

# EPC eGaN® FETs Automotive Qualification Report EPC2219



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*This report summarizes the Product Qualification results for EPC part numbers EPC2219 which meets all required AEC-Q101 requirements and is released for production.*

## Scope

The testing matrix in this report covers the qualification of EPC2219 in accordance with the component level AEC-Q101 Rev D1 requirements. For all tests other than ESD, EPC2219 is qualified by matrix with in-family automotive products EPC2214, EPC2206, EPC2202, EPC2203 and EPC2212. Automotive devices within this family are compared in the table below.

EPC2219 uses identically the same epitaxy, process flow and device construction as EPC2202 and EPC2203. However, the overall gate width of EPC2219 is 30x smaller than EPC2203, and 140x smaller than EPC2202. Furthermore, the critical gate-drain spacing of EPC2219 is more relaxed, and the peak voltage rating (65V) is also more conservative, than all the other in-family products. For these reasons, we assert that EPC2219 AEC qualification is fully covered by matrix with the full 80V/100V automotive family of eGaN FETs.

Part Number	Max $V_{DS}$ (V)	Max $V_{GS}$ (V)	$R_{DS(on)}$ (mΩ)	Die Size (mm x mm)	Maximum Operating Temperature (°C)
EPC2206	80	6	2.2	XL (6.05 x 2.30)	150
EPC2212	100	6	13.5	M (2.11 x 1.63)	150
EPC2202	80	5.75	17	M (2.11 x 1.63)	150
EPC2214	80	6	20	S (1.35 x 1.35)	150
EPC2203	80	5.75	80	S (0.95 x 0.95)	150
EPC2219	65	5.75	3300	S (0.9 x 0.9)	150

## Qualification Test Overview

EPC's EPC2219, EPC2214, EPC2206, EPC2202, EPC2203 and EPC2212 eGaN FETs were subjected to a wide variety of stress tests following the specifications of AEC-Q101 (Rev D1) developed for silicon-based power MOSFETs. These tests include:

- Preconditioning: Parts undergo the following steps in sequence: (1) 125°C bake for a minimum of 24 hours; (2) Moisture Sensitivity Level 1 (MSL1); (3) 3 times reflow.
- Parametric Verification: Device parameters are measured at -40°C, 25°C, and 150°C to ensure compliance with datasheet limits over the entire temperature range.
- Electrostatic Discharge (ESD) Characterization: Parts are tested under both Human Body Model (HBM) and Charged Device Model (CDM) to assess device susceptibility to electrostatic discharge events.
- High temperature reverse bias (HTRB): Parts are subjected to a drain-source voltage at the maximum rated temperature and maximum rated voltage.
- High temperature gate bias (HTGB): Parts are subjected to a gate-source voltage at the maximum rated temperature and maximum rated gate voltage.
- Unbiased highly accelerated test (uHAST): Parts are soaked for 96 hours at 130°C, 85% humidity, and vapor pressure 33.3 psia.
- Temperature cycling (TC): Parts are subjected to alternating high and low temperature extremes from -55°C to 150°C for a total of 1000 cycles.
- High temperature high humidity reverse bias (H3TRB): Parts are subjected to 1000 hours of 85°C, 85% humidity with the drain biased at 80% of maximum rating.
- Moisture sensitivity level 1 (MSL1): Parts are subjected to moisture, temperature, and three cycles of reflow. MSL1 is the most stringent of the moisture sensitivity levels, requiring 85°C and 85% humidity for 168 hours.
- Intermittent Operating Life (IOL): Parts are temperature cycled with short period and device heating through internal electrical power dissipation.
- Destructive Physical Analysis: Parts are delayered and physically analyzed looking for defects resulting from stress testing.

All devices put on test as part of this qualification underwent external visual inspection prior to test. This microscope inspection checks for physical damage to the chip-scale package, such as edge chipping or cracks, that may have resulted from assembly or transit. Damaged parts are removed from the test population.

For all qualification tests, the stability of the devices is verified with DC electrical tests before and after stress. In many cases, interim readouts are also performed. Electrical parameters are measured at room temperature. The parameters include: gate-source threshold voltage ( $V_{TH}$ ), on-state resistance  $R_{DS(on)}$ , off-state drain leakage ( $I_{DSS}$ ), and gate leakage ( $I_{GSS}$ ). For  $V_{TH}$  and  $R_{DS(on)}$ , a failure is recorded when either of the following occurs: (1) the measurement exceeds the datasheet specifications; or (2) the measurement has changed by more than 20% of its initial value. For  $I_{DSS}$  and  $I_{GSS}$ , a failure is recorded if the measurement exceeds datasheet limit, or if it has increased by more than 5x during test. All testing requirements and specifications for AEC-Q101 (Rev D1) were followed.

For certain qualification tests, parts were mounted onto FR5 (high Tg FR4) or polyimide PCB adaptor cards. These cards simplify the process of post-screening and electrically stressing the parts. Adaptor cards (1.6 mm in thickness) with two copper layers were used. The top copper layer was 1 oz. or 2 oz., and the bottom copper layer was 1 oz. Kester NXG1 type 3 SAC305 solder no clean flux was used in mounting the part onto an adaptor card. After assembly, parts were either baked or flux-cleaned.

For other qualifications tests, including MSL1 and TC, parts were not mounted to adaptor cards. Electrical tests were performed using probe needles touching the solder pads of the bare die.

While the AEC-Q101 standard was developed for silicon devices, many of the environmental reliability tests apply directly to EPC’s eGaN FETs for the following reasons:

- 1) eGaN devices consist of a very thin film of GaN/AlGaN grown on a standard silicon substrate. Thermo-mechanically, they behave the same as a standard silicon die.
- 2) eGaN devices are fabricated using mostly standard processes in a silicon CMOS foundry. These include internal metal layers, dielectric layers, vias, passivation, and bump processes.

For tests such as HTRB and HTGB, the distinct physics of failure of eGaN compared to MOSFETs requires further study in order to confidently project service life based on 1000 hours of accelerated stress testing. In these cases, EPC takes a three-prong approach to help automotive customers gain confidence the needs of their mission profile will be met:

- 1) EPC conducts standard AEC-Q101 qualification of eGaN FETs, following all requirements and standards exactly. This establishes a reliability baseline.
- 2) EPC conducts traditional accelerated voltage/temperature testing, which gives lifetime extrapolations under ordinary use conditions resulting from intrinsic failure mechanisms. Accelerated test results are available on the EPC website.
- 3) EPC conducts additional operating life testing in test circuits that emulate the stress conditions seen in the application environment. Examples include both LIDAR and dc-dc conversion. These tests are often designed and implemented in cooperation with the end-users. The tests are designed to directly verify that the service life of the eGaN product will exceed mission requirements (typically 10-15 years of continuous operation).

**High Temperature Reverse Bias**

EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2212, EPC2202, and EPC2203. As shown in Table 1 below, parts were subjected to 100% of the rated drain-source voltage at the maximum rated temperature (150°C) for a stress period of 1000 hours.

Parts were mounted on high Tg FR-4 adapter cards. Testing was conducted in accordance with MIL-STD-750-1 (M1038 Method A). This standard requires the parts to be under bias during temperature ramp up and cool down. In addition, post-screening must occur within 24 hours after bias has been removed.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)
HTRB	EPC2206	80	XL (6.05 x 2.30)	T=150°C, $V_{DS}$ = 80 V	0	77 x 3	1000
HTRB	EPC2212	100	M (2.11 x 1.63)	T=150°C, $V_{DS}$ = 100 V	0	77 x 3	1000
HTRB	EPC2202	80	M (2.11 x 1.63)	T=150°C, $V_{DS}$ = 80 V	0	77 x 3	1000
HTRB	EPC2203	80	S (0.95 x 0.95)	T=150°C, $V_{DS}$ = 80 V	0	77 x 3	1000
HTRB	EPC2214	80	S (1.35 x 1.35)	T=150°C, $V_{DS}$ = 80 V	0	77 x 1	1000

Table 1. High Temperature Reverse Bias Test

**High Temperature Gate Bias**

EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2212, EPC2202, and EPC2203. As shown in Table 2, parts were subjected to maximum rated gate-source bias at the maximum rated temperature (150°C) for a stress period of 1000 hours.

Parts were mounted on high Tg FR-4 adapter cards. Testing was conducted in accordance with JESD22-A108. This standard requires the parts to be under bias during temperature ramp up and cool down. In addition, post-screening must occur within 96 hours after bias has been removed.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)
HTGB	EPC2206	80	XL (6.05 x 2.30)	T = 150°C, V <sub>GS</sub> = 6 V	0	77 x 3	1000
HTGB	EPC2212	100	M (2.11 x 1.63)	T = 150°C, V <sub>GS</sub> = 6 V	0	77 x 3	1000
HTGB	EPC2202	80	M (2.11 x 1.63)	T = 150°C, V <sub>GS</sub> = 5.75 V	0	77 x 3	1000
HTGB	EPC2203	80	S (0.95 x 0.95)	T = 150°C, V <sub>GS</sub> = 5.75 V	0	77 x 3	1000
HTGB	EPC2214	80	S (1.35 x 1.35)	T = 150°C, V <sub>GS</sub> = 6 V	0	77 x 1	1000

Table 2. High Temperature Gate Bias Test

**Unbiased Highly Accelerated Test**

Parts were subjected to 96 hours at a temperature of 130°C, relative humidity of 85%, and vapor pressure of 33.3 psia. As summarized in Table 3 below, EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2202, and EPC2203.

Parts were not mounted onto PCB adapter cards. Instead, they were loaded into trays and underwent pre-conditioning prior to uHAST as required by AEC-Q101. Parametric pre- and post-screening was conducted using probe needles touching down on the solder bumps.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)
uHAST	EPC2206	80	XL (6.05 x 2.30)	T = 130°C, RH = 85%, VP = 33.3 psia	0	77 x 3	96
uHAST	EPC2202	80	M (2.11 x 1.63)	T = 130°C, RH = 85%, VP = 33.3 psia	0	77 x 3	96
uHAST	EPC2203	80	S (0.95 x 0.95)	T = 130°C, RH = 85%, VP = 33.3 psia	0	77 x 3	96
uHAST	EPC2214	80	S (1.35 x 1.35)	T = 130°C, RH = 85%, VP = 33.3 psia	0	77 x 1	96

Table 3. Unbiased Highly Accelerated Test

**Temperature Cycling**

Parts were subjected to temperature cycling between -55°C and +150°C for a total of 1000 cycles. A minimum of 5 minutes dwell time and 2-3 cycles per hour were used in accordance with the JEDEC Standard JESD22A104 Condition B. All parts went through pre-conditioning prior to TC.

EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2202, and EPC2203.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)	Format
TC	EPC2206	80	XL (6.05 x 2.30)	-55 to 150°C, Air	0	77 x 3	1000	Bare Die
TC	EPC2206	80	XL (6.05 x 2.30)	-55 to 150°C, Air	0	48 x 1	1000	PCB (Arlon 85NT)
TC	EPC2202	80	M (2.11 x 1.63)	-55 to 150°C, Air	0	77 x 3	1000	Bare Die
TC	EPC2202	80	M (2.11 x 1.63)	-55 to 150°C, Air	0	77 x 2	1000	PCB (Arlon 85NT)
TC	EPC2202	80	M (2.11 x 1.63)	-55 to 150°C, Air	0	77 x 2	500	PCB(FR5)
TC	EPC2214	80	S (1.35 x 1.35)	-55 to 150°C, Air	0	77 x 1	1000	Bare Die
TC	EPC2203	80	S (0.95 x 0.95)	-55 to 150°C, Air	0	77 x 3	1000	Bare Die
TC	EPC2203	80	S (0.95 x 0.95)	-55 to 150°C, Air	0	77 x 2	500	PCB (FR5)

Table 4. Temperature Cycling Test

**High Temperature High Humidity Reverse Bias**

Parts were subjected to a drain-source bias of 80% maximum voltage rating, 85% RH and 85°C for a stress period of 1000 hours. The testing was done in accordance with the JEDEC Standard JESD22-A101, as required by AEC-Q101. All parts were mounted on FR4 adaptor boards. All parts went through pre-conditioning before H3TRB. EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2212, EPC2202, and EPC2203. Test results are summarized in Table 5.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)
H3TRB	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 3	1000
H3TRB	<a href="#">EPC2212</a>	100	M (2.11 x 1.63)	T = 85°C, RH = 85%, V <sub>DS</sub> = 80 V	0	77 x 3	1000
H3TRB	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 5	1000
H3TRB	<a href="#">EPC2214</a>	80	S (1.35 x 1.35)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 1	1000
H3TRB	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 3	1000

Table 5. High Temperature High Humidity Reverse Bias Test

**Moisture Sensitivity Level 1**

MSL1 test results are summarized in Table 6. Parts were subjected to 85% RH at 85°C for a soak period of 168 hours. Within 4 hours after the soak, the parts underwent three cycles of Pb-free reflow in accordance with the IPC/JEDEC joint Standard J-STD-020. These conditions correspond to a moisture sensitivity level 1, the most stringent level of moisture sensitivity testing. For this testing, devices were either attached to PCB test coupons, or tested in bare die format. (For bare die, pre-screen and post-screen were performed using probe needles to contact the solder pads of the bare die). EPC2219 is qualified by matrix with in-family AEC devices EPC2206, EPC2202, and EPC2203.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Hrs)	Format
MSL1	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	T = 85°C, RH = 85%, 3 reflow	0	77 x 4	168	PCB (FR4)
MSL1	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	T = 85°C, RH = 85%, 3 reflow	0	77 x 3	168	Bare Die
MSL1	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	T = 85°C, RH = 85%, 3 reflow	0	77 x 3	168	Bare Die
MSL1	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	T = 85°C, RH = 85%, 3 reflow	0	77 x 3	168	Bare Die

Table 6. Moisture Sensitivity Level Test

**Destructive Physical Analysis**

EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2212, EPC2202, and EPC2203. In accordance with AEC-Q101 requirements, two parts for each product were selected for physical analysis after successfully completing H3TRB testing. The physical analysis was conducted in three steps: (1) removal of die from PCB adapter card; (2) chemical removal of solder bumps/bars; (3) removal of top-layer passivation layers via dry etch. After each step, a high magnification optical microscope inspection was performed. No damage or abnormalities were observed resulting from the environmental stress testing.

**Electrostatic Discharge (ESD) Sensitivity**

EPC2219 was tested for ESD sensitivity using the human body model (HBM) in accordance with AEC Q101-001 procedures. Device parameters were measured before and after ESD testing. As shown in Table 7, EPC2219 achieved a 250V HBM rating. Based on extensive testing of in-family AEC products, EPC2219 has a CDM rating in excess of 1 kV. Full ESD results for in-family products EPC2202, EPC2203, EPC2214 and EPC2206 are shown in the table as well.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)
ESD-HBM	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	500 V	0	10 x 1
ESD-HBM	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	1000 V	1	10 x 1
ESD-CDM	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	1000 V	0	10 x 1
ESD-HBM	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	500 V	0	10 x 1
ESD-HBM	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	1000 V	1	10 x 1
ESD-CDM	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	500 V	0	10 x 1
ESD-CDM	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	750 V	0	10 x 1
ESD-CDM	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	1000 V	0	10 x 1
ESD-CDM	<a href="#">EPC2214</a>	80	S (1.35 x 1.35)	1000 V	0	10 x 1
ESD-HBM	<a href="#">EPC2214</a>	80	S (1.35 x 1.35)	500 V	0	10 x 1
ESD-HBM	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	250 V	0	10 x 1
ESD-HBM	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	500 V	1	10 x 1
ESD-CDM	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	500 V	0	10 x 1
ESD-CDM	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	750 V	0	10 x 1
ESD-CDM	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	1000 V	0	10 x 1
ESD-HBM	<a href="#">EPC2219</a>	65	S (0.9 x 0.9)	250 V	0	10 x 1

Table 7. ESD HBM and CDM Test

**Parametric Verification**

EPC2219 is qualified by matrix with in-family AEC devices EPC2214, EPC2206, EPC2212, EPC2202, and EPC2203. In accordance with AEC-Q101 requirements, device parameters were measured at -40°C, 25°C, and 150°C to ensure compliance with datasheet specifications over the entire temperature range. Parametric verification was performed 1 lots x 25 parts, for EPC2214, and 3 lots x 25 parts for EPC2206, EPC2212, EPC2202 and EPC2203.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)
Parametric Verification	<a href="#">EPC2206</a>	80	XL (6.05 x 2.30)	T = 40°C, 25°C, 150°C	0	25 x 3
Parametric Verification	<a href="#">EPC2212</a>	100	M (2.11 x 1.63)	T = 40°C, 25°C, 150°C	0	25 x 3
Parametric Verification	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	T = 40°C, 25°C, 150°C	0	25 x 3
Parametric Verification	<a href="#">EPC2214</a>	80	S (1.35 x 1.35)	T = 40°C, 25°C, 150°C	0	25 x 1
Parametric Verification	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	T = 40°C, 25°C, 150°C	0	25 x 3

Table 8. Parametric Verification Test

**Intermittent Operating Life**

EPC2219 is qualified by matrix with EPC2202, EPC2203, and EPC2206. In accordance with MIL-STD-750 (Method 1037), parts are power cycled over a  $\Delta T_j = 125^\circ\text{C}$  temperature range. Devices are heated through internal electrical power dissipation by biasing them in the linear mode, with combined gate and drain bias and a regulated drain current. With a 1 minute temperature ramp, and a 5 minute cool down, a minimum of 5000 cycles are required. Die were assembled onto low CTE polyimide PCBs (Arlon 85NT). As seen in Table 9, two lots of EPC2202 passed 5000 cycles, and one lot of EPC2203 passed 7500 cycles (exceeding AEC requirements). In addition, one lot (32 parts) of EPC2206 was also tested to 5000 cycles with no failures.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (sample x lot)	Duration (Cycles)	Format
IOL	<b>EPC2206</b>	80	XL (6.05 x 2.30)	$\Delta T_j = 125^\circ\text{C}$ ; ton/toff = 1 min/5 min	0	32 x 1	5000	PCB (Arlon 85NT)
IOL	<b>EPC2202</b>	80	M (2.11 x 1.63)	$\Delta T_j = 125^\circ\text{C}$ ; ton/toff = 1 min/5 min	0	77 x 2	5000	PCB (Arlon 85NT)
IOL	<b>EPC2203</b>	80	S (0.95 x 0.95)	$\Delta T_j = 125^\circ\text{C}$ ; ton/toff = 1 min/5 min	0	77 x 1	7500	PCB (Arlon 85NT)

Table 9. Intermittent Operating Life Test