

# EPC eGaN® FET Automotive Qualification Report EPC2221



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*This report summarizes the Product Qualification results for EPC part number EPC2221. The EPC2221 meets all required qualification requirements and is released for production.*

## Scope

The testing matrix in this report covers the qualification of EPC2221 in accordance with the component level AEC-Q101 Rev D1 requirements. For some of the required tests, EPC2221 is qualified by matrix with EPC2214, EPC2206, EPC2202, EPC2203, and EPC2212, also AEC qualified products within the same device family. All six of these automotive devices are compared in the table below.

Part Number	Max $V_{DS}$ (V)	Max $V_{GS}$ (V)	Max $R_{DS(on)}$ (mΩ)	Die Size (mm x mm)	Max Operating Temperature (°C)
EPC2206	80	6	2.2	XL (6.05 x 2.3)	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
EPC2221	100	6	2 x 58	S (1.35 x 1.35)	150
EPC2203	80	5.75	80	S (0.95 x 0.95)	150
EPC2214	80	6	20	S (1.35 x 1.35)	150

*EPC 80 V/100 V Automotive Product Family*

## Qualification Test Overview

EPC’s EPC2221, 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 stressed in a non-condensing humid environment 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 delayed 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.

For certain qualification tests, parts were mounted onto high Tg FR-4 (FR-5 or NP-175) or polyimide (Arlon 85NT) 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. Type 3 or 4 SAC305 solder 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 tests apply directly to EPC's eGaN FETs for the following reasons:

- 1) eGaN devices consist of a very thin film of GaN/AlGaIn 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 two-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**

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. As shown in Table 1 below, three lots of EPC2221 were stressed at 150°C for 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 (unit x lot)	Duration (Hrs)
HTRB	EPC2206	80	XL (6.05 x 2.3)	T = 150°C, V <sub>DS</sub> = 80 V	0	77 x 3	1000
HTRB	EPC2212	100	M (2.11 x 1.63)	T = 150°C, V <sub>DS</sub> = 100 V	0	77 x 3	1000
HTRB	EPC2202	80	M (2.11 x 1.63)	T = 150°C, V <sub>DS</sub> = 80 V	0	77 x 3	1000
HTRB	EPC2221	100	S (1.35 x 1.35)	T = 150°C, V <sub>DS</sub> = 100 V	0	77 x 3	1000
HTRB	EPC2203	80	S (0.95 x 0.95)	T = 150°C, V <sub>DS</sub> = 80 V	0	77 x 3	1000
HTRB	EPC2214	80	S (1.35 x 1.35)	T = 150°C, V <sub>DS</sub> = 80 V	0	77 x 1	1000

Table 1. High Temperature Reverse Bias Test

**High Temperature Gate Bias**

Parts were subjected to maximum rated gate-source bias at the maximum rated temperature. As shown in Table 2, three lots of EPC2221 were stressed at 6 V and 150°C for 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 (unit x lot)	Duration (Hrs)
HTGB	EPC2206	80	XL (6.05 x 2.3)	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	EPC2221	100	S (1.35 x 1.35)	T = 150°C, V <sub>GS</sub> = 6 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, three lots of EPC2221 were tested.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (unit x lot)	Duration (Hrs)
uHAST	EPC2212	100	M (2.11 x 1.63)	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	EPC2221	100	S (1.35 x 1.35)	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 approximately 2 cycles per hour were used in accordance with the JEDEC Standard JESD22A104 Condition B. All parts went through pre-conditioning prior to TC. Three lots of EPC2221 passed 1000 cycles.

For this test, the samples were in a bare die (package) form, loaded into trays.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (unit x lot)	Duration (Cys)	Format
TC	EPC2206	80	XL (6.05 x 2.3)	-55 to +150°C, Air	0	48 x 1	1000	PCB (Arlon 85NT)
TC	EPC2206	80	XL (6.05 x 2.3)	-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 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	EPC2221	100	S (1.35 x 1.35)	-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 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)
TC	EPC2214	80	S (1.35 x 1.35)	-55 to +150°C, Air	0	77 x 1	1000	Bare Die

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, and all parts went through pre-conditioning before H3TRB. The test results are summarized in Table 5, where it is shown that three lots of EPC2221 passed 1000 hours at 80 V. Table 5 also shows data for EPC2203 (small), EPC2214 (small), EPC2202 (medium), EPC2212 (medium) and EPC2206 (extra-large) within the same device family.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (unit x lot)	Duration (Hrs)
H3TRB	EPC2206	80	XL (6.05 x 2.3)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 3	1000
H3TRB	EPC2212	100	M (2.11 x 1.63)	T = 85°C, RH = 85%, V <sub>DS</sub> = 80 V	0	77 x 3	1000
H3TRB	EPC2202	80	M (2.11 x 1.63)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 5	1000
H3TRB	EPC2221	100	S (1.35 x 1.35)	T = 85°C, RH = 85%, V <sub>DS</sub> = 80 V	0	77 x 3	1000
H3TRB	EPC2203	80	S (0.95 x 0.95)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 3	1000
H3TRB	EPC2214	80	S (1.35 x 1.35)	T = 85°C, RH = 85%, V <sub>DS</sub> = 64 V	0	77 x 1	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). EPC2214 is qualified by matrix (similarity) with in-family products EPC2202, EPC2203, and EPC2206.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (unit x lot)	Duration (Hrs)	Format
MSL1	<b>EPC2206</b>	80	XL (6.05 x 2.3)	T = 85°C, RH = 85%, 3x reflow	0	77 x 4	168	PCB (FR4)
MSL1	<b>EPC2206</b>	80	XL (6.05 x 2.3)	T = 85°C, RH = 85%, 3x reflow	0	77 x 3	168	Bare Die
MSL1	<b>EPC2202</b>	80	M (2.11 x 1.63)	T = 85°C, RH = 85%, 3x reflow	0	77 x 3	168	Bare Die
MSL1	<b>EPC2221</b>	100	S (1.35 x 1.35)	T = 85°C, RH = 85%, 3x reflow	0	77 x 3	168	PCB (FR4)
MSL1	<b>EPC2221</b>	100	S (1.35 x 1.35)	T = 85°C, RH = 85%, 3x reflow	0	77 x 3	168	Bare Die
MSL1	<b>EPC2203</b>	80	S (0.95 x 0.95)	T = 85°C, RH = 85%, 3x reflow	0	77 x 3	168	Bare Die

Table 6. Moisture Sensitivity Level Test

**Destructive Physical Analysis**

In accordance with AEC-Q101 requirements, two EPC2221 parts were selected for physical analysis after successfully completing H3TRB testing. The physical analysis was conducted in two steps: (1) removal of die from PCB adapter card; (2) high magnification (50x) optical microscope inspection was performed. No damage or abnormalities were observed resulting from the environmental stress testing.

**Electrostatic Discharge (ESD) Sensitivity**

EPC2221 was tested for ESD sensitivity using both the human body model (HBM). Testing was conducted according to AEC Q101-001 and Q101-005 standards. Device parameters were measured before and after ESD testing. Results are shown in Table 7 below. EPC2221 passed HBM with a 500 V rating. 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 (unit x lot)
ESD - HBM	<b>EPC2206</b>	80	XL (6.05 x 2.3)	500 V	0	10 x 1
ESD - HBM	<b>EPC2206</b>	80	XL (6.05 x 2.3)	1000 V	1	10 x 1
ESD - CDM	<b>EPC2206</b>	80	XL (6.05 x 2.3)	1000 V	0	10 x 1
ESD - HBM	<b>EPC2202</b>	80	M (2.11 x 1.63)	500 V	0	10 x 1
ESD - HBM	<b>EPC2202</b>	80	M (2.11 x 1.63)	1000 V	1	10 x 1
ESD - CDM	<b>EPC2202</b>	80	M (2.11 x 1.63)	500 V	0	10 x 1
ESD - CDM	<b>EPC2202</b>	80	M (2.11 x 1.63)	750 V	0	10 x 1
ESD - CDM	<b>EPC2202</b>	80	M (2.11 x 1.63)	1000 V	0	10 x 1
ESD - HBM	<b>EPC2221</b>	100	S (1.35 x 1.35)	500 V	0	10 x 1
ESD - HBM	<b>EPC2221</b>	100	S (1.35 x 1.35)	1000 V	8	10 x 1
ESD - HBM	<b>EPC2214</b>	80	S (1.35 x 1.35)	500 V	0	10 x 1
ESD - CDM	<b>EPC2214</b>	80	S (1.35 x 1.35)	1000 V	0	10 x 1
ESD - HBM	<b>EPC2203</b>	80	S (0.95 x 0.95)	250 V	0	10 x 1
ESD - HBM	<b>EPC2203</b>	80	S (0.95 x 0.95)	500 V	1	10 x 1
ESD - CDM	<b>EPC2203</b>	80	S (0.95 x 0.95)	500 V	0	10 x 1
ESD - CDM	<b>EPC2203</b>	80	S (0.95 x 0.95)	750 V	0	10 x 1
ESD - CDM	<b>EPC2203</b>	80	S (0.95 x 0.95)	1000 V	0	10 x 1

Table 7. ESD HBM and CDM Tests

**Parametric Verification**

In accordance with AEC-Q101 requirements, EPC2221 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 3 lots x 25 parts.

Stress Test	Part Number	Voltage (V)	Die Size (mm x mm)	Test Condition	# of Failure	Sample Size (unit x lot)
PV	<a href="#">EPC2206</a>	80	XL (6.05 x 2.3)	T = -40°C, T = 25°C, 150°C	0	25 x 3
PV	<a href="#">EPC2212</a>	100	M (2.11 x 1.63)	T = -40°C, T = 25°C, 150°C	0	25 x 3
PV	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	T = -40°C, T = 25°C, 150°C	0	25 x 3
PV	<a href="#">EPC2221</a>	100	S (1.35 x 1.35)	T = -40°C, T = 25°C, 150°C	0	25 x 3
PV	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	T = -40°C, T = 25°C, 150°C	0	25 x 3
PV	<a href="#">EPC2214</a>	80	S (1.35 x 1.35)	T = -40°C, T = 25°C, 150°C	0	25 x 1

Table 8. Parametric Verification Tests

**Intermittent Operating Life**

EPC2221 is qualified by matrix with EPC2202, EPC2203, and EPC2206. In accordance with MIL-STD-750 (Method 1037), parts are power cycled over a  $\Delta T = 125^\circ\text{C}$  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. The samples 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 (unit x lot)	Duration (Hrs)
IOL	<a href="#">EPC2206</a>	80	XL (6.05 x 2.3)	$\Delta T_j = 125^\circ\text{C}; t_{\text{on}} / t_{\text{off}} = 1 \text{ min} / 5 \text{ min}$	0	32 x 1	5000
IOL	<a href="#">EPC2202</a>	80	M (2.11 x 1.63)	$\Delta T_j = 125^\circ\text{C}; t_{\text{on}} / t_{\text{off}} = 1 \text{ min} / 5 \text{ min}$	0	77 x 2	5000
IOL	<a href="#">EPC2203</a>	80	S (0.95 x 0.95)	$\Delta T_j = 125^\circ\text{C}; t_{\text{on}} / t_{\text{off}} = 1 \text{ min} / 5 \text{ min}$	0	77 x 1	7500

**Note** - EPC2221 is qualified by matrix.

Table 9. Intermittent Operating Life Tests