48 V GaN Point-of-Load Converter

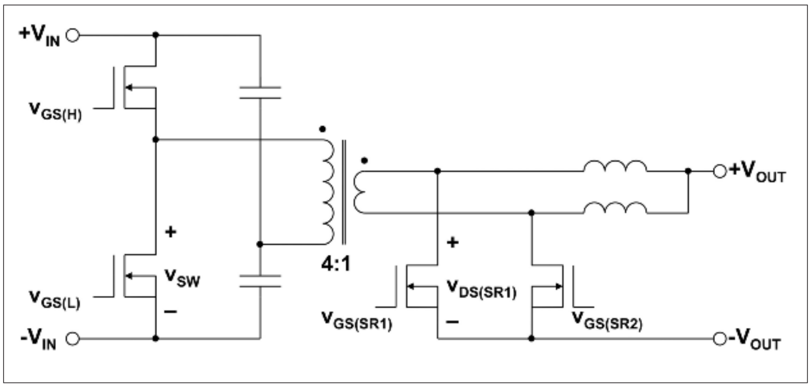
Gallium nitride (GaN) devices have hit the power electronics market with force. By offering lower capacitances and zero reverse recovery, they promise to dramatically improve efficiency and open up new markets. One of these new opportunities is powering high-current loads directly from the 48 V bus, common in server and telecommunications environments. This approach provides advantages over the traditional two-stage solution of using a bus converter followed by a point-of-load (PoL) voltage regulation module (VRM). The single-stage provides a more-efficient solution while providing improved transient response and form factor improvements. **Michael Seeman, Systems and Applications Engineering Manager, Texas Instruments, Dallas, USA**

This application is focused on 48 V bus rails, within the range of 36 V to 60 V, which are becoming more common in the server and telecommunication space. This design will be focusing on 40 A, 1.8 V output typical of many digital loads. The design can be scaled in a straightforward manner to lower output voltages and higher output currents. For processor-type loads, customers expect very fast transient response in both the current slew rate and voltage slew rate. This article addresses both of these design considerations when analyzing the converter.

Traditional designs are done in two stages. The 48 V bus, typically supplied by an AC/DC rectifier with a battery bank backup, is fed to the server module through the backplane. The 48 V bus is then down-converted to 9-12 V using a regulated or unregulated bus converter. These converters come in “brick” form factors (for example, quarter-brick and eighth-brick) and have efficiencies in the order of 96 %. The second stage is a multiphase buck converter that delivers current to the load. Operating at around 500 kHz, these converters are optimized to achieve fast transient performance and have efficiencies around 92 %. Since this second stage must convert voltage at a 5 :1 or higher ratio, a fairly-large inductor must be used to manage the ripple current to improve efficiencies, especially at light load. The proposed single-stage solution can operate at the same or higher switching frequency while reducing form-factor and improving efficiency.

Single-stage conversion

The selected topology for the single stage 48 V to 1.8 V conversion is a hard-switched, half-bridge isolated converter with current doubler output. Figure 1 shows the circuit construction. It has an identical number of switches as a two-phase buck converter, and its operation can be likened to the two-phase buck. The primary-side half-bridge is made up of a half-bridge GaN module and a set of DC-blocking capacitors for the other transformer terminal. The secondary-side current doubler comprises two synchronous rectifier (SR) transistors and two output inductors. The duty cycle of the primary-side switches determines the conversion ratio, while the SR FETs operate complementary to the primary side switches.



RIGHT Figure 1: Schematic of single-stage 48V to 1.8V converter

	GaN LMG5200	EPC 2023	Si 100 V, 16 mΩ	Si 25 V, 1.05 mΩ
	18 mΩ, 80V	1.3 mΩ, 30V	16 mΩ, 100V	1.05 mΩ, 25V
Q_G	3.4 nC @ 5V	20 nC @ 5V	19 nC @ 10V	29 nC @ 4.5V
Q_{OSS}	16 nC @ 50V	12 nC @ 5V	25 nC @ 50V	21.5 nC @ 5V
t_{sw}	~ 1.5 ns	~ 1.5 ns	~ 5 ns	~ 5 ns
Q_{RR}	0 nC	0 nC	83 nC	5 nC
Q_G Loss	117 mW		335 mW	
Q_{OSS} Loss	912 mW		1458 mW	
t_{SW} loss	180 mW		600 mW	
Q_{RR} loss	0 mW		60 mW	

Table 1: Device parameters and loss components

$$P_{sw}=f_{sw}\left(2\left(Q_{G,pri}V_{G,pri}+Q_{G,sec}V_{G,sec}\right)+2\left(Q_{OSS,pri}+\frac{Q_{OSS,sec}}{n}\right)V_{i}+t_{sw}I_{PRI}V_{i}+2\frac{Q_{RR,sec}V_{i}}{n}\right) \quad (1)$$

GaN provides a significant advantage in this application through its lack of reverse recovery and improved switching characteristics [1]. Because of the fast switching frequency required to achieve a small form factor and fast transient response, a low output capacitance and switching loss is necessary. On the secondary side, low reverse recovery charge switches are necessary for performance and to minimize power loss. Table 1 shows the relevant performance metrics of the LMG5200 GaN module compared with some comparable Silicon FETs.

The advantage of GaN comes in terms of switching loss, while magnetics loss and conduction loss remain the same as for silicon switches with the same on-resistance. The switching loss is given by the sum of the gate drive loss, output capacitance energy, V-I switching loss and the reflected reverse recovery of the secondary-side switches according to equation 1 (above), where $Q_{G,PRI}$ and $Q_{G,SEC}$ are the total gate charges, VG,PRI and $V_{G,SEC}$ are the gate drive voltages and $Q_{OSS,PRI}$ and $Q_{OSS,SEC}$ are the output charges of the primary-side and secondary-side switches, respectively. V_{IN} is the input voltage, T_{SW} is the switching time, I_{PRI} is the current flowing through the primary-side switches, QRR,SEC is the reverse recovery charge of the SR FETs, and n is the transformer turns ratio. Note that the first component of the loss can be reduced based on the ringing during the dead-time; partial valley switching would improve the efficiency.

Table 1 shows the per-cycle loss for each of these loss components for both a GaN implementation and a Silicon-based implementation. Note that these losses do not include magnetics or conduction loss, as these components do not change when using GaN. With a transformer turns ratio of 4 :1 and switching frequency of 500 kHz, GaN yields a gating and switching loss of 1.21 W, compared with a loss of 2.45 W with the Silicon-based solution.

Transient performance advantages

The single-stage 48 V to PoL converter exhibits transient response advantages over the traditional 12 V solution. The value of the output inductor determines how fast the load current can slew. The smaller the inductance, the larger the potential slew rate. Many buck PoL controllers have a minimum on-time which restricts the maximum operating frequency of the converter and, thus, minimum allowable inductance. Since the single-stage solution utilizes a transformer for the majority of the conversion ratio, the duty cycle can be effectively larger than a 12 V buck converter.

A higher duty cycle allows for a higher switching frequency and a smaller inductance for a given minimum on-time. As the converter topology and control are symmetric, the capacitors on the primary side balance any offset in the circuit, enabling fast duty-cycle transitions without having to worry about core saturation. Compared with soft-switched converter topologies, this hard-switched converter exhibits faster transients as there is no high-Q resonant network or other impedance network to enable soft-switching.

Experimental results

Figure 2 shows a photo of the prototype 48 V to PoL converter, which is optimized for 500 kHz operation. The LMG5200 80 V GaN half-bridge module [2] is located on the left of the transformer. The transformer has a 4 :1 turns ratio using stamped windings to reduce resistance. An ungapped core minimizes magnetizing current and leakage inductance. Two 440 nH output inductors are located on the right with the SR MOSFETs located on the underside of the PCB. The footprint of the power stage is 28 mm by 50 mm. This implementation is a hybrid Silicon/GaN combination, using the LMG5200 GaN device on the primary side and a 25 V, 1.05 mΩ Silicon MOSFET on the secondary side.

Figure 3 shows the converter's switching waveforms with a 48 V input and 1.8 V, 20 A output load. The converter is duty-cycle controlled with the primary-side switches operating with less than 50 % duty cycle and the SR FETs operating above 50 % duty cycle. During the dead-time on the primary side, the leakage inductance rings with the output capacitance of the primary-side switches. The leakage inductance causes some

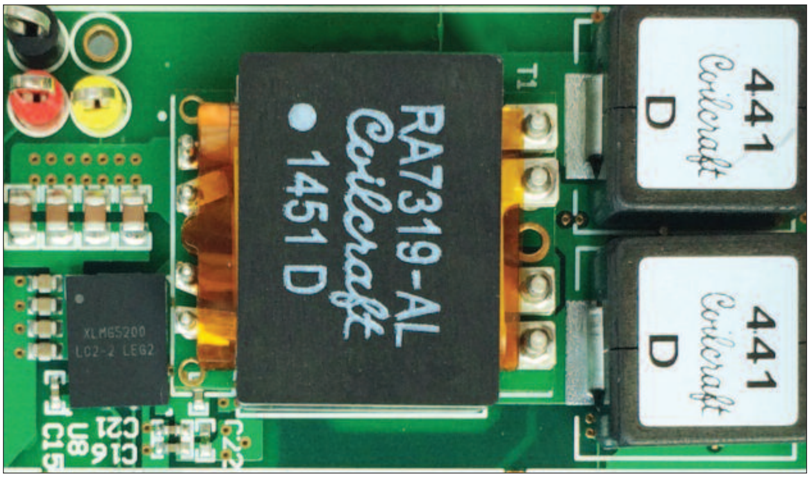


Figure 2: PCB Layout of 48V to PoL converter

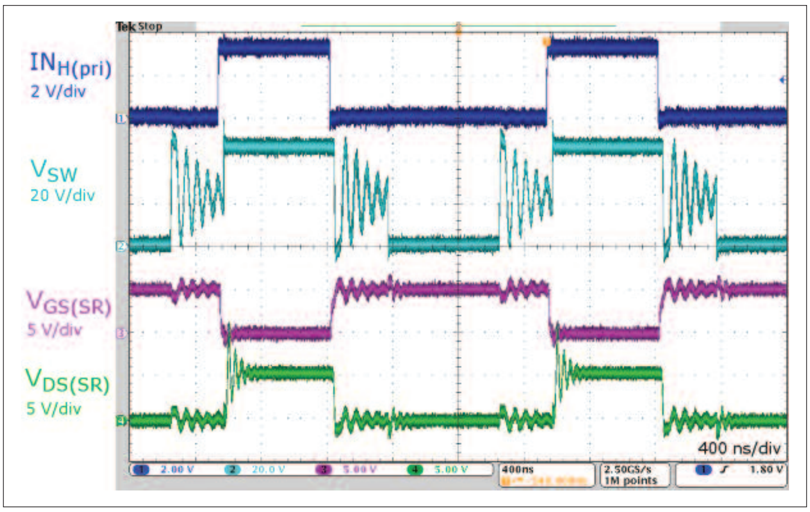


Figure 3: Oscilloscope capture from 48 V to 1.8 V converter

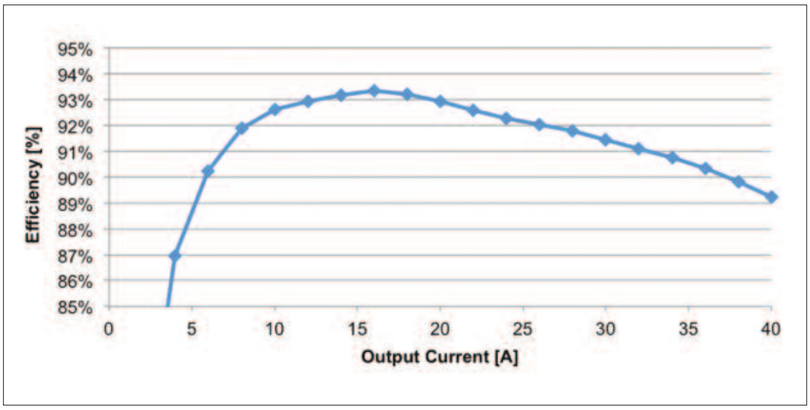


Figure 4: System efficiency 48 V to 1.8 V at 500 kHz

ringing on the output waveform which is minimized through good PCB and transformer design.

Figure 4 exhibits the efficiency of the converter operating at 500 kHz. It achieves a peak efficiency exceeding 93 % and a half-load efficiency of 92.9 %. This efficiency significantly exceeds the performance of a two-stage solution. At high load currents, the performance is impacted by DC and AC resistances in the circuit and the reverse recovery of the SR FETs. Further efficiency benefits can be realized by using GaN in the SR stage to eliminate reverse recovery loss.

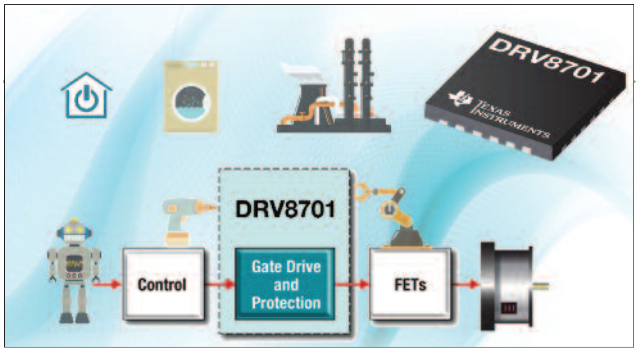
Conclusion

The advantages of GaN show strongly in this application, where the single-stage conversion can be done with higher efficiency and smaller size than traditional solutions, while simultaneously improving transient response. This article discussed the design of such a converter using a GaN half-bridge module which integrates two GaN FETs and an optimized driver inside a low-inductance package. This module, along with TI's controllers and MOSFET drivers, enables a compact, flexible solution for 48 V PoL converters such as the described 48 V to 1.8 V, 40 A converter achieving over 92 % peak efficiency.

Literature

[1] Narendra Mehta, GaN FET Performance Advantage Over Silicon, Power Electronics Europe, May 2015

[2] Texas Instruments, 80-V, GaN Half-Bridge Power Stage, LMG5200 datasheet, March 2015



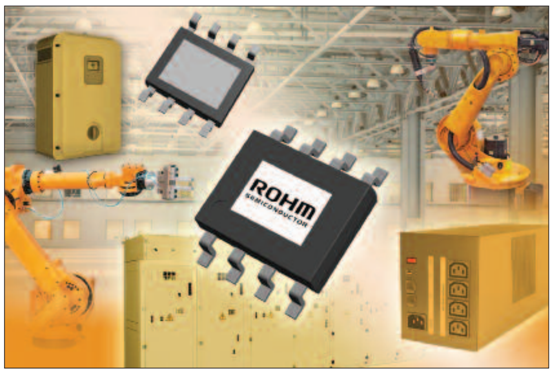
Brushed DC Gate Driver with Adjustable Current Drive

Texas Instruments introduced an integrated gate driver that offers adjustable gate drive settings with the flexibility to drive a wide range of external FETs, supporting multiple motors, speeds or varying loads. The DRV8701 enables designers to scale their platforms using a single gate driver across various brushed DC motor models in equipment such as white goods, household appliances, robotics, home automation, power tools, and industrial pumps and valves. With its adjustable gate drive, integrated two low-dropout regulators (LDOs), a current-sense amplifier and full protection features reduces system board footprint by 40 % compared to and discrete solutions by replacing up to 45 discrete components. The DRV8701 is available now in a 4 mm by 4 mm quad flat no-lead (QFN) PowerPAD™ package, a thermally enhanced standard-size package designed to eliminate the need for bulky heat sinks and slugs. Pricing starts at $0.92 in 1,000-unit quantities. Engineers can test the new gate driver in their system with the DRV8701EVM evaluation module, which also incorporates the MSP430G2553 ultra-low power microcontroller and CSD18532Q5B NexFET. The EVM supports up to 15 A current in a compact form factor that is about the size of a business card.

www.ti.com/drv8701-pr-eu

AC/DC SiC Control IC

ROHM has recently announced the development of an AC/DC converter control IC BD7682FJ-LB designed specifically for SiC MOSFET drive in industrial equipment such as servers and other high-power applications. Compared to Silicon MOSFETs used in conventional AC/DC converters, SiC MOSFETs enable AC/DC converters with improved power efficiency by up to 6 %. Furthermore, components used for heat dissipation are not required (50W class power supplies), leading to greater compactness. However, until now there has not been a control IC that can sufficiently draw out the performance of SiC MOSFETs, particularly in AC/DC converter systems. As a result designers are faced with numerous problems related to power consumption and stability in a variety of high power applications. ROHM utilizes market-proven analogy technology with SiC power semiconductor expertise to develop the industry's first AC/DC converter controller specialized for driving SiC MOSFETs. The specification of the new BD7682FJ-LB also include multiple protection functions that enable support for high voltages up to 690 VAC, making them suited for general 400 VAC industrial applications. And in addition to overvoltage protection for the supply voltage pin and brown in/out (undervoltage) countermeasure for the input voltage pin, overcurrent and secondary overvoltage protection functions are included, enabling continuous operation in industrial equipment while improving reliability considerably.



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