

# GaN FET module performance advantage over silicon



**Narendra Mehta**

*Senior Systems Engineer, GaN products  
High Voltage Power Solutions  
Texas Instruments*

# Learn how GaN improves energy efficiency, power density and solution size in next generation DC/DC converters.

Gallium-nitride (GaN) FETs are increasingly finding use as next-generation, high-power devices for power electronics systems [1]. GaN FETs can realize ultra-high-power-density operation with low power loss due to high carrier mobility in the two-dimensional electron gas (2DEG) channel, and high breakdown voltage due to large critical electric field. GaN FETs are a majority carrier device, therefore, the absence of reverse recovery charge creates a value proposition for high-voltage operation.

## Introduction

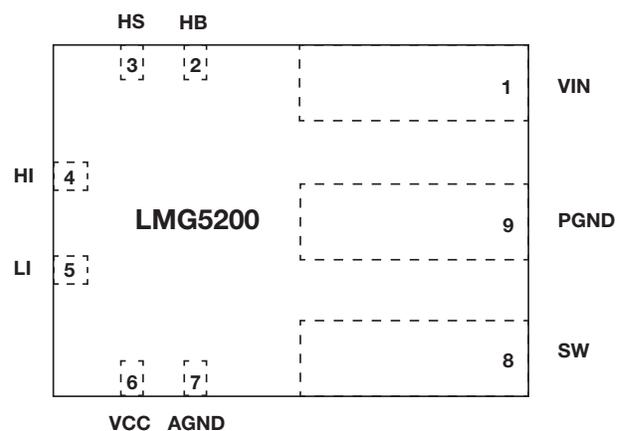
All these characteristics are suitable for power electronics applications featuring reduced power loss under high-switching-frequency operation.

With GaN devices now being grown on affordable silicon substrates, compared to GaN on sapphire or bulk GaN, power GaN FETs will find an increasing rate of adoption for highly efficient and form factor constrained applications in the 30V and higher DC/DC voltage conversion space. In this paper we investigate the loss mechanisms in a hard-switched DC/DC converter and how a GaN FET power stage can outperform Si MOSFETs. In this paper we compare a 80V GaN FET power stage to 80V Si devices.

A GaN FET power stage device such as the LMG5200 is an 80V GaN half-bridge power module. This device integrates the driver and two 80V GaN FETs in a 6 mm x 8 mm QFN package, optimized for extremely low-gate loop and power loop impedance [2]. The inputs are 3V CMOS and 5V TTL logic compatible. Due to GaN's intolerance for excessive gate voltage, a proprietary clamping technique ensures that the gate voltage of the GaN FETs is always below the allowed limit. This device extends the advantage of discrete GaN FETs by

offering a user-friendly package, which is easy to layout and assemble into the final product.

The LMG5200 meets the IPC-2221B and the IEC 60950 pollution degree 1 clearance and creepage requirements without any need for underfill. This is because the minimum spacing between high- and low-voltage pins is greater than 0.5 mm. This eliminates the need for boards to be manufactured with underfill and greatly simplifies board design and reduces cost. The pin-out also eliminates the need for a via-in-pad design as there is adequate spacing between the power pins for via placement. Additionally, this helps in to reduce board complexity and cost (**Figure 1**).



**Figure 1.** Top-down view of a GaN FET power stage device, showing pin-out.

## DC/DC converter losses

In this section we briefly discuss mechanisms that cause losses in hard switched converters.

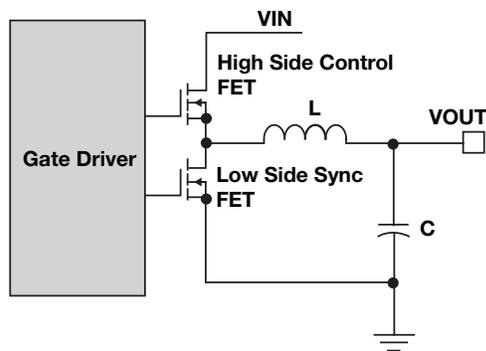


Figure 2. Simplified view of the buck power stage

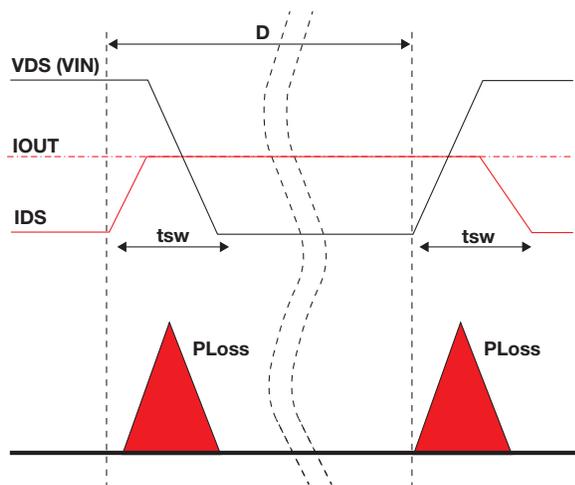


Figure 3. Turn-on and turn-off losses during inductive switching

In this paper, a synchronous buck converter (Figure 2) is used as a DC/DC converter to compare the losses in a hard-switched converter. The approach for comparing the loss mechanism can be applied to other hard-switched converters as well. Losses in a switched-mode converter can be broadly divided into conduction losses and switching losses. The high-side MOSFET dissipates most of the switching losses. Conduction losses are a function of the duty cycle and are shared between the high- and low-side devices. For low-duty cycle

DC/DC converters, the low-side FET has a higher amount of conduction loss, which can be calculated as:

$$P_{\text{COND(HS)}} = R_{\text{DS(ONHS)}} \times I_{\text{RMS(HS)}}^2 \quad (1)$$

$$P_{\text{COND(LS)}} = R_{\text{DS(ONLS)}} \times I_{\text{RMS(LS)}}^2 \quad (2)$$

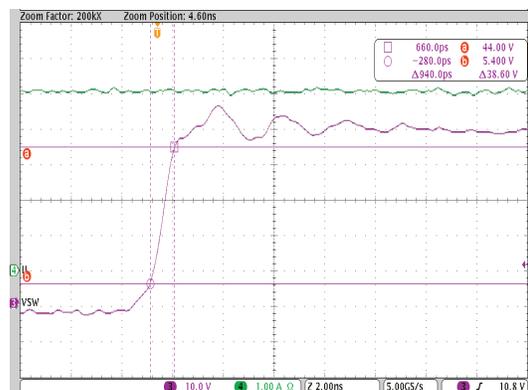
where  $R_{\text{DS(ONLS)}}$ ,  $R_{\text{DS(ONHS)}}$  is the low-side and high-side FET resistance, and  $I_{\text{RMS(LS)}}$ ,  $I_{\text{RMS(HS)}}$  are the low- and high-side RMS currents, respectively.

The switching loss (Figure 3) due to the  $I_{\text{DS}}$  current and  $V_{\text{DS}}$  overlap is in the high-side of a buck converter and can be estimated as:

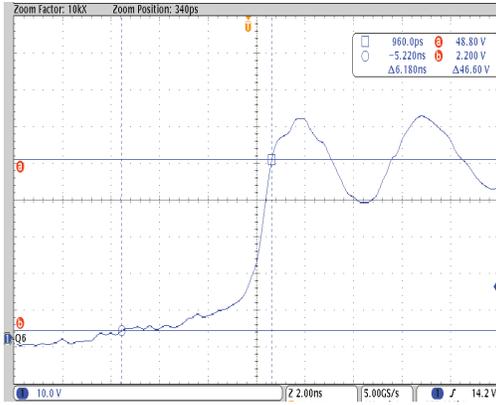
$$P_{\text{SWHS}} = V_{\text{IN}} \times I_{\text{OUT}} \times f_{\text{SW}} \times t_{\text{SW}} \quad (3)$$

where  $t_{\text{SW}}$  is the switching time. This includes the current commutation time through the FET and the time for the FETs drain-to-source voltage to rise / fall by  $V_{\text{IN}}$  during turn-off and turn-on, respectively.

The low-side FET does not have any switching loss due to zero voltage switching (ZVS) turn-on and turn-off. The actual waveforms for inductive switching are more complicated than those shown in Figure 3, however, the error in the calculated loss is acceptable as long as the correct switching time is used for the turn-on and turn-off.



a) LMG5200 switch node



b) Si7852DP 80v FET SW node

**Figure 4.** Comparison of a GaN FET power stage switch-node to silicon switch-node voltage waveform

The device construction of GaN allows very short, switching times due to small gate and output capacitance for the same  $R_{DS(on)}$ . As noted in **Figure 4**, switching time for the GaN FET power stage is less than 1 ns compared to 6 ns for a Si FET with a comparable breakdown voltage (Si7852DP).

Faster switching edges means the switching losses are significantly lowered in the GaN module compared to the Si MOSFET-based buck converter. Also note that there is minimal overshoot in the GaN FET power stage switch-node waveforms due to an extremely small (<300 pH) power loop inductance. The gate loop and common source inductance are also minimized in the GaN FET power stage package to be below 200 pH. High parasitic inductance in these loops can cause a significant power loss [3].

Besides the high-side turn-on and turn-off losses, forced commutation of the low-side MOSFETs body diode is a significant source of switching loss in high-voltage DC/DC converters. This loss is primarily due to the reverse recovery charge (QRR) in the freewheeling low-side FET. The power loss due to reverse recovery is given by:

$$P_{RR} = f_{sw} \cdot Q_{RR} \cdot V_{IN} \quad (4)$$

Because GaN is a majority carrier device, it does not have reverse recovery-based losses.

The body diode of the low-side MOSFET conducts during dead time. This causes a power loss in the diode associated with the forward voltage of the diode. GaN has a higher third quadrant conduction voltage ( $V_{SD}$  of 2V at 10A for LMG5200) compared to ~1V for Si FETs. Hence, the GaN device exhibits a higher power loss during dead time. It is critical to ensure that the dead time is small in order to minimize this loss [4]. The power loss associated with the body diode can be calculated as:

$$P_{BD} = f_{sw} \cdot V_{SD} \cdot I_{OUT} \cdot (T_{DEADON} + T_{DEADOFF}) \quad (5)$$

The energy stored in the output capacitance of the MOSFETs is dissipated during turn-on. Since the output capacitance is a strong function of the drain-to-source voltage, the proper way to calculate this power loss PCAP is:

$$P_{CAP} = f_{sw} \cdot Q_{OSS(VIN)} \cdot V_{IN} \quad (6)$$

where  $Q_{OSS(VIN)}$  is the output charge of the MOSFET, evaluated at the input voltage. GaN devices, due to their small output capacitance for the same  $R_{DS(on)}$  compared to Si, exhibit a much smaller PCAP loss as well.

Gate driver losses are another contributor to switching loss. A detailed explanation of losses associated with the gate driver can be found in the LM5113 application report [5].

Besides the active device-related losses in a hard-switched buck converter discussed in this paper,

there are losses associated with the inductor. These losses include core loss and AC- and DC-winding loss, which also should be taken into account when calculating system efficiency [6, 7].

## Efficiency improvements compared to Si

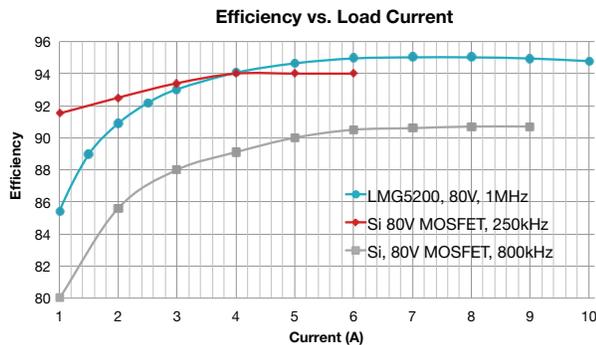


Figure 5. LMG5200 vs Si at different frequencies

Figure 5 shows the efficiency delta between a 48V:12V LMG5200 buck and 80v Si MOSFET-based buck. The LMG5200 is switching at 1 MHz while the Si-based implementation is switching at 250 kHz and 800 kHz, respectively. As shown, the LMG5200 has higher efficiency versus load than the Si solution switching at a lower frequency (1 MHz vs 800 kHz). This is indicative of the fact that switching and conduction losses in the GaN FET power stage are much lower compared to the similarly rated Si MOSFET. When the Si MOSFET-based converter is redesigned for a 250 kHz switching frequency, we see higher efficiency for Si designs at light loads as expected. However, as the load increases to 4A, the GaN FET power stage switching at 1 MHz shows a much higher efficiency.

A comparison with Si at 800 kHz shows that the efficiency of the GaN FET power stage is much higher across a wide load range, even while switching at 1 MHz.

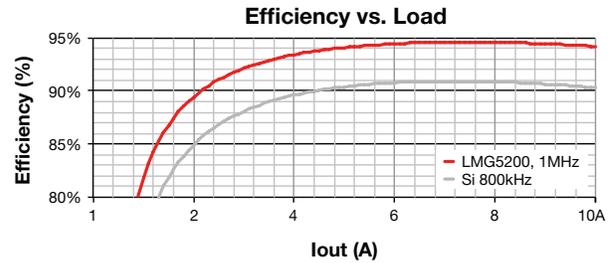


Figure 6. Calculated efficiency comparison between the GaN FET power stage design at 1 MHz and Si FET design at 800 kHz

A comparison of the efficiencies observed in the hard-switched buck with the calculated results indicates that the calculations are within the margin of error for the simplified model presented (Figure 6).

## Summary

Power GaN FETs, due to their extremely low-gate charge and output capacitance, can be switched at extremely high speeds with significantly reduced switching losses and improved efficiency compared to silicon FETs. The LMG5200, an 80V GaN FET power stage, has been optimized for applications requiring high efficiency and/or small form factor. Its advanced package greatly simplifies manufacturability and board design while reducing costs. The LMG5200 can improve the performance across a wide variety of applications while reducing adoption risk. These applications include multi-MHz synchronous buck converters, Class D amplifiers for audio, and 48V to POL converters for data communications and telecommunications servers. GaN FET power stage devices provide significant efficiency benefits across a wide load range while improving switching frequency and power density.

To learn more about TI's GaN solutions, please visit [www.ti.com/GaN](http://www.ti.com/GaN).

## References

1. Lidow, A. Integrated Power Electronics Systems (CIPS), 2010 6th International Conference, 2010
2. [LMG5200](#) datasheet
3. David Jauregui, Bo Wang, and Rengang Chen. [Power Loss Calculation With Common Source Inductance Consideration for Synchronous Buck Converters](#), Application Report (SLPA009A), Texas Instruments, July 2011
4. Di Han; Sarlioglu, B. [Wide Bandgap Power Devices and Applications \(WiPDA\)](#), 2014 IEEE Workshop on DOI: [10.1109/WiPDA.2014.6964627](#)
5. Narendra Mehta, [Design Considerations for LM5113 Advanced GaN FET Driver During High-Frequency Operation](#), Application Report (SNVA723), Texas Instruments, November 2014
6. Reinert, J.; Brockmeyer, A.; De Doncker, R.W.A.A. [Calculation of losses in ferro- and ferrimagnetic materials based on the modified Steinmetz equation](#), Industry Applications, IEEE Transactions on Volume: 37 , Issue: 4
7. Jieli Li; Abdallah, T.; Sullivan, C.R. [Improved calculation of core loss with nonsinusoidal waveforms](#), Industry Applications Conference, 2001. Thirty-Sixth IAS Annual Meeting. Conference Record of the 2001 IEEE Volume: 4

**Important Notice:** The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

The platform bar is a trademark of Texas Instruments.  
All other trademarks are the property of their respective owners.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)