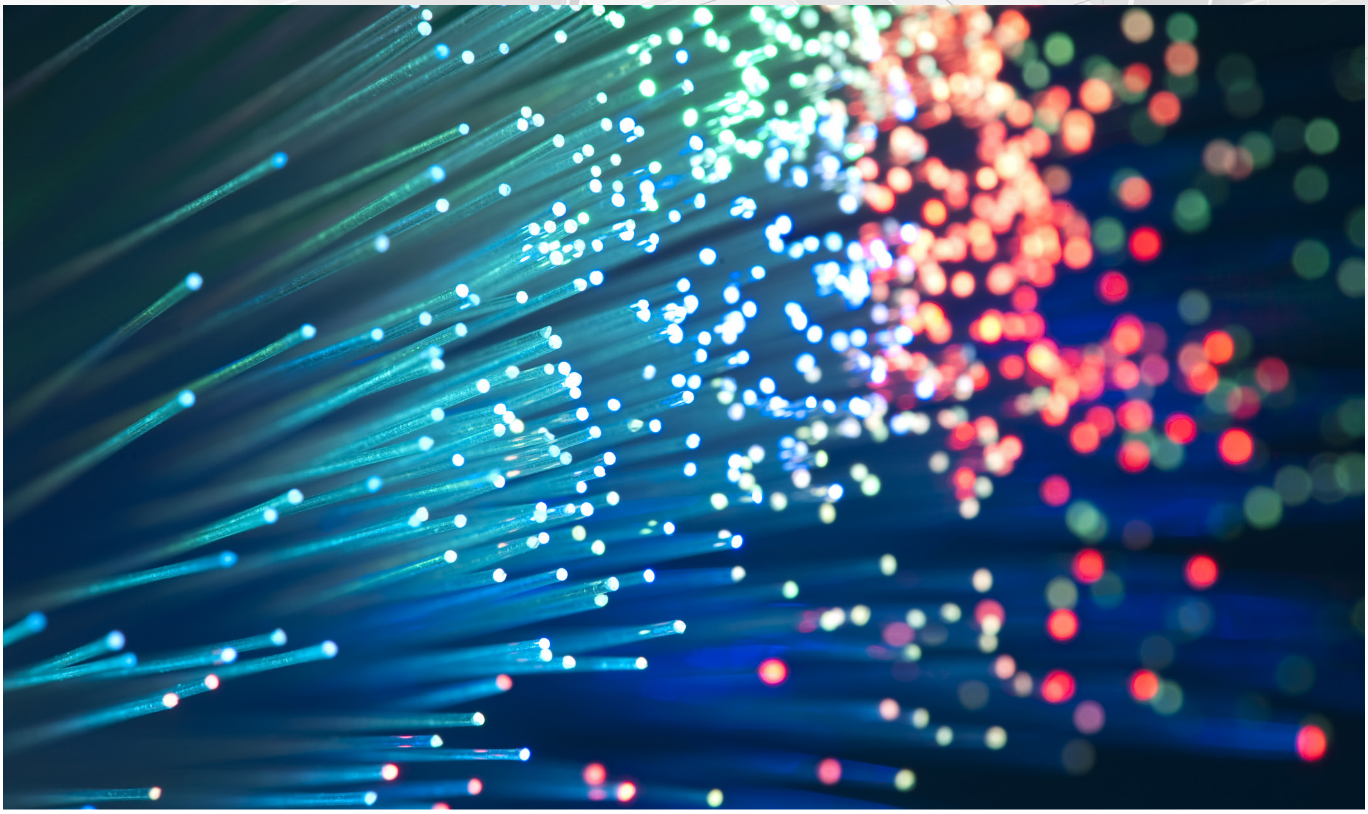
Gallium Nitride (GaN) and Silicon Carbide (SiC)

Devices and Technology



GaN Enabling a Revolution in Charger Design

By Chris Lee

Gallium nitride (GaN) switch technology has enabled a major advance in the miniaturization of chargers and adapters.

GaN transistors switch very efficiently. This allows the development of converters that can either operate at much higher switching frequency than a circuit using equivalent silicon devices, potentially reducing transformer size, or provide solutions that deliver significant system efficiency improvements, reducing or eliminating the need for heat sinks.

By using GaN-based transistors and ICs, designers have been able to deliver small chargers — often also incorporating USB PD interfaces and fast-charge protocols — that significantly increase the amount of power that can be delivered for a given size, and which can be used to drive a wide variety of personal portable devices in all corners of the world.

Power Integrations has been at the forefront of the GaN revolution, delivering complete power supply solutions in volume to major customers. This article explores the capabilities of GaN devices and discusses strategies for addressing the challenges raised by the technology.

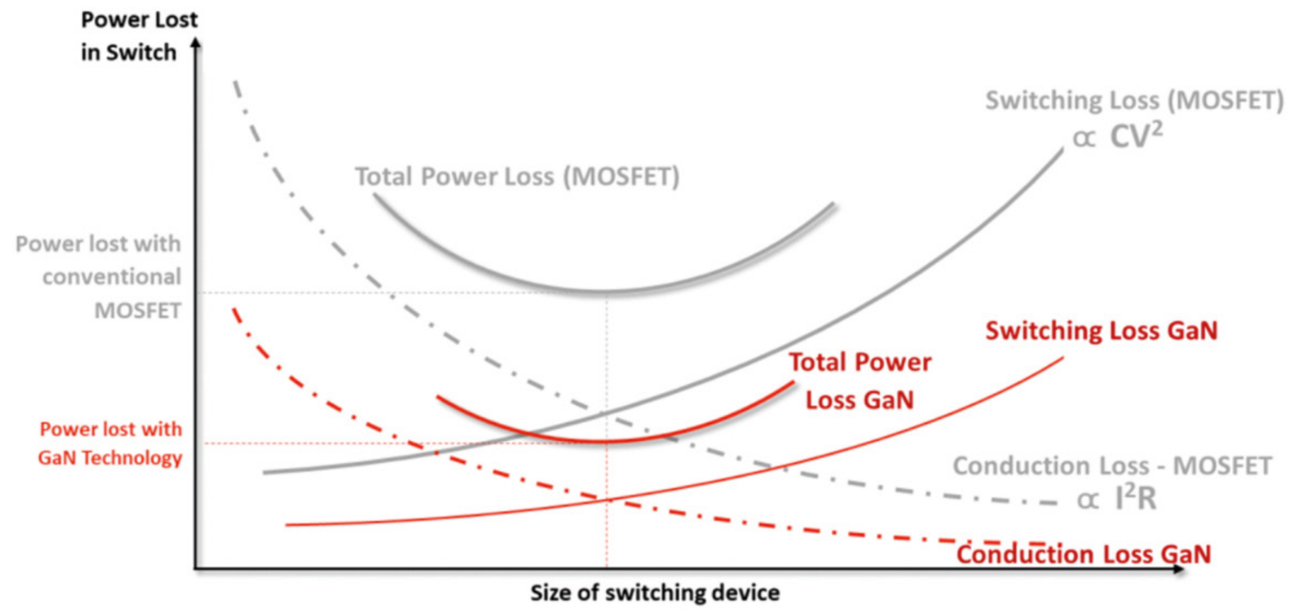


Figure 1: GaN technology (shown in red) is able to reduce the total switching loss for a power switch operating at offline flyback voltages (switch rating 600–750 V).

HOW GOOD IS GAN? CHANGES TO POWER ARCHITECTURES

The 1-in.[3] charger became an iconic footprint for low-power flyback chargers a little over a decade ago. The technology pushed the size envelope as far as efficiency limits would allow and was the best that could be achieved with the technology available at the time. The power switch in any flyback design is the largest contributor to power loss, dissipating power during each switch transition and during conduction. Switching losses and conduction losses are inversely proportional to each other. As switch die area is increased to

Description	Full-Load Efficiency	Heat Energy (W)	Surface Area (Adapter)	Thermally Limited Volume
Legacy Adapter	87%	5.85	1	1
“High Efficiency” Design	90%	4.5	0.77	0.67
InnoSwitch	92%	3.6	0.62	0.48
InnoSwitch3	**94%**	**2.7**	**0.48**	**0.3**
InnoSwitch3 GaN	**95.5%**	**2.0**	**0.35**	**0.21**

Figure 2: As efficiency in power switches increases, lost energy (heat) decreases. The reduction in heat means that the surface area needed to conduct heat away from the device also decreases. The reduction in surface area means that the thermally limited volume of the power supply (the minimum size the power supply must be in order to process the heat generated) also reduces. Interestingly, the highest-efficiency design is also achieved with a quasi-resonant flyback power supply operating at an average switching frequency of 70 kHz. Thermally limited volume ∝ ((1-efficiency)/6)3/2

reduce $R_{DS(ON)}$ (conduction loss), switching loss increases.

Different silicon transistor technologies — super-junction, vertical, and lateral — all compete to reduce the combined losses in the device. GaN, however, dramatically improves switching efficiency in chargers and adapters by fundamentally reducing both switching and conduction losses. A comparison between technologies that illustrates this performance shift is shown in Figure 1. GaN devices are intrinsically rugged, the avalanche breakdown seen in conventional MOSFETs does not occur in GaN switches, making them ideal for use in offline power conversion in regions where mains voltage is subject to wide variation.

The change in switching efficiency created by the introduction of the GaN switch also dramatically reduces the thermal challenges, leading to a further miniaturization of chargers. A summary of those changes is shown in Figure 2, which compares the characteristic performance of legacy and previous high efficiency adapters with those powered by Power Integrations' InnoSwitch AC/DC converter ICs, including the latest family members, which use GaN power switches.

The step change in efficiency from GaN switches first began appearing in chargers and adapters in 2018 and has led to a dramatic reduction in charger/adapter footprint and a volume ratio that closely matches the one described in Figure 2. Figure 3 shows the latest GaN charger, which uses Power Integrations' PowiGaN GaN transistor technology compared to both the groundbreaking 2008 design and a high-performance design using the best available silicon switch technology.

ADDRESSING THE CHALLENGES OF GAN

GaN devices have reshaped power density thinking. The most successful power designs harness

Parameter	Cube	Higher Density Cube	2020 Prototype
Date	2008	2019	2020
Topology	Isolated QR Flyback	Isolated QR Flyback	Isolated QR Flyback
Average $f_{(SW)}$	70 kHz	70 kHz	90 kHz
Transistor Technology	Vertical Silicon	Lateral MOSFET	PowiGaN™ GaN
Switch $V_{DS(MAX)}$		650 V	750 V
Power Delivery (W)	5 W	18 W	30 W
X x Y x Z (mm³)	26.3 x 27.9 x 27.5	27.4 x 29.8 x 27.4	27.4 x 29.8 x 27.4
Volume (mm³)	20,000	22,000	22,000
Relative Power Density	1	3.3	5.5

Figure 3: The introduction of GaN technology has dramatically reduced the size of power chargers. Switching frequency has remained similar, and topology is somewhat similar, but improvements to power switch technology and significant integration have dramatically improved performance.

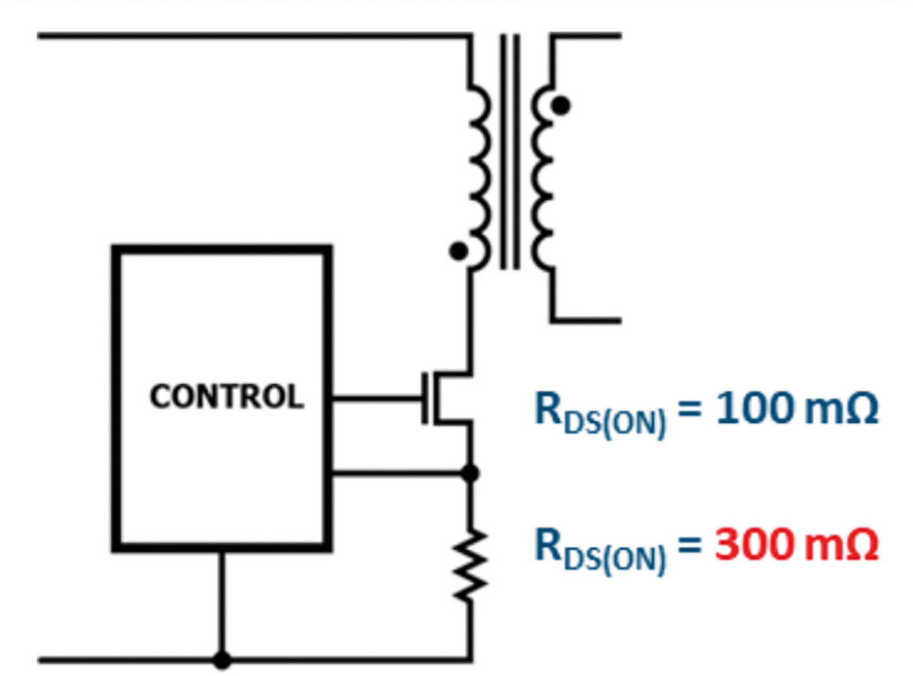


Figure 4: The requirement for current-sense resistors in discrete GaN circuits is a challenge. In order to induce a rapid loop response, resistance must be increased to create sufficient voltage drop for strong biasing of the current-sense circuit. In the simplified schematic above, the resistance values are those prescribed by an actual reference design.

the increased switching efficiency to reduce converter size. Driving GaN devices presents challenges for the designer which must be overcome in a practical design. GaN devices switch very quickly. Parasitic capacitances between the gate and source connection, and the gate-drain capacitance normally seen between the Gate well and the Drain substrate (Miller capacitance), are very small (in the order of a few nC) which ensures very fast switch transition leading to low switching losses.

In order to provide a shutdown of the GaN device while avoiding false triggering, discrete current-sense circuits insert a series impedance that approaches (and, in some cases, exceeds) the on-resistance of the GaN switch. The large resistance is necessary to ensure accurate short-circuit detection and fast loop response for the protection circuit. In designs striving for maximum efficiency this is clearly a disadvantage; engineers are therefore turning to integrated lossless current sensing circuits that build a SenseFET into the structure of the GaN device.

Left unregulated, the fast switch transition will generate significant noise issues in the circuit. The combination of trace inductance and switch capacitance causes high frequency ringing during

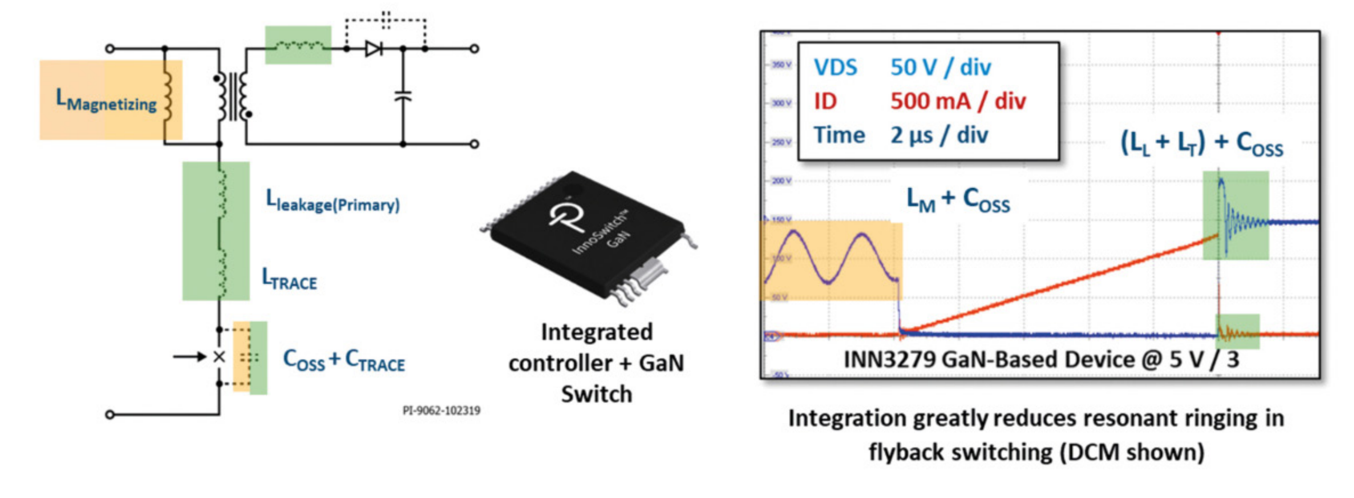


Figure 5: Elements contributing to switching oscillations during transitions. Note the contribution of secondary trace inductance magnified by the transformer turns ratio to primary leakage inductance.

switching events which cause noise problems with circuit operation. For GaN switches, it is important to reduce parasitic inductance by reducing the size of the switching loop (and secondary rectifier loop which appears as "extra" leakage inductance in the transformer) by a combination of good layout and GaN integration. Figure 5 shows the circuit elements that contribute to ringing in a GaN switching circuit.

In addition to controlling loop inductance, consideration must be made in sizing the gate drive circuit appropriately for the size of power switch and gate charge characteristics. Fast gate transition is desirable to reduce crossover losses (gate voltage and current transitioning at the same time), but to reduce EMI it is important that this rate of change is limited by a combination of gate resistance and drive source/sink current which should be matched to the GaN device being used. Figure 6 compares the transition rates for GaN and Si switches driven from an appropriately-sized gate driver.

There are several other aspects to consider when driving power FETs, such as how to control the normally-on GaN structure during start-up; the comparison of the breakdown and avalanche associated with excess drain voltages in silicon switches to the more robust parametric-shift phenomenon seen in GaN devices; optimization of switching frequency and the trade-offs in transformer size versus smaller thermally limited volume; the limits in circuit efficiency imposed by programmable power conversion and USB PD and PPS. Each one is a separate article in its own right.

GaN devices provide an opportunity to provide dramatic improvements in the size, appearance, and even the appeal of power conversion devices in modern electronics equipment. The benefits are not limited to adapters. Appliance applications benefit from the removal of heat sinks which lessons mechanical issues reducing vibration and transport induced failure, while metering and industrial applications are beginning to take advantage of the ruggedness of GaN switches when there are exposed line voltage fluctuations. GaN is no longer nascent; market adoption is already well advanced with Power Integrations alone shipping millions of power supply ICs that include GaN switches. Engineers will continue to innovate and provide better switching solutions based on the benefits the technology provides, the future is bright — the future is GaN, and the future is now.

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