D-mode GaN Remains a Natural Fit for High-Voltage Applications

Davide Bisi, Senior Manager, Device Design and Integration
Ashish Ekbote, Senior Manager GaN Application Engineering
Aalok Bhatt, Senior Manager, GaN Product Marketing

Renesas D-Mode GaN combines the best of both GaN and Silicon – high-speed, high-voltage GaN switching with a robust 4V threshold gate compatible with standard gate drivers and extensive package variety which is not available with other GaN technologies.

GaN Power Devices: Driving Efficiency Across Voltage Ranges

The world is seeing an unprecedented surge in power demand. From personal devices to AI infrastructure, solar energy to battery systems and servo motors to automotive systems, higher power levels are required with greater efficiency in smaller system sizes. Gallium Nitride—with its superior semiconductor properties—is enabling the revolution. A true renaissance in power electronics is being fueled by the advent of the fastest and smallest power switches ever made.

But not all GaN devices are alike. Depending on voltage requirements, one device architecture is preferred over another. For low-voltage applications with device ratings up to 200V, enhancement-mode GaN (E-mode) is a great candidate. Single-chip E-mode can achieve record low resistance below 1 mΩ and although its threshold voltage is small (typically 1.4-1.6V) it doesn't normally require ancillary driving components to ensure safe operations at low voltage. But for higher voltage applications, for example those connected to the AC grid or high-voltage buses (400V or 800V), noise immunity and transient

tolerance are essential. That's where depletion-mode GaN (D-mode) comes into play. In the same package, a high-voltage D-mode GaN device is connected in cascode configuration with a low-voltage silicon MOSFET, resulting in a product with GaN speed *and* silicon's gate robustness, with high threshold voltage up to 4V and compatibility with standard gate drivers.

Simplest Gate Drive

D-mode GaN is a natural solution for high-voltage applications combining the strengths of two proven technologies: high-voltage D-mode GaN HEMTs and low-voltage silicon MOSFETs, see figure 1. The high threshold (up to 4V) and high gate margin (up to 20V) make cascode GaN products compatible with standard gate drivers, without the need for negative drive, special supply voltages or extra protection components. Effectively, it is like driving silicon at the speed of GaN. In contrast, E-mode GaN has lower Vgs threshold voltage which can introduce the risk of shoot through or false turn-on in high power applications and normally requires negative gate bias at turn off, increasing the driver circuit complexity, component counts and cost.

Standard gate drivers with standard supply voltages (9V to 12V) can be used with D-Mode GaN. The gate of the silicon MOSFET is fully insulated, resulting in very low leakage and no gate current required to maintain the device on. No additional circuitry like clamping diodes, decoupling capacitors, ferrite beads or snubbers are required, making design easy with the smallest board area and lowest BOM cost.

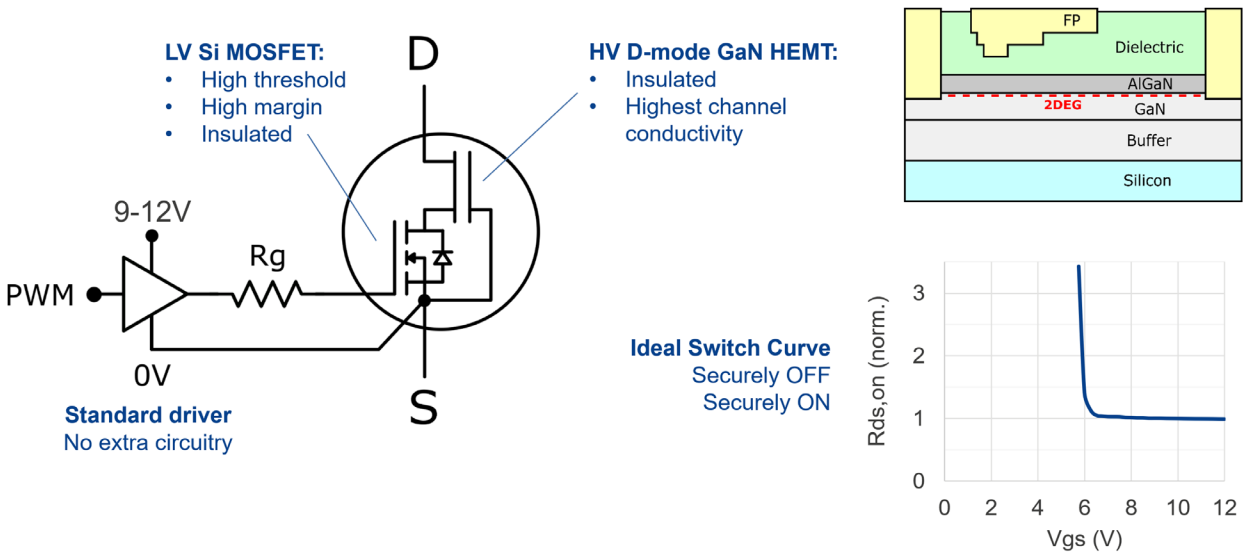

Figure 1: Renesas GaN combines the strengths of D-mode GaN and silicon MOSFETs.

Cascode architectures are an example of the excellent heterogeneous integration. Renesas implements cascode products through a stacked-die approach, where the silicon MOSFET—which has the drain at the back—is attached *on top* of the Gallium Nitride chip. With this stacked approach, no extra package area and no additional wires are needed for the connections. The number of wires is the same as a single chip solution which results in a low inductance device, eliminating ringing and increasing di/dt immunity, see figure 2.

The current Gen IV Plus GaN platform takes the advantages of previous-generation GaN devices to the next level, offering both higher performance and lower cost. The platform also delivers up to a 50% improvement in the Ron × Qg figure of merit (FOM) and >20% improvement in Ron × Qoss FOM compared to previous generation devices, enabling higher efficiency and power density in high-voltage applications.

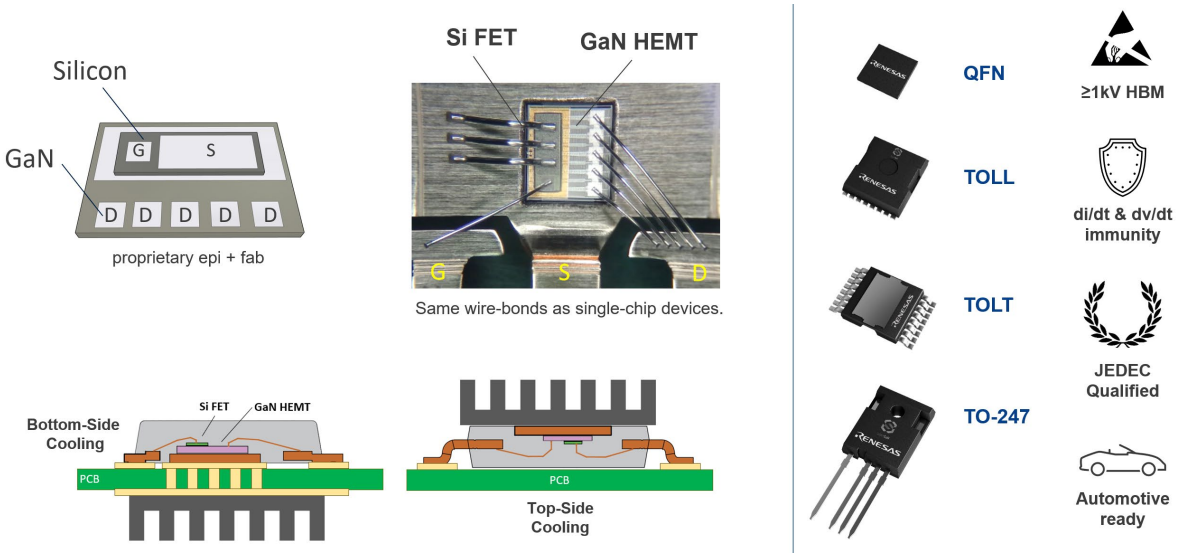

Figure 2: Renesas GaN architecture uses a stacked-die approach with the silicon MOSFET on top of the GaN chip in industry-standard packages for easy design compatibility.

In addition to inherent architecture advantages, Renesas D-mode GaN adds value for designers in several other respects:

Proprietary epi platform: GaN devices are made with Renesas GaN epitaxial layers grown on low-cost silicon substrates with epi IP developed over more than 15 years, resulting in stable dynamic Ron *and* high breakdown voltage..

High-quality wafer fab and device processes: Devices are fabricated in Renesas' own GaN fab, maintaining end-to-end control of process IP and know-how.

Industry-standard and performance packaging options: The stacked-die GaN is packaged in industry-standard packages such as TO-, SMT and top-side cooled with or without Kelvin source and pinout

compatibility to other major supplier products, ensuring broad market adoption where second- and third-source compatibility is essential. Renesas D-mode products range from compact QFN for low-power designs to bigger surface-mount packages such as DPAK, D2PAK, TOLL or TOLT for higher power. With high gate margin and exceptional di/dt and dv/dt immunity, Renesas GaN is also available in large through-hole packages like TO-220 and TO-247, further increasing the application reach. This is not easily achievable with E-mode GaN as the p-type gate with no gate voltage margin will fail under di/dt-related events without additional protection circuitry added inside leaded packages like the TO-247, an industry workhorse also used for SiC replacement.

Reliability and robustness: All Renesas GaN products feature high ESD immunity (≥1 kV HBM). The products are qualified to JEDEC standards and beyond. In addition to conventional JEDEC standard testing for high temperature, reverse-bias and gate-bias, accelerated humidity tests, temperature cycling and package integrity, Renesas carries out additional qualification tests targeted specifically to GaN, including dynamic on-state resistance, switching and transient reliability and low-temperature reliability.[1] These thoroughly designed tests ensure product robustness in all environmental conditions, not only for consumer and industrial, but also for automotive use. The result is 400+ billion hours in the field, including both lower and higher power (multi-kW) applications with a sub 0.1 FIT rate, a claim no other GaN manufacturer can make today.

Transient capability: Renesas GaN has high margin. It has a 650V *continuous* rating and an 800V *transient* rating with drain leakage well under control, never rising above 2µA thanks to the fully insulated GaN chip, which is a key enabler for industrial as well as automotive applications. Some may point out that SiC is rated for 750V, in that case it can be said that GaN is rated for 800V in terms of *transient* rating, which is what really matters during switching.

Short circuit capability: Renesas GaN is technologically ready to enable the capability to withstand short-circuit events, a critical requirement in many motor drive applications. Using a Renesas-patented approach, the gate of the D-mode GaN can be tuned to limit the saturation current and increase the short-circuit withstand time. This adjustment requires just a single-layer modification in the HEMT design. Depending on customer needs—whether one microsecond, two microseconds or even five microseconds—the design can be tailored to meet specific requirements with a predictable trade-off with on-resistance[2] as in any semiconductor power switch. Achieving this level of short-circuit robustness and design flexibility is difficult to realize with other GaN technologies.

Low reverse voltage drop: As depicted in figure 1, there's a built-in low-voltage body diode in the silicon MOSFET. During deadtime, the diode conducts current and because it’s made with silicon (a

[1] Steven Wienecke, IRPS 2025

[2] Bisi et al., APEC 2024

narrow band-gap material), the voltage drop is very small (less than 2V), achieving very efficient reverse conduction. At high switching frequencies where dead time constitutes a significant portion of the switching cycle, a low-voltage drop yields a substantial efficiency improvement compared to E-mode solutions where the lack of a body diode and the need for a negative drive causes a significantly higher voltage drop (as high as 6V or more). When it comes to the reverse recovery, the body diode of the silicon MOSFET doesn't add any significant reverse recovery charge because the MOSFET is designed for low voltage (30V) with lowest charge and resistance. It is in fact the GaN HEMT, with low parasitic capacitance and no minority carries that blocks high voltage (650V and beyond) with no Qrr and minimal Qoss.

Slew rate control: While D-mode GaN can switch fast, enabling designers to benefit from low cross-over and switching losses, if slower transients are needed to meet EMI targets or other application-specific requirements (like dv/dt limits in motor drives), it allows for slew rate control. A close examination of the cascode structure reveals an inherent capacitive coupling between the gate of the silicon MOSFET and the drain of the GaN HEMT (see figure 3). This coupling offers a feedback loop controlled with the gate resistor (Rg). By tuning the Rg from low to high, the transitions slow down during both turn-on and turn-off through the entire voltage range, confirming that slew rate of cascode GaN can be tuned as easily as any other power device.

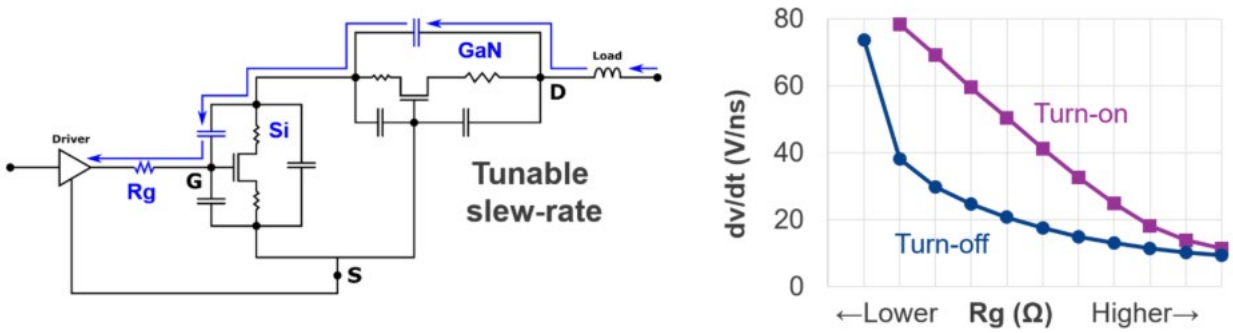

Figure 3: The Inherent capacitive coupling between the gate of the silicon MOSFET and the drain of the GaN HEMT offers a feedback loop to easily control the slew-rate in D-mode GaN cascode architectures through the gate resistor.

Great for Hard Switching

When it comes to performance, D-mode GaN offers the highest levels of efficiency across the power spectrum, including both hard and soft switching. The latest generation products were tested in a 400V half-bridge configuration switched at 100 kHz with hard commutations as shown in figure 4. The device has

an on-state resistance of 30 mΩ in a TOLT package and is driven with a commercially available driver with a gate voltage of 0V to 12V. The gate loop has one gate resistor for turn-on and one gate resistor for turn-off. No additional circuitry, like snubbers or ferrite beads, is added to the board. See the Designing with Renesas High-Voltage GaN Devices app note for a step-by-step approach to implement Renesas GaN with simple gate drive, as well as layout recommendations and measurement results.

The switching waveforms are extremely clean with fast transient above 60V/ns, minimal overshoot and no ringing. Even at high current, the device achieves a fast rise time of 5 nanoseconds thanks to high transconductance and drain saturation current, and very competitive turn-on and turn-off delays. Because of the fast, clean transients, this converter achieves 99.3% peak efficiency and an output power tested up to 4.5 kW with an estimated junction temperature of 90°C, leaving ample margin towards the 150°C maximum rating.

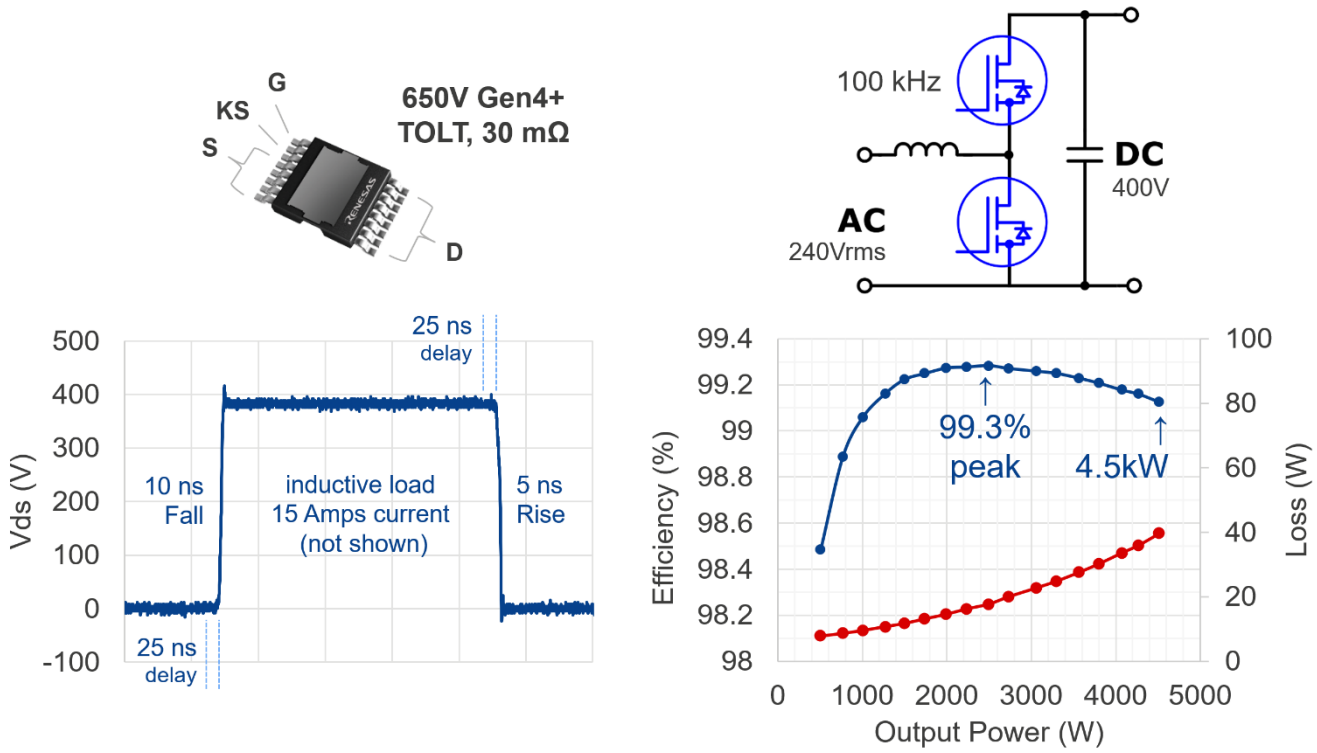

Figure 4: Clean switching waveforms of Renesas GaN with fast rise time leading to 99.3% efficiency at 100 kHz hard switching with 4.5 kW max power.

Great for Soft Switching

Due to its excellent switching characteristics, D-mode GaN excels not only in hard switching but soft switching, too. The research team at the University of South Carolina led by Professor Kristen Booth

implemented Renesas D-mode GaN in an ultra-compact DC/DC converter using a resonant LLC topology[3]. The circuit has a switching frequency of 1 MHz and is capable of achieving 5 kW of power with high efficiency due to the extremely fast ZVS transition times of D-mode GaN. Renesas GaN can achieve 25 nanoseconds turn-off delay and less than 10 nanoseconds fall time, completing a ZVS transition fast enough to efficiently work into the megahertz regime. Similarly, the Renesas Applications team has developed an ultra-compact (100 x 80 x 11 mm) resonant DC/DC converter for AI infrastructure using Renesas GaN between 650 kHz and 1 MHz (shown in figure 5) achieving top performance with lowest design complexity. Thanks to its modular approach, the converter can be used on both ±400V and 800V systems[4].

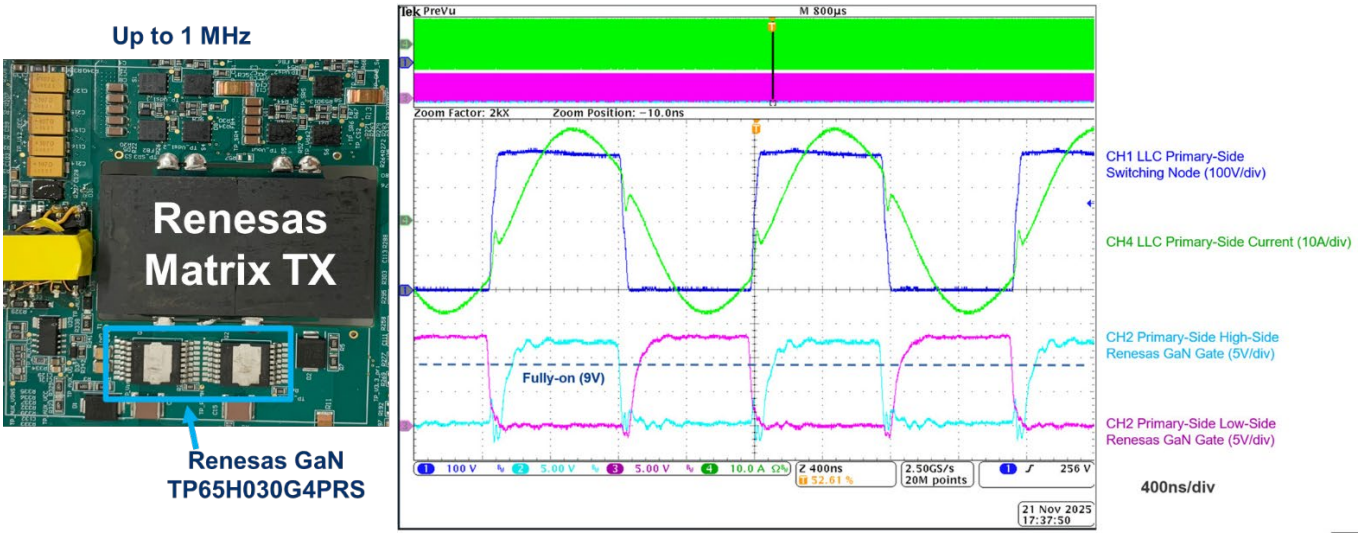

Figure 5: Resonant DC/DC converter using D-mode GaN switching between 650 kHz and 1 MHz achieves top performance with lowest design complexity.

Going Beyond 10 kW

GaN can serve not only low- to medium-power applications but also high-power applications, with increasing interest from customers in displacing SiC. Renesas has a 9 mΩ prototype which is one of the biggest GaN chips to fit into a discrete package. This device yields a peak power of 14 kW in hard-switching boost configuration, see figure 6. When even higher power levels are required, paralleling D-mode devices is straightforward. This is facilitated by the silicon MOSFET, which benefits from ample gate-drive headroom and inherent process tolerance, simplifying parallel operation and ensuring reliable performance. Renesas GaN device paralleling was demonstrated at APEC 2025 using three transistors

[3] Hussain et al. DOI: 10.22541/au.174405149.96282758/v1

[4] Power Architecture Evolution in Data Centers, Pietro Scalia et al.

switching in parallel[5]. The demonstration extended the power level up to 30 kW, at which point testing was limited not by the GaN devices themselves but by the capabilities of the measurement instrumentation.

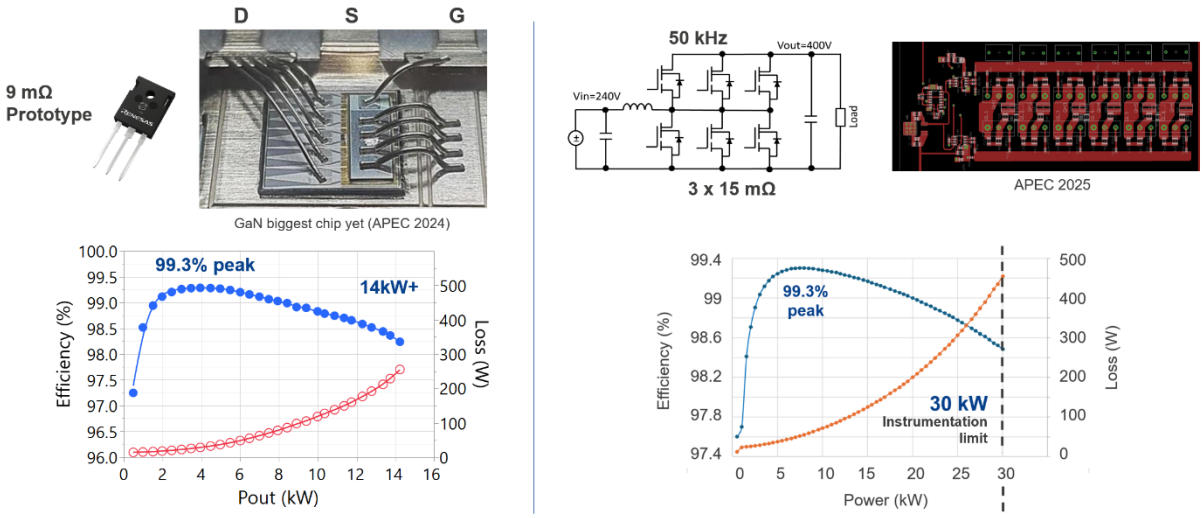

Figure 6: Renesas 9 mΩ prototype yields a peak power of 14 kW in hard-switching boost configuration (left) and demonstrates the paralleling of multiple devices (right).

Bi-directional Switch Capability

With the advent of single-stage topologies without PFC or DC-link capacitors for solar inverters or onboard chargers, Renesas is ready with bi-directional GaN capability as shown in figure 7. Bi-directional switches (BDS) are implemented using bi-directional D-mode GaN monolithically integrated in a common drain configuration to minimize specific Ron and connected in cascode configuration to retain the high-threshold, ease of usability and the built-in free-wheeling diode[6].

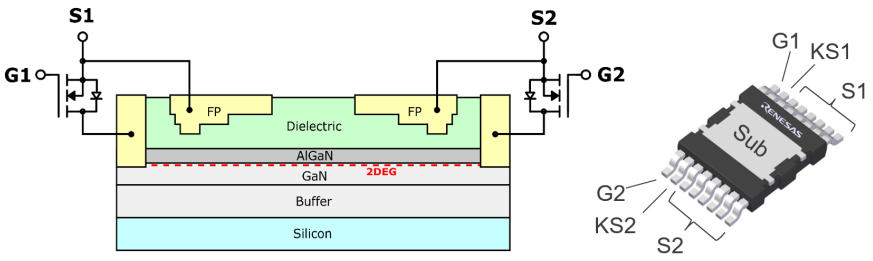

Figure 7: Bi-directional switches can be implemented with monolithic D-mode GaN for lowest specific Ron, while retaining a cascode architecture with the benefits of the simple gate drive and built-in free-wheeling diode.

[5] Huang et al., APEC 2025

[6] Bisi et al., PCIM 2025

Conclusion

With all the values in performance, robustness and ease of design, Renesas D-Mode GaN is a great fit for high-voltage topologies. Testing confirms it is best suited for both hard-switching for PFC and inverters, as well as soft-switching as in DC/DC converters and emerging single-stage AC/DC converters, as shown in figure 8.

Enabling simpler, more flexible gate driver design, higher threshold voltage and improved gate immunity makes Renesas GaN technology suitable for high-voltage and high-power applications. D-Mode GaN is ideal for high-voltage applications such as those in infrastructure, solar and automotive, as it is capable of covering the whole spectrum from low to high power and from low to high frequency with the simplest gate drive scheme, both surface mount and TO- packages and an ideal combination of high-performance and high-reliability.

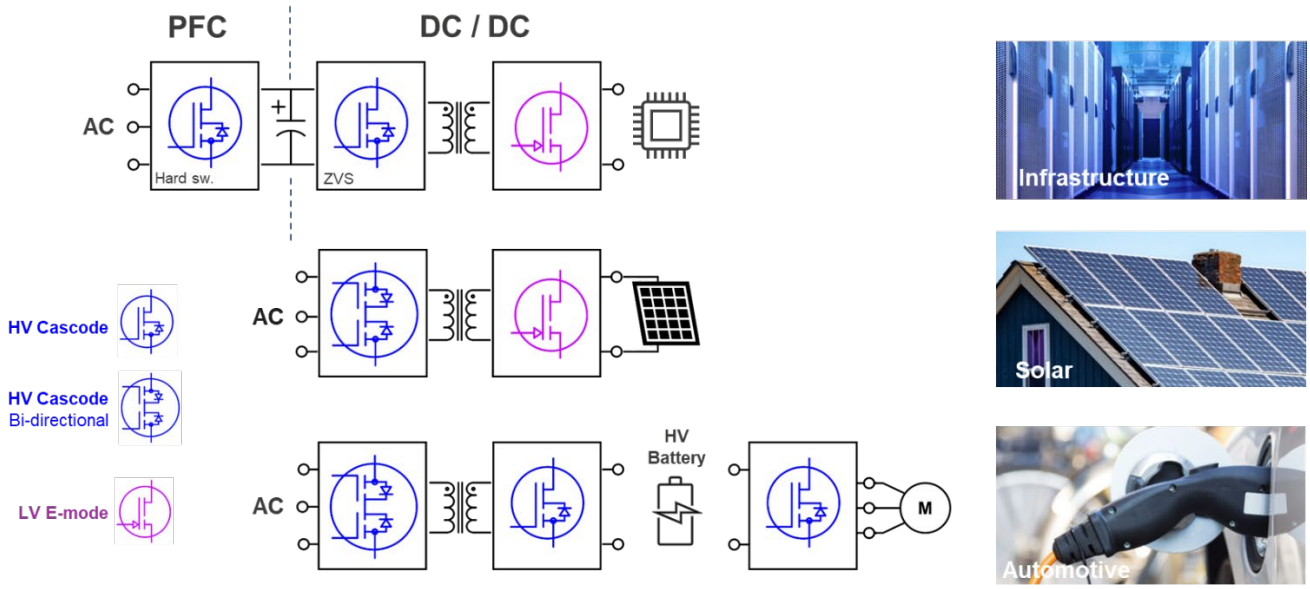

Figure 8: Cascode GaN is ideal for high-voltage topologies with key advantages in performance, transient immunity and robustness.

Visit renesas.com/GaN for more information including design resources, full datasheets and samples. See the complete discrete GaN portfolio at renesas.com/GaN-FETs.

(Rev.1.0 Mar 2020)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu, Koto-ku, Tokyo 135-0061, Japan
https://www.renesas.com

Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:
https://www.renesas.com/contact-us

Trademarks

Doc Number: R16WP0012EU0100