



GaN Power Architectures Guide



GaNEXUS

An introduction to a new way of utilizing wide-bandgap, high-frequency gallium nitride power components to radically reduce size, volume, and switching losses

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Why Power Architecture Matters

Modern power architectures are all being shaped by a variety of new demands, many of which come from industries that influence change in the entire global power ecosystem:

- In **hyperscale data centers**, to meet the high power demands of AI workloads, server rack standards are being modified. Now, three-phase AC-DC conversion components are being disaggregated from server rack power systems, and moved to *sidecar racks* with entirely new designs and much greater tolerances.
- For **renewable power generation** facilities, new bidirectional energy storage systems (BESS) are improving energy utilization and reducing the effective cost per kWh by storing excess generation and returning it to the grid — requiring rack-mounted battery cells, some with capacities over 1000 V.
- The diverse power requirements for **robotics and automated manufacturing**, which include multiple power characteristics within the same confined space, have necessitated new, lighter, more modular, power distribution systems that move DC-DC power conversion closer to the point-of-load.
- The high power density demands of modern **industrial power supplies** are driving the development of 800 V HVDC architecture, which involves devising new architectures for power racks that perform AC-to-DC front-end conversion and drive intermediate bus conversion closer to the actuation point.

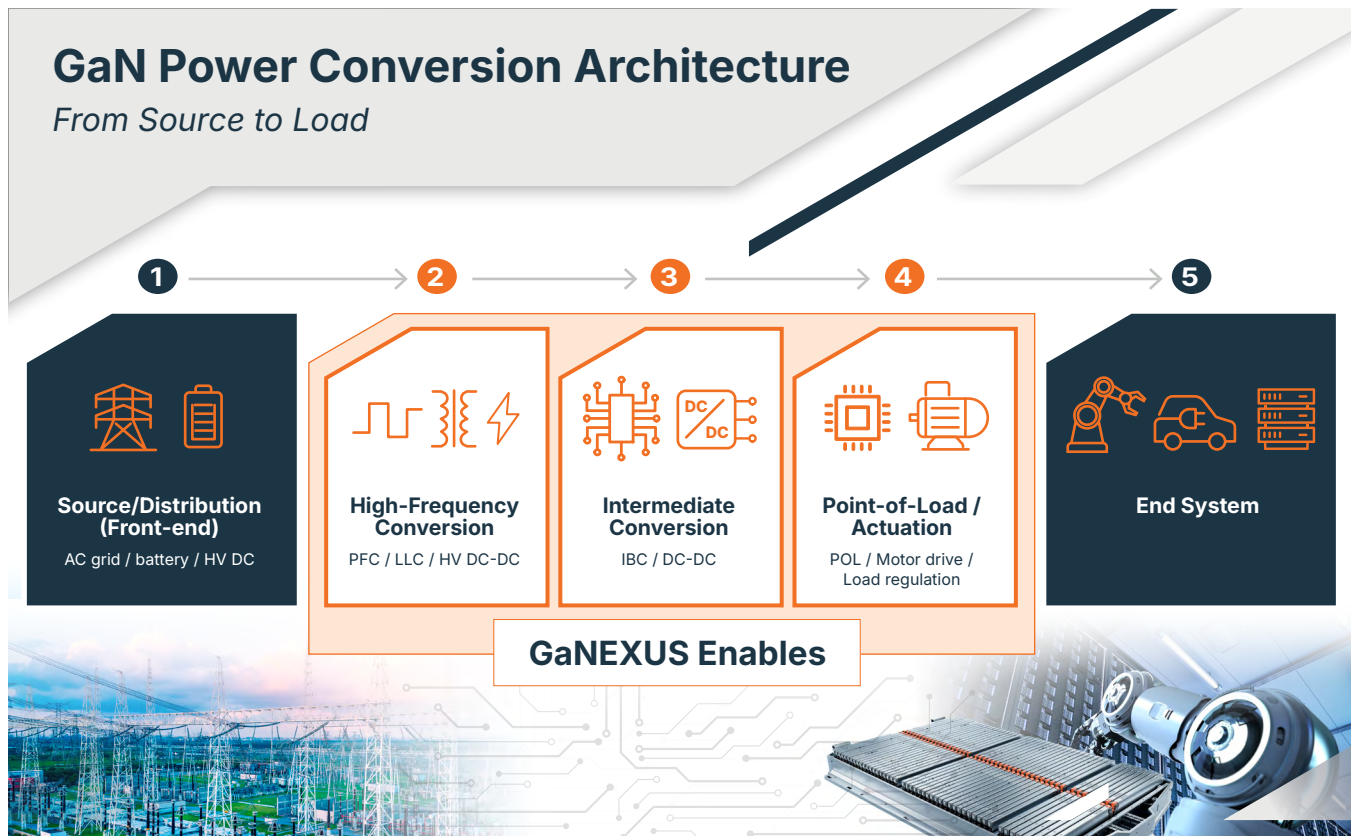


Figure 1. The Power Path, a way to think of the energy ecosystem in the modern world.

The power challenges at issue today, for engineers everywhere, are systemic. Designers are being asked to move more power through smaller spaces. At the same time, they're pressed to reduce thermal burden, improve transient response, and preserve system reliability. These simultaneous demands cannot be resolved just by swapping out parts, or substituting different components. Any choice to optimize even one part of a system affects the rest of the system.

Gallium nitride (GaN) wide-bandgap power semiconductors provide a compelling option for optimized power distribution, particularly in environments where switching loss, thermal limits and component size are dominant constraints. GaN's **higher switching frequency** now makes it possible to build systems smaller, more dense, quieter and with more easily regulated output than ever before. onsemi has developed its **GaNEXUS semiconductor portfolio**, featuring its new vertical GaN technology, to enable designers to selectively and conscientiously apply GaN in their power systems — specifically, in those places where GaN can deliver the most system-level value.

Modern Power Systems: From Source to Load

Today's global electricity ecosystem is dependent upon a process by which electric power, once generated, is delivered and then converted to the form in which it will eventually be consumed. This is a multi-stage process, but we can break that process down into six phases, which we'll call the **Power Path**. The first phase is, simply enough, the point of generation; the last phase is the point of actuation, or *point-of-load* (POL).

In-between are four phases, each of which transforms and conditions raw power into a form that is closer to the shape, volume, and type of power that is ready for consumption by electric motors, appliances and electronic devices:

- 1 Front-End Conversion**
Once it's generated, power is conditioned and converted into a usable bus to support further conversion stages downstream. This front-end stage may include power factor correction (PFC), rectification, EMI filtering and creation of a regulated, high-voltage DC bus.
- 2 High-Frequency / Isolated Conversion**
Isolated conversion processes perform major voltage transformation and, where required, galvanic isolation. Think of the power converter as a factory compartmentalized into mechanisms, each of which shapes the raw material into a form closer to the one necessary for power to be productive. Moving these conversion stages closer to the load reduces distribution losses and parasitic effects, while enabling each stage along the way to be optimized for greater efficiency, safety, density and importantly, control.
- 3 Intermediate Conversion**
For power systems that may utilize multiple voltages, *intermediate bus conversion* (IBC) creates system distribution rails in steps, with multiple separate voltage levels including the intermediate stages. For example, an HV bus may be converted to 48 V, then from there a new rail may convert 48 V to 12 V, and from there the 12 V rail a converter may produce a 5 V rail.

4

Point-of-Load Regulation

Final point-of-load regulation (POL) occurs near the point of power utilization. In this stage, there's no galvanic isolation barrier, so energy is converted into its final, useful form through successive switching and filtering. Shorter interconnects reduce impedance from cables and traces, improving both voltage accuracy and transient response.

This Power Path framework enables designers to balance competing requirements. Robustness and voltage handling are provided by high-power front-end stages, while high switching speed, compact size and fast transient response are handled in downstream stages. With each successive stage of power conversion, one source of uncertainty is removed.

Understanding what happens within each stage of the Power Path is essential to being able to choose and apply the right semiconductor technology. Each stage in power conversion optimizes a different problem. It is mainly for this reason that no single technology can optimize every stage.



Figure 2. A visualization of the four stages of power conversion, as power flows from its source of generation to its final point-of-load.

Where GaN Delivers the Most Value

Gallium nitride maintains several noteworthy material advantages. Yet what has limited GaN from becoming widely utilized in higher-voltage power applications up to now is the practical difficulty of scaling systems laterally while maintaining breakdown robustness, low current collapse rates and predictable transient behavior.

GaN delivers the greatest benefit for power systems where its higher switching frequency, bi-directional switching and reduced thermal burdens improve system architectures end-to-end. These gains are not incremental, but rather architectural and systemic. Greater frequency, higher power delivery efficiency and tighter density can all play roles in reducing system size while improving performance.

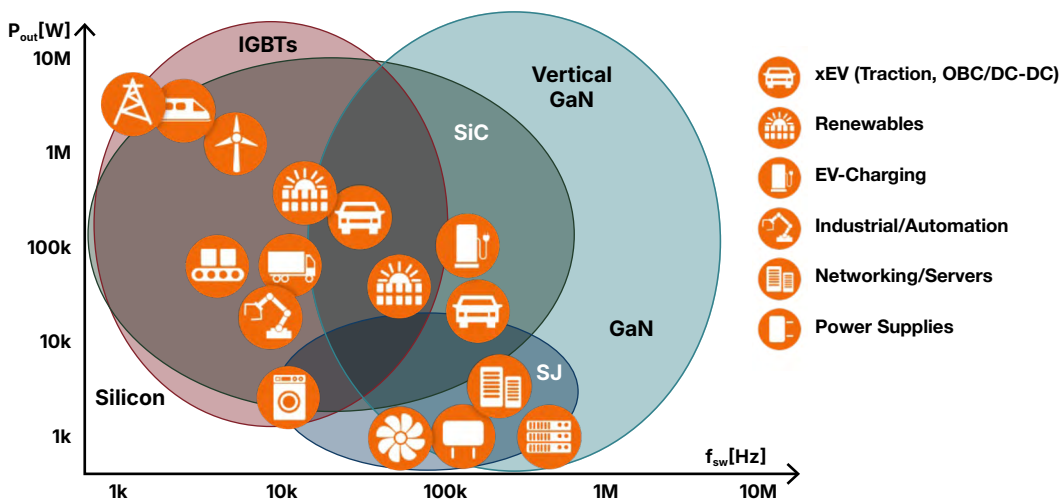


Figure 3. The power switching technologies best suited for various industrial applications.

Gallium Nitride's Material Advantages

What makes GaN compelling are several of its material properties, such as its high critical electric breakdown field of 3.3 MV/cm, enabling stable operation at much higher temperatures with lower leakage current. GaN's wider bandgap of 3.4 eV allows for thinner, more highly doped drift regions improving the theoretical tradeoff between breakdown voltage and specific on-resistance. These advantages are realized in GaN high electron mobility transistors (HEMTs), a type of field-effect transistor (FET) that uses a heterojunction structure to create a high-speed electron channel, enabling faster switching and lower losses than conventional silicon-based devices.

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	Silicon (Si)	Silicon carbide (4H-SiC)	Gallium nitride (GaN)
Bandgap energy E_g	1.12 eV	3.26 eV	3.40 eV
Critical breakdown field E_{crit}	0.3 MV/cm	3.0 MV/cm	3.3 MV/cm
Electron mobility μ_n	1500 $\text{cm}^2/\text{V}\cdot\text{sec}$	700 $\text{cm}^2/\text{V}\cdot\text{sec}$	1500 $\text{cm}^2/\text{V}\cdot\text{sec}$ (~2000 $\text{cm}^2/\text{V}\cdot\text{sec}$ with 2DEG in HEMT)
Saturated electron velocity V_{sat}	$1.0 \cdot 10^7$ cm/sec	$2.0 \cdot 10^7$ cm/sec	$2.5 \cdot 10^7$ cm/sec
Thermal conductivity λ	1.5 W/cm-k	4.9 W/cm-k	1.3 - 2.1 W/cm-k
Baliga Figure of Merit (relative to silicon)	1.0 W/cm ²	392 W/cm ²	993 W/cm ²

Table 1. Key material properties of silicon, silicon carbide and gallium nitride.

Perhaps most importantly, GaN has a higher electron mobility rate, coupled with an electron saturation velocity 25% faster than SiC and 2.5 times that of Si. Collectively, these properties give GaN stronger theoretical tradeoffs between breakdown voltage and on-resistance, with switching frequencies attainable above 1 MHz. While Si frequencies are higher, their practical operating frequencies are typically restricted to below 200 kHz in order to maintain efficiency levels while keeping thermal and EMI burdens low.

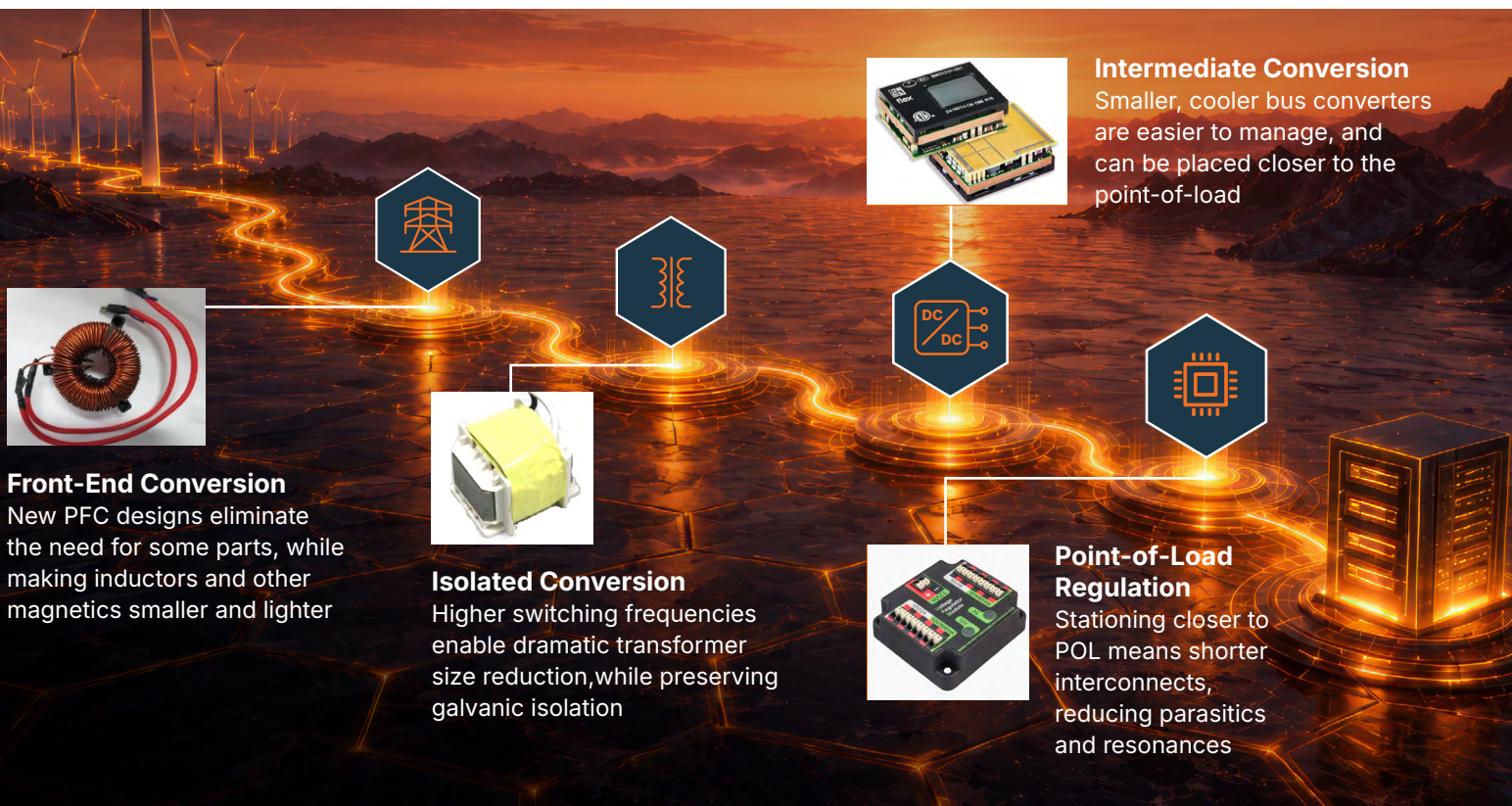
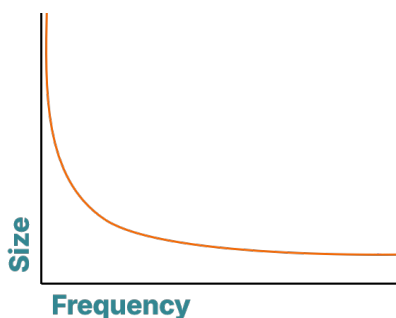


Figure 4. How each stage of the Power Path is impacted uniquely by the influence of GaN.

Front-End Conversion

In this phase, GaN enables switching frequencies as high as a full order of magnitude above typical Si- and SiC-based PFCs. This enables designers to replace heavy inductors with much lighter parts, freeing up space while driving dramatic power density improvements. GaN enables new power factor correction (PFC) designs, such as bridgeless totem-pole design. Now, the traditional input diode may be eliminated entirely, reducing conduction loss at the AC input, and the body-diode reverse recovery mechanism can be avoided as well.

High-Frequency / Isolated Conversion



The faster switching capability and low output capacitance of GaN allows transformers, inductors and other magnetics to shrink very significantly. By allowing isolated converters to operate at higher switching frequencies, GaN can reduce transformer size while preserving the galvanic isolation provided by the transformer's insulation structure. In power conversion stages such as half-bridge, full-bridge and LLC, GaN's reduced switching losses and parasitic penalties make high-frequency isolated conversion more practical.

With magnetic design, layout and thermal path optimization, volume, weight and thermal mass are all dramatically reduced. This leads to more efficient and more compact power subsystems for more extreme, demanding conditions, with lower system cost. These attributes are valuable in telecom and data center environments, where densities are tight and power utilization goals cannot be renegotiated.

Intermediate Conversion

High-frequency intermediate bus converters have the added virtue of greater thermal manageability. Now that IBCs are not only smaller but cooler, even with greater power density, they may be stationed more closely to active loads, where fast control and reduced energy storage both help to improve overall system responsiveness.

Point-of-Load Regulation

Long cables, traces, connectors, busbars and planes all add parasitic resistance, inductance and resonances, complicating the process of regulating the behavior of converted power. These parasitic effects are all reduced when conversion stages are moved closer to the load. GaN's fast switching capability, coupled with low switching losses, enable more compact power systems to be placed nearer to sensitive electronics or motors.

How GaN Eliminates the Need for Reverse Recovery

When a conventional MOSFET's body diode has been conducting, stored charge must be removed during commutation. **Reverse recovery** takes place as current flows back through this body diode, as the circuit transitions between an on and off state. This process typically results in switching loss, heat and EMI.

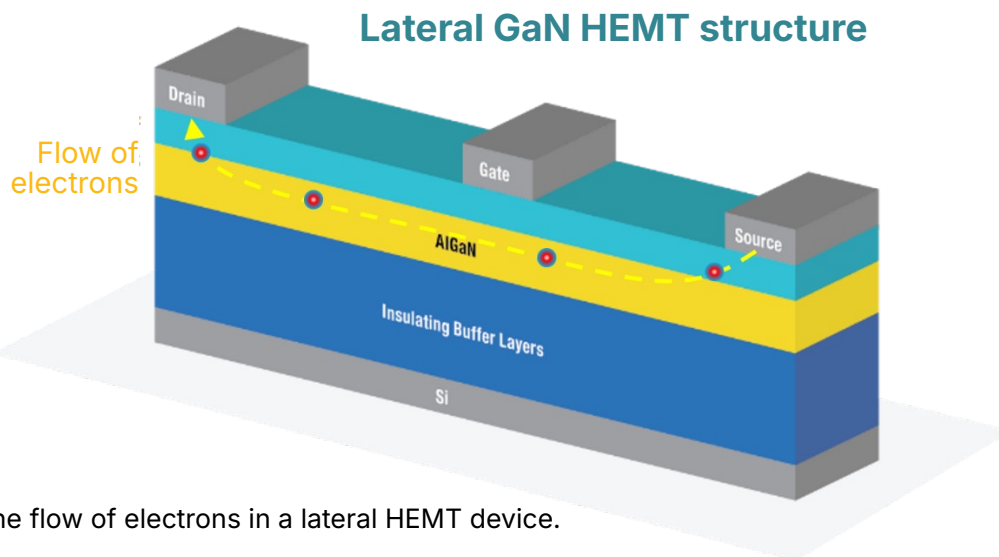
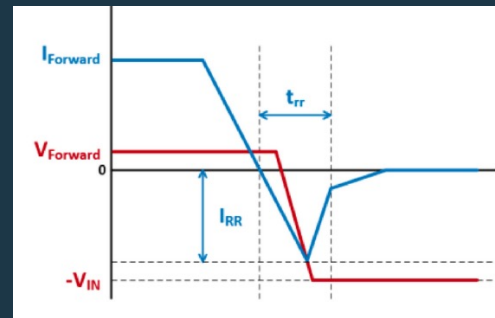


Figure 5. The flow of electrons in a lateral HEMT device.

GaN offers a potential advantage to designers simply by not having a native body diode. In a lateral GaN HEMT design, electricity flows sideways across the surface, through a microscopically narrow AlGaIn channel formed from **two-dimensional electron gas (2DEG)**. No minority carriers are stored in this device, thus removing the need for a reverse recovery mechanism. In turn, GaN HEMT eliminates one common source of switching power loss and heat loss, by virtue of switches spending far less time in the “partially open,” intermediate linear switching region.



Technology Fit by Stage: Silicon, SiC, and GaN

Modern power systems rely on multiple semiconductor technologies, each of which is optimized for a variety of factors. The balance is most often between performance, efficiency and cost. There may never be a single technology which addresses each power conversion role with the same degree of balance. Optimizing power systems architecture requires designers to *deploy each technology where it performs best*, rather than forcing a single technology across each and every role. The choices designers should make are stage-dependent.

Although GaN can play some role in each of the stages listed in this table, it should not be considered the all-purpose materials solution for every application. The more appropriate question to be asking is where each device technology may best be utilized to optimize and improve the system and end-product.






Stage	Primary design need	Technology best fit			Where GaN can help
		Si	SiC	GaN	
 Front-end conversion	Robustness, voltage handling, PFC efficiency	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <small>(depending on topology)</small>	Higher-frequency PFC, reduced passive size
 High-frequency / isolated conversion	Transformer size, isolation, efficiency		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Smaller magnetics, lower switching losses
 Intermediate conversion	Density, thermal control, fast responsiveness	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	Compact DC-DC conversion, higher frequency
 Point-of-load regulation	Transient response, proximity to load	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	Smaller local conversion, reduced parasitics
 Bidirectional power paths	Flexible energy flow, lower component count	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <small>(GaN BDS ICs)</small>	Simplified two-way power flow

Table 2. The best fit materials technologies for every stage in the Power Path, including for bidirectional power systems.

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GaNEXUS™ from onsemi brings gallium nitride into real power systems through a scalable portfolio of device types. Each of these types addresses discrete, bidirectional and integrated design requirements.

- **GaNEXUS FETs** — GaN HEMTs span low (40V) to ultra high (1200V) voltage domains, supporting high efficiency switching across multiple stages. Lateral GaN devices address today’s density driven applications, while vertical GaN extends GaN capability toward future ultra high voltage, high-density architectures.
- **GaNEXUS BDS** — Bidirectional GaN HEMTs enable efficient two way power flow using simplified device structures, helping reduce component count and support flexible system operation.
- **GaNEXUS Integrated Power**, including Drive, Smart and Control functionality, combine switching with drive, protection, sensing and control. Increasing levels of integration simplify design, reduce parasitics and enable more intelligent power stages.

In addition, onsemi Treo Platform™ mixed signal ICs support these architectures by providing GaN optimized gate driving, power management and control functions essential for reliable system operation. As **Table 2** indicates, adoption of GaN technologies in power systems may progress over time in five stages, each of which addresses and resolves performance and reliability issues with wider scope over the behavior of the system as a whole.

GaN Power Architecture Capability Matrix

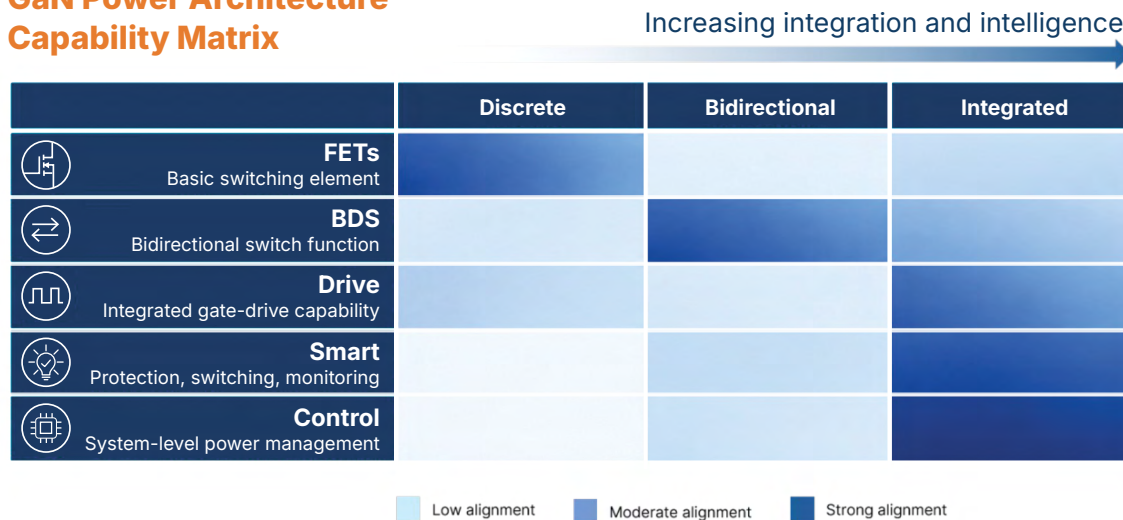
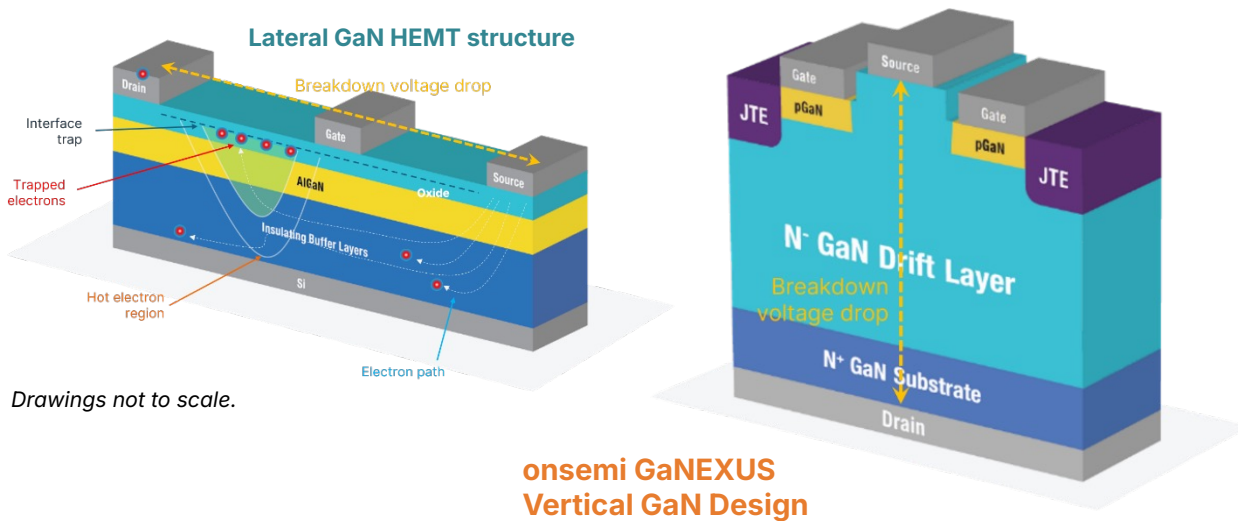


Table 3. The GaN Power Architecture Capability Matrix.

Vertical GaN's "Skyscraper" Breakthrough

One of the more common performance issues historically related to GaN HEMTs is current collapse, also known as "dynamic $R_{DS(on)}$." Current collapse happens when high electric fields at the gate edge of an HEMT accelerate electrons, leading them to become trapped in places like the dielectric interface and barrier layers. The result is that trapped charge depletes or modulates the channel, resulting in reduced available drain current and degraded, higher dynamic on-resistance, both of which negatively impact heat and efficiency. onsemi's lateral GaN technology largely mitigates this behavior, though vGaN offers even greater improvement.

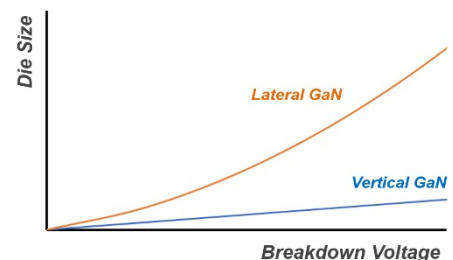


Drawings not to scale.

Figure 6. Lateral and vertical GaN architectures compared.

To counter these effects, onsemi has introduced **vertical GaN** design into its **GaNEXUS** portfolio. Nicknamed "skyscraper tech," this technology enables power conduction straight down through the monolithic die, rather than dropping voltage over the horizontal plane of the chip area.

As a result, attaining higher breakdown voltage no longer requires widening the surface area of the chip. Moving the voltage blocking path from a lateral surface plane to a vertical die structure essentially neutralizes the chances for current collapse (dynamic $R_{DS(on)}$) under specified operating conditions, while also improving vertical GaN's on-resistance temperature coefficient over lateral GaN by up to 30% at 150 °C.



Applying Architectural Focus Across Applications

Viewed in this light, it's plain to see that **GaN technology in power systems complements Si and SiC** rather than replacing them. However, the introduction of vertical GaN architecture does expand the horizon for higher-voltage industrial power like never before.



Figure 7. The areas of our industrial world most likely to see design improvements from GaN.

- **In infrastructure for digital workload automation and artificial intelligence**, GaN is immediately relevant in intermediate bus and high-frequency DC-DC conversion stages, where fast load response, power density and switching efficiency are critical. Modern data centers are deploying much higher rack-level power to support the vast power demands of AI workloads. Here, it will become critical to move power conversion not only closer to the load, but in very close proximity to the compute power itself. GaN HEMT supports these high-density compute architectures by making high-frequency intermediate bus converters, high-voltage bus converters, and battery backup units more compact and efficient.
- **In robotics and industrial automation**, where compact, distributed motor drives must switch efficiently at high pulse-width modulation (PWM) frequencies, GaN offers numerous opportunities for optimization, and vertical GaN will only improve those opportunities further. Here, lower switching losses reduce heat, while higher-frequency control reduces current ripple while improving actuator precision in space-constrained assemblies.

- **In automotive power systems**, where multiple voltage domains coexist, high-voltage batteries, 48 V subsystems and legacy voltage rails must all be made to work together. Here, GaN can support compact, efficient conversion for on-board chargers (OBC) and DC-DC stages, including HV-to-48 V or 48 V-to-low-voltage conversion. In bidirectional designs, these converters should also support more flexible energy management for the battery, auxiliary systems and external charging loads.
- **In energy and industrial power**, long lifecycles and reliability drive architectural choices. Here, GaN is most relevant where high-frequency, isolated stages can benefit most from greater power efficiency and minimal footprint, improving system-level outcomes. Vertical GaN will have maximum influence upon industrial power systems that incorporate solar microinverters and optimizers and energy storage systems (ESS).

What scales across power systems is the need for architecture-level thinking. Designers must select the right power topologies and technologies for each stage to achieve performance that is optimized for the system.

Designing for Production Power Systems

The transition from the technology evaluation phase of power system design to the deployment phase introduces a variety of new constraints and challenges, as well as opportunities. Production power systems require consistent performance, robust design margins and long-term supply continuity.

Designing GaN into real systems requires more than fast switches. It also requires integrated thinking across power, control and protection. GaNEXUS is developed with attention to balancing the requirements for both system integration and rapid deployment. This includes attention to these critical production factors:

- **Manufacturability** — onsemi enhances the manufacturability of GaN devices and technologies through a comprehensive set of strategies, including process expertise in both vertical GaN and GaN-on-silicon platforms, dual-source manufacturing capabilities, innovative screening methodologies, and advanced packaging solutions that improve heat dissipation. These capabilities enable reliable, easy-to-use solutions that accelerate the integration of GaN technology into existing power systems.
- **Qualification** — All onsemi GaN parts undergo rigorous qualification tests including ensuring gate reliability at extreme temperatures, and minimizing on-resistance degradation (current collapse) during high-frequency switching.
- **Interoperability** — Integrating high-frequency silicon drivers on many onsemi GaN components produces cleaner drive waveforms, while simplifying PCB layout by eliminating external drivers that could introduce gate-loop parasitics.
- **Mixed signal coordination** — onsemi takes into full account all the timing, sensing, protection, and control elements necessary for high-voltage, high-speed GaN power switching to behave safely and tolerably under the command of low-voltage control, sensing and protection circuits.

Build Smaller, Faster, More Efficient Power Systems With Architectural Intent

When applied with architectural intent across the power system, gallium nitride is capable of enabling higher power density, faster response, smaller sizes and volumes and more efficient designs. GaNEXUS from onsemi supports these architectural shifts by delivering scalable vertical GaN architectures — discrete, bidirectional and integrated — capable of working alongside silicon and silicon carbide power semiconductors in production-ready systems.

Meeting the challenges of a world demanding faster access to more reliable power — and often more of it — requires a holistic, architectural approach to innovation. The changes that need to be made now to power delivery systems around the world are deliberate, structural and systemic. Every design choice made now ripples through not just electricity delivery systems, but the ecosystem as a whole. Gallium nitride is an enabler for a new approach to architectural thinking in power system design — one that incorporates GaN amid a wealth of other materials and production techniques that are still valid and still functional. **onsemi GaNEXUS** helps engineers to apply new methods and new materials in precisely those places in the Power Path that deliver the most value.



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