Exploring the frontiers of GaN power devices

GaN power semiconductors allow for innovation in the harsh radiation environments of space applications, says **David Reusch**

Improvements to power semiconductors are vital to overall system performance. Advances in design techniques and improved component technologies enable engineers to achieve higher efficiency and higher power density while maintaining high reliability and minimising cost.

Gallium nitride (GaN) power semiconductors offer designers of high-reliability (hi-rel) power systems a sudden and significant improvement in electrical performance over silicon power mosfet predecessors (see Table).

It can be hard to estimate how the GaN device improvements referenced in the table will translate into real-world circuit performance where the power semiconductor is part of a larger system.

The VPT SGRB10028S is a space-qualified DC-DC converter based on EPC Space GaN technology. It is a radiation-tolerant, high-efficiency device with a fixed-frequency reduced voltage switching topology for low input and output noise.

The SGRB series has been designed specifically for space-borne telecommunications where high efficiency, low noise and radiation tolerance are imperative. It was developed to increase power supply efficiency while reducing system size, weight and cost.

The SGRB10028S has a 100V input, an adjustable single output of 12-28V, output power up to 400W and efficiencies above 96%. The phase-shifted, full-bridge circuit topology with GaN devices is used for both the primary devices and the secondary synchronous rectifiers.

Voltage stresses

The first entry in the table, VDS, the maximum drain-to-source blocking voltage of the power semiconductor, must be large enough to support the off-state drain-to-source voltage shown in Figure 1. This blocking voltage must also have adequate margin, which includes circuit voltage ringing, introduced mainly by parasitic inductances in the circuit. Most of the blocking voltage is dependent on the isolation transformer leakage inductance spike and the design input and output voltages. Thus, for GaN and silicon (Si) designs, the voltage stresses and therefore maximum drain-to-source blocking voltage will be the same.

Device on-state drain-to-source resistance determines conduction losses. In this design example, a high current is required to reach the high-power demands and the lowest on-resistance devices available were selected, which are similar between GaN and Si power semiconductors at 26mΩ and 28mΩ, respectively.

While the on-resistance of these two power semiconductors is similar, the device area and PCB space required by each are very different. The GaN power semiconductor is about 1/10 of the size of the Si mosfet. Figure 1 shows that the GaN power semiconductor occupies roughly 5-10% of the board space on one side of the design. If the

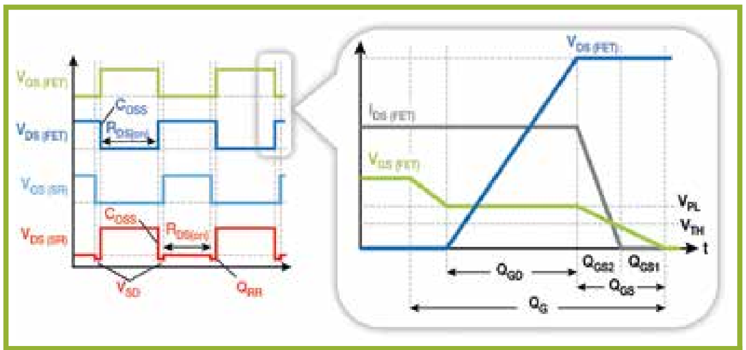

Figure 1: Ideal waveforms and loss mechanisms for a hard-switched synchronous power converter including voltage and resistance

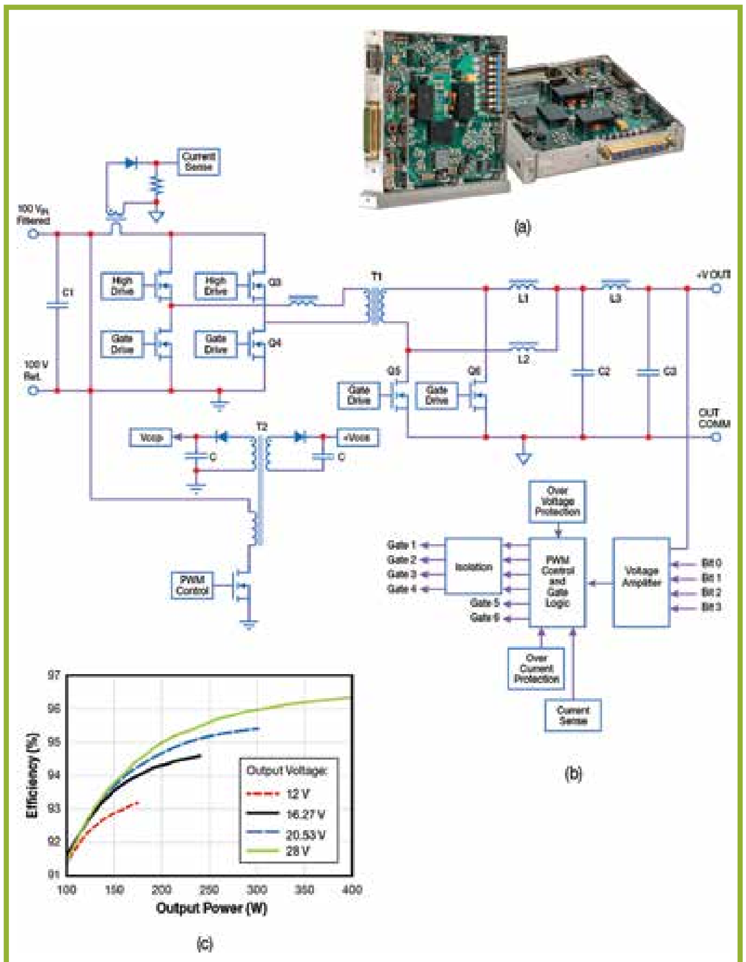

Figure 2: The VPT SGRB10028S DC-DC converter (a) hardware, (b) topology, and (c) VIN = 100V efficiency

Table: Comparison of radiation-hardened GaN and Si power semiconductor devices

Device characteristic	200 V GaN (EPC Space FBG20N18B)	200 V Si mosfet (Infineon IRHNA67260)	Technology comparison
V_{DS}(V)	200	200	Same
$R_{DS(ON)}$(mΩ)	26	28	Similar
Device area (mm^2)	23	237	10 x reduction
Q_G(nC)	6	240	40 x reduction
Q_{GD}(nC)	2	60	30 x reduction
Q_{GS}(nC)	2	70	35 x reduction
C_{OSS}(pF) at 50 V V_{DS}	300	900	3 x reduction
C_{OSS}(pF) at 1 V V_{DS}	950	10000	10 x reduction
Q_{RR}(nC)	0	11700	Infinite reduction
V_{DS}(V)	1.75	1.2	1.5 x increase

designer had to use a 10 times larger Si mosfet, the board space occupied would jump to more than 50%. This would greatly impact the design of the other components, in particular the magnetics, forcing them to become smaller and limiting the use of integrated magnetics, both of which increase losses and degrade converter efficiency. Advantages like this do not show up in the table and Figure 1, but have a major impact on system performance.

As the device size shrinks, the losses must be reduced proportionally to avoid becoming a thermal bottleneck in the design. The remainder of the table relates to switching-related losses that occur during a switching cycle.

Gate drive losses

Gate charge (QG), is the total amount of charge required to turn on the device, shown in Figure 1. For the GaN device, QG is 40 times lower than the Si device, resulting in lower gate drive losses. Another benefit of lower gate drive loss is a reduction in the power required by an auxiliary power supply, which often occupies notable board space and has non-negligible power loss.

Gate-to-drain charge (QGD), often referred to as Miller charge, is the amount of charge during voltage commutation, shown in Figure 1. For the GaN device, QGD is 30 times lower than the Si device, resulting in lower voltage commutation losses.

Gate-to-source charge (QGS), is the amount of charge needed to reach the device's threshold voltage (QGS1) and rise to the Miller plateau voltage (QGS2), shown in Figure 1. For the GaN device, QGS is 35 times lower than the Si device, resulting in lower current commutation losses, which occur in the QGS2 timing of Figure 1.

Output capacitance (COSS) is the sum of drain-to-source and gate-to-drain capacitance. Output capacitance must be discharged or soft-commutated during each switching cycle. For the GaN device, COSS is three to 10 times lower than the Si device, respectively for high (50V) and low (1.0V) blocking voltages. In hard-switching applications, output capacitance loss is related to VDS2 and the higher blocking voltage output capacitance condition is of more importance. In soft-switching applications, where soft-switching is generally achieved in relation to VDS, the larger output capacitance value, which occurs at lower blocking voltages, is of more importance. Regardless of the design topology, the GaN device has lower COSS-related losses.

Reverse recovery (QRR) is the stored charge in the body diode of a mosfet that must be discharged before the mosfet can block voltage and is a major source of loss in a synchronous rectifier. For the GaN device, which has no minority carriers and zero QRR, reverse recovery losses are infinitely lower than the Si device.

Forward voltage

Source-to-drain forward voltage (VSD), also known as body diode forward voltage in mosfets, is the conduction voltage when a synchronous rectifier device is off and must conduct current for generally a short dead time before the control device is commanded on, as shown in Figure 1.

For the GaN device, the forward conduction losses are 1.5 times higher than a Si device. GaN also has significantly lower charges/capacitances and associated losses compared to a Si mosfet.

For the design shown in Figure 2, the GaN power semiconductor losses are reduced by a large enough factor that, at only 1/10th the size of a Si mosfet, the GaN device is still not the thermal bottleneck of the system. ☐

About the author

David Reusch, PhD is principal scientist at VPT in collaboration with EPC Space.

EPC-Space is a joint venture between GaN fet provider EPC and VPT, a Heico company, which specialises in DC-DC power converters, EMI filters and custom engineering services for avionics, military, space and industrial applications.