POWER DENSITY EVALUATION REPORT

FCC 47 CFR § 2.1093

For
Car Mounted Device

FCC ID: 2AZKTRADE8C
Model Name: RADE8C

Report Number: 14841575-S1V1
Issue Date: 11/8/2023

Prepared for
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CERT #0751.05

REVISION HISTORY

Rev.	Date	Revisions	Revised By
V1	11/8/2023	Initial Issue	--

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1. Attestation of Test Results

Applicant Name	Waymo	
FCC ID	2AZKTRADE8C	
Model Name	RADE8C	
Applicable Standards	FCC 47 CFR § 2.1093	
Exposure Category	Radiofrequency (RF) Radiation Exposure (above 6GHz)	
	Uncontrolled (mW/cm^2 over 4 cm^2) 30 min average	Occupational/controlled (mW/cm^2 over 4 cm^2) 6 min average
	1.0	5
Applicable limit	☒ Uncontrolled / ☐ Occupational/controlled	
PD Result (mW/cm^2 over $4cm^2$)	0.195	
Date Tested	10/31/2023	
Test Results	Pass	

UL Verification Services Inc. tested the above equipment in accordance with the requirements set forth in the above standards. The test results show that the equipment tested can demonstrate compliance with the requirements as documented in this report.

This report contains data provided by the customer which can impact the validity of results. UL Verification Services Inc. is only responsible for the validity of results after the integration of the data provided by the customer.

The results documented in this report apply only to the tested sample, under the conditions and modes of operation as described herein. It is the manufacturer's responsibility to assure that additional production units of this model are manufactured with identical electrical and mechanical components. All samples tested were in good operating condition throughout the entire test program. Measurement Uncertainties are published for informational purposes only and were not considered unless noted otherwise.

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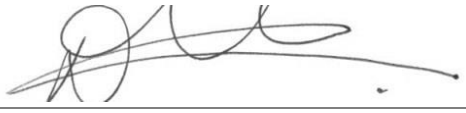
Approved & Released By:	Prepared By:
	
Dave Weaver Senior Staff Engineer UL Verification Services Inc.	Christopher Kuwatani Laboratory Engineer UL Verification Services Inc.

2. Test Specification, Methods and Procedures

The tests documented in this report were performed in accordance with FCC 47 CFR § 2.1093, the following FCC Published RF exposure KDB procedures:

- 447498 D01 General RF Exposure Guidance v06
- 865664 D02 RF Exposure Reporting v01r02
- SPEAG DASY 6System Handbook; part 4 cDASY6 Module mmWave
- SPEAG, DASY8 Application Note: SAR, APD & PD at 6 – 10 GHz (Version 5), April 2022
- IEC TR 63170: 2018

In addition to the above, TCB workshop information was used.

- TCB workshop November, 2017; RF Exposure Procedures (Power Density Evaluation)
- TCB workshop October, 2018; RF Exposure Procedures (Millimeter Wave Assessment)
- TCB workshop April, 2019; RF Exposure Procedures (Millimeter Wave RF Exposure Evaluation)
- TCB workshop November, 2019; RF Exposure Procedures (Millimeter Wave Scan Requirements)
- TCB workshop October 2022; RF Exposure Policies and Procedures (f-above-6 GHz Portable Devices)

3. Facilities and Accreditation

The test sites and measurement facilities used to collect data are located at

47266 Benicia Street
SAR Lab D

UL Verification Services Inc. is accredited by A2LA, Certificate Number 0751.05

The Test Lab Conformity Assessment Body Identifier (CABID)

Location	CABID	Company Number
47173 Benicia Street, Fremont, CA, 94538 UNITED STATES	US0104	2324A
47266 Benicia Street, Fremont, CA, 94538 UNITED STATES		

4. Measurement System & Test Equipment

4.1. EUmmWVx / E-Field 5G Probe

E-Field mm-Wave Probe for General Near-Field Measurements

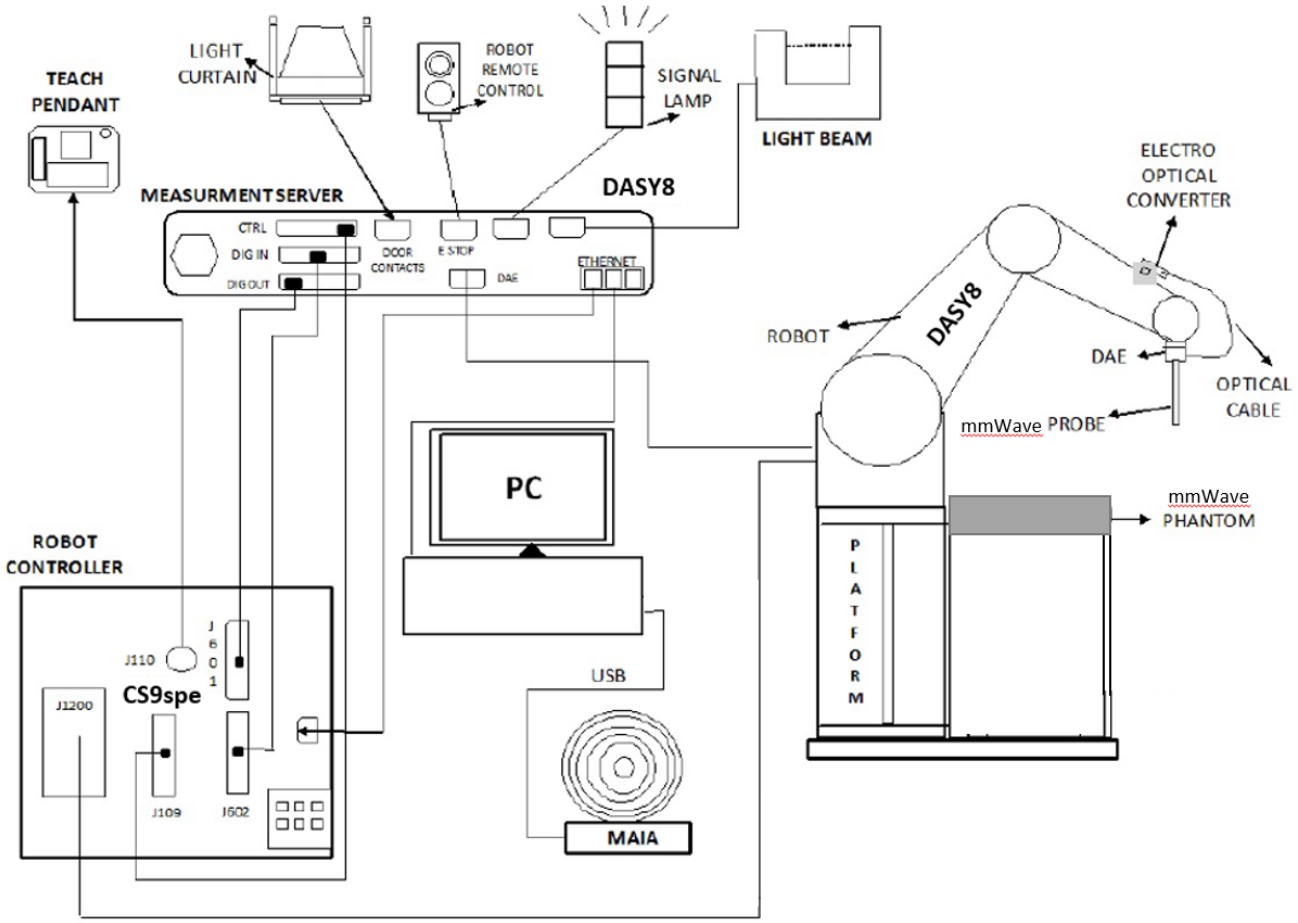
	Two dipoles optimally arranged to obtain pseudo-vector information Minimum 3 measurements/point, 120º rotated around probe axis Sensors (0.8mm length) printed on glass substrate protected by high density foam Low perturbation of the measured field Requires positioner which can do accurate probe rotation
Frequency Range	6G Hz – 110 GHz (EUmmWV2)
Dynamic Range	< 20 V/m - 10'000 V/m with PRE-10 (min < 50 V/m - 3000 V/m)
Position Precision	< 0.2 mm (DASY8)
Dimensions	Overall length: 337 mm (tip: 20 mm) Tip diameter: encapsulation 8 mm (internal sensor < 1mm) Distance from probe tip to dipole centers: < 2 mm Sensor displacement to probe's calibration point: < 0.3 mm
Applications	E-field measurements of 5G devices and other mm-wave transmitters operating above 6GHz in < 2 mm distance from device (free-space) Power density, H-field and far-field analysis using total field reconstruction (DASY8 Module mmWave)
Compatibility	DASY8 Module mmWave V3.2.0.1840

4.2. Data Acquisition Electronics(DAE)

	Serial optical link for communication with DASY embedded system (fully remote controlled) Two-step probe touch detector for mechanical surface detection and emergency robsot stop
Measurement Range	−100 – +300 mV (16 bit resolution and two range settings: 4 mV, 400 mV)
Input Offset Voltage	<5 µV (with auto zero)
Input Resistance	200 Mohm
Input Bias Current	<50 fA
Battery Power	>10 hours of operation (with two 9.6 V NiMH batteries)
Dimensions (L × W × H)	60 × 60 × 68 mm

4.3. Measurement System

The DASY8 system used for performing compliance tests consists of the following items:



- A standard high precision 6-axis robot with controller, teach pendant and software. An arm extension for accommodating the data acquisition electronics (DAE).
- The EUmmWVx probe is based on the pseudo-vector probe design, which not only measures the field magnitude but also derives its polarization ellipse.
- A data acquisition electronics (DAE) which performs the signal amplification, signal multiplexing, AD-conversion, offset measurements, mechanical surface detection, collision detection, etc. The unit is battery powered with standard or rechargeable batteries. The signal is optically transmitted to the EOC.
- The Electro-optical converter (EOC) performs the conversion from optical to electrical signals for the digital communication to the DAE. To use optical surface detection, a special version of the EOC is required. The EOC signal is transmitted to the measurement server.
- The function of the measurement server is to perform the time critical tasks such as signal filtering, control of the robot operation and fast movement interrupts.
- The Light Beam used is for probe alignment. This improves the (absolute) accuracy of the probe positioning.
- A computer running Win10 and the DASY8[1] software.
- Remote control and teach pendant as well as additional circuitry for robot safety such as warning lamps, etc.
- The phantom which is specialized for 5G other accessories according to the targeted measurement.

[1] DASY8 software used: DASY 8 mmWave V3.2.0.1840 and older generations.

4.4. Measurement Procedures

4.2.1. System Verification Scan Procedures

DASY8_Module mmWave supports “5G Scan”, a fine resolution scan performed on two different planes which is used to reconstruct the E- and H-fields as well as the power density; the average power density is derived from this measurement.

Step 1: Power Reference Measurement
The Power Reference Measurement and Power Drift Measurements are for monitoring the power drift of the device under test in the batch process. The minimum distance of probe sensors to surface determines the closest measurement point to devise under test.

Step 2: 5G Scan
The steps in the X, Y, and Z directions are specified in terms of fractions of the signal wavelength, lambda. Area Scan Parameters extracted from SPEAG DASY 8 System Handbook; part 4 DASY8 Module mmWave.

Recommended settings for measurement of verification sources

Frequency [GHz]	Grid step	Grid extent X/Y [mm]	Measurement points
10	0.125 $\left(\frac{\lambda}{8}\right)$	60/60	18×18
30	0.25 $\left(\frac{\lambda}{4}\right)$	60/60	26×26
45	0.25 $\left(\frac{\lambda}{4}\right)$	42/42	28×28
60	0.25 $\left(\frac{\lambda}{4}\right)$	32.5/32.5	28×28
90	0.25 $\left(\frac{\lambda}{4}\right)$	30/30	38×38

The minimum distance of probe sensors to the verification source surface, horn antenna, is 10 mm for 10 GHz and 5.55mm for 30 GHz and above.

Step 3: Power drift measurement

The Power Drift Measurement measures the field at the same location as the most recent power reference measurement within the same procedure, and with the same settings. The Power Drift Measurement gives the field difference in dB from the reading conducted within the last Power Reference Measurement. This allows a user to monitor the power drift of the device under test within a batch process. The measurement procedure is the same as Step 1.
When the drift is larger than ± 5 %, test is repeated from step1.

4.2.2. Scan Procedures

Step 1: Power Reference Measurement
Same as System Verification Scan Procedures step 1.

Step 2: 5G Scan
Same as System Verification Scan Procedures step 2. But measurement area is defined based on TCB work shop April 2019, “A sufficiently large measurement region and proper measurement spatial resolution are required to maintain field reconstruction accuracy”.
–Fields at the measurement region boundary should be ~20-30 dB below the peaks

Step 3: Power drift measurement
Same as System Verification Scan Procedures step 3.
When the drift is smaller than ± 5 %, it is considered in the uncertainty budget if drifts larger than 5%, uncertainty is re-calculated.

4.5. Test Equipment

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

Lab Equipment

Name of Equipment	Manufacturer	Type/Model	Serial No.	Cal. Date	Cal. Due Date
E-Field Probe (SAR Lab D)	SPEAG	EUmmWV4	9589	9/5/2023	9/5/2024
Data Acquisition Electronics	SPEAG	DAE4	1239	3/16/2023	3/16/2024
System Validation Dipole	SPEAG	5G Vefification Source 60GHz	1003	9/5/2023	9/5/2024

Note(s):

*Equipment not used past calibration due date.

5. Measurement Uncertainty

a		b	c	d f(d,k)	e	f = b×*e/d*	g
Error Description		Unc.Value (±dB)	Probab. Distri.	Div.	*ci*	Std. Unc. (±dB)	vi
Uncertainty terms dependent on the measurement system							
CAL	Calibration Repeatability	0.49	Normal	1	1	0.49	∞
COR	Probe correction	0	Rectangular	1.732	1	0.00	∞
FRS	Frequency response (BW 1 GHz)	0.20	Rectangular	1.732	1	0.12	∞
SCC	Sensor cross coupling	0	Rectangular	1.732	1	0.00	∞
ISO	Isotropy	0.50	Rectangular	1.732	1	0.29	∞
LIN	Linearity	0.20	Rectangular	1.732	1	0.12	∞
PSC	Probe scattering	0	Rectangular	1.732	1	0.00	∞
PPO	Probe positioning o set	0.30	Rectangular	1.732	1	0.17	∞
PPR	Probe positioning repeatability	0.04	Rectangular	1.732	1	0.02	∞
SMO	Sensor mechanical o set	0	Rectangular	1.732	1	0.00	∞
PSR	Probe spatial resolution	0	Rectangular	1.732	1	0.00	∞
FLD	Field impedance dependance	0	Rectangular	1.732	1	0.00	∞
APD	Amplitude and phase drift	0	Rectangular	1.732	1	0.00	∞
APN	Amplitude and phase noise	0.04	Rectangular	1.732	1	0.02	∞
TR	Measurement area truncation	0	Rectangular	1.732	1	0.00	∞
DAQ	Data acquisition	0.03	Normal	1	1	0.03	∞
SMP	Sampling	0	Rectangular	1.732	1	0.00	∞
REC	Field reconstruction	0.60	Rectangular	1.732	1	0.35	∞
TRA	Forward transformation	0	Rectangular	1.732	1	0.00	∞
SCA	Power density scaling	-	Rectangular	1.732	1	-	∞
SAV	Spatial averaging	0.10	Rectangular	1.732	1	0.06	∞
SDL	System detection limit	0.04	Rectangular	1.732	1	0.02	∞
Uncertainty terms dependent on the DUT and environmental factors							
PC	Probe coupling with DUT	0	Rectangular	1.732	1	0	∞
MOD	Modulation response	0.40	Rectangular	1.732	1	0.23	∞
IT	Integration time	0	Rectangular	1.732	1	0	∞
RT	Response time	0	Rectangular	1.732	1	0	∞
DH	Device holder influence	0.10	Rectangular	1.732	1	0.06	∞
DAQ	DUT alignment	0	Rectangular	1.732	1	0	∞
AC	RF ambient conditions	0.04	Rectangular	1.732	1	0.02	∞
AR	Ambient reflections	0.04	Rectangular	1.732	1	0.02	∞
MSI	Immunity / secondary reception	0	Rectangular	1.732	1	0	∞
DRI	Drift of the DUT	0.21	Rectangular	1.732	1	0.12	∞
Combined Standard Uncertainty Uc(f) =			RSS			0.76	∞
Expanded Uncertainty U, Coverage Factor = 2, > 95 % Confidence =						1.52	

6. Device Under Test (DUT) Information

Device Dimension	Overall (Length x Width x Height): 201 mm x 73 mm x 127 mm This is a car-mounted device.
Test sample information	**S/N** **Notes** WNT012311000445
Hardware Version	N/A
Software Version	cl@549997726

7. RF Exposure Conditions (Test Configurations)

7.1. DUT description

The EUT is a radar sensor, operating in 76 - 81 GHz band, with a digital beam-forming scanning antenna. Four modes in FMCW modulation of each range for operation are available as shown.

Mode	Frequency Band (GHz)
LRES W6	79.036 – 80.978
LRES W4	79.036 – 80.978
MRES	79.046 – 80.968
HRES	79.044 – 80.950

7.2. Maximum Output Power

Mode	Max. Avg EIRP (dBm)	Max. Peak EIRP (dBm)
LRES W6	33.10	34.98
LRES W4	33.39	36.67
MRES	32.85	41.25
HRES	33.45	43.98

Taken from UL report 14841575-E1

7.3. Antenna Description

The EUT uses four sets of integral patch antenna arrays. A single antenna array has 16 dBi gain and its dimension is 25 mm x 2 mm x 1 mm. During operation, the fundamental emissions are sequentially radiating from each antenna array.

7.4. Modulation

Modulation is FMCW and parameters are as follows:

Mode	Chirp Width (MHz)	Waveform Chirp Sweep Time (us)
LRES W6	90	31.4
LRES W4	90	29.4
MRES	361	29.4
HRES	615	29.4

Taken from UL report 14841575-E1

7.5. Test Rationale

Maximum power is achieved with HRES mode. As a result power density measurements were performed in this mode directly above the radiating structures. Testing was performed at 10 cm separation distance. Limitations on the test system measurement height prevented testing at 20 cm.

8. System Performance Check

Per Nov 2017,TCB Workshop

System validation is required before a system is deployed for measurement.

System check is also required before each series of continuous measurement and, as applicable, repeated at least weekly.

Peak and spatially averaged power density at the peak location(s) must be compared to calibrated results according to the defined test conditions

- the same spatial resolution and measurement region used in the waveguide calibration should be applied to system validation and system check.
- 1 cm^2 and 4 cm^2 spatial averaging have been recommended in the AHG10 draft TR with reference targets available for specific waveguide.
- power density distribution should also be verified, both spatially (shape) and numerically (level) through visual inspection for noticeable differences.
- the measured results should be within 10% of the calibrated targets.

The system components, software settings and other system parameters shall be the same as those used for the compliance tests. The system check shall be performed at the closest probe calibration frequency point as in the compliance tests, e.g., if the EUT operates at 80 GHz, it is recommended to perform the validation at 60 GHz.

Frequency (GHz)	5G Probe SN	DAE SN	5G Verification Source SN	Source Cal. Due Data	Measured psPDn (W/m²) over 4cm²	Target psPDn (W/m²) over 4cm²	Deviation (dB)	Delta ±10 %	Measured psPDtot (W/m²) over 4cm²	Target psPDtot (W/m²) over 4cm²	Deviation (dB)	Delta ±10 %	Measured psPDmod (W/m²) over 4cm²	Target psPDmod (W/m²) over 4cm²	Deviation (dB)	Delta ±10 %	Plot
60	9589	1239	1003	9/5/2024	239.0	232.5	0.12	3%	242.0	236.3	0.10	2%	243.0	237.3	0.10	2%	1

Note(s):

Input power,20dBm, is same as calibration data.

9. Measured and Reported (Scaled) Results

Per TCB workshop October 2018, 4 cm^2 averaging area is considered.

9.1. 80 GHz Test Result

Signal Type	Channel	Freq. (MHz)	Dist (mm)	DUT Surface	4cm² Normal psPD (W/m²)	4cm² Mod psPD (W/m²)	4cm² Total psPD (W/m²)	4cm² Normal psPD (mW/cm²)	4cm² Mod psPD (mW/cm²)	4cm² Total psPD (mW/cm²)	Plot No.
CW	Mid	80649.0	100	Edge Top	1.95	1.97	1.95	0.195	0.197	**0.195**	1

Note(s):

Appendixes

Refer to separated files for the following appendixes.

Appendix A: Setup Photos

Appendix B: System Check Plots

Appendix C: Highest PD Test Plots

Appendix D: Probe Certificates

Appendix E: Verification source Certificates

END OF REPORT