

Demystifying GaN Drivers in Clean Energy Applications

By Vashist Bist, Shashank Wekhande, and Emil Pavlov





Demystifying GaN Drivers in Clean Energy Applications

By Vashist Bist, Shashank Wekhande, and Emil Pavlov, Allegro MicroSystems

Abstract

The next generation of electric switches based on wide bandgap semiconductors are gaining popularity in the market. This article compares the relatively newer silicon carbide (SiC) and gallium nitride (GaN) power devices to the established silicon (Si) metal-oxide semiconductor field-effect transistors (MOSFETs) and insulated gate bipolar transistors (IGBTs) by their physical properties and technical performance. This article focuses on clean energy applications and understanding why GaN power devices are needed in such applications. Various types of GaN FETs are explored, and the advantages of enhancement mode high-electron-mobility transistors (HEMTs) for clean energy applications are highlighted. Furthermore, the article delves into concrete advantages of GaN FETs for specific power electronic components such as the power factor correction converter, DC-DC converter, and solar inverters in clean energy applications and compares the power losses in a system comprised of a GaN device with a Si device. Additionally, the article analyzes the current and projected cost of GaN FETs as individual components and their impact on the overall system cost. Finally, the article explains how to drive GaN FETs and presents the newly released Allegro high-voltage isolated gate drivers and key advantages over existing solutions.

Introduction

A fundamental component in any power control or conversion system is an electrically controlled switch. While there are multiple ways to implement this functionality, transistors offer unparalleled robustness, capabilities, and versatility. Traditionally, silicon MOSFETs and IGBTs are the most widely used semiconductors in power electronics applications, which has resulted in and has reinforced a high level of technological maturity, low cost, and wide availability. However, the drawback of any established technology is that it is difficult to make any performance advancements because the manufacturing process is already approaching its theoretical limit. In this regard, there is always market demand for improved system performance, driving the requirements of lower cost, reduced size and weight of passive (magnetic) components, higher efficiency, higher power density, faster transient response, and reduced electromagnetic interference. This is where next-generation wide bandgap devices enter to fill this performance gap.

Outline

- Introduction
- Wide Bandgap Devices
 - Introduction to Wide Bandgap Devices
 - Comparison of Si vs. SiC vs. GaN vs. IGBT Devices
 - GaN Devices in Clean Energy Applications
- GaN Power Devices
 - Types of GaN FETs
 - Comparison of Different Types of GaN FETs and Advantages of HEMT GaN FETs
- GaN Power Devices in Key Power Electronic Components for Clean Energy Applications
 - Power Factor Correction
 - Solar Inverter
 - DC-DC Converter
 - Power Loss Comparison of Si, SiC, and GaN Power Devices
- Cost Trends
 - Current Cost Impact
 - Future Cost Trends
- GaN Gate Drivers
 - Key Parameter Requirements for GaN Drivers
 - Allegro MicroSystems Portfolio of GaN Drivers
- Conclusion
- References

Wide Bandgap Devices

Wide bandgap (WBG) devices offer a much larger bandgap (greater than ~ 2 eV) when compared to traditional Si and IGBT power devices (typically ~ 1.1 eV). Bandgap refers to the difference in energy between the highest occupied state of the valence band and the lowest unoccupied state of the conduction band, i.e., the energy an electron needs to receive for it to become mobile to allow the material to conduct electricity. This larger required energy allows WBG power devices to operate at higher voltage, higher temperature, and higher switching frequency.

Gallium nitride and silicon carbide are the most widely used materials for WBG power devices. SiC devices have been commercially established for longer and are gaining more popularity in higher voltage (typically greater than 800 V) and higher temperature applications such as electric vehicles, whereas GaN power devices are most suited for mid-range voltage (less than ~ 650 V) and higher frequency applications where they offer the highest efficiency and lowest system size per watt.

Comparison of Si, SiC, GaN, and IGBTs Power Devices

Table 1 summarizes a comparison between power devices and systems made from silicon, insulated gate bipolar transistor, silicon carbide, and gallium nitride. Traditionally, silicon devices are the most used devices which have good thermal performance and are more economical but are limited in terms of high-frequency and high-temperature applications. Silicon MOSFETs are primarily used in mid-frequency (less than ~ 500 kHz), low current (less than ~ 100 A), and mid-voltage applications (less than ~ 600 V). IGBTs combine the advantages of MOSFETs and bipolar transistors and are commonly used in medium to high-power applications. However, IGBTs have the limitation of higher switching frequency (less than ~ 100 kHz), moderate temperature performance, and moderate power density. The switching losses for both Si and IGBT power devices are on the higher side as compared to the WBG devices.

Table 1: Comparison of Various Technologies

Attributes	Silicon (Si)	Insulated Gate Bipolar Transistor (IGBT)	Silicon Carbide (SiC)	Gallium Nitride (GaN)
Bandgap	1.1 eV	1.1 eV	3.3 eV	3.4 eV
Switching Speed	Moderate (<500 kHz)	Slow (<100 kHz)	Fast (<1.5 MHz)	Fastest (<10 MHz)
Operating Voltage	< ~ 600 V	< ~ 600 -1200 V	< ~ 1200 V	~ 650 V
Operating Current	< ~ 100 A	< ~ 100 -200 A	< ~ 100 -200 A	< ~ 50 A
Operating Temperature	High	Moderate	Highest	High
Thermal Conductivity	Moderate	Moderate	Highest	Moderate
Breakdown Voltage	Moderate (0.3 MV/cm)	High (3-5 MV/cm)	High (3.2-3.5 MV/cm)	High (3.3 MV/cm)
Efficiency	Moderate	Moderate	High	Highest
Cost	Low	Moderate	High $\rightarrow$ High/Mid	High $\rightarrow$ Low/Mid
Applications	General Purpose Power Electronics	Industrial Motor Drives, Power Inverters	Electric Vehicles, Clean Energy	Power Supplies, Clean Energy

GaN devices offer high electron mobility which enables high-frequency operation. These devices are smaller, lighter, and have lower on-resistance compared to Si and SiC devices. They are suitable for applications where size and efficiency are critical, whereas the SiC devices offer a higher breakdown voltage, better thermal conductivity, and can operate at higher temperatures when compared to silicon devices and are more suitable for high-power and high-frequency applications.

A key characteristic of a transistor is its capability to conduct current in reverse in its off state, sometimes referred to as freewheeling. The reason this is important is because it provides a safe path for the discharging of inductive elements when their current supply is switched off, during the off state of the transistors, due to the generated inductive current. IGBTs cannot conduct in reverse; therefore, they are usually paired with a discrete diode in parallel, which can either be external or integrated in the package by the manufacturer. MOSFETs have an inherent parasitic body diode, which gives them the advantage of freewheeling functionality by default.

However, a major challenge is the reverse recovery of these parallel diodes. This is the period the diode needs from its conducting to its non-conducting state. This process is not instantaneous and requires additional gate charge during switch-on and prolongs the switch-on process, incurring additional switching losses. The most common type of GaN transistor can conduct in reverse without an intrinsic body diode or an external diode. When a negative voltage on the drain is applied ($V_{DS} < 0$ V), a negative voltage gradient is created along the conduction channel, creating a potential difference between the gate and the channel. If that difference is higher than the threshold voltage (V_{TH_GD}), the channel starts conduction in a phenomenon called self-commutation. The voltage drops across the transistor in this case is $V_{TH_GD} + (-V_{GS}) + I \times R_{ON}$ which is typically around 2 to 4 V and is higher than the typical voltage drop of 0.6 to 0.7 V across IGBTs and MOSFETs [1]. This increases the losses during dead time but is negated by shortening the dead time, which on its own has additional positive effects. An additional advantage for GaN power devices is that they do not suffer from recovery losses and times as their Si counterparts.

Figure 1 shows a spider chart comparison of Si, GaN, and SiC devices on various material parameters such as the energy gap, breakdown field, electron mobility, electron saturation velocity, and thermal conductivity.

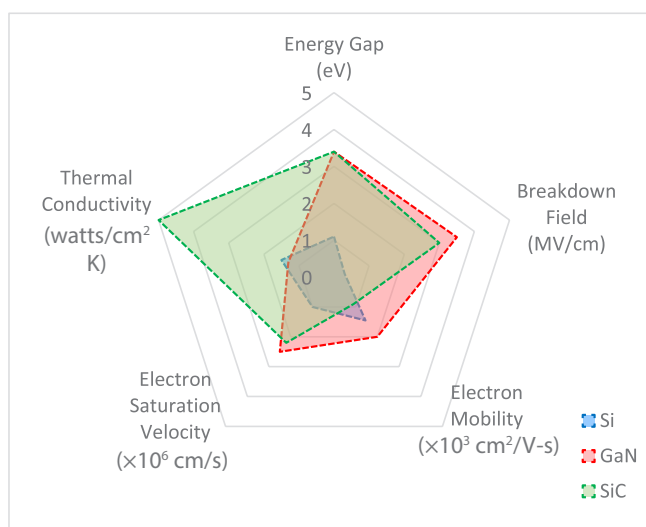


Figure 1: Comparison of Si, GaN, and SiC Power Device

GaN Device in Clean Energy Applications

GaN devices have found use in the following clean energy applications due to their unique electrical properties, high efficiency, and fast switching capabilities.

- **Charging Infrastructure:** GaN power devices are used in the charging infrastructure of electric vehicles, such as power factor correction converters and DC-DC converters. GaN's high switching frequencies and efficiency contribute to reducing the size and weight of power electronics systems in electric vehicles, enhancing overall energy efficiency.
- **Power Factor Correction (PFC) Converters:** Power factor correction becomes crucial for almost all grid-connected AC-DC conversion systems (either single-phase or three-phase systems) to realize a unity power factor at AC mains with lower content of harmonics in the supply current (typically lower than 5%). GaN device operation in high-frequency switching allows the size reduction of bulky inductors and isolation transformers, reducing the overall cost and size/volume of the overall PFC system.
- **Data Centers:** In data centers, GaN devices play a crucial role in managing and distributing electrical power efficiently. The key components of the data center, such as the power supplies, high-frequency DC-DC converters, high-current supplies for high-performance computing systems—realized though GaN devices for faster switching operation and better efficiency—allow the system to reach Titanium efficiency level with a smaller rack footprint.

- **Solar Energy:** GaN-based power inverters are employed in solar energy systems to convert direct current (DC) generated by solar panels into alternating current (AC). The high switching speeds of GaN devices enable a lower magnetics size (inductor and transformer) and effectively helps in reducing the overall cost and size of the system and additionally improving the overall photovoltaic efficiency.
- **Energy Storage:** GaN devices find applications in various energy storage systems, such as inverters for batteries, DC-DC converters, uninterruptible power supply (UPS) system, and grid connected systems. The high-frequency operation and efficiency of GaN devices contributes to more compact and lightweight energy storage solutions.

Figure 2 shows an application map of the power and frequency requirements of the various clean energy applications.

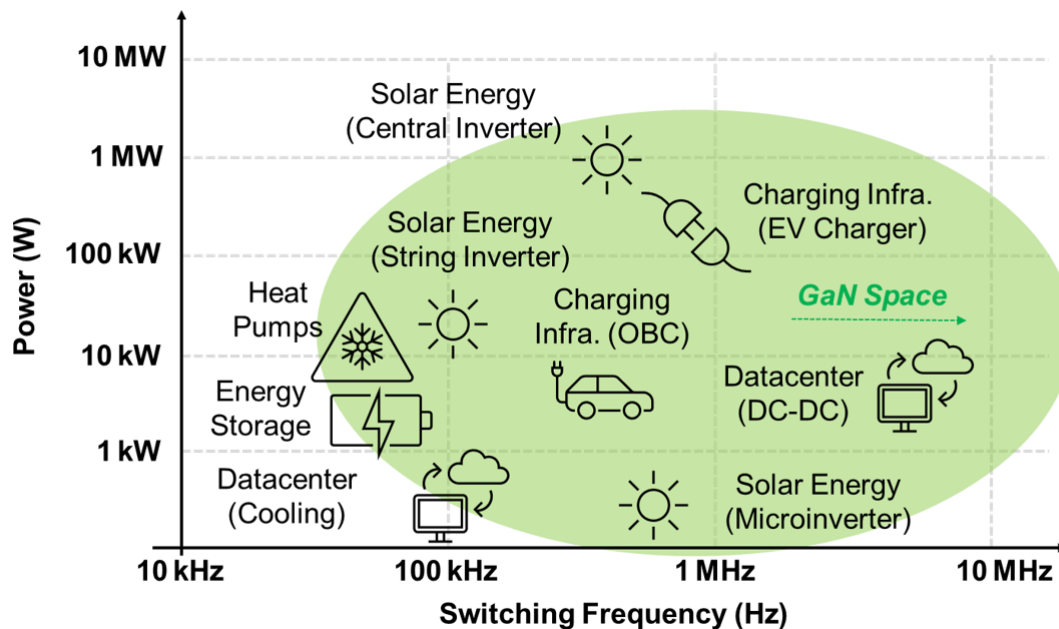


Figure 2: Clean Energy Applications Map

GaN Power Devices

Thanks to recent manufacturing advancements, it is now possible to deposit GaN transistor structures on Si substrates. This is advantageous due to lower Si cost, already established Si manufacturing capabilities, and higher breakdown threshold, thermal conductivity, faster switching speeds, and lower on-state resistance of GaN.

GaN devices have the ability to form a two-dimensional electron gas (2DEG) when combined with another material such as aluminum to form aluminum gallium nitride (AlGaN) as shown in Figure 3. This results in power devices called high-electron-mobility transistors (HEMT). The intrinsically high saturation velocity and high 2DEG mobility allows high switching frequency operation of the power device. Moreover, there is no body diode in the HEMT, but it is able to conduct in the reverse direction, improving efficiency due to lower losses and reducing node capacitances to allow a higher slew rate.

Types of GaN Power Devices

There are multiple categories in which GaN power devices are classified by various semiconductor manufacturers; however, primarily GaN power devices can be classified in four subcategories as follows.

Depletion Mode (D-Mode) HEMT

The GaN power HEMTs typically use Si substrates for fabrication. The depletion mode device allows natural formation of the 2DEG channel without any gate biasing, as shown in Figure 3. Therefore, these devices are conducting in the default state and are called “normally on” devices. A negative voltage, typically -5 to -20 V is required at the gate of D-Mode HEMT to turn the switch off. These types of devices are not very common and are used in specific applications where a default-on state is required.

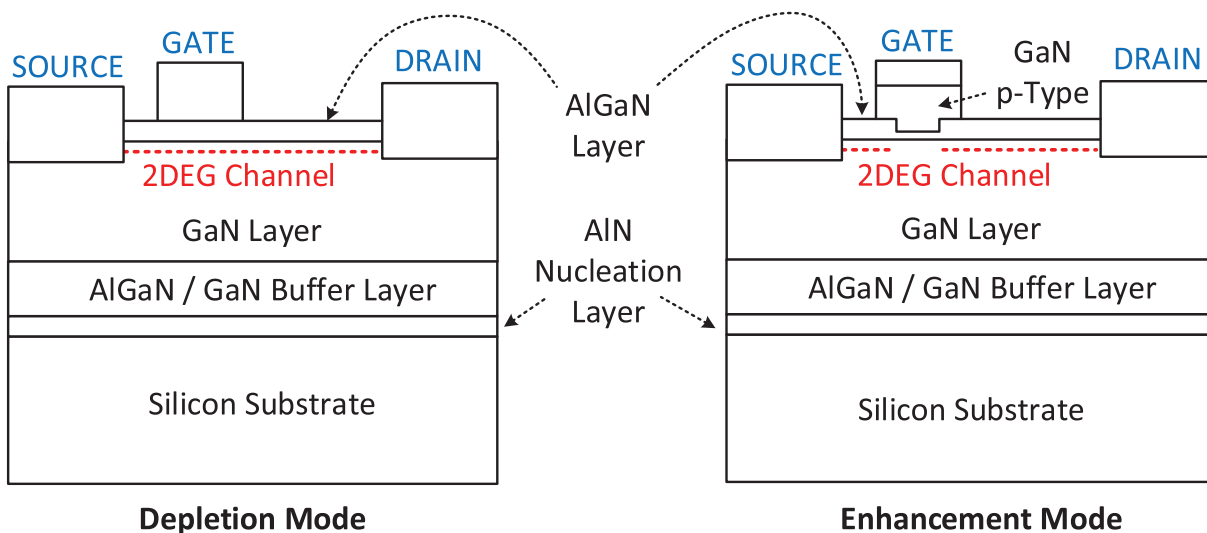


Figure 3: A Depletion (D-Mode) and Enhancement Mode (E-Mode) GaN Power Device

Depletion Mode (D-Mode) HEMT with Cascode Configuration

When a D-Mode HEMT is combined with a low-voltage Si MOSFET, a cascode GaN is obtained (as shown in Figure 4) which has the added benefit compared to D-Mode HEMT that it is a “normally off” device. The gate driver implementation is very simplified in this configuration since the gate voltage threshold for the silicon MOSFET is much lower (~ 3 to 4 V) as compared to the gate oxide ratings ($\sim \pm 20$ V). This configuration offers a wider safety margin and better noise performance. A simplified unipolar gate driver can be used for driving D-Mode HEMT in cascode configuration.

There are few disadvantages of this configuration, such as the higher gate and output capacitance, diode reverse recovery loss, switching speed limitation, and lower efficiencies at lower voltages (less than 200 V) due to the Si MOSFET.

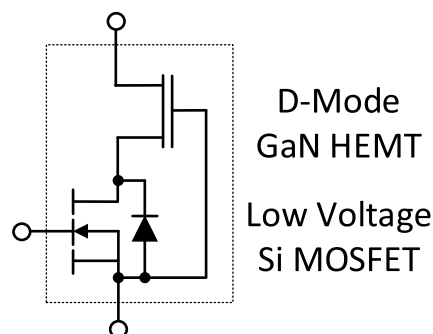


Figure 4: A Cascode Configuration

Enhancement Mode (E-Mode) HEMT

Enhancement mode HEMT is the widely used and most commercially available configuration of GaN power devices. The E-Mode devices have an additional P-type region between the gate and the channel, which ensures that the 2DEG channel is depleted when the gate is 0 V and starts conducting when the gate bias is higher than a typical threshold voltage of ~4 V. Due to this, the E-Mode devices are “normally off” devices and a positive voltage at the gate is required to turn the device on. These devices offer excellent frequency response and lower switching losses.

On the other hand, due to the lower threshold voltage, E-Mode devices suffer from lower gate noise immunity and require a negative voltage for device turn-off implementation. Moreover, the packaging and gate resistance and inductance become a critical component in handling the gate driver noise spikes to prevent voltage overshoot and ringing.

Vertical GaN (v-GaN) FET

Typically, high-power, high-voltage devices such as the SiC power devices are grown vertically. The vertical devices inherit advantages such as lower on-state resistance ($R_{DS(on)}$) and better reliability. Most GaN power applications are focused on supply voltages lower than 800 V and are grown laterally; however, due to an interest in high-voltage GaN power devices, vertically grown devices are also fabricated. These types of devices provide an added advantage of high-voltage operation like the SiC power devices and high switching frequency like the GaN power devices; however, the selection criteria against SiC devices are highly dependent on overall device cost. The v-GaN devices are in a very early stage of development and commercial viability of SiC devices is yet to be determined.

Comparison of Different Types GaN FETs and Advantages of HEMT GaN FETs

Table 2 summarizes the key differences between the four different GaN power device configurations. Typically, D-Mode devices are used in very specific “normally on” applications and are the cheapest due to their simpler structure. Cascode D-Mode and E-Mode HEMT devices are two of the most widely used configurations, whereas the vertical GaN devices are for higher voltage applications.

Table 2: Comparison of Four GaN Power Devices

Attributes	D-Mode HEMT	Cascode D-Mode HEMT	E-Mode HEMT	Vertical GaN (v-GaN) FET
Normal State	Normally On	Normally Off	Normally Off	Normally Off
Voltage Ratings	Medium (<650 V)	Medium (<650 V)	Medium (<650 V)	High (>650 V)
Switching Speed	High	Medium	High	Medium
Gate / Output Capacitance	Lower	Higher	Lower	Lower
Noise Performance	Good	Good	Poor	Good
GD Complexity	Moderate	Simpler	Simpler	Simpler
GD Voltage Polarity	Negative Voltage	Positive Voltage	Positive Voltage	Positive Voltage
GD Voltage Levels	Medium (~20 V)	Medium (~20 V)	Low (~5 V)	Medium (~20 V)
Cost	Cheapest	Medium	Medium	Optimized for Higher Voltages
Applications	Very specific requiring “Normally On” state	High-Frequency Power Supplies and Inverters, Motor Drives		High-Voltage Inverters
Typical Use Case	Rarely Used	Most Used		Under Development

GaN Power Devices in Key Power Electronics Components for Clean Energy Applications

Because of advantages such as high-frequency operation and lower power losses, GaN power devices are used in a variety of clean energy applications. Three of the widely used power electronic subsystems, i.e., power factor correction converters (AC-DC), solar inverters (DC-AC), and DC-DC power converter, are explained below.

Power Factor Correction Converter (AC/DC)

In many medium to high-power applications, i.e., consumed power above 75 W, power factor correction for grid connected applications is mandatory according to the EN 61000-3-2 standard. The PFC converter ensures zero reactive power is drawn from the AC grid by maintaining a unity power factor and lower total harmonic distortion (THD) of the supply current at AC mains. In many non-isolated applications, a boost PFC converter is commonly used, as shown in Figure 5, providing a stable DC output of ~400 V for an input single-phase AC supply of 230 V with a unity power factor at AC mains (similarly ~200 V DC is generated for 110 V single-phase AC supply). By increasing the switching frequency, it is possible to reduce the dimensions of the boost inductor, which is only possible with GaN power devices. Since for an inductor, the reactive inductance is proportional to $N^2 \times A \times f$, by increasing the frequency (f), cross-section (A) or the number of the turns (N) can be reduced while still fulfilling the system requirements. Therefore, GaN FETs enable the use of smaller inductors without a loss of performance. Consequently, the overall cost of the PFC converter is decreased, and volume or power density is increased. Furthermore, GaN devices contribute to lower power losses (conduction and switching), thereby enhancing the overall efficiency of the system.

The PFC boost converter shown in Figure 5 shows a combination of GaN FETs and MOSFETs to realize a cost-effective solution without compromising the overall efficiency of the system. High-frequency switching is applied to the GaN FETs, and the MOSFETs are operated with a low switching frequency to implement the DC voltage and inductor current-control algorithm of the PFC converter.

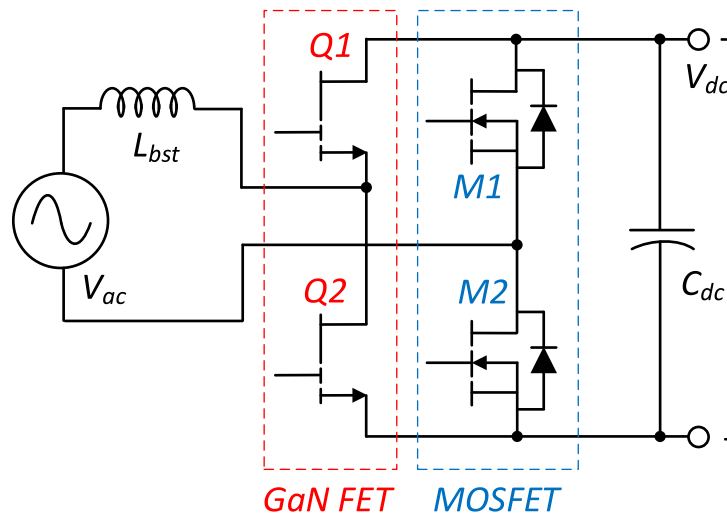


Figure 5: Boost Power Factor Correction Converter

Solar Inverter (DC-AC)

Solar grid-connected installations are becoming increasingly popular due to higher energy demands, higher energy cost, and the ever-decreasing cost of solar panels. The solar microinverter is a crucial component of a solar grid-connected system, as this converts the high-voltage DC (typically ~400 V for single phase system) to 230 V AC, which can be supplied to electrical loads or fed to the grid.

Figure 6 shows a simplified block diagram of a solar grid-connected system. The solar PV panel is connected to a maximum power point tracking (MPPT) boost converter to extract the maximum power from the solar PV panel. The output of the MPPT boost converter is fed to a solar inverter which converts DC voltage to AC voltage with proper frequency and phase synchronization for connecting to the grid or supplying power to local loads. The LCL filter acts as a low-pass filter to limit high-frequency switching currents to the grid. GaN power devices are increasingly finding applications in solar inverters due to their high efficiency and fast switching speeds, which contribute to overall system efficiency, help in size reduction of filter components due to their increased switching frequency, and to maximize the power output of the solar panels.

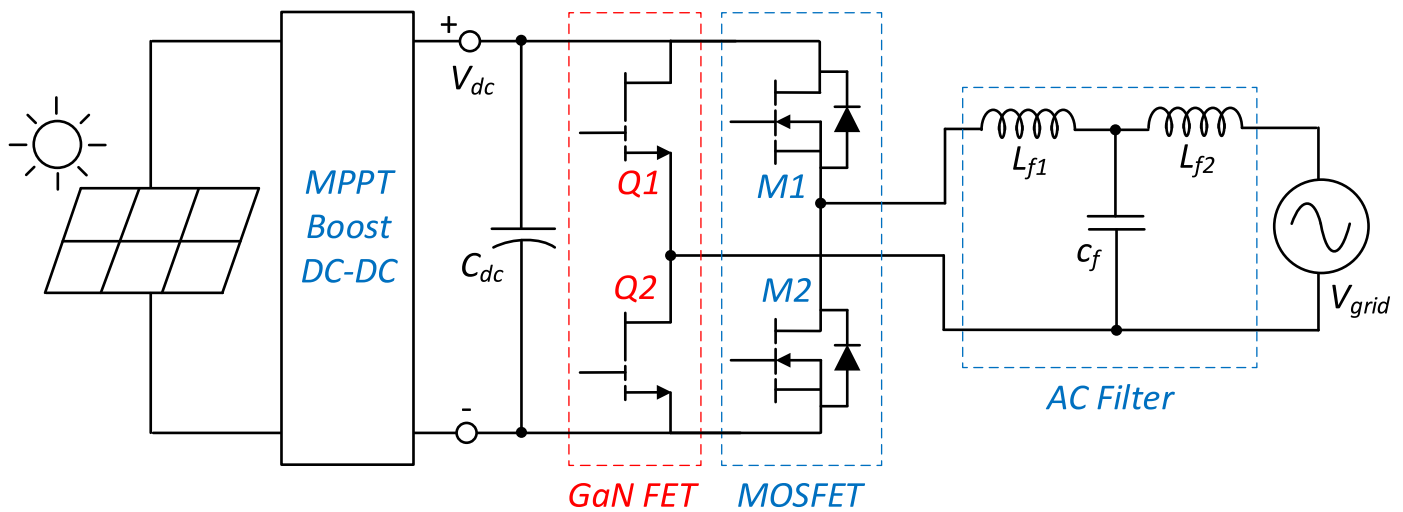


Figure 6: Solar Grid Connected System Using a Solar Inverter

DC-DC Converter

DC-DC power conversion is a pivotal part of any system where voltage levels (and frequencies with the addition of AC-DC and DC-AC blocks) must be converted. DC-DC converters provide the necessary voltage transformation (buck, boost, or buck-boost), regulation with line/load variation, and necessary isolation between high-voltage and low-voltage circuitry, for use in battery charging and discharging applications. LLC resonant DC-DC converters are one such category of DC-DC converters which are often used in clean energy applications due to advantages such as soft-switching, higher efficiency, reduced electromagnetic interference, and a wide range of operation of load and supply voltage.

Figure 7 shows an LLC DC-DC converter employing a high switching inverter using GaN power devices at the input stage. The LLC components (magnetizing inductance of transformer, series inductor, and series capacitor) form a series-resonant circuit which is used for attaining a zero-voltage switching (ZVS) operation to achieve lower switching losses. The fast-switching capabilities of GaN power devices contribute to a lower size of the high-frequency inductor. Additionally, the transformer can also be smaller while retaining the same power performance, because higher switching frequencies allow higher energy transfer per unit of time.

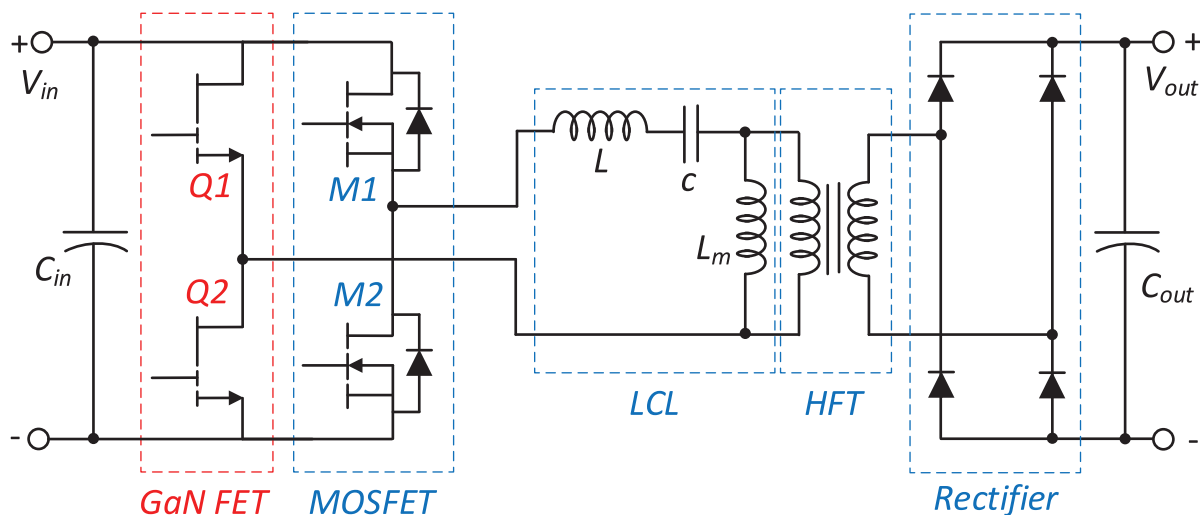


Figure 7: LLC DC-DC Converter

Power Loss Comparison of Si, SiC, and GaN Power Devices

Figure 8 shows the power loss comparison of Si, SiC, and GaN power devices, considering a 400 V, 15 A power device. As shown in this figure, the losses of the Si device is higher compared to the counterparts GaN and SiC devices for operation up to 20 kHz; whereas, for 100 and 200 kHz operation, the losses in the SiC device increases significantly due to the higher switching losses. Typically, for a medium voltage and higher frequency application, the GaN device is preferred; whereas, if a higher voltage rating is required, then the SiC is preferred due to the higher cost of the higher-voltage GaN device [2].

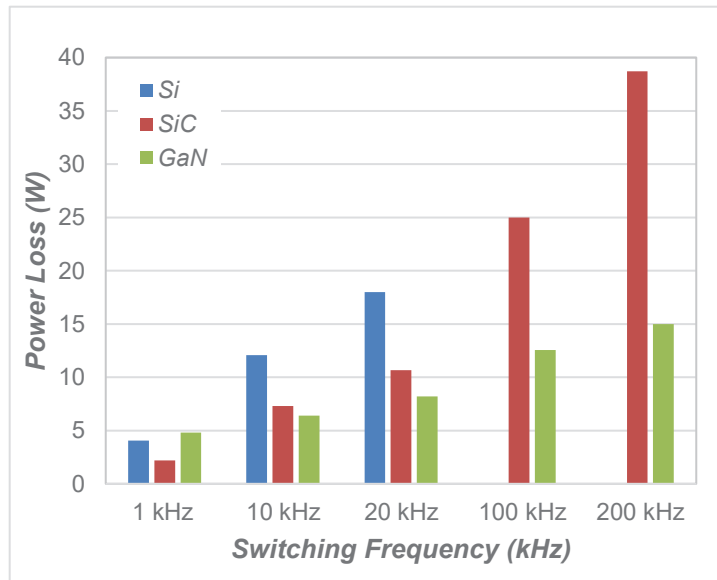


Figure 8: Power Loss Comparison of GaN power device with Si and SiC

Switching losses of silicon MOSFETs are the key contributing factor of overall power losses which are primarily affected by gate charge. Table 3 highlights key gate charge differences of silicon MOSFETs as compared to GaN and SiC power devices for similar power ratings [3-6]. As shown in this table, the gate-charge is much lower in GaN (E-Mode) and SiC FETs, which assists in achieving a lower switching loss. Moreover, the reverse-recovery charge and time can be seen in the cascode configuration due to the body diode of the low-voltage Si MOSFETs used for driving D-Mode GaN devices to realize a cascode configuration.

Table 3: Comparison of Silicon, GaN, and SiC Power Devices Parameters

Attributes	Silicon MOSFET	GaN FET (Cascode)	GaN FET (E-Mode)	SiC FET	Comments
Company	Infineon	Nexperia	GaN Systems (Now Infineon)	Infineon	
Part Number	IPP65R060CF D7	GAN063-650WSA	GS66508B	IMDG65R050 M2H	
V_{DS} (V)	650 V	650 V	650 V	650 V	Similar breakdown voltage
$R_{DS(on)}$ (m Ω) (typ./max.)	52/60 m Ω	50/60 m Ω	50/63 m Ω	50/62 m Ω	Similar on-state resistance
V_{TH} (V) (min./typ.)	3.5/4 V	3.4/3.9 V	1.1/1.7 V	3.5/4.5 V	Similar threshold voltage
Q_G (nC)	68 nC	15 nC	6.1 nC	22 nC	GaN is ~22% of Si Q_G
Q_{GS} (nC)	19 nC	6 nC	1.7 nC	5.7 nC	GaN is ~32% of Si Q_{GS}
Q_{GD} (nC)	21 nC	4 nC	2.2 nC	4.3 nC	GaN is ~19% of Si Q_{GD}
Q_{RR} (nC)	860/1720 nC	125 nC (typ.)	0	44 nC	GaN is ~14% of Si Q_{RR}
t_{RR} (ns)	156/234 ns	54 ns (typ.)	0	10.4 ns (typ.)	GaN is ~35% of Si t_{RR}

Cost Trends

A common misconception is that GaN devices are not worth using because of their higher cost when compared to their traditional Si counterparts. However, a few aspects are directly reflected in the price of individual devices; these are improved performance, additional component cost, and the price trend of GaN devices.

Current Cost Impact

Generally, GaN power devices have a high initial cost due to their complex manufacturing process, lower yield rates, and limited market penetration. However, the efficiency and performance advantages offered by GaN power devices in the long run are significant. Here is a short summary of improved system characteristics and costs due to GaN FETs:

- **Lower Energy Consumption:** GaN devices offer higher efficiency due to lower conduction losses (lower on-state resistance) and lower switching losses (due to faster switching frequency and lower gate capacitances). Due to these factors, the overall energy consumption is reduced, offsetting the running cost of the system.
- **Smaller System Size, Weight, and Cost:** GaN power devices can achieve high power density and lower size of passive components due to high switching frequency. This allows for lighter and more compact systems, reducing material and transportation costs.
- **Thermal Design:** The thermal design cost is reduced due to higher efficiency and lower power loss.

Future Cost Trends

GaN power devices are experiencing a trend of decreasing cost over time, making them more commercially viable for various applications. There are multiple reasons for this trend, such as:

- **Scalability:** As demand for GaN power devices increases, production volumes also increase, which gives an economic benefit to semiconductor manufacturers, leading to reduced production costs.
- **Technology:** Recent advancements in the manufacturing process of GaN power devices can lead to more efficient manufacturing, improved yields, and eventually to cost reduction. Unlike SiC devices, they are fabricated on a Si substrate, making them much more cost-effective and removing the bottleneck of a limited supply of raw materials.
- **Competition:** As more semiconductor manufacturers start production of GaN power devices, the overall market cost of these devices tends to go down for manufacturers to gain more market share.
- **Adoption:** With numerous emerging applications in consumer, automotive, or commercial space, GaN power devices are becoming more widely adopted which increases the overall demand. This increase in demand directly contributes to cost reduction.
- **Optimization:** Supply chain optimization, including raw materials, assembly machinery, and manufacturing and test equipment, leads to cost reductions.

As technology matures and adoption increases, GaN drivers, GaN power devices, and overall system cost are expected to become more cost competitive. Figure 9 shows the cost trends of the GaN FET (typically 650 V, 20 V), GaN drivers (<650 V), and the overall system cost (considering three GaN drivers and six GaN FETs for realizing a 5 kW three-phase system) [7]. While GaN carries a higher initial cost when compared to silicon, its efficiency and performance benefits offer potential cost savings in the long run. As discussed previously, the cost of GaN devices is expected to be lower with better benefits than traditionally available Si and IGBT power devices in upcoming years.

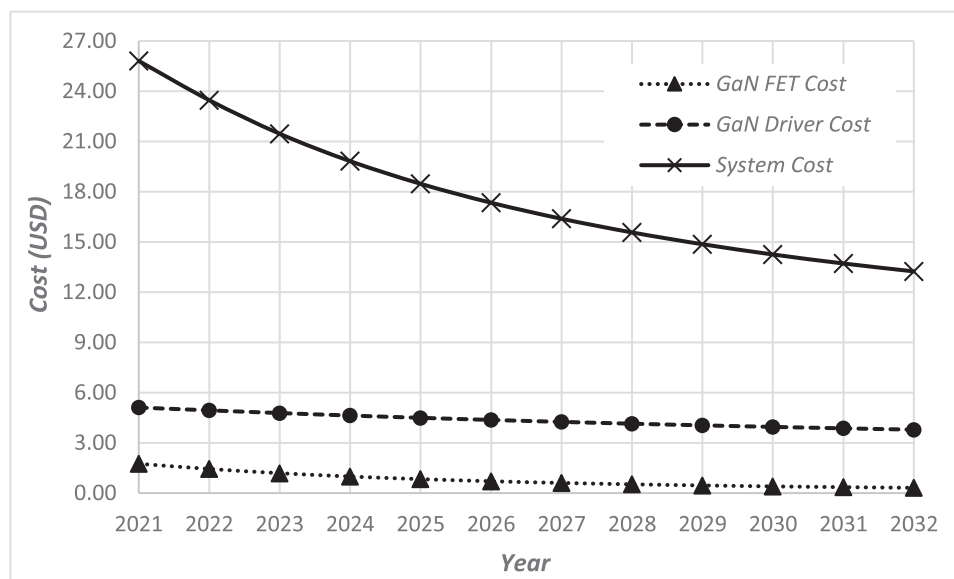


Figure 9: Cost Trend of GaN FETs, GaN drivers, and Overall System

GaN Gate Drivers

This section highlights key parameter requirements for selection of GaN gate drivers and common roadblocks towards wide-spread adoption of GaN for switching devices.

Key Parameter Requirements for GaN Drivers

There are multiple parameters to consider for GaN gate drivers:

- **Gate Voltage:** Depending on the GaN power device type (specifically cascode D-Mode and E-Mode HEMTs), there is a requirement of a positive turn-on (typically 5 to 12 V) and turn-off voltage (typically -2 to -5 V). For the D-Mode, the voltage polarity is reversed.
- **Gate Current:** The gate current of GaN FETs is selected based on the gate capacitance and the required switching frequency of the application. Since the gate capacitance of GaN power devices is lower than their silicon counterparts, a smaller gate charge is required for achieving similar performance at similar switching frequency. However, the higher switching frequency dictates faster charging times, resulting in higher gate current.
- **Rise and Fall Times:** Lower rise and fall times are required to match the driver switching speed to the GaN FET capabilities. Faster switching speeds can improve the overall system efficiency but may increase EMI, which eventually requires careful layout consideration.
- **Switching Transients:** Due to higher switching frequencies, the sensitivity of the driver to parasitic inductance and capacitances is increased, which impacts the overall ringing performance of the system and is catered with a low parasitic PCB layout design.
- **Dead Time:** This parameter determines the off-time between the switching periods of the high-side and low-side FETs. Proper dead time setting minimizes shoot-through current and optimizes efficiency.
- **Propagation Delay:** This parameter determines the digital and analog signal delay of the gate driver from the input signal application to the actual output on the gate. Lower propagation delays ensure a quicker switching response and overall optimized performance.
- **Isolation:** Based on the application requirements, the galvanic isolation between the input and output is required for safety concerns and preventing ground loops.

- **Protection:** Multiple protection features are implemented in gate drivers to protect the gate driver and the GaN power device in fault states. Undervoltage lockout (UVLO) is used for preventing operation at insufficient gate voltage. Overvoltage protection (OVP) limits the gate voltage to prevent breakdown. Overcurrent protection (OCP) detects the overcurrent in case of short circuit and shoot-through faults. The thermal shutdown feature protects the driver from overheating due to excessive load or environmental conditions.
- **Fault Reporting:** Many applications require faults to be reported back to the main controller, where fault reporting features like error flags or diagnostic outputs are used for troubleshooting and system monitoring.
- **Package Size and Thermal Dissipation:** Package size is crucial in determining package power dissipation and impacts the overall size of the PCB.
- **Cost and Availability:** The overall cost, availability, and future trends are important factors of consideration for selection of such gate drivers.

Allegro MicroSystems Portfolio of GaN Drivers

Allegro MicroSystems offers a family of isolated GaN FET drivers with innovative proprietary Power-Thru integrated isolated bias supply. The Power-Thru technology from Allegro is the only existing solution on the market today that eliminates the need for external power supplies and simplifies the design process while reducing cost and complexity. The current offerings include [AHV85110](#) [8] and [AHV85111](#) [9] gate drivers which extend the following advantages [10-13].

- **Integrated Inductive Isolation:** Allegro gate drivers are integrated with inductive isolation, supported up to $5 V_{RMS}$ (UL1577), which makes them ideal in applications requiring isolation, level-shifting, or ground separation for noise immunity.
- **Integrated Power Supply:** Allegro isolated gate drivers integrate an isolated output bias supply, thus eliminating the need for any external gate drive auxiliary bias supply or high-side bootstrap.
- **Reduced EMI:** Their integrated power supply also reduces the total common-mode (CM) capacitance which helps to reduce EMI. The typical CM capacitance of Allegro gate drivers is in the order of ~ 1 pF, whereas this can be as high as 8 to 15 pF in other solutions available on the market.
- **High-Power Density:** Their isolated power supply integration also increases the overall power density of the system which enables Allegro to build smaller and more efficient systems while reducing the development time and cost.
- **High-Efficiency:** Allegro gate drivers deliver power on demand, which in turn offers higher efficiency. The combined power savings in Allegro drivers is typically ~ 1.3 to 2 W per high-side switch, which also reduces the size and cost of the cooling system.
- **Easier Design and Lower Development Cost:** Due to their power supply integration, a separate isolated power stage is not needed, greatly simplifying system design and reducing overall development time and cost.
- **Low External Bill-of-Materials (BOM) Count and Cost:** With their power supply integration, the number of components required externally is greatly reduced, thus enabling a lower BOM solution at lower cost.

Conclusion

Silicon devices offer maturity and availability but are nearing peak performance in meeting demands for smaller and more efficient systems. WBG devices cater to such requirements in a more effective way. SiC devices have been available for longer but are more suited for higher voltage and higher power applications, whereas GaN power devices are the perfect choice for clean energy applications due to better efficiency and high-frequency operation of the power electronics system. GaN devices combined with Allegro MicroSystems isolated gate drivers offer a robust, small, and lower cost solution for various clean energy applications with unparalleled performance.

References

- [1] J. Styles, "[Common misconceptions about the MOSFET body diode](#)", EE World Online Article from GaN Systems, October 17, 2019.
- [2] S. Rai, "[GaN, SiC or Silicon Mosfet – A Comparison Based On Power Loss Calculations](#)", DiscoverEE, PCIM Asia Expo, Nov. 2020.
- [3] "[IPP65R060CFD7, 650VCoolMOS CFD7 SJ Power Device](#)", Infineon Datasheet, Rev. 2.1, August 12, 2020.
- [4] "[GAN063-650WSA, 650 V, 50 mΩ Gallium Nitride \(GaN\) FET](#)", Nexperia Datasheet, March 20, 2020.
- [5] "[GS66508B, Bottom-side cooled 650 V E-mode GaN transistor Datasheet](#)", GaN System (now Infineon) Datasheet, Rev. 200402.
- [6] "[IMBG65R050M2H, CoolSiC MOSFET650V G2](#)", Infineon Datasheet, Rev 2.1, Feb. 2024.
- [7] R. Eden and C. Middleton, "[SiC & GaN Power Semiconductors Report – 2023](#)", Market Research Report, Omdia, 2023.
- [8] AHV85110, "[Self-Powered Single-Channel Isolated GaN FET Driver with Power-Thru Integrated Isolated Bias Supply](#)", Allegro MicroSystems Datasheet, June 20, 2023.
- [9] AHV85111, "[Self-Powered Single-Channel Isolated GaN FET Driver with Regulated Bipolar Output Drive](#)", Allegro MicroSystems Datasheet, September 13, 2023.
- [10] D. Dobbyn, "[FET Gate Drive and Bipolar Output Applicable to AHV85110KNHTR Gate Drivers](#)", Allegro MicroSystems Application Information, August 2022.
- [11] "[Simplify Designs and Reduce Overall Systems Cost by Eliminating External Power Supplies](#)", Allegro MicroSystems Technical Article, November 22, 2022.
- [12] A. Wang, "[Solving the Challenges of Increasing Power Density by Reducing Number of Power Rails](#)", Allegro MicroSystems Technical Article, March 28, 2023.
- [13] "[Solving Gate Drive Challenges with Technology for Improved Power Design](#)", Allegro MicroSystems Technical Article, January 8, 2024.

Revision History

Number	Date	Description
-	May 13, 2024	Initial release

Copyright 2024, Allegro MicroSystems.

The information contained in this document does not constitute any representation, warranty, assurance, guaranty, or inducement by Allegro to the customer with respect to the subject matter of this document. The information being provided does not guarantee that a process based on this information will be reliable, or that Allegro has explored all of the possible failure modes. It is the customer's responsibility to do sufficient qualification testing of the final product to ensure that it is reliable and meets all design requirements.

Copies of this document are considered uncontrolled documents.