FAR FIELD EIRP MEASUREMENT TEST REPORT
TO SUPPORT
POWER DENSITY REPORT

FOR

MODEL: DELL P58G

FCC ID: PD917265NG

REPORT NUMBER: 15U19818-E2, Revision C

ISSUE DATE: August 5, 2015

Prepared for
INTEL MOBILE COMMUNICATIONS
100 CENTER POINT CIRCLE, SUITE 200
COLUMBIA, SC 29210 USA

Prepared by
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NVLAP LAB CODE 200065-0

Revision History

Rev.	Issue Date	Revisions	Revised By
--	04/05/2015	Initial Issue	M. Heckrotte
A	04/06/2015	Revised title and model number	M. Heckrotte
B	07/28/2015	Added conducted output power, revised MU, revised FCC ID	M. Heckrotte
C	08/05/2015	Added Clarification to Section 2 and 7.1	C. Cheung

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1. ATTESTATION OF TEST RESULTS

COMPANY NAME:	INTEL MOBILE COMMUNICATIONS 100 CENTER POINT CIRCLE, SUITE 200 COLUMBIA, SC 29210 USA
EUT DESCRIPTION:	Intel Wireless Gigabit radio installed in Dell laptop
MODEL:	Dell P58G
SERIAL NUMBER:	ZAU7002850
DATE OF TESTS:	FEBRUARY 17, 23 and March 31, 2015

APPLICABLE PROCEDURES	
FCC	**IEEE**
FCC § 2.1093	IEEE Std C95.3-2002

UL Verification Services Inc. tested the above equipment in accordance with the requirements set forth in the above standards. All indications of Pass/Fail in this report are opinions expressed by UL Verification Services Inc. based on interpretations and/or observations of test results. Measurement Uncertainties were not taken into account and are published for informational purposes only. The test results show that the equipment tested is capable of demonstrating compliance with the requirements as documented in this report.

Note: The results documented in this report apply only to the tested sample, under the conditions and modes of operation as described herein. This document may not be altered or revised in any way unless done so by UL Verification Services Inc. and all revisions are duly noted in the revisions section. Any alteration of this document not carried out by UL Verification Services Inc. will constitute fraud and shall nullify the document. This report must not be used by the client to claim product certification, approval, or endorsement by NVLAP, NIST, any agency of the Federal Government, or any agency of any government.

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2. PURPOSE AND SCOPE

This report documents the results of radiated measurements of the power density and EIRP of a radio operating in the 60 GHz unlicensed band. The purpose is to enable a comparison with power density simulations in far field and assist in the determination of the far field boundary.

Due to the lack of standardized code validation, benchmarking and uncertainty of the simulation software, the far field results are provided for the purpose of providing confidence for the software simulation model used and that the results produced were within an acceptable range when compared with the measured results.

3. TEST METHODOLOGY

The tests documented in this report were performed in accordance with IEEE Std C95.3-2002, “IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz–300 GHz” and the measurement distance limitations specified in FCC Rules § 2.1093(d).

4. FACILITIES AND ACCREDITATION

The test sites and measurement facilities used to collect data are located at 47173 and 47266 Benicia Street, Fremont, California, USA. Line conducted emissions are measured only at the 47173 address. The following table identifies which facilities were utilized for radiated emission measurements documented in this report. Specific facilities are also identified in the test results sections.

47173 Benicia Street	47266 Benicia Street
☐ Chamber A	☐ Chamber D
☐ Chamber B	☐ Chamber E
☐ Chamber C	☐ Chamber F
	☐ Chamber G
	☐ Chamber H

UL Verification Services Inc. is accredited by NVLAP, Laboratory Code 200065-0. The full scope of accreditation can be viewed at http://ts.nist.gov/standards/scopes/2000650.htm.

5. CALIBRATION

The measuring equipment utilized to perform the tests documented in this report has been calibrated in accordance with the manufacturer's recommendations, and is traceable to recognized national standards.

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6. MEASUREMENT UNCERTAINTY

The following measurement uncertainty levels have been estimated for tests performed on the apparatus:

PARAMETER	UNCERTAINTY	
Power Density	+/- 19.36 %	+0.77 / - 0.93 dB

Uncertainty figures are valid to a confidence level of 95%.

6.1. EUT MEASUREMENT

EUT Measurement Uncertainty						
Input quantity	(+/- %)	Distribution or (Units)	Divisor	U (Xi) (+/- %)	Ci	Ci U (Xi) (+/- %)
Mismatch during Calibration						
Calibrator Output =	0.035	(Rho)				
Power Sensor =	0.029	(Rho)				
Mismatch error, conducted thru	0.102	U-shaped	1.414	0.07	1	0.07
Mismatch during Measurement						
RX Probe Assembly =	0.660	(Rho)				
Power Sensor =	0.029	(Rho)				
Mismatch error, transmit ant	1.914	U-shaped	1.414	1.35	1	1.35
Aperture Probe						
Probe Gain	17.53	Expanded	1.96	8.94	1	8.94
Power Sensor/Meter Contributions						
Power Meter Instrumentation Error	0.500	Gaussian	2	0.25	1	0.25
Power Meter Instrumentation Error During Calibration	0.500	Gaussian	2	0.25	1	0.25
Power Meter Calibrator Output Power	0.500	Gaussian	2	0.25	1	0.25
Power Sensor Calibration Factor Uncertainties	6.600	Gaussian	2	3.30	1	3.30
Power Sensor Linearity	1.000	Gaussian	2	0.50	1	0.50
Zero Set	0.316	Gaussian	2	0.16	1	0.16
Zero Drift	0.064	Gaussian	2	0.03	1	0.03
Sensor Noise	0.172	Gaussian	2	0.09	1	0.09
Other Contributions						
Positioning uncertainty	3.45	Rectangular	1.732	1.99	1	1.99
Random uncertainty	1.15	Rectangular	1.732	0.66	1	0.66
Combined Standard Uncertainty =						9.88
Expanded Uncertainty U, Coverage Factor = 1.96, > 95 % Confidence =						19.36
Expanded Uncertainty U, Coverage Factor = 1.96, > 95 % Confidence =				0.77	dB	
Expanded Uncertainty U, Coverage Factor = 1.96, > 95 % Confidence =				-0.93	dB	

6.2. APERTURE PROBE GAIN MEASUREMENT

Aperture Probe Gain Measurement Uncertainty						
Input quantity	(+/- %)	Distribution or (Units)	Divisor	U (Xi) (+/- %)	Ci	Ci U (Xi) (+/- %)
Thru Line Mismatch						
SOURCE =	0.17	(Rho)				
Power Sensor =	0.11	(Rho)				
Mismatch error, conducted thru	1.87	U-shaped	1.414	1.32	1	1.32
Tx antenna side Mismatch 1-2						
SOURCE =	0.17	(Rho)				
Tx Ant =	0.22	(Rho)				
Mismatch error, transmit ant	3.74	U-shaped	1.414	2.64	1	2.64
Tx antenna side Mismatch 1-P						
SOURCE =	0.17	(Rho)				
Tx Ant =	0.22	(Rho)				
Mismatch error, transmit ant	3.74	U-shaped	1.414	2.64	1	2.64
Tx antenna side Mismatch 2-P						
SOURCE =	0.17	(Rho)				
Tx Ant =	0.22	(Rho)				
Mismatch error, transmit ant	3.74	U-shaped	1.414	2.64	1	2.64
Rx antenna side Mismatch 1-2						
RX Ant =	0.22	(Rho)				
Power Sensor =	0.11	(Rho)				
Mismatch error, receive ant	2.42	U-shaped	1.414	1.71	1	1.71
Rx antenna side Mismatch 1-P						
RX Probe Assembly =	0.66	(Rho)				
Power Sensor =	0.11	(Rho)				
Mismatch error, Rx probe assembly	7.26	U-shaped	1.414	5.13	1	5.13
Rx antenna side Mismatch 2-P						
RX Probe Assembly =	0.66	(Rho)				
Power Sensor =	0.11	(Rho)				
Mismatch error, Rx probe assembly	7.26	U-shaped	1.414	5.13	1	5.13
Power Sensor/Meter Contributions						
Sensor Linearity	1.500	Gaussian	2	0.75	1	0.750
Zero Set	0.064	Gaussian	2	0.03	1	0.032
Zero Drift	0.012	Gaussian	2	0.01	1	0.006
Sensor Noise	0.782	Gaussian	2	0.39	1	0.391
Other Contributions						
Positioning uncertainty	1.15	Rectangular	1.732	0.66	1	0.66
Random uncertainty	1.15	Rectangular	1.732	0.66	1	0.66
Combined Standard Uncertainty =						8.94
Expanded Uncertainty U, Coverage Factor = 1.96, > 95 % Confidence =						17.53

7. EQUIPMENT UNDER TEST

7.1. DESCRIPTION OF EUT

The EUT is an Intel Wireless Gigabit radio model 17265NGW LC, FCC ID PD917265NG installed in an Dell P58G convertible 2 in 1 laptop.

Please note, Dell model P58G is the regulatory model number. This identical host is also marketed under the name Dell Latitude 7350. In the report we refer only to P58G model.

7.2. DESCRIPTION OF ANTENNA

The antenna is an integral phased array antenna with a maximum gain of 15.45 dBi.

7.3. SOFTWARE AND FIRMWARE

.
Intel Wireless Gigabit 17265 Driver Version: 1.1.3028

Test Tool: DRTU, version 1.7.6-1123

The EUT is set to transmit on MCS1 with 50% duty cycle.

7.4. DESCRIPTION OF TEST SETUP

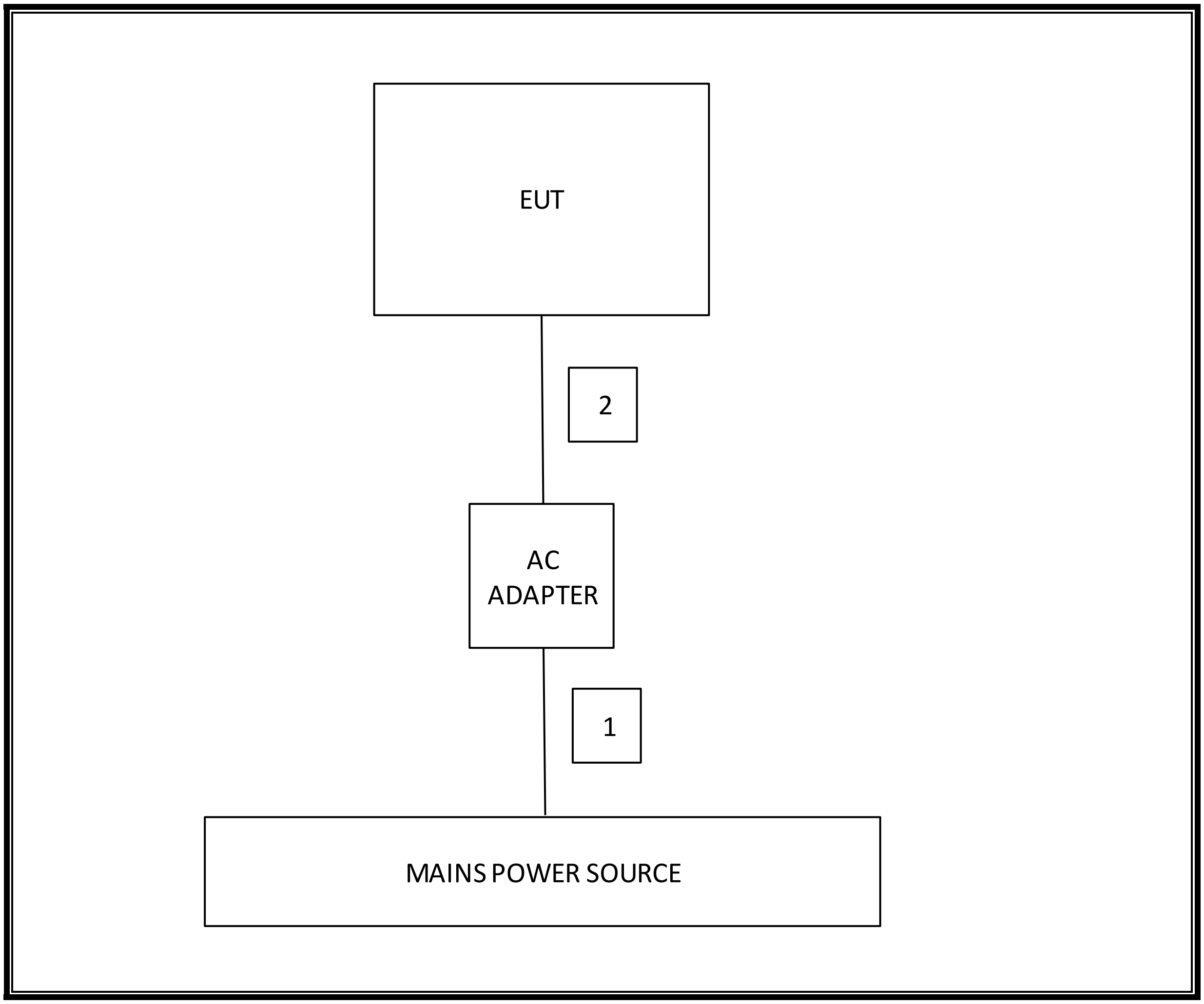
SUPPORT EQUIPMENT

Description	Manufacturer	Model	Serial Number
AC / DC Adapter	DELL	DA45NM131	CN-04H6NV-48661-46R-11M1-A01

I/O CABLES

Cable No.	Port	Cable Length (m)	Remarks
1	AC Power	0.8	AC Mains
2	DC power	1.9	EUT Power

SETUP DIAGRAM FOR TESTS



8. TEST AND MEASUREMENT EQUIPMENT

The following test and measurement equipment was utilized for the tests documented in this report:

Description	Manufacturer	Model	Asset	Cal Date	Cal Due
Power Sensor	HP	V8486A-H01	T234	12/16/2014	12/16/2015
Power Sensor	Agilent	V8486A-H02	T433	5/6/2014	5/6/2015
Power Meter	Agilent	N1913A	T412	5/1/2014	5/1/2015
Spectrum Analyzer	Agilent	N9030A	T313	9/13/2014	9/13/2015
Signal Generator	Agilent	E8257D	T181	9/26/2014	9/26/2015
Downconverter	Agilent	MT463	T499	8/6/2014	8/6/2015
Harmonic Mixer 50-80GHz	Agilent	M1970V	T994	6/18/2014	6/18/2015
Aperture Probe Antenna	UL	60 GHz Probe	Copper	12/16/2014	12/16/2015

9. MEASUREMENT PROCEDURES

9.1. EQUATIONS

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)

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POWER DENSITY

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

The measured power is converted to Pt*Gt using the far-field Friis equation:

Pt*Gt = 32.44 + 20*Log(Distance/100) + Measured Power - Aperture Probe Gain + 20*Log(Frequency)

Where:

Pt*Gt is (dBm)
Distance is (cm)
Measured Power is (dBm)
Aperture Probe Gain is (dBi)
Frequency is (GHz)

Pt*Gt is converted to power density using

Power Density = (Pt*Gt) / [4 * π * $(\text{Distance})^2$]

Where:

Power Density is (mW/cm^2)
Pt*Gt is (mW)
Distance is (cm)

Pt*Gt is also converted to EIRP during the ON time of the burst using

EIRP = (Pt*Gt) + Duty Cycle Correction Factor

Where:

EIRP is (dBm)
Pt*Gt is (dBm)
Duty Cycle Correction Factor is (dB)

9.2. SETUP AND PROCEDURE

Optical-grade linear and rotation stages enable fine adjustments of X / Y / Z / Polarization, and are used to maintain a consistent and accurate placement of probe.

Absorber material 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 at a distance of 0.5 cm. The probe is scanned over X / Y / Polarization to maximize the emissions level.

The power is measured and recorded, then Pt*Gt, Power density and EIRP are calculated as described above.

The measurement distance is varied from 10 to 20 cm in 1-cm steps and the power and results of subsequent calculations are recorded for each distance.

The measurement distance is the distance from the surface of the enclosure of the laptop display to the probe antenna aperture. The antenna separation distance is the measurement distance plus the internal spacing between the antenna and the outside surface of the enclosure. Calculations of Pt*Gt, power density and EIRP are based on the antenna separation distance.

10. RESULTS

10.1. DUTY CYCLE

10.1.1. CALCULATIONS

Duty cycle is calculated as either [(ON Time)/Period] or {1-[(OFF 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 Correction Factor is calculated as 10 * Log (Duty Cycle).

10.1.2. EUT MEASUREMENTS

CH 1

Description	ON Time (ms)	Period (ms)	Duty Cycle (Linear)	Duty Cycle Correction (dB)
Duty Cycle within Burst	1.994	2.037	0.979	
Duty cycle over Burst Period	498.8	1000	0.499	
Duty Cycle			0.488	3.11

CH 2

Description	ON Time (ms)	Period (ms)	Duty Cycle (Linear)	Duty Cycle Correction (dB)
Duty Cycle within Burst	1.996	2.038	0.979	
Duty cycle over Burst Period	498.8	1001	0.498	
Duty Cycle			0.488	3.12

CH 3

Description	ON Time (ms)	Period (ms)	Duty Cycle (Linear)	Duty Cycle Correction (dB)
Duty Cycle within Burst	1.995	2.036	0.980	
Duty cycle over Burst Period	498.8	1001	0.498	
Duty Cycle			0.488	3.11

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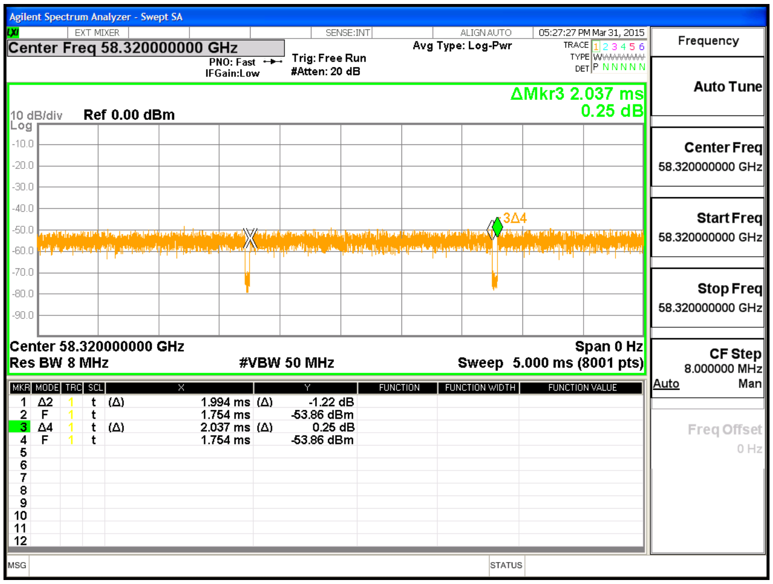
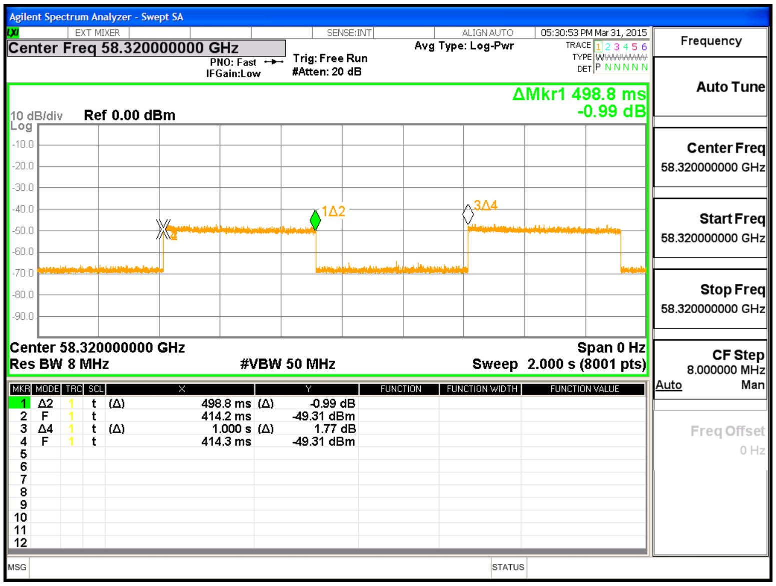
DUTY CYCLE PLOTS

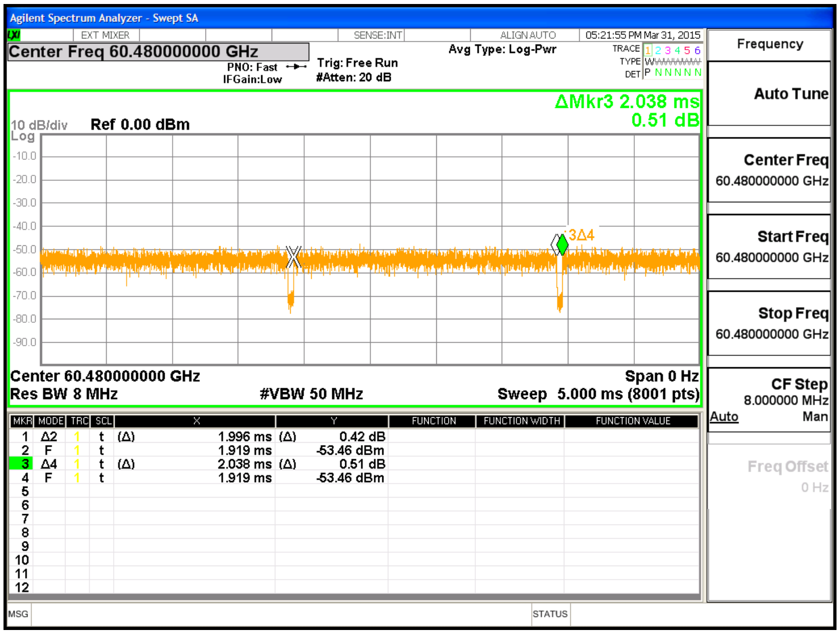
DUTY CYCLE WITHIN BURST CH1



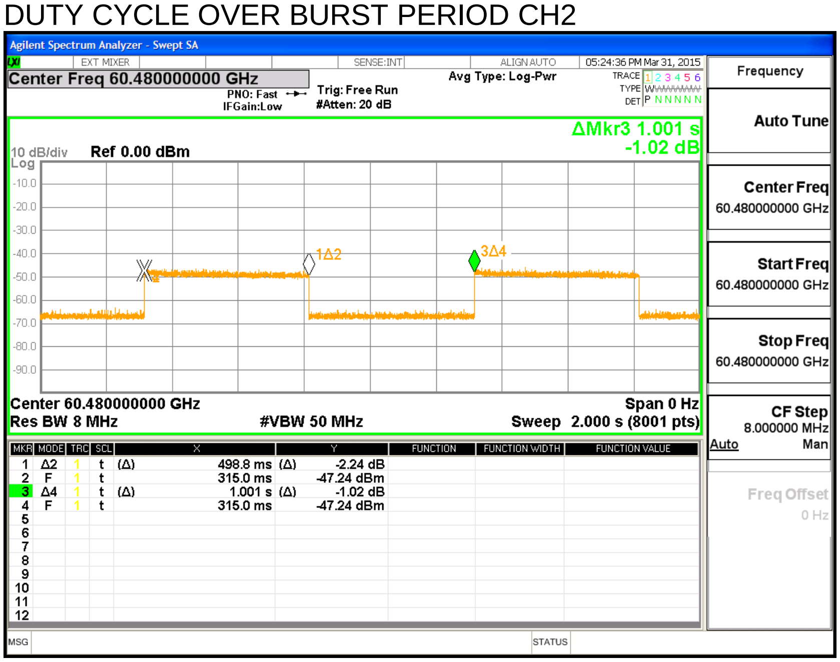
DUTY CYCLE OVER BURST PERIOD CH1



DUTY CYCLE WITHIN BURST CH2

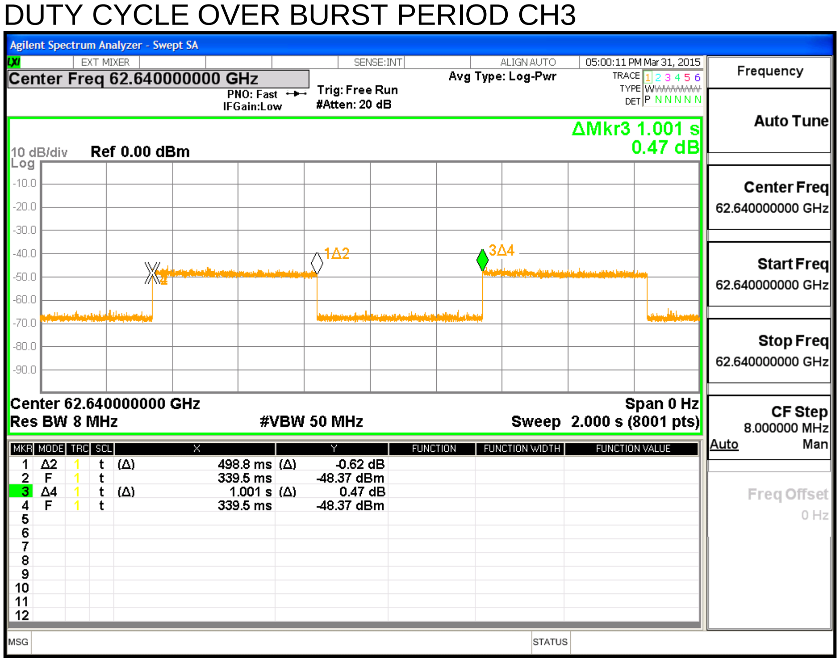


DUTY CYCLE OVER BURST PERIOD CH2



DUTY CYCLE WITHIN BURST CH3

DUTY CYCLE OVER BURST PERIOD CH3



10.1.3. POWER SENSOR CONSIDERATIONS

The averaging settings of the power meter / power sensor combination must be adjusted to respond properly to the modulation bursts and burst period.

The power sensor is connected to a microwave signal generator with a mm-wave source module extension. The output frequency of the generator is set to 60.48 GHz, corresponding to EUT channel 2. The generator is adjusted for pulse modulation using the nominal timing values for the Duty cycle across the Burst Period (500 msec ON, 1000 msec Period).

The power meter averaging number is then adjusted to provide a stable measurement (after the published settling time has elapsed).

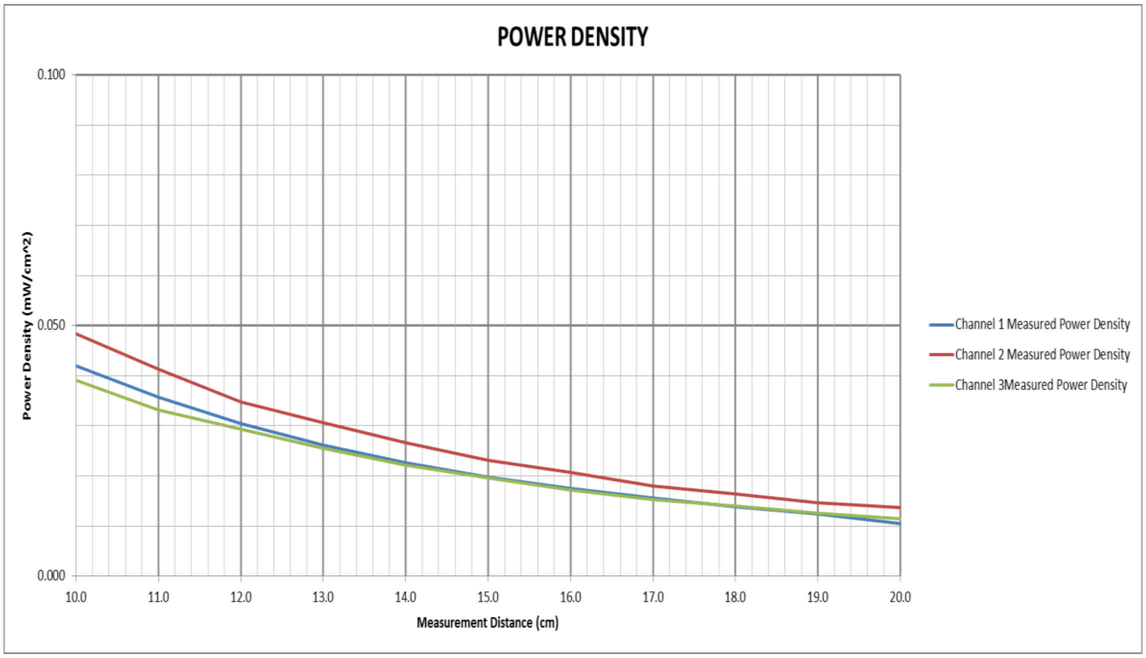
Pulse modulation is then turned off, the delta between Modulation OFF and ON is calculated, and compared to the expected value of 10 * Log (Nominal duty cycle across Burst period) = 3.00 dB.

Description	ON Time (ms)	Period (ms)	Duty Cycle (Linear)	Duty Cycle Correction (dB)
Nominal Duty Cycle across Burst Period	500	1000	0.50	3.00

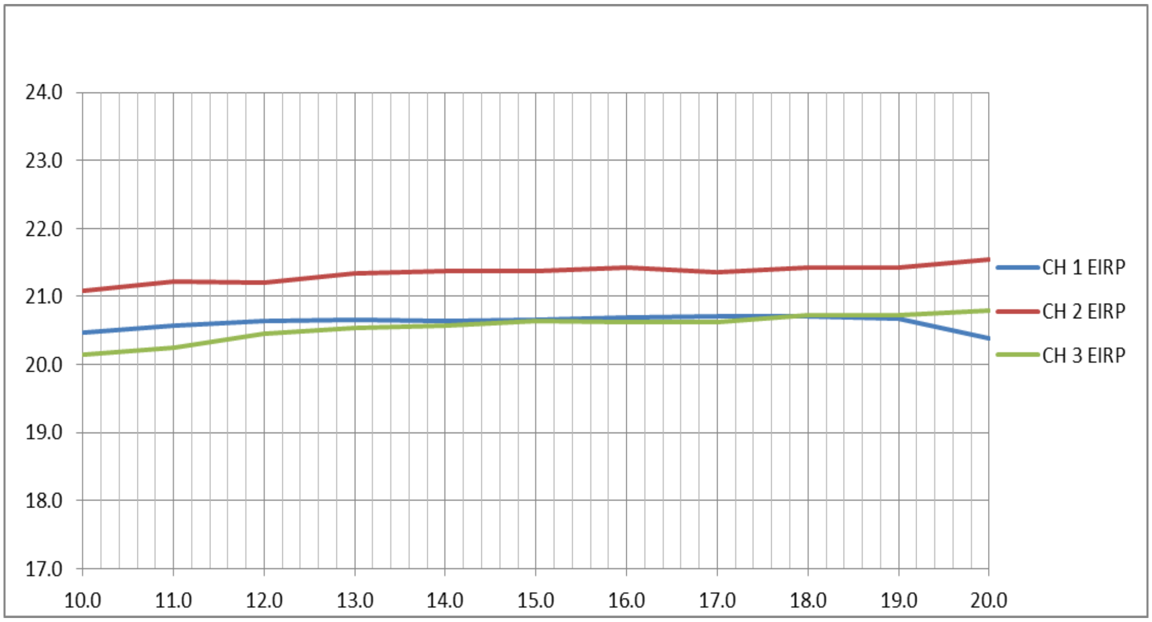
10.1.4. POWER SENSOR PULSE RESPONSE

An averaging number of 500 provided measurements stable to within approximately 0.1 dB for the EUT’s nominal pulse characteristics documented above. The V8486A-H01 power sensor showed a measured difference of 2.95 to 3.03 dB, between CW and modulated.

10.2. POWER DENSITY PLOTS



10.3. EIRP PLOTS



10.4. TABULAR RESULTS FOR CHANNEL 1

Frequency (GHz)	58.32
Probe Gain (dBi)	26.0
Antenna Offset inside platform (cm)	0.15
EUT Antenna Gain (dBi)	15.45
Duty Cycle Correction (dB)	3.11

Measurement Distance (cm)	Distance From Antenna (cm)	Meas Avg Power (dBm)	(Pt*Gt) (dBm)	(Pt*Gt) (mw)	Measured Power Density (mW/cm^2)	EIRP (dBm)	Conducted Output Power (dBm)
10.0	10.150	-4.53	17.4	54.4	0.042	20.5	5.0
11.0	11.150	-5.24	17.5	55.7	0.036	20.6	5.1
12.0	12.150	-5.92	17.5	56.6	0.031	20.6	5.2
13.0	13.150	-6.58	17.6	56.9	0.026	20.7	5.2
14.0	14.150	-7.23	17.5	56.7	0.023	20.6	5.2
15.0	15.150	-7.81	17.6	56.9	0.020	20.7	5.2
16.0	16.150	-8.34	17.6	57.2	0.017	20.7	5.2
17.0	17.150	-8.84	17.6	57.5	0.016	20.7	5.3
18.0	18.150	-9.34	17.6	57.4	0.014	20.7	5.3
19.0	19.150	-9.84	17.6	57.0	0.012	20.7	5.2
20.0	20.150	-10.57	17.3	53.3	0.010	20.4	4.9

10.5. TABULAR RESULTS FOR CHANNEL 2

Frequency (GHz)	60.48
Probe Gain (dBi)	25.8
Antenna Offset inside platform (cm)	0.15
EUT Antenna Gain (dBi)	15.45
Duty Cycle Correction (dB)	3.12

Measurement Distance (cm)	Distance From Antenna (cm)	Meas Avg Power (dBm)	(Pt*Gt) (dBm)	(Pt*Gt) (mw)	Measured Power Density (mW/cm^2)	EIRP (dBm)	Conducted Output Power (dBm)
10.0	10.150	-4.43	18.0	62.6	0.048	21.1	5.6
11.0	11.150	-5.12	18.1	64.5	0.041	21.2	5.8
12.0	12.150	-5.87	18.1	64.4	0.035	21.2	5.8
13.0	13.150	-6.42	18.2	66.5	0.031	21.3	5.9
14.0	14.150	-7.03	18.3	66.9	0.027	21.4	5.9
15.0	15.150	-7.63	18.2	66.8	0.023	21.4	5.9
16.0	16.150	-8.13	18.3	67.7	0.021	21.4	6.0
17.0	17.150	-8.71	18.2	66.8	0.018	21.4	5.9
18.0	18.150	-9.15	18.3	67.6	0.016	21.4	6.0
19.0	19.150	-9.61	18.3	67.7	0.015	21.4	6.0
20.0	20.150	-9.93	18.4	69.6	0.014	21.5	6.1

10.6. TABULAR RESULTS FOR CHANNEL 3

Frequency (GHz)	62.64
Probe Gain (dBi)	25.0
Antenna Offset inside platform (cm)	0.15
EUT Antenna Gain (dBi)	15.45
Duty Cycle Correction (dB)	3.11

Measurement Distance (cm)	Distance From Antenna (cm)	Meas Avg Power (dBm)	(Pt*Gt) (dBm)	(Pt*Gt) (mw)	Measured Power Density (mW/cm^2)	EIRP (dBm)	Conducted Output Power (dBm)
10.0	10.150	-6.46	17.0	50.6	0.039	20.2	4.7
11.0	11.150	-7.18	17.1	51.8	0.033	20.3	4.8
12.0	12.150	-7.72	17.3	54.3	0.029	20.5	5.0
13.0	13.150	-8.33	17.4	55.2	0.025	20.5	5.1
14.0	14.150	-8.93	17.5	55.7	0.022	20.6	5.1
15.0	15.150	-9.46	17.5	56.5	0.020	20.6	5.2
16.0	16.150	-10.02	17.5	56.5	0.017	20.6	5.2
17.0	17.150	-10.55	17.5	56.4	0.015	20.6	5.2
18.0	18.150	-10.93	17.6	57.8	0.014	20.7	5.3
19.0	19.150	-11.41	17.6	57.6	0.013	20.7	5.3
20.0	20.150	-11.78	17.7	58.6	0.011	20.8	5.3

11. APERTURE PROBE ANTENNA

11.1. DESCRIPTION OF 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 20 cm straight section of WR15 rectangular waveguide with a standard UG-385/U flange at one end.

Several improvements to the basic design have been made.

The aperture end is tapered to reduce diffraction and scattering.

An isolator is connected to the output of the probe to reduce reflections and improve matching.

A low noise amplifier (LNA) is connected to the output of the isolator to increase the system sensitivity.

A 16 cm long absorber sleeve is wrapped around the probe to minimize reflections, scattering and coupling. The placement of the absorber sleeve along the probe is optimized by varying the sleeve position upon setting up for the probe calibration. No difference in received power is observed as the sleeve is moved along the probe, as long as the end of the sleeve does not extend past the end of the probe. After the sleeve is extended beyond the probe tip, the power begins to drop. A repeatable sleeve position is established by aligning the end of the sleeve with the corner of the taper and the full-thickness portion of the rectangular waveguide.

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11.2. DERIVATION OF CALIBRATION EQUATIONS

The far-field gain of the Aperture Probe is measured in accordance with IEEE Std C95.3-2002, "IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz–300 GHz."

IEEE Std C95.3, Clause 5.5.1.1.2 Antenna gain determination, states that the power transmitted between a pair of antennas is measured in the far field then apply C95.3 Equation (2), excerpted as follows:

$G_T * G_R = (P_R / P_T) * (4 * \pi * d / \lambda)^2$

Converting to the log form yields:

$G_T + G_R = P_R - P_T + 20*\text{Log}(4 * \pi * d / \lambda)$

$G_T + G_R = P_R - P_T + 21.98 + 20*\text{Log}(d) - 20*\text{Log}(\lambda)$

Denoting distance by D rather than d, and converting from wavelength in meters to frequency in GHz yields:

$G_T + G_R = P_R - P_T + 21.98 + 20*\text{Log}(D) - 20*\text{Log}(0.3 / f)$

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

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Although a single path loss measurement of (P_R - P_T) is insufficient to solve for two unknowns G_T and G_R, the individual far-field gain of each of three different antennas is 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.

Equation (1) is applied to each of the three path loss measurements as follows:

$(G_1 + G_2) = (P_{R12} - P_T) + 32.44 + 20*Log (D) + 20*Log (f)$ Equation (2)

$(G_1 + G_3) = (P_{R13} - P_T) + 32.44 + 20*Log (D) + 20*Log (f)$ Equation (3)

$(G_2 + G_3) = (P_{R23} - P_T) + 32.44 + 20*Log (D) + 20*Log (f)$ Equation (4)

Where

$(G_1 + G_2)$ is the sum of the gains of Antennas 1 and 2
$(G_1 + G_3)$ is the sum of the gains of Antennas 1 and 3
$(G_2 + G_3)$ 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 power transmitted (dBm)
D is the distance between the antennas (m)
f is the frequency (GHz)

The gain of each individual antenna is calculated as follows:

$G_1 = [(G_1 + G_2) + (G_1 + G_3) - (G_2 + G_3)] / 2$ Equation (5)

$G_2 = [(G_1 + G_2) + (G_2 + G_3) - (G_1 + G_3)] / 2$ Equation (6)

$G_3 = [(G_1 + G_3) + (G_2 + G_3) - (G_1 + G_2)] / 2$ Equation (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)
$(G_1 + G_2)$ is the result of applying Equation (2)
$(G_1 + G_3)$ is the result of applying Equation (3)
$(G_2 + G_3)$ is the result of applying Equation (4)

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11.3. CALIBRATION 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).

11.4. CALIBRATION RESULTS

11.4.1. FAR-FIELD DISTANCE

IEEE Std C95.3 Clause 5.5.1.1.2 Figure 5 gives the estimated gain reduction (relative to the far-field gain G_∞) of an antenna 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. IEEE Std C95.3 further states that the far-field gain holds for distances greater than about $(8a^2)/\lambda$ ($n > 8$).

For WR15 waveguide, a = 0.0038 m

For Channel 1 (58.32 GHz), λ = 0.0051 m, thus a^2/λ = 0.0028 m

For Channel 2 (60.48 GHz), λ = 0.0050 m, thus a^2/λ = 0.0029 m

For Channel 3 (62.64 GHz), λ = 0.0048 m, thus a^2/λ = 0.0030 m

The probe is calibrated in the far field at a 0.1 m distance, corresponding to normalized distances as follows:

$(35.6a^2)/\lambda$ ($n > 35$) for 58.32 GHz

$(34.5a^2)/\lambda$ ($n > 34$) for 60.48 GHz

$(33.3a^2)/\lambda$ ($n > 33$) for 62.64 GHz

The selected calibration distance of 0.1 m is greater than the minimum distance indicated by IEEE Std C95.3.

11.4.2. STANDALONE PROBE

		Distance (m) --->	0.1
Channel	Freq (GHz)	Power Tx (dBm)	Free Space Path Loss = 32.44 + 20*Log (D) + 20*Log (f) (dB)
1	58.32	11.62	47.76
2	60.48	11.65	48.07
3	62.64	12.29	48.38

Channel	Freq (GHz)	Tx Antenna	Rx Antenna	Power Rx (dBm)	Pr Minus Pt (dB)	Gain of Pair ([dBi]^2)
1	58.32	Probe Under Cal	Brass Probe 1	-24.16	-35.78	11.98
2	60.48	Probe Under Cal	Brass Probe 1	-23.68	-35.33	12.74
3	62.64	Probe Under Cal	Brass Probe 1	-25.06	-37.35	11.03
1	58.32	Brass Probe 2	Brass Probe 1	-24.55	-36.17	11.59
2	60.48	Brass Probe 2	Brass Probe 1	-24.22	-35.87	12.20
3	62.64	Brass Probe 2	Brass Probe 1	-24.47	-36.76	11.62
1	58.32	Brass Probe 2	Probe Under Cal	-23.96	-35.58	12.18
2	60.48	Brass Probe 2	Probe Under Cal	-23.45	-35.1	12.97
3	62.64	Brass Probe 2	Probe Under Cal	-24.61	-36.9	11.48

Channel	Freq (GHz)	Antenna	Gain (dBi)
1	58.32	Probe Under Cal	6.28
2	60.48	Probe Under Cal	6.76
3	62.64	Probe Under Cal	5.44
1	58.32	Brass Probe 1	5.69
2	60.48	Brass Probe 1	5.99
3	62.64	Brass Probe 1	5.58
1	58.32	Brass Probe 2	5.89
2	60.48	Brass Probe 2	6.22
3	62.64	Brass Probe 2	6.03

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11.4.3. PROBE/ISOLATOR/LNA ASSEMBLY

The aperture probe antenna is configured as a receive-only antenna assembly consisting of the WR15 Aperture Probe, Isolator, LNA and Absorber Sleeve.

Channel	Freq (GHz)	Power Tx (dBm)	Distance (m) ---> 0.1 Free Space Path Loss = 32.44 + 20*Log (D) + 20*Log (f) (dB)
1	58.32	10.39	47.76
2	60.48	10.52	48.07
3	62.64	11.11	48.38

Channel	Freq (GHz)	Tx Antenna	Rx Antenna	Power Rx (dBm)	Pr Minus Pt (dB)	Gain of Pair ([dBi]^2)
1	58.32	Brass Probe 1	Brass Probe 2	-25.6	-35.99	11.77
2	60.48	Brass Probe 1	Brass Probe 2	-25.84	-36.36	11.71
3	62.64	Brass Probe 1	Brass Probe 2	-25.45	-36.56	11.82
1	58.32	Brass Probe 1	Probe Under Cal	-5.41	-15.8	31.96
2	60.48	Brass Probe 1	Probe Under Cal	-6.01	-16.53	31.54
3	62.64	Brass Probe 1	Probe Under Cal	-6.75	-17.86	30.52
1	58.32	Brass Probe 2	Probe Under Cal	-5.46	-15.85	31.91
2	60.48	Brass Probe 2	Probe Under Cal	-5.72	-16.24	31.83
3	62.64	Brass Probe 2	Probe Under Cal	-6.01	-17.12	31.26

Channel	Freq (GHz)	Antenna	Gain (dBi)	Isolator/LNA Gain (dB)	Effective Gain of Probe (dBi)
1	58.32	Probe Under Cal	26.05	17.78	8.27
2	60.48	Probe Under Cal	25.83	17.78	8.05
3	62.64	Probe Under Cal	24.98	17.45	7.53
1	58.32	Brass Probe 1	5.91		
2	60.48	Brass Probe 1	5.71		
3	62.64	Brass Probe 1	5.54		
1	58.32	Brass Probe 2	5.86		
2	60.48	Brass Probe 2	6.00		
3	62.64	Brass Probe 2	6.28		

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11.5. VALIDATION OF EQUATIONS AND DESIGN CHANGE

11.5.1. VALIDATION OF EQUATIONS

The measured gain of the original probe antenna is compared to the realized gain from a theoretical model of an open ended V-band rectangular waveguide provided by Zhong Chen of ETS-Lindgren.

Frequency (GHz)	Measured Gain Standalone Probe (dBi)	Theoretical Model Gain Standalone Probe (dBi)	Delta to Model (dB)
58.32	6.3	6.1	0.2
60.48	6.8	6.3	0.5
62.64	5.4	6.5	-1.1
Average Delta to Model (dB)			-0.1

11.5.2. VALIDATION OF DESIGN CHANGE

The effectiveness of the isolator is validated by comparing the gain measured with and without the isolator. Since the received power increases when reflections are reduced and matching is improved, an increase in the measured antenna gain indicates that the isolator is effective.

Frequency (GHz)	Effective Gain of Probe (Less Isolator & LNA) (dBi)	Measured Gain of Standalone Probe (dB)	Gain Increase (dB)
58.32	8.3	6.3	2.0
60.48	8.1	6.8	1.3
62.64	7.5	5.4	2.1
Average Gain Increase (dB)			1.8

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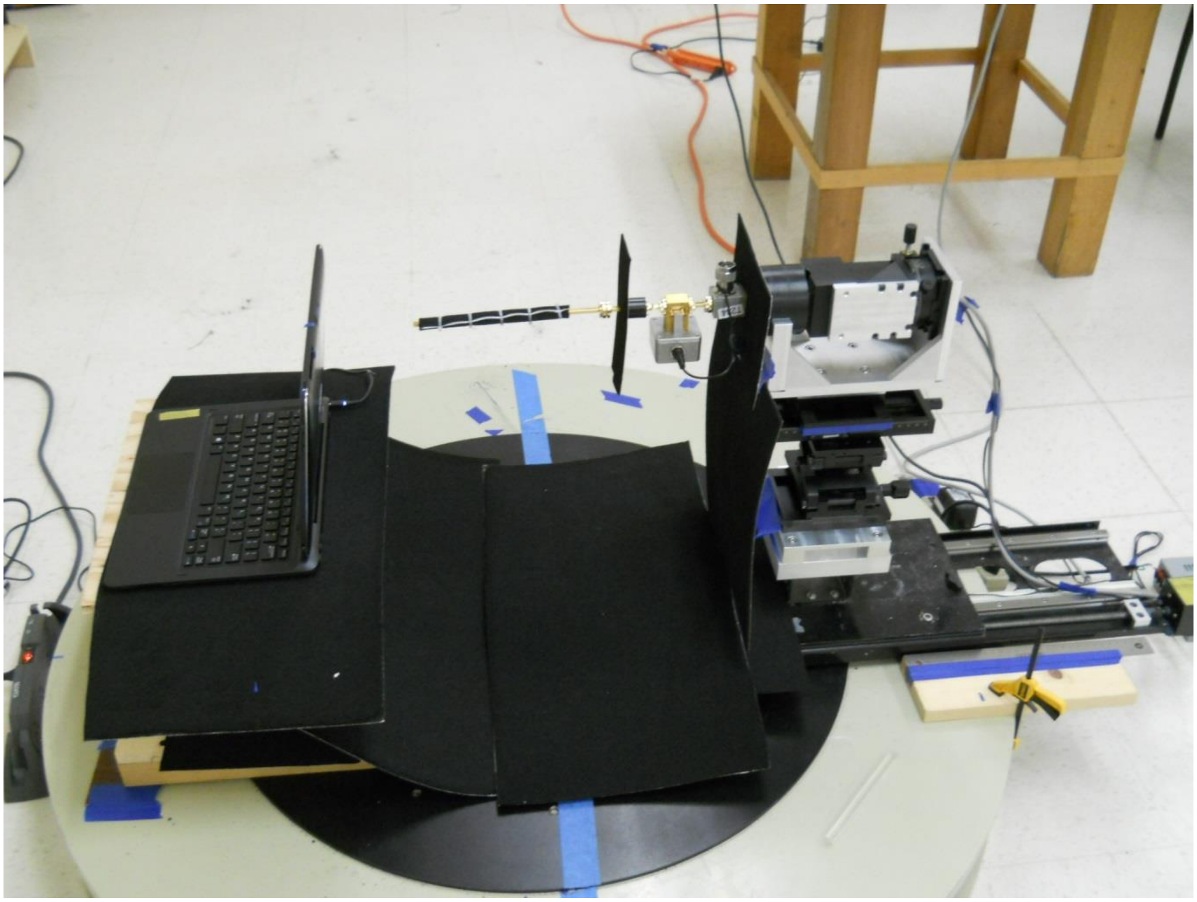
12. SETUP PHOTO



END OF REPORT