | 5.37                                  | 44.66                       | -22.73                     | 16.56             | 45.29            | 0.07355                             | 0.1745                     | 16.73      |
| 58.32      | 8                   | 5.37                                  | 45.82                       | -23.33                     | 17.12             | 51.52            | 0.06406                             | 0.1745                     | 17.29      |
| 58.32      | 9                   | 5.37                                  | 46.84                       | -24.07                     | 17.40             | 54.99            | 0.05403                             | 0.1745                     | 17.58      |
| 58.32      | 10                  | 5.37                                  | 47.76                       | -25.19                     | 17.20             | 52.46            | 0.04174                             | 0.1745                     | 17.37      |
| 58.32      | 11                  | 5.37                                  | 48.59                       | -25.56                     | 17.66             | 58.29            | 0.03834                             | 0.1745                     | 17.83      |
| 58.32      | 12                  | 5.37                                  | 49.34                       | -26.44                     | 17.53             | 56.65            | 0.03130                             | 0.1745                     | 17.71      |
| 58.32      | 13                  | 5.37                                  | 50.04                       | -27.00                     | 17.67             | 58.44            | 0.02752                             | 0.1745                     | 17.84      |
| 58.32      | 14                  | 5.37                                  | 50.68                       | -27.49                     | 17.82             | 60.54            | 0.02458                             | 0.1745                     | 18.00      |
| 58.32      | 15                  | 5.37                                  | 51.28                       | -28.27                     | 17.64             | 58.08            | 0.02054                             | 0.1745                     | 17.81      |
| 58.32      | 16                  | 5.37                                  | 51.84                       | -28.47                     | 18.00             | 63.10            | 0.01962                             | 0.1745                     | 18.18      |
| 58.32      | 17                  | 5.37                                  | 52.37                       | -28.90                     | 18.10             | 64.52            | 0.01777                             | 0.1745                     | 18.27      |
| 58.32      | 18                  | 5.37                                  | 52.86                       | -29.27                     | 18.22             | 66.43            | 0.01632                             | 0.1745                     | 18.40      |
| 58.32      | 19                  | 5.37                                  | 53.33                       | -29.92                     | 18.04             | 63.73            | 0.01405                             | 0.1745                     | 18.22      |
| 58.32      | 20                  | 5.37                                  | 53.78                       | -30.40                     | 18.01             | 63.22            | 0.01258                             | 0.1745                     | 18.18      |
| 58.32      | 21                  | 5.37                                  | 54.20                       | -30.74                     | 18.09             | 64.45            | 0.01163                             | 0.1745                     | 18.27      |
| 58.32      | 22                  | 5.37                                  | 54.61                       | -31.15                     | 18.09             | 64.37            | 0.01058                             | 0.1745                     | 18.26      |
| 58.32      | 23                  | 5.37                                  | 54.99                       | -31.39                     | 18.23             | 66.57            | 0.01001                             | 0.1745                     | 18.41      |
| 58.32      | 24                  | 5.37                                  | 55.36                       | -31.83                     | 18.16             | 65.50            | 0.00905                             | 0.1745                     | 18.34      |
| 58.32      | 25                  | 5.37                                  | 55.72                       | -32.04                     | 18.31             | 67.72            | 0.00862                             | 0.1745                     | 18.48      |

### Channel 2

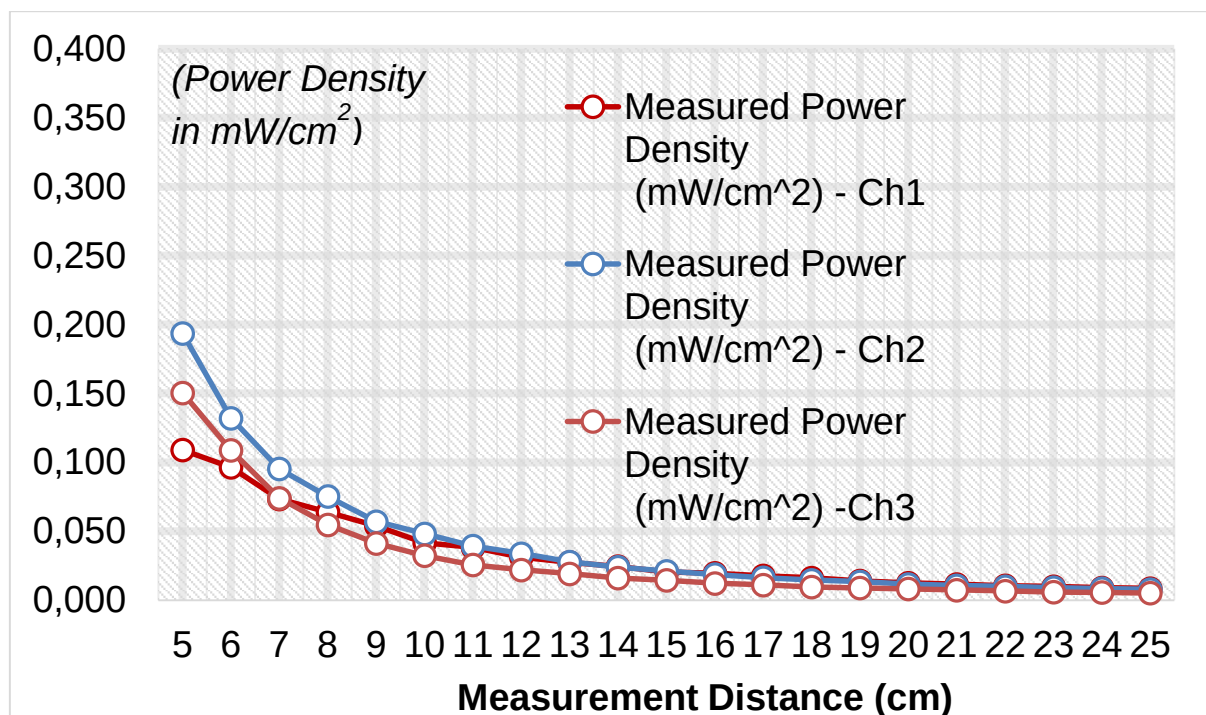
EUT antenna gain = 15.20 dBi

| 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 <sup>2</sup> ) | Duty Cycle Correction (dB) | EIRP (dBm) |
|------------|---------------------|---------------------------------------|-----------------------------|----------------------------|-------------------|------------------|-------------------------------------|----------------------------|------------|
| 60.48      | 5                   | 5.86                                  | 42.05                       | -18.35                     | 17.84             | 60.86            | 0.19373                             | 0.1901                     | 18.03      |
| 60.48      | 6                   | 5.86                                  | 43.64                       | -20.01                     | 17.77             | 59.80            | 0.13219                             | 0.1901                     | 17.96      |
| 60.48      | 7                   | 5.86                                  | 44.98                       | -21.43                     | 17.69             | 58.69            | 0.09532                             | 0.1901                     | 17.88      |
| 60.48      | 8                   | 5.86                                  | 46.14                       | -22.45                     | 17.83             | 60.62            | 0.07537                             | 0.1901                     | 18.02      |
| 60.48      | 9                   | 5.86                                  | 47.16                       | -23.65                     | 17.65             | 58.20            | 0.05717                             | 0.1901                     | 17.84      |
| 60.48      | 10                  | 5.86                                  | 48.07                       | -24.38                     | 17.83             | 60.73            | 0.04833                             | 0.1901                     | 18.02      |
| 60.48      | 11                  | 5.86                                  | 48.90                       | -25.27                     | 17.77             | 59.87            | 0.03937                             | 0.1901                     | 17.96      |
| 60.48      | 12                  | 5.86                                  | 49.66                       | -25.91                     | 17.89             | 61.48            | 0.03398                             | 0.1901                     | 18.08      |
| 60.48      | 13                  | 5.86                                  | 50.35                       | -26.76                     | 17.73             | 59.33            | 0.02794                             | 0.1901                     | 17.92      |
| 60.48      | 14                  | 5.86                                  | 51.00                       | -27.40                     | 17.74             | 59.38            | 0.02411                             | 0.1901                     | 17.93      |
| 60.48      | 15                  | 5.86                                  | 51.60                       | -27.97                     | 17.77             | 59.78            | 0.02114                             | 0.1901                     | 17.96      |
| 60.48      | 16                  | 5.86                                  | 52.16                       | -28.50                     | 17.80             | 60.21            | 0.01872                             | 0.1901                     | 17.99      |
| 60.48      | 17                  | 5.86                                  | 52.68                       | -29.08                     | 17.74             | 59.47            | 0.01638                             | 0.1901                     | 17.93      |
| 60.48      | 18                  | 5.86                                  | 53.18                       | -29.56                     | 17.76             | 59.70            | 0.01466                             | 0.1901                     | 17.95      |
| 60.48      | 19                  | 5.86                                  | 53.65                       | -29.93                     | 17.86             | 61.08            | 0.01346                             | 0.1901                     | 18.05      |
| 60.48      | 20                  | 5.86                                  | 54.09                       | -30.54                     | 17.69             | 58.81            | 0.01170                             | 0.1901                     | 17.88      |
| 60.48      | 21                  | 5.86                                  | 54.52                       | -30.91                     | 17.75             | 59.54            | 0.01074                             | 0.1901                     | 17.94      |
| 60.48      | 22                  | 5.86                                  | 54.92                       | -31.21                     | 17.85             | 60.99            | 0.01003                             | 0.1901                     | 18.04      |
| 60.48      | 23                  | 5.86                                  | 55.31                       | -31.59                     | 17.86             | 61.07            | 0.00919                             | 0.1901                     | 18.05      |
| 60.48      | 24                  | 5.86                                  | 55.68                       | -31.95                     | 17.87             | 61.21            | 0.00846                             | 0.1901                     | 18.06      |
| 60.48      | 25                  | 5.86                                  | 56.03                       | -32.26                     | 17.91             | 61.84            | 0.00787                             | 0.1901                     | 18.10      |

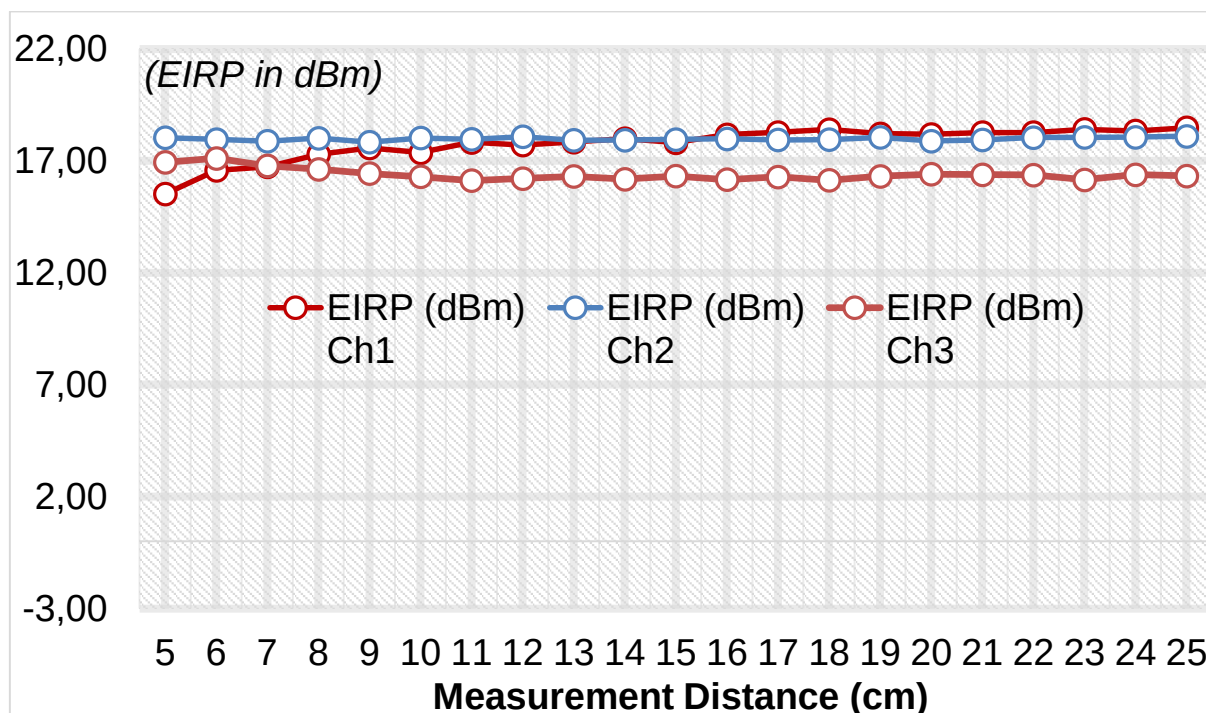
### Channel 3

EUT antenna gain = 15.00 dBi

| 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 <sup>2</sup> ) | Duty Cycle Correction (dB) | EIRP (dBm) |
|------------|---------------------|---------------------------------------|-----------------------------|----------------------------|-------------------|------------------|-------------------------------------|----------------------------|------------|
| 62.64      | 5                   | 7.56                                  | 42.36                       | -18.05                     | 16.75             | 47.30            | 0.15055                             | 0.1894                     | 16.94      |
| 62.64      | 6                   | 7.56                                  | 43.94                       | -19.46                     | 16.92             | 49.22            | 0.10881                             | 0.1894                     | 17.11      |
| 62.64      | 7                   | 7.56                                  | 45.28                       | -21.13                     | 16.59             | 45.61            | 0.07407                             | 0.1894                     | 16.78      |
| 62.64      | 8                   | 7.56                                  | 46.44                       | -22.44                     | 16.44             | 44.06            | 0.05479                             | 0.1894                     | 16.63      |
| 62.64      | 9                   | 7.56                                  | 47.46                       | -23.66                     | 16.24             | 42.11            | 0.04137                             | 0.1894                     | 16.43      |
| 62.64      | 10                  | 7.56                                  | 48.38                       | -24.72                     | 16.10             | 40.73            | 0.03241                             | 0.1894                     | 16.29      |
| 62.64      | 11                  | 7.56                                  | 49.21                       | -25.72                     | 15.93             | 39.14            | 0.02574                             | 0.1894                     | 16.12      |
| 62.64      | 12                  | 7.56                                  | 49.96                       | -26.38                     | 16.02             | 40.02            | 0.02211                             | 0.1894                     | 16.21      |
| 62.64      | 13                  | 7.56                                  | 50.66                       | -26.98                     | 16.12             | 40.90            | 0.01926                             | 0.1894                     | 16.31      |
| 62.64      | 14                  | 7.56                                  | 51.30                       | -27.75                     | 15.99             | 39.73            | 0.01613                             | 0.1894                     | 16.18      |
| 62.64      | 15                  | 7.56                                  | 51.90                       | -28.21                     | 16.13             | 41.03            | 0.01451                             | 0.1894                     | 16.32      |
| 62.64      | 16                  | 7.56                                  | 52.46                       | -28.93                     | 15.97             | 39.55            | 0.01229                             | 0.1894                     | 16.16      |
| 62.64      | 17                  | 7.56                                  | 52.99                       | -29.33                     | 16.10             | 40.72            | 0.01121                             | 0.1894                     | 16.29      |
| 62.64      | 18                  | 7.56                                  | 53.48                       | -29.98                     | 15.94             | 39.30            | 0.00965                             | 0.1894                     | 16.13      |
| 62.64      | 19                  | 7.56                                  | 53.95                       | -30.27                     | 16.12             | 40.96            | 0.00903                             | 0.1894                     | 16.31      |
| 62.64      | 20                  | 7.56                                  | 54.40                       | -30.62                     | 16.22             | 41.87            | 0.00833                             | 0.1894                     | 16.41      |
| 62.64      | 21                  | 7.56                                  | 54.82                       | -31.07                     | 16.19             | 41.62            | 0.00751                             | 0.1894                     | 16.38      |
| 62.64      | 22                  | 7.56                                  | 55.23                       | -31.49                     | 16.18             | 41.47            | 0.00682                             | 0.1894                     | 16.37      |
| 62.64      | 23                  | 7.56                                  | 55.61                       | -32.09                     | 15.96             | 39.48            | 0.00594                             | 0.1894                     | 16.15      |
| 62.64      | 24                  | 7.56                                  | 55.98                       | -32.23                     | 16.19             | 41.62            | 0.00575                             | 0.1894                     | 16.38      |
| 62.64      | 25                  | 7.56                                  | 56.34                       | -32.64                     | 16.14             | 41.09            | 0.00523                             | 0.1894                     | 16.33      |

**Results graph****Power Density**

Power Density in  $\text{mW}/\text{cm}^2$  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<sup>2</sup>.

## 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:

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

Converting from wavelength in meters to frequency in GHz yields:

$$G_T + G_R = P_R - P_T + 20\text{Log}(D) + 20\text{Log}(f) + 32.44 \quad (1)$$

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

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

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

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

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:

$$G_1 = 0.5 (A + B - C) \quad (5)$$

$$G_2 = 0.5 (A + C - B) \quad (6)$$

$$G_3 = 0.5 (B + C - A) \quad (7)$$

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  $G_\infty$ ) 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,  $\lambda$  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 $\lambda$ (m) | Largest aperture dimension $a$ (m) | Ratio ( $a^2/\lambda$ ) | Minimum distance $d$ (cm) |
|-----------------|--------------------------|------------------------------------|-------------------------|---------------------------|
| 58.32           | 0.005144033              | 0.005                              | 0.00486                 | <b>3.888</b>              |
| 60.48           | 0.004960317              | 0.005                              | 0.00504                 | <b>4.032</b>              |
| 62.64           | 0.004789272              | 0.005                              | 0.00522                 | <b>4.176</b>              |

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:

#### 1<sup>st</sup> 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       |

#### 2<sup>nd</sup> 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       |

#### 3<sup>rd</sup> 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:

| <b>Antenna</b>                     | <b>Channel 1<br/>Gain (dBi)</b> | <b>Channel 2<br/>Gain (dBi)</b> | <b>Channel 3<br/>Gain (dBi)</b> |
|------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 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)

| <b>Channel</b> | <b>Frequency<br/>(GHz)</b> | <b>Dimension a<br/>(m)</b> | <b>Theoretical Gain (dBi)<br/><math>10 \log(21.6 \cdot f[GHz] \cdot a)</math></b> | <b>Measured<br/>Gain<br/>(dBi)</b> | <b>Delta to<br/>Theoretical<br/>Gain<br/>(dB)</b> |
|----------------|----------------------------|----------------------------|-----------------------------------------------------------------------------------|------------------------------------|---------------------------------------------------|
| 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

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## Test Setup

