# Reaching Beyond 1200 V: Lateral GaN HEMTs for High-Reliability EV and Industrial Applications

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## Abstract

The industry's first, true 1250 V-rated lateral GaN HEMT allows significant transient overvoltage capability making it ideal for high-voltage, high-reliability EV and industrial applications. Based on the PowiGaN™ technology platform of Power Integrations, the 1250 V GaN cascode device shows stable off-state leakage beyond 2000 V with a typical breakdown voltage of 2300 V. Reliability qualification data is presented confirming the advantage of the 1250 V device for such applications. In this work, we have also demonstrated high-efficiency power supply operation at high-input voltages using a 1250 V flyback switcher IC, confirming its readiness for real-world use.

## 1 Introduction of InnoSwitch with PowiGaN

GaN-based power semiconductor devices are ideally suited for high-efficiency power converters due to their superior material properties [1]. Lateral GaN HEMTs have been adopted into many commercial power supply designs covering a broad range of applications [2]. Devices available from various manufacturers typically offer voltage ratings <200 V and 650 V. Beyond 650 V, only a few manufacturers have released lateral GaN HEMTs with a rated voltage of 900 V [3-5]. Because of this, applications needing wide-bandgap power devices with 1200 V rating and beyond have been constrained to using SiC switches. However, cost is still a significant barrier to SiC adoption [6]. Besides improved efficiency and higher switching frequency, GaN offers the advantage of a significantly lower cost when compared to SiC [7], making it a compelling alternative even at 1200 V and beyond.

While 1200 V lateral GaN HEMTs have recently been reported as a cost-effective, high-performance platform for EV and industrial applications [8], the off-state drain to source leakage characteristics are shown to only be stable up to 1200 V, which leaves no margin for transient overvoltage conditions. Similarly, another lateral GaN HEMT device rated at 1200 V has an actual breakdown of only 1500 V leaving no margin for overvoltage capability [9]. Rapidly increasing off-state drain-to-source leakage current beyond 1000 V is also observed in a reported 1200 V GaN Polarisation Superjunction (PSJ) HFET [10]. Significant dynamic RDS(ON) increases ranging between 40% and 50% were observed even at a 600 V switching condition on the reported 1200 V GaN FET [11] making it unsuitable for applications that require a true 1200 V rating. In addition, none of these works have reported reliability qualification test results, which are essential to demonstrate readiness for field deployment.

Surge-robust, high-performance flyback power supplies with 750 V GaN-based InnoSwitch™ ICs operate reliably through surge events without any hard failure or change in converter efficiency over 90 VAC to 264 VAC line conditions [12]. Subsequently, flyback switcher ICs with 900 V GaN targeting industrial applications and 400 V-system automotive power supplies up to 100 W were introduced [4]. The AEC-Q100-qualified product family by Power Integrations is ideal for EVs based on 400 V bus systems where the 900 V GaN switch provides more power and increased design margin with enhanced efficiency over silicon-based converters. The efficiency improvement is valued both for range extension and thermal management.

In this work, we present device level characterization, reliability qualification and power supply operation results of a 1250 V lateral GaN HEMT cascode device, also built on the PowiGaN technology platform. Development of the 1250 V-rated device now allows us to take advantage of the proven benefits of lateral GaN HEMTs in power conversion applications at a higher voltage. With this device, power supply designers can reliably specify an operating peak VDS of 1000 V, while allowing for industry-standard 80% derating from the 1250 V device rating.

For industrial applications, this provides significant headroom and is particularly beneficial in challenging power grid environments where robustness is an essential defense against grid instability, surge, and other power perturbations. For EV, a reliable 1250 V lateral GaN technology can provide significant cost benefits over SiC in high-power 800 V system bus applications such as in an OBC.

## 2 Device Structure and Electrical Characteristics

The 1250 V GaN is a normally-on, depletion mode device built using PowiGaN technology with a proprietary field plate architecture optimized to control peak electric fields across the device. It is connected in series with a low-voltage silicon MOSFET in a cascode configuration to achieve effective normally-off operation, which is essential for safe operation of power electronic systems. The circuit schematic for the cascode switch with the 1250 V GaN and low-voltage silicon MOSFET is shown in **Figure 1**.

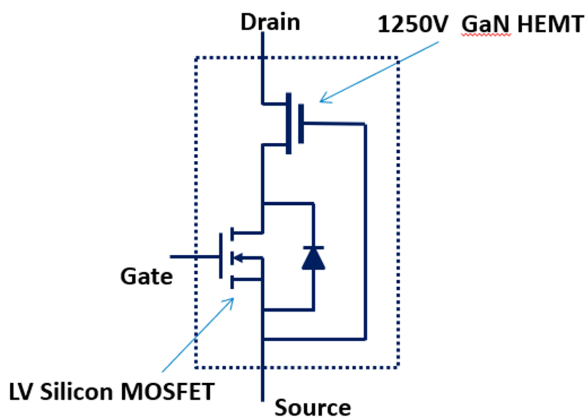


**Figure 1 Circuit schematic for the 1250V GaN cascode switch.**

Pulsed output characteristics of a typical 330 mOhm, 1250 V GaN cascode device are shown in **Figure 2**, illustrating high current capability.

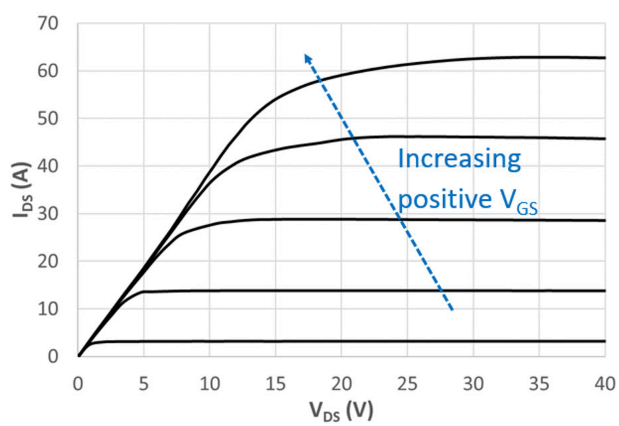


**Figure 2 Output characteristics of a 330 mOhm, 1250 V GaN cascode device.**

Off-state characteristics of a typical 1250 V cascode device are shown in **Figure 3** illustrating stable leakage behavior to beyond 2000 V. This ensures that the device has excellent transient overvoltage capability, and demonstrates significant margin compared to silicon or SiC devices with similar voltage ratings.

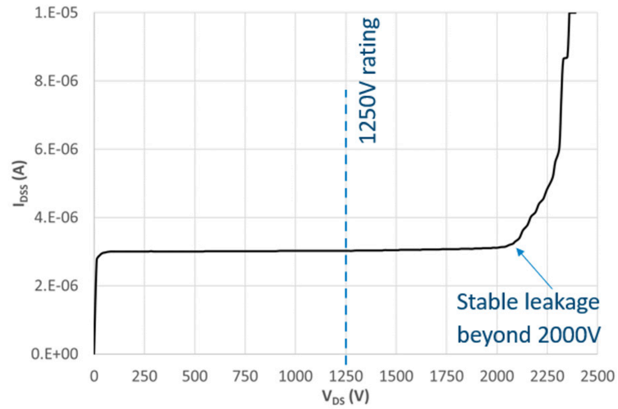


**Figure 3 Typical off-state characteristics demonstrating stable leakage beyond 2000 V.**

At the product level, the 1250 V GaN cascode has been incorporated into an integrated flyback switcher IC belonging to the InnoSwitch™3-EP product family [13]. This InnoSwitch IC includes the 1250 V GaN cascode as the high-voltage primary-side switch, a primary-side controller, and a secondary-side controller for synchronous rectification as shown in **Figure 4**. Inside the IC, secondary-side generated primary-switch timing requests are transferred across the safety isolation barrier using proprietary high-speed digital Flux-Link™ technology [14].

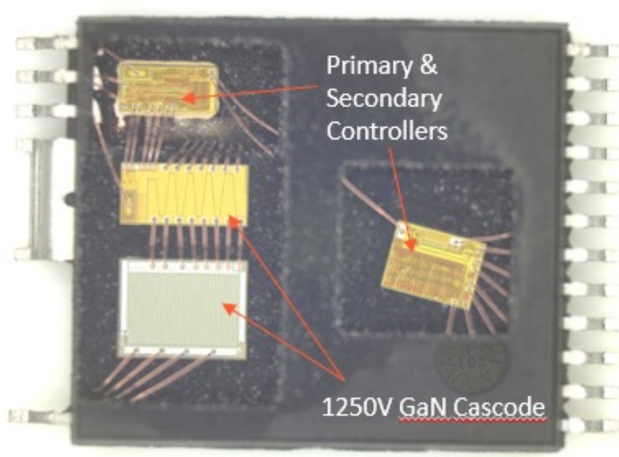


**Figure 4 InnoSwitch flyback switcher IC with the 1250V GaN cascode, primary, and secondary controllers.**

## 3 Device Reliability Evaluation

In this section, results from key reliability qualification tests performed on the 1250 V GaN device in both the off-state and switching modes of operation are described.

High Temperature Reverse Bias (HTRB) is an off-state reliability stress test that evaluates the long-term stability of the power device under high drain-to-source bias and is intended to accelerate thermally activated failure mechanisms under high E-fields over an extended period. An HTRB stress test of the 1250 V GaN cascode device was performed in a 150 °C ambient environment and stressed with an off-state VDS of 1000 V (80% of 1250 V rating) for 1000 hrs with passing results in accordance with the specifications laid out in JEP198 [15]. JEP198 is the JEDEC guideline for reverse bias reliability evaluation procedures for gallium nitride power conversion devices. One of the most important parameters monitored during the course of the HTRB stress test is the off-state drain to source leakage current. The excellent device leakage stability is shown in **Figure 5**, validating its suitability for high-reliability applications at high voltage.

In addition to the HTRB qualification test described above, intrinsic off-state failure rates were exposed by running tests on a large number of units under accelerated VDS conditions (2100 V to 2200 V) across multiple temperatures (80 °C to 120 °C) as shown in **Table 1**.

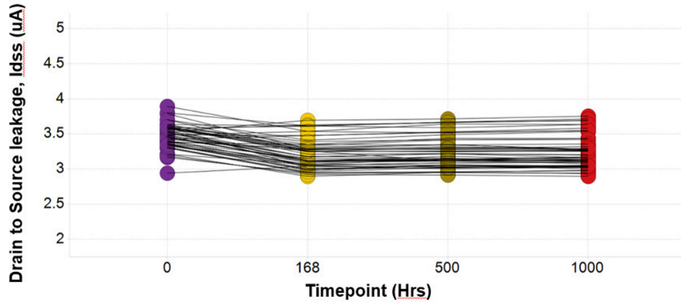


**Figure 5 Stable off-state drain leakage through 1000 hrs of HTRB stress at 1000 V / 150 °C.**

| Voltage/ Temperature | 80 °C | 100 °C | 120 °C |
|---|---|---|---|
| 2100 V | | | |
| 2150 V | | | |
| 2200 V | | | |

**Table 1 Accelerated evaluation conditions for exposing intrinsic failure rate in the off-state.**

Based on the time to failure Weibull distribution obtained from this set of experiments, voltage and temperature acceleration factors were extracted and the projected failure rate under typical use conditions was calculated. As shown in **Figure 6**, the model predicts a cumulative failure rate of 1 ppm in >15 thousand years of operation at 1000 V / 100 °C indicating a significant built-in reliability margin for the 1250 V GaN cascode power device.

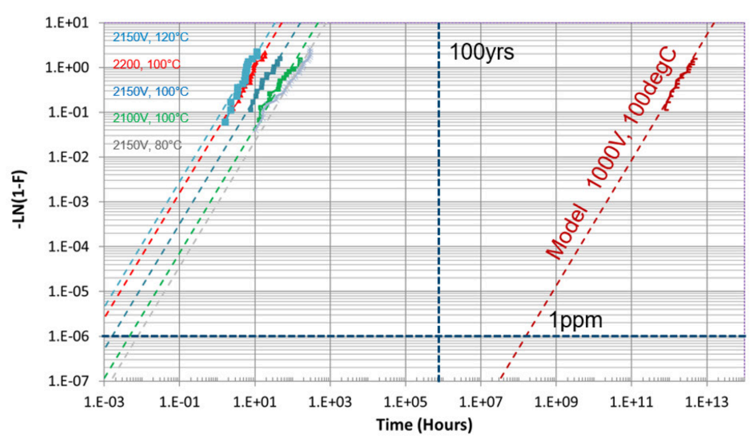


**Figure 6 Weibull distributions indicating time to failure under multiple accelerated stress conditions and the projected distribution at 1000 V / 100 °C.**

Switching reliability at the product level was evaluated using the 1250 V InnoSwitch flyback switcher IC with a Dynamic High Temperature Operating Life (DHTOL) test, conditions for which are specified in JEP 180 [16], which is the JEDEC guideline for switching reliability evaluation procedures for gallium nitride power conversion devices. A custom test bed was developed to evaluate multiple units in parallel at 125 °C (**Figure 7**). The most stringent operating conditions possible were chosen — hard-switched turn-on and turn-off at 1000 V (80% of 1250 V). The hard-switching waveform seen in the evaluation is illustrated in **Figure 8**.

**Figure 7 Custom test bed used to perform DHTOL on multiple 1250V InnoSwitch ICs in parallel at 125 °C.**

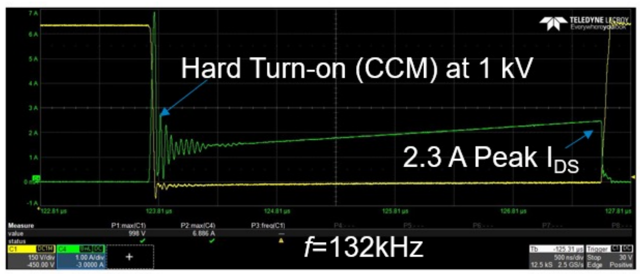


**Figure 8 Hard-switching waveform used during DHTOL evaluation of the 1250 V InnoSwitch IC.**

For lateral GaN HEMT power devices, dynamic RDS(ON) during high-voltage switching is of particular interest. An improperly designed device will likely exhibit a significant increase in RDS(ON) during high-voltage switching transitions due to additional electron trapping, which can have a detrimental effect on the converter efficiency.

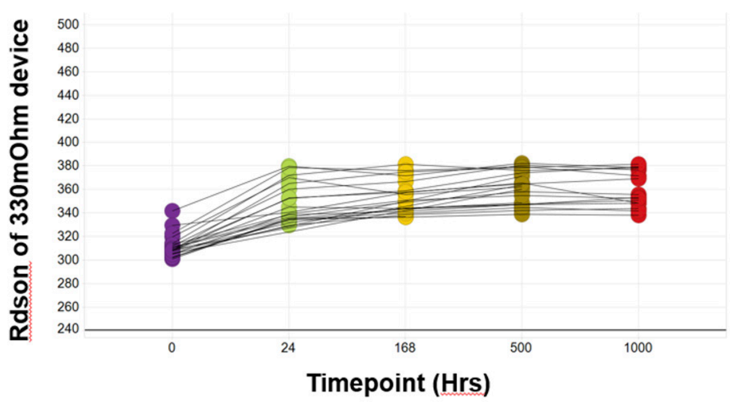


**Figure 9  Stable RDS(ON) observed during 1000 hrs of DHTOL with minimal shift (<20%).**

RDS(ON) of the 1250 V GaN cascode monitored over the course of 1000 hrs of DHTOL stress at 1000 V / 2.3 A / 125 °C is shown in **Figure 9**, and shows stable performance from the earliest timepoint with a minimal shift of <20%. This result confirms the hard-switching capability of the Power Integrations 1250 V lateral GaN HEMT device and demonstrates its robustness to meet all potential high-reliability industrial and EV application use cases.

## 4 Power Supply Evaluation

The 1250 V InnoSwitch IC, introduced in Sec. 2, was evaluated in an automotive flyback power supply design using a 60 W, 24 V / 2.5 A test setup described in RDR-919Q [17]. The schematic for the power supply design, detailed in RDR-919Q, is shown in **Figure 10**, along with the top-side photograph of the circuit board used in the evaluation (**Figure 11**).

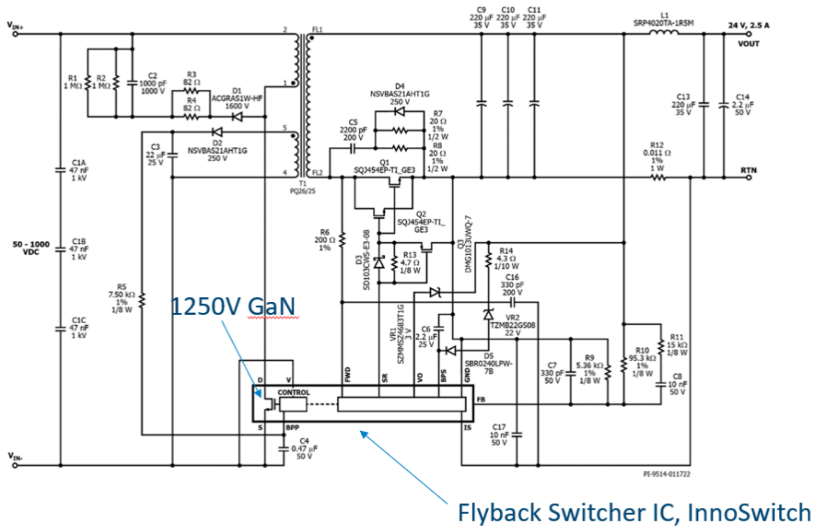


**Figure 10 Circuit schematic of the power supply design used to evaluate the 1250 V GaN flyback switcher IC.**

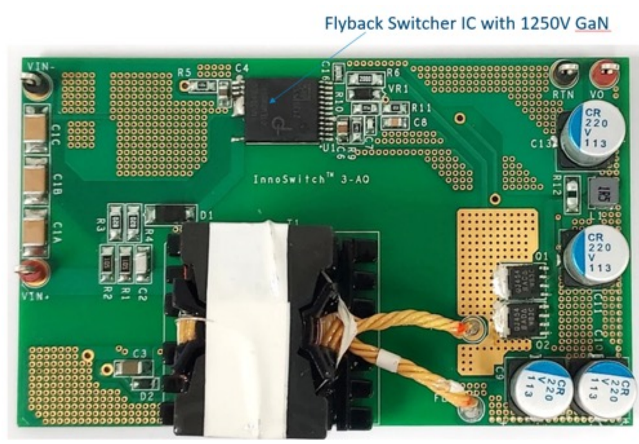


**Figure 11 Top-side photograph of the power supply design used in the evaluation.**

Steady-state operation of the flyback power supply with a peak VDS of 1000 V (80% of 1250 V) was evaluated using a DC input of 585 V. The corresponding switching waveforms are shown in **Figure 12**. Temperatures measured after 2 hours of stable operation at this condition showed a maximum temperature of 54.6 °C for the GaN HEMT, indicating a temperature rise of below 30 °C compared to the 25 °C ambient (**Figure 13**).

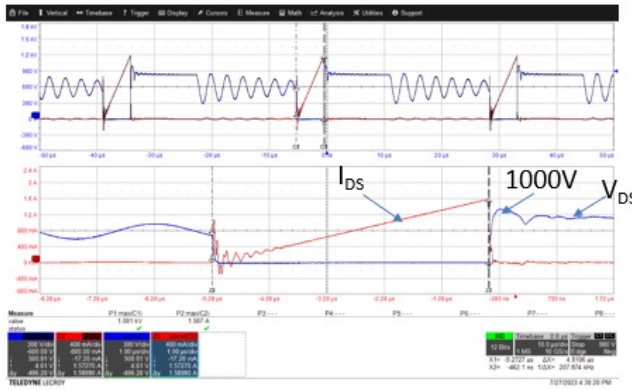


**Figure 12 Steady-state switching waveform illustrating peak VDS of 1000 V.**

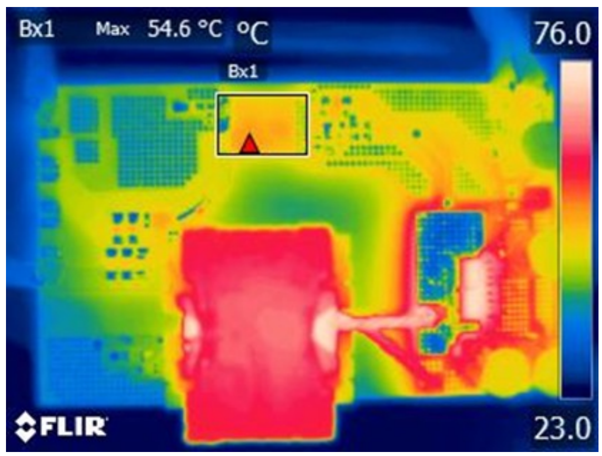


**Figure 13 Steady-state thermals indicating temperature rise below 30 °C during continuous switching and a VDS(PK) of 1000 V.**

While the GaN cascode is designed to operate with peak VDS below 1000 V in a continuous mode, it can accommodate momentary increases in supply voltage up to 1250 V. This transient voltage capability of the GaN cascode allows it to continue to switch through the surge event for short periods without suffering a hard failure. This capability of the device was demonstrated by increasing the input voltage until the peak VDS during switching reached the maximum rated value of 1250 V without any issues. An illustrative waveform showing the 1250 V VDS stress is shown in **Figure 14**.

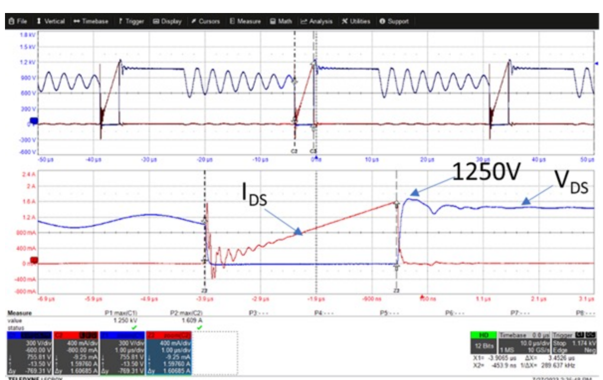


**Figure 14 Switching waveform illustrating transient overvoltage capability up to 1250 V.**

Besides being extremely robust, the flyback power supply designed with the 1250 V InnoSwitch IC achieves best-in-class full-load efficiency exceeding 92% at 700 V input, as illustrated in **Figure 15**.

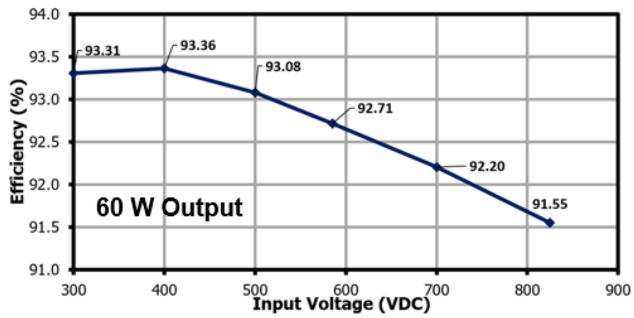


**Figure 15 Efficiency vs. input voltage.**

This power supply evaluation demonstrated the capability of 1250 V lateral GaN HEMTs as a credible alternative wide-bandgap technology to SiC in the 1200 V space and beyond. When higher switching frequency, improved efficiency and lower costs compared to SiC are factored in, lateral GaN HEMTs will become compelling in high-reliability EV and industrial applications.

## 5 Conclusion

This work introduces an industry-first, high-reliability 1250 V-rated lateral GaN HEMT and its readiness for real-world use at very high input voltage is illustrated by means of a high voltage flyback power supply design using a 1250 V InnoSwitch flyback switcher IC.

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