

# **Application-Specific MOSFETs and Wide Bandgap Semiconductor Devices to Maximize Automotive Power, Efficiency, and Reliability**

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## A. INTRODUCTION

The automotive industry is transforming, particularly with the shift towards electric vehicles (EVs) and hybrid electric vehicles (HEVs). Advancements in semiconductor technology help drive these changes with application-specific Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), which are crucial for high-power automotive applications.

From systems such as electronic fuel injection to airbag deployment and beyond, MOSFETs are becoming the backbone of the next generation of automotive power systems. However, there are many applications where a standard MOSFET isn't ideally suited. For the instances where traditional MOSFETs fall short, Nexperia's specialized, application-specific MOSFETs, called ASFETs, provide the perfect solution.

Furthermore, wide bandgap semiconductor devices such as gallium nitride (GaN) and silicon carbide (SiC) are enhancing the efficiency, durability, and power density in various automotive and industrial applications.

Nexperia, a leader in the semiconductor industry, recently presented its work on application-specific MOSFETs, emphasizing the importance of these components in high-power automotive applications.

In this white paper, we will explore the significance of MOSFETs in automotive power systems, Nexperia's innovations including its exclusive 100% copper clip technology and revolutionary LFPACK, and the role of wide bandgap semiconductor devices in advanced automotive electronics.

A review of Nexperia's comprehensive solutions, including advanced MOSFETs and wide bandgap semiconductor technologies, is included and covers:

1. **Application-specific MOSFETs** that offer optimized performance for high-power automotive systems.
2. **Copper clip packaging technology** that improves thermal management and efficiency in high-current scenarios.
3. **Wide bandgap semiconductors (SiC and GaN)** that provide higher efficiency, faster switching speeds, and better thermal performance for high-power applications.

These innovative solutions help automotive manufacturers overcome the challenges posed by modern EV and HEV systems and drive the next generation of superior automotive power applications.

## **B. PROBLEM STATEMENT / BACKGROUND**

### **Efficient Power Management in High-Power Automotive Applications**

As the automotive industry moves towards more EVs and HEVs, power management becomes increasingly critical. High-power applications such as electronic fuel injection, onboard chargers and battery management systems require components that can operate efficiently while tempering significant thermal and electrical loads. Traditional silicon-based semiconductors often struggle to meet these demands, resulting in power losses, overheating, reduced system reliability, and safety concerns.

Furthermore, the shift towards fast-charging, high-voltage systems requires components that can handle rapid switching frequencies, high currents, and elevated temperatures without compromising efficiency or safety. The growing need for compact, lightweight power electronics further pressures designers to find solutions that minimize the size and weight of these systems while maximizing performance.

Wide bandgap semiconductors gallium nitride (GaN) and silicon carbide (SiC) offer enhanced performance over traditional MOSFETs. Still, their adoption is impacted by a limited marketplace understanding of the many specialized, application-specific designs and advanced packaging solutions currently available or in development.

This white paper seeks to answer the following question:

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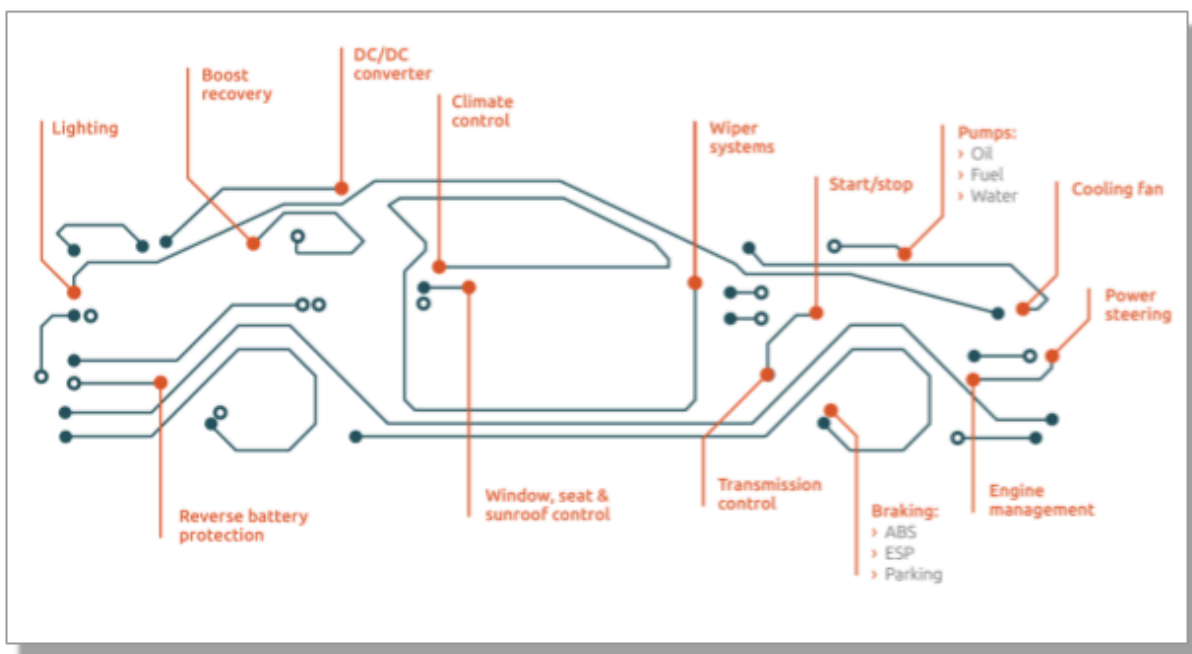
***How can EV manufacturers address the increasing demands for efficiency, thermal management, and compact sizing for high-power automotive applications while ensuring maximum performance, reliability, and safety?***

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## C. INDUSTRY-LEADING SOLUTIONS: NEXPERIA'S APPLICATION SPECIFIC MOSFETs AND WIDE BANDGAP SEMICONDUCTOR DEVICES

### 1. Overview: The Role of MOSFETs in High-Power Automotive Applications

MOSFETs are fundamental to many power electronics systems due to their efficiency, high switching speed, and reliability. In automotive applications, MOSFETs control power flow in critical systems such as electronic fuel injection, battery management and a variety of other systems indicated by the diagram below.



- **Electronic Fuel Injection (EFI)**

Electronic fuel injection systems require fast and efficient power switching to optimize combustion. Nexperia's value is that, unlike a normal MOSFET, the company's ASFETs can drive the fuel injection solenoid directly without the need for additional diodes for back EMF protection, saving space and cost.

- **ABS Braking**

MOSFETs in ABS systems control brake valves and pump motors by acting as fast, efficient electronic switches. They regulate power to solenoid valves, modulating brake

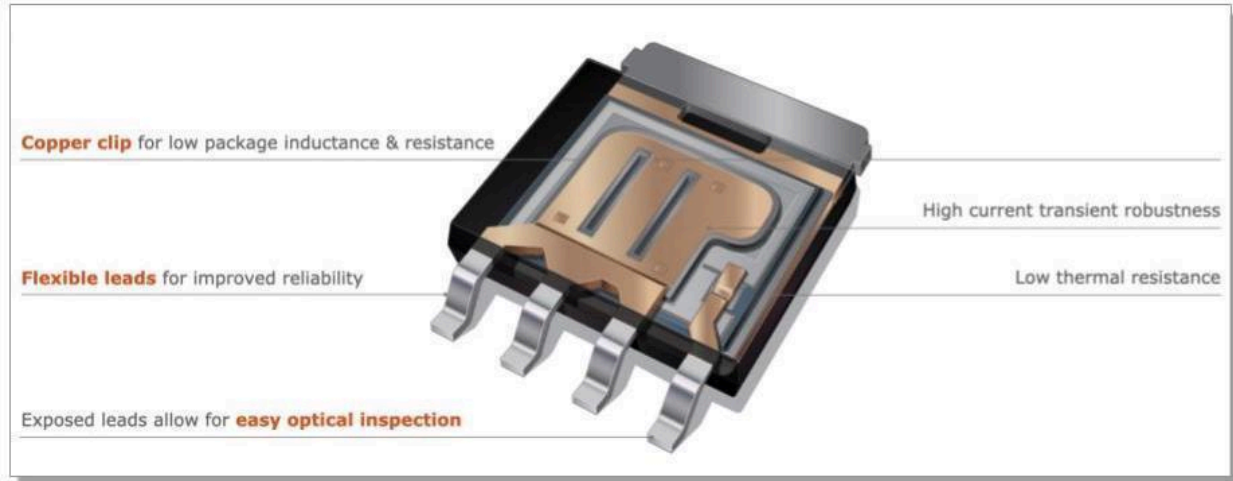
pressure and maintaining hydraulic pressure, ensuring responsive and reliable ABS function for improved braking safety.

- **Battery Management Systems (BMS)**

Battery management systems monitor and control the battery's charge and discharge cycles, ensuring safety and prolonging battery life. MOSFETs are integral to BMS's switching circuits, controlling the power flow to and from the battery.

## 2. Nexperia's Exclusive Copper Clip Technology

While the above are typical applications in the marketplace, this white paper will review MOSFETs available for solving specific problems. Nexperia's key solution is not just the MOSFETs or the silicon but *the package itself*. One of Nexperia's standout innovations is its 100% copper clip technology, which is optimized for use in MOSFETs.



Nexperia's revolutionary copper clip technology replaced traditional wire bonding and provides a wide current path that supports enormous amounts of current. The company has continued to further develop and refine both the technology and packaging for the past 20 years. The LFPAK series features double copper clamps, one on the top and one on the bottom. While most suppliers in the marketplace have the bottom clamp, the top clamp is the differentiator. It allows heat to flow off the top of the die, then down the thermal vias into the board itself.

This advanced double-sided cooling significantly improves thermal management and electrical efficiency while providing maximum current capability—making it an ideal solution for high-power automotive applications.

## 2.1 LFPAK: A Game-Changer for Automotive Power Systems

Nexperia's LFPAKs feature MOSFET packaging incorporating 100% copper clip technology to deliver superior performance in automotive applications. These advanced copper clip solutions can be integrated with nearly any technology and for any application inside the EV marketplace.

LFPAKs offer several key advantages over traditional MOSFET packages, including:

- **Lower Resistance:** The LFPAK features lower RDS(on) than conventional packages, reducing power losses and improving overall system efficiency.
- **High Current Capability:** With its enhanced thermal management and robust design, the LFPAK can handle higher current loads, making it suitable for high-power automotive applications such as fuel injection and ABS braking.
- **Compact Design:** The LFPAK's compact form allows for higher power density, enabling automotive designers to integrate more powerful MOSFETs into smaller spaces, which is critical for the space-constrained environments of modern EVs.

Nexperia offers the LFPAK in four different sizes, depending on the application and power needed:

### 1. LFPAK33

- 3x3 millimeters
- Rated up to 80 amps; max fusing current of 160 amps
- Example application: ABS braking

### 2. LFPAK56

- 5x6 millimeters
- Rated up to 220 amps; max fusing current of 350 amps
- Example application: DC/DC converter

### 3. LFPAK88

- 8x8 millimeters
- Rated up to 500 amps
- Example applications: Power steering, electrical superchargers

### 4. LFPAK1212 - the newest package, designed specifically for high-voltage devices

- 12x12 millimeters
- Can handle in excess of 500 (not yet rated)
- Example application: Main motor inverter

### 3. Automotive Power MOSFETs

One of Nexperia's key advantages is the company's commitment to recommend and supply the right solution depending on the manufacturer's needs. Nexperia's innovative MOSFET solutions suite enables expert sourcing of the best solution for specific applications versus competitors who only produce one type of solution.

Because a singular MOSFET that fits every need doesn't exist, Nexperia has created a comprehensive, three-tier line to accommodate nearly any customer need.

#### 3.1 Standard MOSFETs for Cost Effectiveness

Nexperia's standard MOSFET line offers solid reliability, focusing on cost without compromising performance for lower power applications.

**Applications:** Body control (windows, seats, etc.) and lighting.

#### 3.2 Premium MOSFETs for Superior Reliability

Nexperia's premium MOSFETs feature the highest performance, quality and reliability for mission-critical applications. These copper clip, fully automotive-plus-rated MOSFETs are available in a wide variety of 3x3, 5x6 and 8x8 applications.

**Applications:** Engine management control unit, electric power steering.

#### 3.3 Application-Specific MOSFETs for Unique Applications

These devices feature a large body diode for handling EMF and running the device in repetitive avalanche mode. Nexperia took a regular MOSFET and modified its process, or in some cases its package, to allow it to do things a normal MOSFET can't.

ASFETs are MOSFETs modified for specific applications that require repetitive avalanche mode operation or expanded linear mode operation.

**Applications:** Motor control applications, airbag technologies, repetitive avalanche topologies.

## 3.4 New Nexperia MOSFETs Overview

### 3.4(a) New Small Signal MOSFETs - New Package

This line features 1-2 amp devices that control small signals and are now offered in smaller packages, enabling more performance from the same die. Added heat pads enable more power with no change to the silicon but rather to the package itself, offering improved headroom and better performance.

**Applications:** Body control units (doors, window lift, seat control), infotainment (vehicle radio, navigation), and safety and control systems (airbags, LED lighting).

### 3.4(b) New LFPK88 - Power Applications

The LFPK88, with its 8x8 footprint, reigns supreme in the automotive marketplace. Manufacturers can put huge amounts of power through this device, which has ultra-low RDS(on) and best-in-class linear mode performance.

**Applications:** Brushless DC motor controls, power steering, ABS braking, DC/DC conversions, air conditioner compressor, electrical supercharger, and a wide variety of high-power, brushless DC motor applications.

### 3.4(c) New Automotive ASFETS - Optimized Parameters for Individual Applications

Nexperia's modified MOSFETs are designed to achieve capabilities beyond what regular MOSFETs can handle. These advanced MOSFETs remain in the linear switching mode for extended periods without sustaining damage, effectively addressing thermal and silicon-related challenges.

They are also capable of managing large amounts of current flowing backward into the FET, a task that would overwhelm a standard MOSFET. This enhanced performance makes them ideal for applications where traditional MOSFETs fall short.

**Applications:** Three-phase powertrain motor control, DC/DC converter, repetitive avalanche topologies, engine and transmission control, actuator and auxiliary loads, airbag topologies, and fuel, oil and water pumps.

### 3.4(d) MLPAK33 - New Cost Effective, Standard Package

The MLPAK33 is a new standard package device for when cost is more critical than superior reliability. It is the most cost-reduced and energy-efficient device in the Nexperia line.

**Applications:** Low RDS(on) load switching, DC/DC conversion, battery management, charging devices, solid state/hard drive.

## 4. Wide Bandgap (WBG) Semiconductor Devices: IGBT, GaN and SiC in Automotive Power Applications

Wide bandgap semiconductors like gallium nitride (GaN) and silicon carbide (SiC) are transforming the automotive power market by offering superior performance compared to traditional silicon-based devices. These materials enable higher efficiency, faster switching, and greater power density, making them ideal for high-power automotive and industrial applications.

### 4.1 Technology Overview

One size does not fit all. Each semiconductor device has its pros and cons, discussed below.

Technology	Benefit	Limitation
(Silicon) IGBT	Rugged, well established, low cost, short-circuit fault robustness	Limited switching frequency; lower efficiency at light loads
eMODE GaN	Low profile packaging; high efficiency, very fast switching	More complex gate drive circuit, higher RDS per unit area vs. DMODE GaN; < 650V ratings
DMODE / Cascode GaN	Straightforward drive circuit, gate robustness, very fast switching (HEMT), high efficiency	< 650V ratings; requires 2-die solution (Si Cascode + DMODE GaN)
SiC MOSFET	Highest efficiency for > 1kV applications; fast switching; <u>best thermal performance per unit area</u>	High body diode conduction loss ( $V_f > 3V$ ) reduces efficiency below 650V; require precise dead-time control

### 4.2 Nexperia IGBTs

Nexperia's Insulated Gate Bipolar Transistor (IGBT) solutions have been designed for high-power applications requiring robustness and reliability. These components have

been a staple in the industry for several decades and continue to provide a cost-effective, efficient option for applications that demand high power, rugged durability with quick charging capabilities.

#### **Key Benefits:**

- **Ruggedness and Reliability:** IGBTs are well-known for their capability to handle high power with strong short-circuit protection, making them ideal for demanding environments like large industrial applications.
- **Cost-Effectiveness:** As an established technology, IGBTs are low cost and widely available, making them a practical choice for applications where budget is a concern.
- **Wide Voltage Range:** Nexperia offers IGBTs in the 600V to 1200V range, which allows them to be used in a variety of power electronics applications.

**Applications:** These components are primarily used in heavy industries such as traction inverters, DC/DC converters and battery management systems.

#### **4.2(a) NP2 Package**

Nexperia also offers IGBT modules in their NP2 package. This format includes multiple IGBT devices and sometimes gate drivers integrated into a single unit. The package offers pre-configured solutions that reduce the complexity and effort needed for system design.

#### **Key Benefits:**

- **Heavy-Duty Motor Control:** Construction vehicles, industrial equipment, and high-power transportation systems benefit from IGBT's robustness.
- **Battery Management and DC/DC Converters:** IGBT solutions effectively manage battery power and convert DC power efficiently.
- **Quick Charging Systems:** IGBTs provide fast and reliable performance in large-scale onboard chargers, ensuring high-throughput charging capabilities.

**Applications:** Common motor control applications, such as elevator controllers, large motor inverters, and industrial control systems.

#### **4.3 Nexperia GaN Devices**

Nexperia offers both Depletion Mode (D-mode) Cascode GaN devices and Enhancement Mode (E-mode) GaN devices, each tailored for specific high-efficiency applications.

GaN technology is capable of switching at extremely high frequencies, up to 1 megahertz. This fast switching significantly reduces magnetic component sizes and switching losses, improving overall system efficiency. Whether manufacturers are designing onboard chargers, DC/DC converters or other inverters, GaN devices are a leading choice for high-efficiency power conversion.

### Key Differences Between D-Mode and E-Mode GaN

	Cascode	E-mode
$V_{DS}$ and $R_{DS(on)}$	Low voltage parts not possible Generally lower $R_{DS(on)}$	High and low voltage versions Generally higher $R_{DS(on)}$
$Q_{rr}$ in excess of $Q_{oss}$	Tens of nC	0
3 <sup>rd</sup> quadrant $V_{DS}$ drop	< 2V	> 6V
Slew rate control	Indirect control	Direct control
Gate robustness	$\pm 20V$	-6V / +7 V

#### 1. E-mode (Enhancement Mode):

- Normally off, like a standard silicon MOSFET.
- Turns on when voltage is applied to the gate.
- Has higher  $R_{DS(on)}$  due to the P-channel gate structure, which adds resistance.
- Easy to control with conventional logic, but less efficient compared to D-mode.

#### 2. D-mode (Depletion Mode):

- Normally on, requiring voltage on the gate to switch off.
- Offers significantly lower  $R_{DS(on)}$ , up to 10 times lower than E-mode devices, making it more efficient for the same die size.
- Better suited for applications where minimizing losses is critical.

#### Applications:

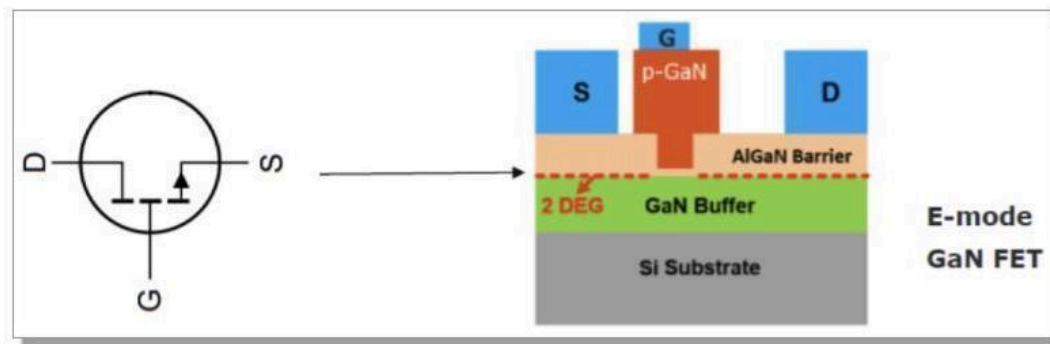
- **E-mode GaN** is favored for its familiar control logic and ease of use in systems requiring straightforward MOSFET-like behavior.
- **D-mode GaN** provides superior efficiency with lower  $R_{DS(on)}$ , making it ideal for applications where performance and power loss reduction are paramount.



- **Heat Management:** Flexible heat sink options (up or down) to accommodate different cooling requirements, ensuring safe thermal management in high-voltage applications.

#### 4.3(b) E-Mode GaN

Enhanced-mode (E-mode) GaN devices are simpler in design and offer high performance in lower-power applications. Unlike Nexperia's D-Mode offerings that feature a Cascode FET, E-Mode GaN devices are generally used in medium-power applications, operating in the 40V to 150V range offering an excellent balance between performance and cost.



#### Applications:

- **Power Converters and Supplies:** GaN devices are used in high-frequency switching power supplies and converters to enhance efficiency and reduce energy losses.
- **Onboard Chargers:** GaN's high efficiency makes it ideal for onboard chargers, especially for EV applications requiring compact, high-performance designs and superior thermal performance.
- **Industrial and Automotive Applications:** Both Cascode and E-mode GaN devices can be applied in various industrial and automotive settings.

#### 4.3(c) AVX GaN

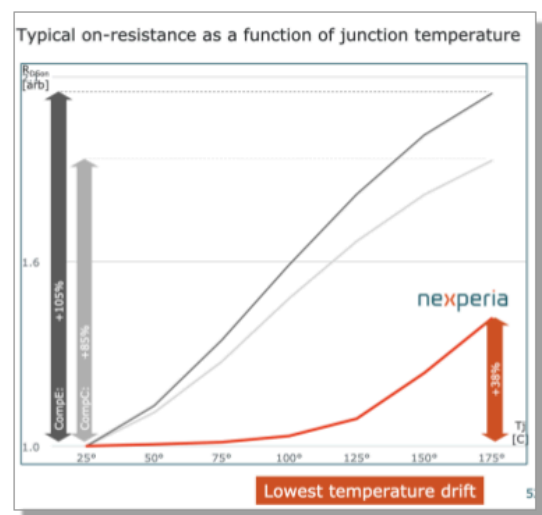
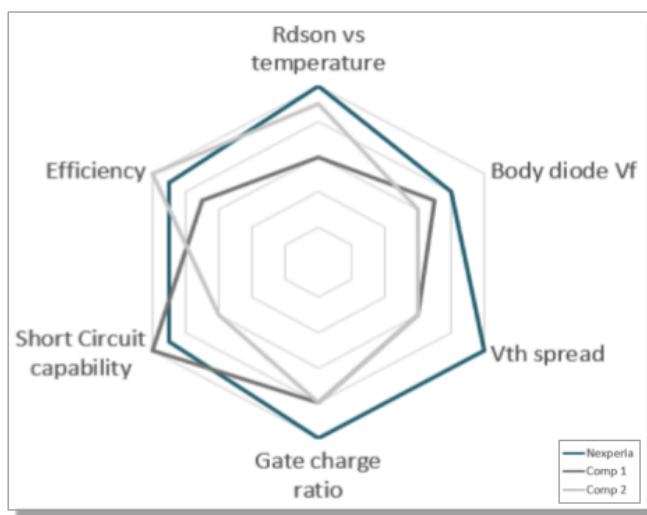
A joint venture between Nexperia and Kyocera, the AVX GaN is a controller built inside a large heatsink module. It proves the concept that gallium nitride can be used inside module applications. In this example it was designed to provide a full brushless DC motor controller with onboard PFC.

This controller epitomizes what Nexperia can do with perfect packaging and the right piece of silicon for a complete gallium nitride-based motor controller application.

#### 4.4 Nexperia Silicon Carbide (SiC) FETs

Silicon carbide (SiC) FETs are part of the wide bandgap semiconductor family that offers superior performance in high-voltage applications compared to traditional silicon-based devices.

Built to solve the most common problems in the marketplace, Nexperia's SiC FETs provide high efficiency, low losses, and high thermal performance, making them an excellent choice for EV and power system applications.



#### Key Benefits:

- **High Efficiency in High-Voltage Applications:** SiC FETs excel in high-voltage (1200V) applications, offering much lower conduction losses compared to silicon counterparts, which improves system efficiency and reduces thermal load.
- **Smallest RDS(on) Temperature Drift:** One significant advantage of Nexperia's SiC FETs is their low RDS(on) temperature drift. This means their heat resistance remains relatively stable even as temperatures increase, ensuring consistent performance and minimizing power losses under high-stress conditions.
- **Superior Gate Charge Ratio:** Nexperia has optimized the gate charge in their SiC FETs, allowing for faster switching and lower DC/DC losses, making these devices highly efficient in applications that require rapid switching.

## Applications:

- **Traction Inverters and Motor Control:** SiC FETs are ideal for traction inverters in EVs where high power and efficiency are crucial for vehicle performance.
- **DC/DC Converters:** SiC FETs are also commonly used in high-voltage DC/DC converters, providing the maximum power conversion with lower losses.
- **Onboard Chargers:** SiC FETs provide high power and efficiency in limited space applications.

## D. CONCLUSION

The automotive power market is experiencing a paradigm shift driven by the increasing demand for EVs and advanced power management systems. As automotive systems become more complex, the need for high-performance semiconductor solutions has never been more apparent. Application-specific MOSFETs and wide bandgap devices like GaN (Gallium Nitride) and SiC (Silicon Carbide) are enabling the development of more efficient, reliable, and safe power solutions.

Nexperia leads this shift with innovations like its Application-Specific MOSFETs and wide bandgap semiconductor devices. The integration of its exclusive copper clip technology in the LFPACK series enhances thermal management and power density, allowing for more compact and efficient systems in critical applications like traction inverters and onboard chargers. Nexperia's GaN and SiC devices further boost efficiency by handling higher voltages and faster switching, reducing losses in high-power automotive systems.

As EV and HEV adoption continues to grow, the need for advanced semiconductor solutions will increase as well. Nexperia's commitment to developing highly specialized MOSFETs and advanced GaN and SiC technologies ensures the company remains at the forefront of driving the future of automotive power, enabling the next generation of safe, energy-efficient and high-performance EVs.