

Low-Voltage Gallium Nitride (GaN) Technology

Enabling Next-Generation Data Center and Motor Drive Applications

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Executive Summary

Low-voltage Gallium Nitride (GaN) power transistors spanning 40V to 200V represent a transformative leap beyond the limits of conventional silicon MOSFETs. The Renesas REXGaN® series of LV GaN transistors are engineered to unlock step-change improvements in efficiency, power density and reliability across two of the fastest-growing power electronics markets: mission-critical AI datacenter infrastructure and advanced motor drive systems.

In data center applications, the industry transition to 800 V DC bus architectures—driven by the insatiable power demands of AI workloads—requires semiconductor solutions that operate efficiently at unprecedented frequencies. 100 V GaN devices placed on the secondary side of LLC DC/DC converters reduce switching losses and improve overall efficiency. Their lower gate charge (Qg) minimizes gate-drive losses, while lower output capacitance (Coss) enables more inductive tank operation, extending the ZVS range at light loads. Additionally, the-zero Qrr of GaN devices eliminates reverse-recovery losses during above-resonant operation, resulting in improved efficiency and switching performance across a wider operating range.

Motors represent approximately 50% of global power consumption and with the growing demand for low-voltage drive systems across industries, GaN is expected to be a key enabler in reducing power losses and carbon emissions. In motor drive applications, GaN transistors enable switching frequencies of 100 kHz and above—a 5~10× leap over conventional silicon-based drives. This transforms system performance as current ripple and

torque ripple are reduced by up to 90%, motor core and copper losses decrease measurably, acoustic noise is significantly attenuated and passive filter components can be dramatically miniaturized. The result is a new generation of compact, efficient and highly integrated drive systems for applications ranging from industrial robotics, servo systems and humanoids to e-mobility and HVAC.

This white paper provides a comprehensive, application-agnostic treatment of low-voltage GaN technology, covering device physics, key performance advantages and quantified system-level impacts to guide engineers, system architects and decision-makers in evaluating and adopting GaN for their next-generation designs.

The Case for Low-Voltage GaN

Silicon power MOSFETs have underpinned power electronics for five decades. Since their commercial introduction in 1976, continuous process refinements have progressively reduced on-state resistance, improved gate characteristics and pushed voltage ratings higher. Yet, after 30 years of incremental optimization, silicon MOSFET performance is approaching its theoretical material limits—and the demands of modern power systems are rapidly outpacing what silicon alone can deliver.

Two macro trends are driving this urgency:

- AI workloads are scaling data center power densities at an extraordinary pace, pushing rack power from tens of kilowatts to over 1 MW. In this environment, even a 2% efficiency improvement translates to massive reductions in electricity cost and cooling burden across multi-megawatt installations.
- Electrification of mobility and automation—spanning industrial servo drives, robotics, drones, e-bicycles, power tools and HVAC—demand motor drives that are smaller, lighter, more efficient and capable of delivering superior torque control with minimal acoustic noise.

Wide-bandgap (WBG) semiconductors, and Gallium Nitride in particular, are answering this challenge. GaN's superior material properties enable devices that switch faster, lose less energy per switching event and operate at higher temperatures than silicon—all in a smaller die area. According to Yole's 2025 GaN Market Report, the GaN power device market is projected to experience double-digit growth, with significant penetration in the 48V - 100V motor drive and data center segments.

This white paper traces the path from GaN's material fundamentals through device architecture and then quantifies the system-level performance gains available in both data center power conversion and motor drive design. Engineers and architects across both domains will find a unified, technology-grounded basis for evaluating GaN adoption.

LV GaN Technology Fundamentals

GaN Material Advantages

Gallium Nitride is a wide-bandgap semiconductor with a bandgap of approximately 3.4 eV, compared to 1.1 eV for silicon. This fundamental difference confers several physical advantages that cascade into device and system performance:

- Higher breakdown field (~3.3 MV/cm vs ~0.3 MV/cm for Si), allowing GaN devices to block the same voltage in a much thinner, smaller drift region
- Higher electron mobility in the 2DEG channel ($>2000 \text{ cm}^2/\text{V}\cdot\text{s}$), enabling lower on resistance for a given die size
- Excellent thermal conductivity, supporting elevated junction temperatures
- Wide bandgap translates to inherently lower intrinsic carrier concentration, reducing leakage

These properties combine to enable GaN power devices that are 3-4 times superior to silicon in both specific on-state resistance (R_{sp}) and switching figure-of-merit (FOM) the two metrics that govern every aspect of power converter design.

Device Architecture: Enhancement-Mode GaN HEMT

GaN high-electron-mobility transistors (HEMTs) exploit the AlGaIn/GaN heterostructure interface, originally demonstrated by M. A. Khan⁽⁷⁾ and T. Mimura⁽⁶⁾. This interface produces a two-dimensional electron gas (2DEG), a thin, high-mobility conduction channel confined by quantum effects. By adding a p-GaN cap layer, device engineers shift the threshold voltage positive, achieving a normally-off (enhancement-mode) device that is safe for direct use in bridge configurations without a cascode.

For voltages below 100V, enhancement-mode (e-mode) GaN HEMTs are preferred over cascode configurations. Cascode approaches, which stack a low-voltage normally-off Si FET with a normally-on GaN device are not preferred at low voltages due to the $R_{ds(on)}$ contribution from the Si FET which can be significant in the low voltage GaN domain.

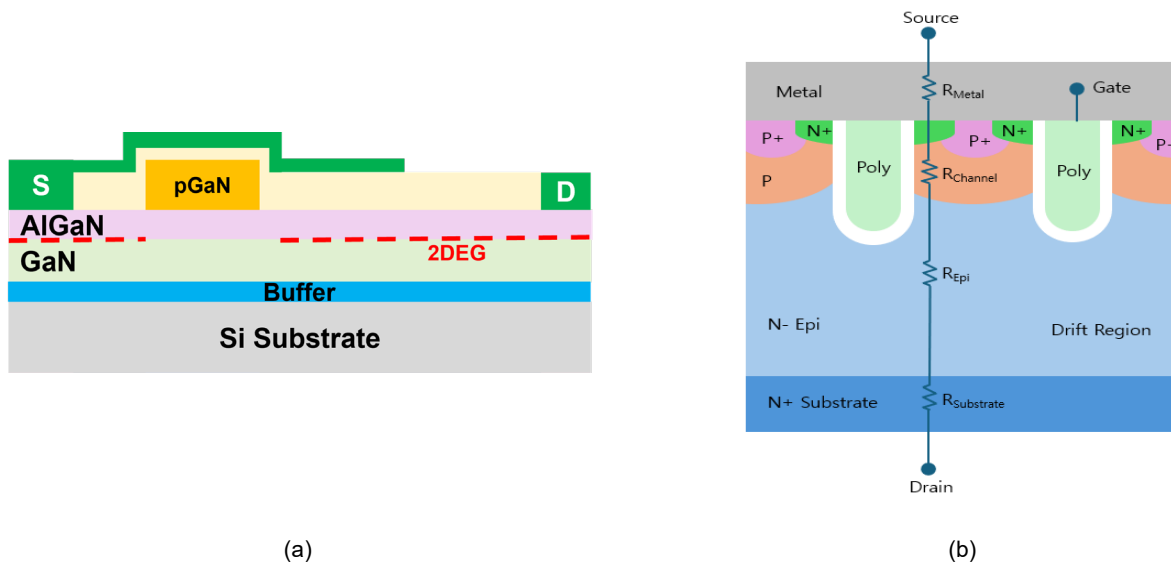


Figure 1. (a) Normally-off enhancement-mode GaN HEMT; (b) Split-Gate Silicon MOSFET technology

The lateral structure of GaN devices brings the additional advantage of an exceptionally small gate-to-drain capacitance (C_{gd}), limited mainly to the gate corner region. Metal gates (replacing polysilicon) exhibit gate resistance of just a few tenths of an ohm, enabling gate charge and discharge in mere nanoseconds. Gate-to-source capacitance (C_{gs}) is approximately 80% lower than in comparable silicon MOSFETs, resulting in shorter propagation delays and superior high-frequency controllability.

Key Performance Metrics

Two metrics define semiconductor technology suitability for power electronics:

- Specific On-State Resistance (Rsp): Measures how much die area is needed to achieve a target RDS(on). Lower Rsp = smaller die = lower cost for equivalent performance.
- Figure of Merit (FOM): Combines RDS(on) × Qg (gate charge) for hard-switched applications, or RDS(on) × Qoss (output charge) for soft-switched applications. Lower FOM = lower switching losses.

GaN achieves 3 – 4× improvement over silicon in both Rsp and FOM, as shown across multiple device generations. A state-of-the-art 100V GaN FET with ~1.2 mΩ RDS(on) carries a total gate charge of only ~28 nC, while a comparable 80V silicon MOSFET (~1.3 mΩ) requires ~170 nC, an order of magnitude difference. The resulting FOM is ~30 mΩ·nC for GaN versus ~220 mΩ·nC for silicon.

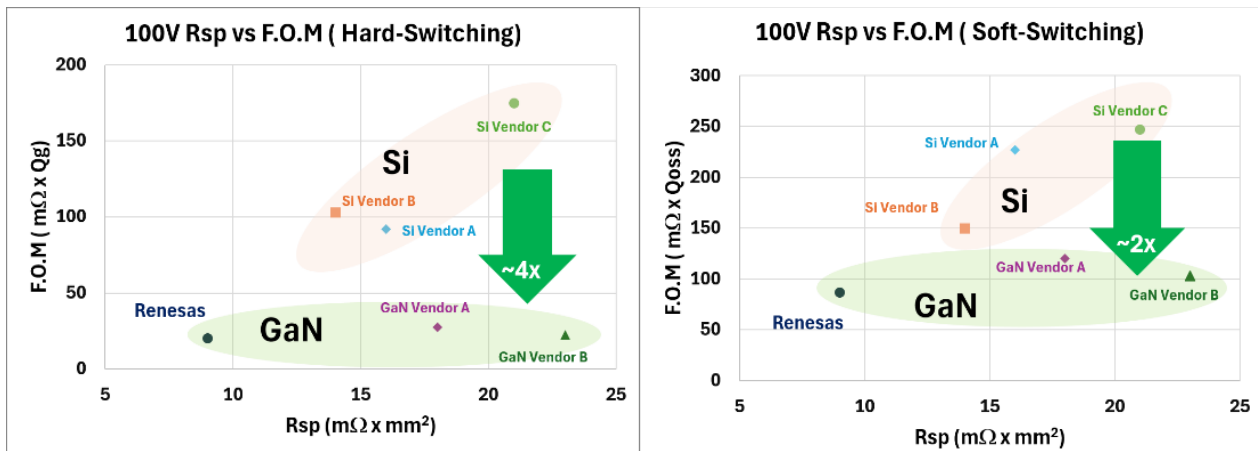


Figure 2. Specific on-state resistance vs. Figure of Merit: GaN vs. Silicon for hard and soft switching

Technology Benefits Over Silicon

Superior Switching Performance

The combination of low gate charge (Q_g), low output charge (Q_{oss}) and ultra-low gate resistance enables GaN devices to complete voltage transitions in mere nanoseconds. This translates directly into lower switching losses per transition and, critically, permits operation at dramatically higher switching frequencies without the switching loss penalty that renders high-frequency operation impractical for silicon.

In hard-switched inverter topologies, the standard in motor drives, GaN's lower hard-switched FOM (~50% better than silicon) keeps switching losses tractable even as frequency climbs from 20 kHz to 100 kHz and beyond. In the soft-switched resonant topologies used in LLC converters for data center DC/DC stages, GaN's lower Q_{oss} enables achievement of zero voltage switching (ZVS) down to very light loads at frequencies at and beyond 1 MHz enabling highly efficient and power dense designs naturally.

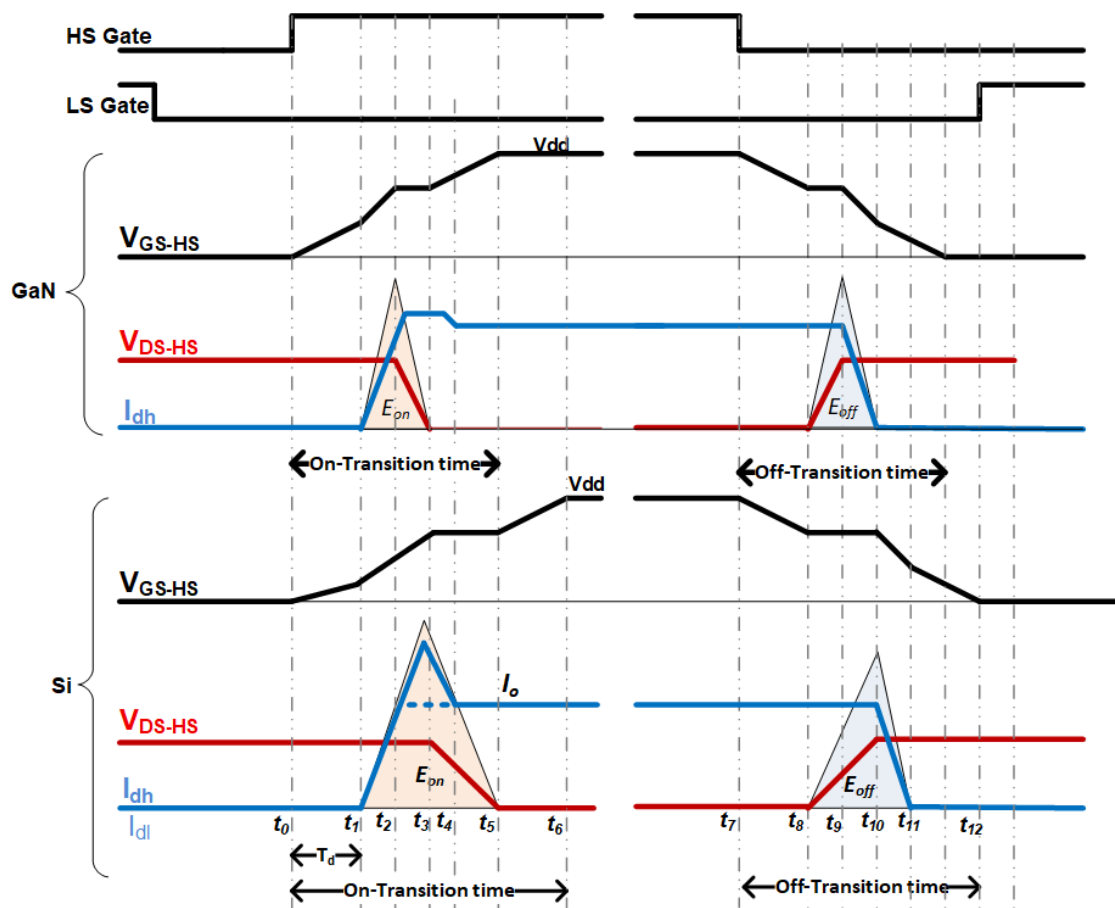


Figure 3. Switching loss characteristics: GaN vs. silicon MOSFET

Elimination of Reverse Recovery

Enhancement-mode GaN HEMTs possess no intrinsic body diode. In silicon MOSFETs, the body diode must conduct during dead-time periods, and when the diode is subsequently reverse-biased, a burst of reverse recovery charge (Q_{rr}) is expelled. Additionally, Q_{rr} increases at high temperatures, which are typically experienced in a practical application, significantly increasing losses and thermal impact on the Si devices. This Q_{rr} creates:

- Additional switching losses proportional to Q_{rr} and switching frequency
- High-frequency current spikes that generate EMI, often requiring snubbers
- Voltage overshoot that stresses the device and requires derating

GaN's zero Q_{rr} completely eliminates this loss mechanism, a particularly significant advantage in three-phase inverters, where six switching events per electrical cycle each carry a reverse recovery penalty in silicon but none in GaN.

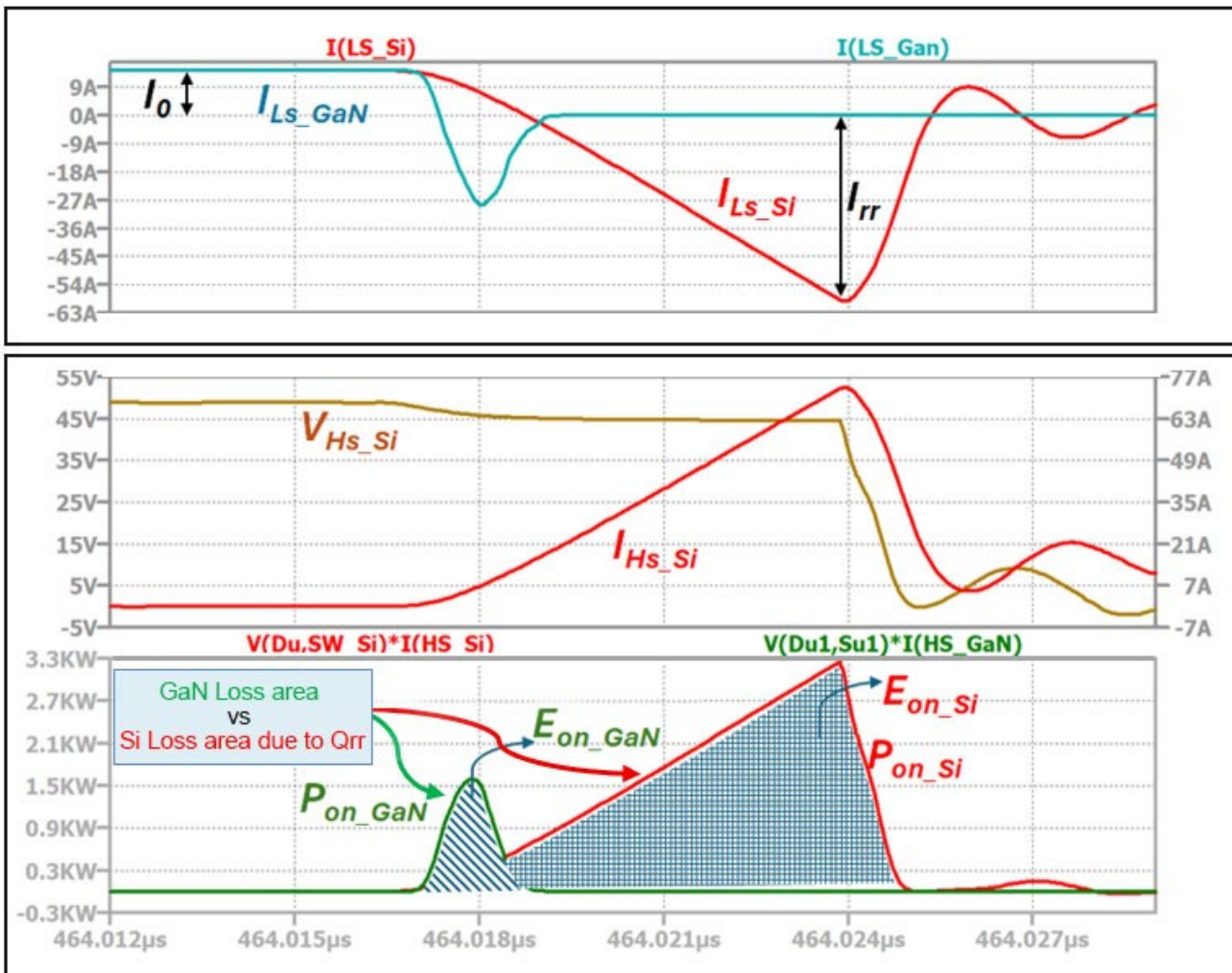


Figure 4. Comparison of turn on loss between GaN and Si and impact of Q_{rr} on Si turn on loss

Gate Charge and Figure of Merit

The Renesas [LV GaN portfolio](#) targets the 40V–200V range with best-in-class $R_{DS(on)} \times Q_g$ figures. Lower gate charge directly reduces gate driver power consumption—important in multi-phase systems with dozens of switches like the ones shown in figure 4—and reduces the minimum achievable dead time, as discussed in Section 5.3.

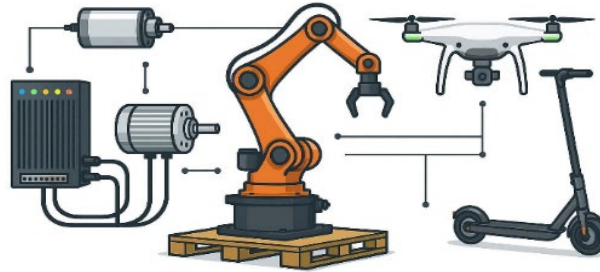


Figure 4. Motor Drive Solutions benefiting from GaN Technologies

Thermal and Packaging Advantages

At equivalent power levels, GaN's higher efficiency means less heat generated per watt of output power. This has cascading positive effects on system design:

- Smaller or eliminated heatsinks, reducing system weight and cost
- Surface-mount packaging becomes viable, enabling compact PCB-level integration and eliminating through-hole assembly
- Lower operating temperatures extend component lifetime and improve overall system reliability
 - Per Arrhenius rule, electrolytic capacitor lifetime roughly halves with each 10°C rise—a GaN-driven reduction in operating temperature directly extends service life)
- In low-voltage motor drives, efficiency can be high enough to allow higher power inverter integration inside the motor housing without active cooling

A comparison performed on a 48V-12V buck converter platform shows Si MOSFET running almost 10°C hotter than GaN at full load which translates to lower efficiency and increased need for cooling in a Si FET based design

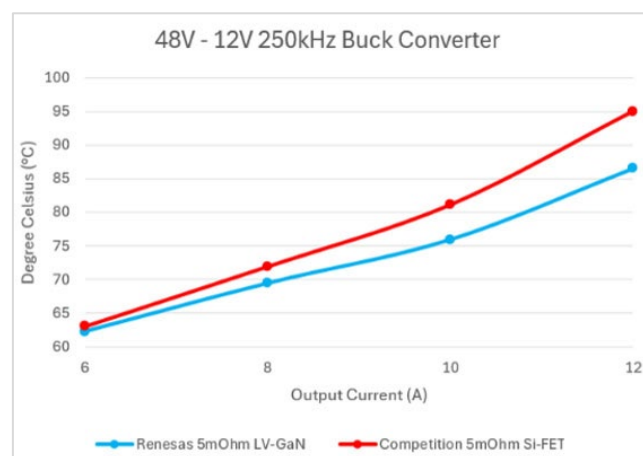


Figure 5. GaN Vs Si device temperature comparison in a buck converter

Impact on Datacenter Applications

The 800V Datacenter Architecture

AI workloads are growing rapidly, driving a surge in data center power demands. This increase is reshaping data center architectures from traditional 54V in-rack distribution to 1 MW IT racks with 800V DC buses. In this environment, high-efficiency power conversion is critical for cost reduction and sustainable operation of multi-MW IT racks. Even a modest 2% gain in server power supply efficiency can lower electricity use by approximately 1.6%.

In a typical 800V DC system powering an IT rack, high-voltage GaN switches operate at 500–650 kHz in the primary stage of DC/DC converters. While GaN adoption is increasing on the primary side, the secondary side has historically still relied on silicon MOSFETs. Transitioning secondary-side medium-voltage FETs to 100V GaN can further boost overall system efficiency and reduce energy consumption. The Open Compute Project (OCP) framework, embraced by hyperscalers, has accelerated the adoption of 800V HVDC architectures in AI factory deployments.

100V GaN on the Secondary Side of DC/DC Converters

100 V GaN devices placed on the secondary side of LLC DC/DC converters provide significant performance and efficiency improvements compared to conventional silicon MOSFETs. Their faster switching transitions enable operation at higher switching frequencies while reducing dead-time requirements and associated losses. The lower output capacitance (C_{oss}) allows the resonant tank to operate in a more inductive region, extending the ZVS range, particularly at light loads. Additionally, the lower gate charge (Q_g) reduces gate-drive losses. During above-resonant operation, the near-zero reverse-recovery charge (Q_{rr}) of GaN devices eliminates body-diode reverse-recovery losses, and reduced C_{oss} losses, further improving efficiency and switching performance across the operating range. As a result, GaN-based LLC converters achieve higher efficiency, higher power density and improved performance over a wider load range.

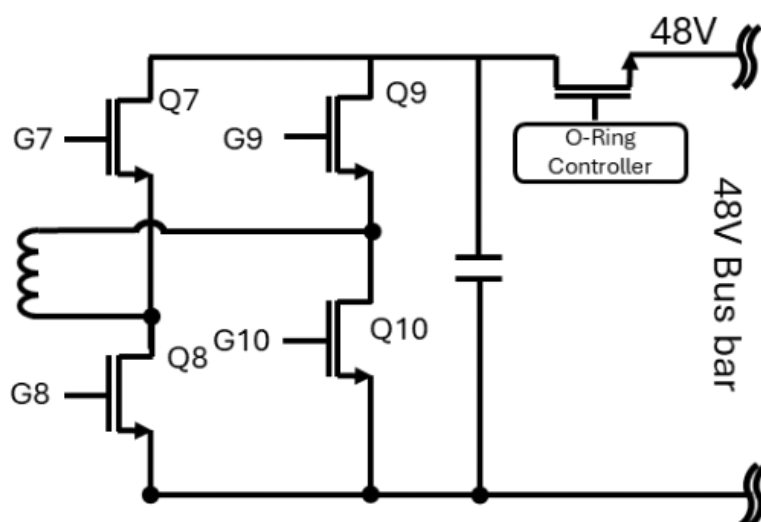


Figure 5. Full-bridge secondary side for HV DC/DC converter (+/-400V to 48V)

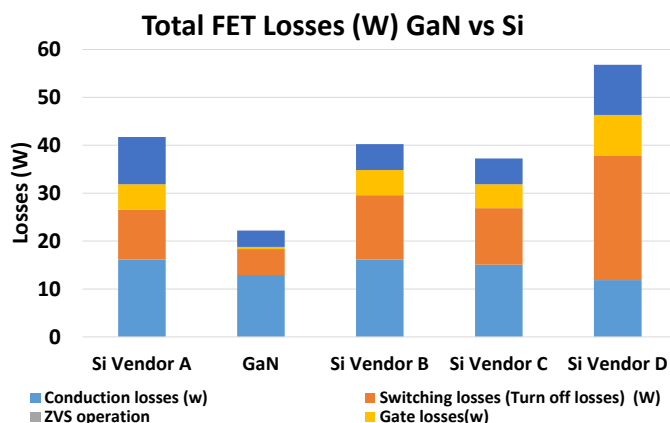


Figure 6. Total device loss comparison: GaN vs. silicon secondary-side FETs in 3 kW LLC converter

High-Frequency Buck Converters for 48V-to-POL

The multi-phase synchronous buck converter remains the preferred topology for 48V to 12V (and POL) conversion in AI server platforms due to its scalability, fast transient response and inherent current balancing across phases. Interleaving multiple phases reduces effective output ripple, enabling smaller inductors and capacitors but realizing the full density benefit requires pushing operating frequency upward, where silicon's Coss losses become prohibitive.

GaN's ~50% lower hard-switched FOM and ultra-low gate charge allow buck converters to operate efficiently at frequencies that are simply unattainable with silicon. Faster rise times with lower device capacitances not only allow higher power density but also reduce the size and cost of the thermal solution. Silicon Coss losses increase steeply with frequency, making high-frequency operation practically impossible. Since the GaN Coss Losses are low, the overall losses at high frequency are lower, enabling efficient multi-MHz operation.

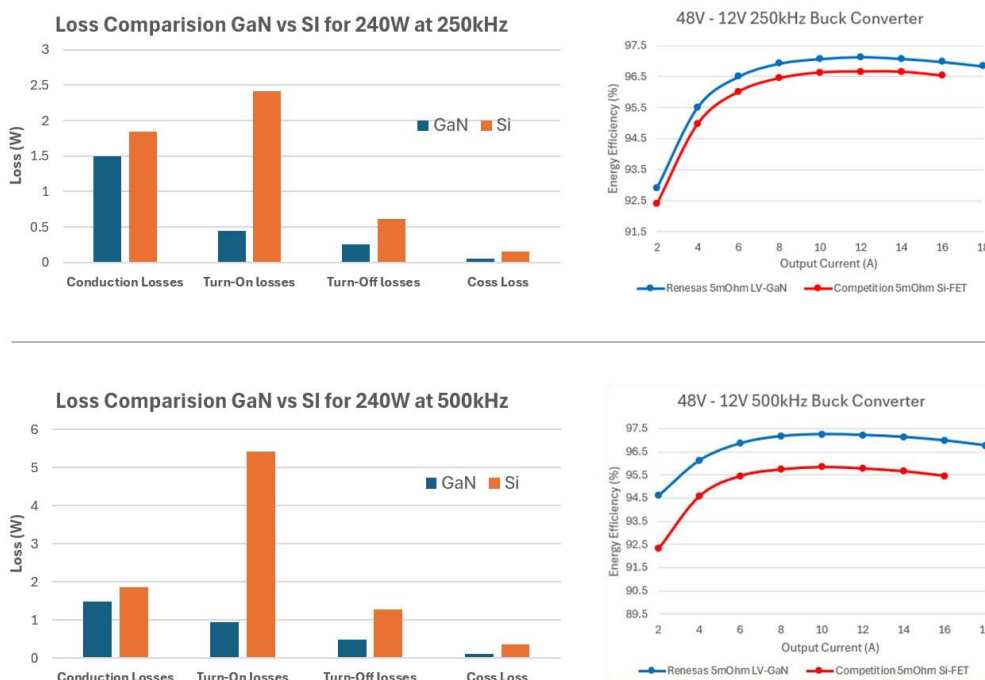


Figure 7. Buck converter loss and efficiency comparison vs. frequency: GaN vs. silicon

System-Level Efficiency and Density Gains

As 800V and 54V converters are packed into dense IT rack architectures, the compound benefits of GaN become decisive:

- 2% full-load efficiency improvement in the DC/DC stage reduces heat generation, lowering cooling costs that represent a significant fraction of total data center operating expense
- Higher power density enables more compute per rack unit, directly improving the economics of AI infrastructure
- Reduced thermal solution footprint (smaller heatsinks, elimination of bulky through-hole packages) opens new form factors for server power delivery
- GaN's higher reliability and longer lifetime further reduce total cost of ownership

Impact on Motor Drive Applications

Enabling High-Frequency Inverters

Traditional silicon MOSFET-based inverters are typically limited to switching frequencies in the low tens of kilohertz (4-20 kHz in many designs), as switching losses rise steeply with frequency. This constraint limits how far engineers can reduce motor losses, torque ripple and filter sizes. GaN transistors enable switching frequencies of approximately 100 kHz – a 5~10× increase over silicon – while keeping switching losses manageable. This leap enables a qualitatively different class of motor drive, potentially enabling reduced motor inductances, lighter rotor designs and innovative construction techniques to make motors smaller and lighter.

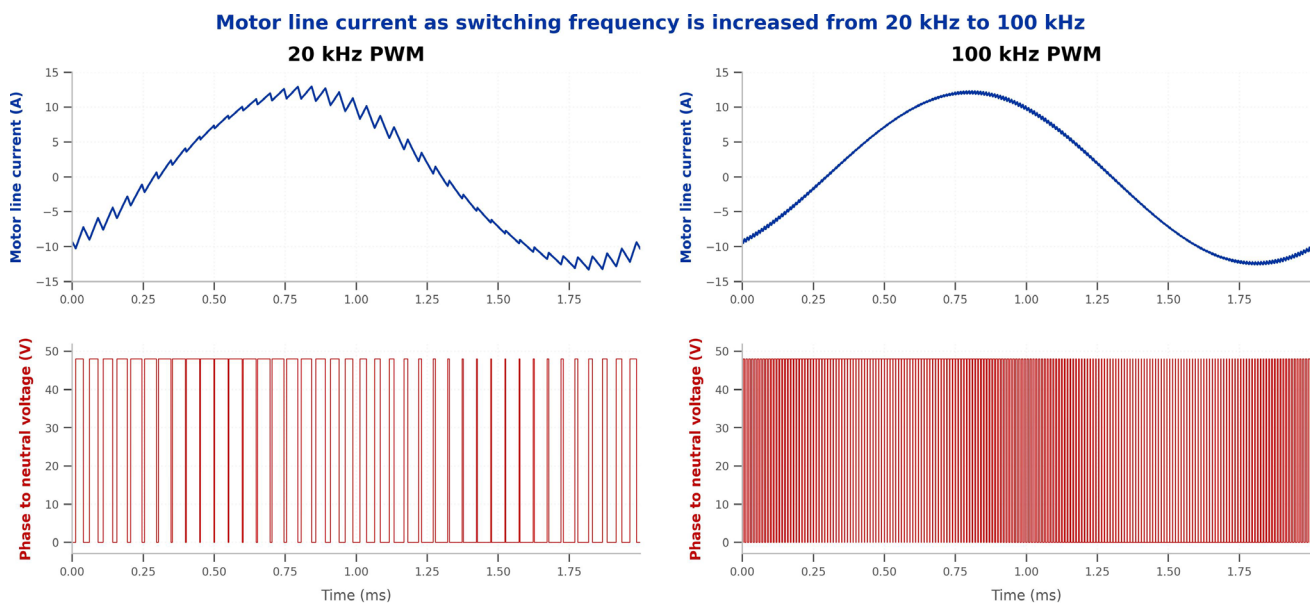


Figure 8. Motor phase current waveform at 20 kHz vs. 100 kHz PWM switching frequency

Motor Performance Improvements

Reduced Current Ripple

In a voltage-source inverter, high-frequency PWM creates AC ripple current in the motor windings, with peak-to-peak amplitude inversely proportional to switching frequency. Increasing switching frequency from 10 kHz to 100

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kHz yields approximately one-tenth the current ripple. This fundamental reduction cascades into multiple motor performance improvements:

- Lower copper (I^2R) losses: Reduced ripple current lowers the RMS stator current closer to the ideal sinusoidal fundamental, directly cutting resistive losses
- Lower core losses: Smaller flux ripple per PWM cycle reduces hysteresis and eddy-current losses in the stator laminations. Doubling the switching frequency can reduce PWM-related motor core losses by approximately 30%
- Higher system efficiency: More input power is converted to fundamental torque rather than wasted in harmonic currents and iron losses, for the most effective way to lower THD.

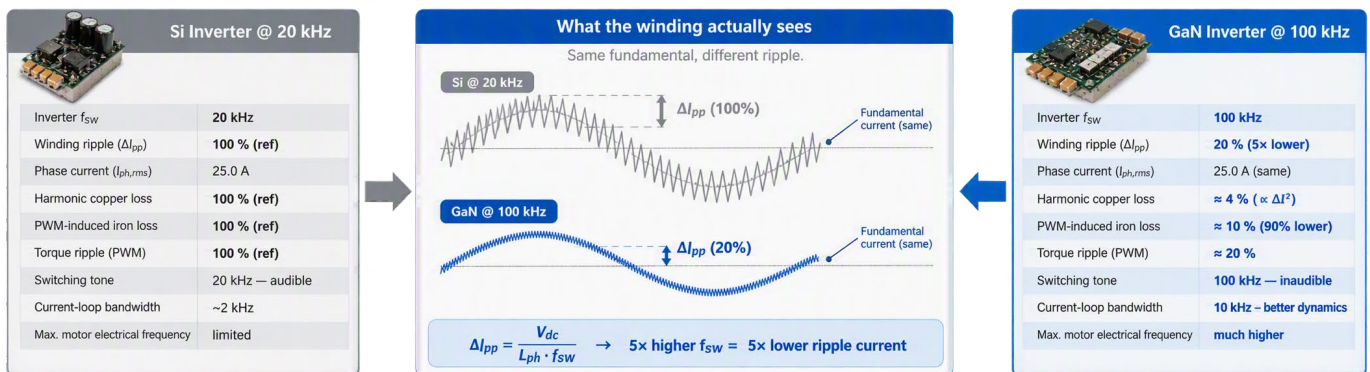


Figure 8. Motor phase current waveform at 20 kHz vs. 100 kHz PWM switching frequency

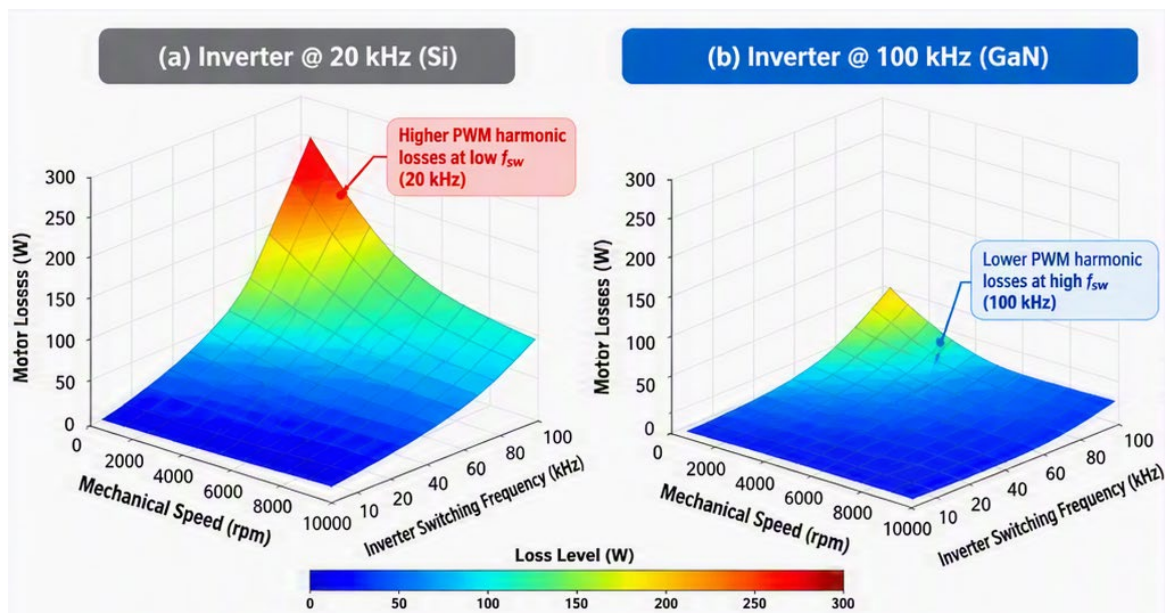


Figure 9. Dynamic motor losses across speed with inverter frequency of 20kHz and 100kHz

Lower Torque Ripple and Reduced Acoustic Noise

Current ripple translates directly into torque ripple. Any deviation of the phase current from its ideal sinusoidal form produces instantaneous torque variation and associated mechanical vibration. At 100 kHz switching,

switching-induced disturbances are pushed into the ultrasonic range, where the motor's mechanical inertia effectively filters them out. The result is dramatically quieter, smoother-running motors—a critical advantage in:

- High-precision servo and robotic systems where torque uniformity governs positional accuracy
- HVAC and fan applications where acoustic noise directly affects user experience
- E-mobility applications (e-bikes, e-scooters) where motor noise affects perceived product quality

The smoother operation also reduces wear on gears and bearings, potentially extending mechanical system lifetime. In some designs, rotor mass can be reduced without compromising performance, lowering material cost and system weight.

Dead Time Reduction

In sinusoidal motor drives using field-oriented control (FOC), switching frequency and control loop update rates determine dynamic response and operating speed range. Silicon MOSFETs require dead times of 0.5~2 μs to ensure safe commutation of body-diode current. GaN's zero Q_{rr} and fast switching allow dead times in the order of tens of nanoseconds—a 20~100 $\times$ reduction.

This has several important consequences:

- Elimination of dead-time-induced output voltage distortion, which appears as 6th-harmonic voltage errors that cause torque pulsations at low motor speeds
- Higher effective voltage applied to the motor (less time lost in zero-voltage dwell), broadening operating speed range.
- GaN delivers superior zero-speed torque smoothness because its ultra-low deadtime preserves accurate voltage vector generation at very low commanded voltages.
- Higher efficiency: current converted to fundamental torque rather than harmonic losses

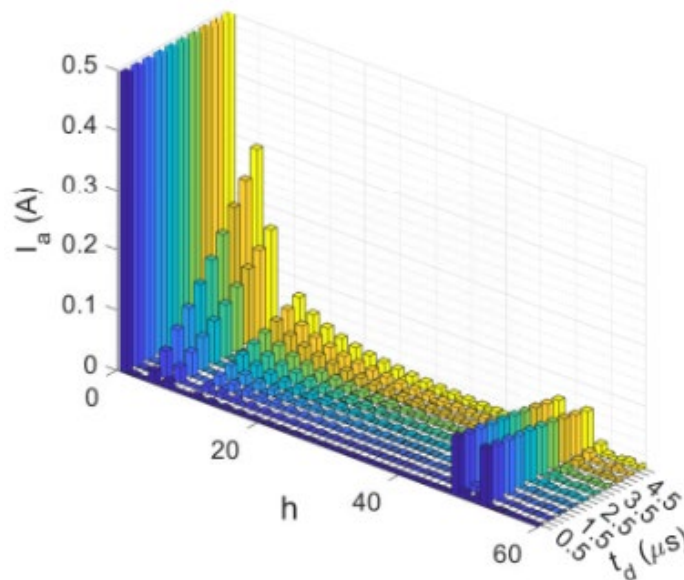


Figure 10. Reduction of harmonic distortion with shorter inverter dead time

System Miniaturization and Reliability

Moving from ~10 kHz to ~100 kHz PWM has a profound impact on passive component sizing. DC-link capacitor ripple current and voltage ripple scale inversely with switching frequency. At 5 - 10 kHz, large electrolytic bulk capacitors are required to handle ripple. At 50 - 100 kHz, ripple is so small that compact film or multilayer ceramic capacitors (MLCCs) become viable on the DC link.

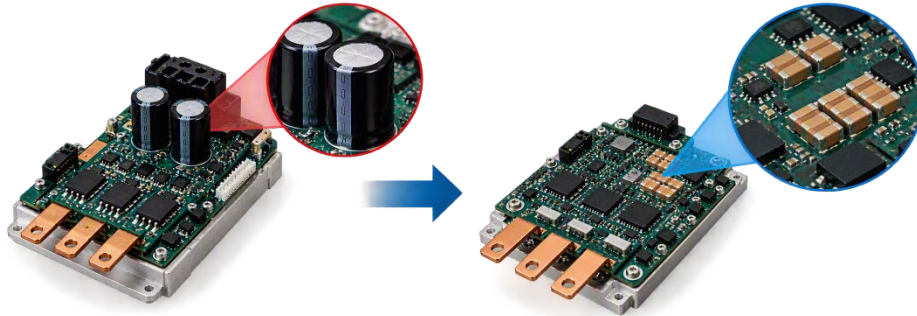


Figure 11. Low-profile, high-power density GaN inverters using ceramic capacitors instead of bulky electrolytic capacitors

MLCCs and film capacitors offer important reliability advantages over aluminum electrolytics:

- No liquid electrolyte: eliminates the primary aging mechanism of electrolytics, whose lifetime halves with each 10°C of temperature rise
- Lower equivalent series inductance (ESL): better high-frequency performance
- Smaller form factor and higher volumetric power density

Similarly, the shift to surface-mount GaN packages—enabled by reduced heat generation—eliminates bulky through-hole power modules, reduces assembly cost and opens the door to full motor drive integration within the motor housing itself. This integration is emerging as a key differentiator in robotics joint actuators, humanoids, e-bikes and compact industrial drives.

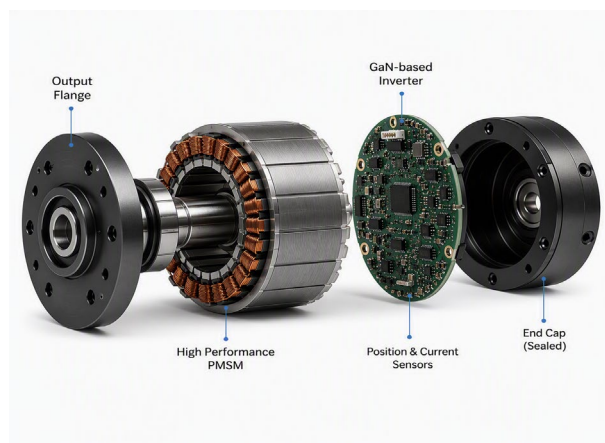


Figure 12. GaN enabling integrated drive-in-motor designs

Conclusion

Low-voltage Gallium Nitride power devices represent a generational shift in power electronics, delivering step-change improvements across every dimension of system performance: efficiency, power density, thermal

management, passives size, acoustic noise and reliability. The same underlying technology advantages—zero Qrr, ultra-low gate and output charge, superior figure of merit and fast switching—translate into decisive gains in both datacenter power delivery and motor drive design.

In datacenters, 100V GaN on the secondary side of LLC converters reduces total device losses by 35-40%, contributing approximately 2% full-load system efficiency improvement that compounds into millions of kilowatt-hours of savings at scale. In multi-phase buck converters, GaN enables the high-frequency operation needed to achieve the power density targets of next-generation AI compute racks.

In motor drives, GaN-based inverters running at 100 kHz transform the motor's electromagnetic environment: one-tenth the current ripple, 30% lower PWM-related motor losses, near-zero deadtime distortion and passives that shrink from bulky electrolytics to compact MLCCs. These improvements enable quieter, more precise, compact and reliable motion systems, from robotic joint actuators to e-mobility drives and industrial servo systems.

The Renesas REXGaN low-voltage GaN transistor portfolio gives engineers access to production-ready devices purpose-built for these applications, backed by reference designs, evaluation kits and application support. The transition from silicon to GaN at low voltages is no longer a future aspiration—it is available today. Visit renesas.com/lv-gan to learn more and explore the portfolio.

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