

Application-Specific MOSFETs and GaN Solutions for the Automotive Market

Key Takeaways

MOSFET packaging technologies are designed to accommodate different application requirements with smaller and more efficient options.

Application-specific FETs are designed for specialized automotive applications, such as repeated avalanche, half-bridge, and airbags, and reduce the cost and complexity of the circuit design.

Gallium nitride (GaN) technology offers higher efficiency, reduced losses and the ability to stack FETs for even higher power applications. GaN technology is becoming increasingly popular in the automotive industry, especially in electric and hybrid vehicles.

Although silicon carbide has been in the market longer than GaN, the latter is gaining popularity due to its efficiency and reduced power losses, making it a competitive choice for automotive applications.

As a whole, the electric vehicle market continues to grow rapidly, and Nexperia continues to build connectivity solutions for 400V vehicles.

Overview







Metal oxide semiconductor field-effect transistors (MOSFETs) are used in a variety of automotive applications, for both I.C.E. vehicles as well as newer electric vehicles. MOSFETs power airbags, turn signals, power controls, infotainment, battery management and more. Nexperia offers a range of MOSFET options and designs optimized for automotive applications, including application-specific FETs and the use of gallium nitride, to meet the needs of the emerging electric vehicle market.

Nexperia MOSFET Design and Capabilities

For more than 20 years, Nexperia has offered a portfolio of copper-clip technology LFPAKs for automotive applications. The latest LFPAK88 8mm x 8mm copper clip packaging is ideally suited to replace the D2PAK by offering more power and avalanche protection due to its larger die size, and was designed to pass all AEC-Q101 specifications. This solution was built for automotive applications that require more power, such as power steering, ABS braking, reverse battery protection, and DC-to-DC converters in hybrid and electric vehicles.

40V portfolio
 $R_{DS(on)}$ [max] in (mΩ) @ $V_{GS} = 10\text{ V}$

High performance Portfolio products

	CCPAK1212	SL	0.3*	0.4*								
		LL										
	LFPAK88	SL	0.55	0.7	1.0	1.2	1.5	2.0	2.5			
		LL										
	LFPAK56 LFPAK56E	SL	1.0	1.4	1.7	2	2.5	3	3.5	7		
		LL	0.9	1.3	1.6	1.9	2.4	2.8	6.5			
	LFPAK56D Dual	SL										
		LL		13								
	LFPAK56D Half-bridge	SL	4.2									
		LL		13								
	LFPAK33	SL	3.3	4.3	5	6	6.7	8.5	9.5	11	15	20
		LL	3.3	4.3	5	6	6.7	8.5	9.5	11	15	20

*Roadmap products

There are a growing number of applications where brushless DC motors and other high-powered functions inside the automobile require additional power. The LFPAK88 can be used in 12V I.C.E. internal combustion engine vehicles while meeting requirements for new applications in the marketplace.

Nexperia's LFPAK portfolio includes innovative design and engineering, including silicon processing, avalanche ruggedness, and fault condition tolerance, to optimize its MOSFETs for automotive applications.

Silicon process and packaging. One key difference of Nexperia MOSFETs over competitors is how the silicon is processed. Many manufacturers use split-gate fence silicon processing, which uses a large number of small, narrow trenches of MOSFET elements, resulting in heat buildup between the trenches. Heating can lead to failure and requires a solution to dissipate the heat through layers of silicon.

Nexperia's super-junction silicon processing approach uses a fewer number of larger, deeper and more robust trenches that go to the bottom of the die itself — this means the heat is spread out more, and can easily dissipate from both the top and bottom of the trenches. This super-junction approach works hand-in-hand with Nexperia's LFPACK copper clip technology, which can move excess heat more efficiently.

Avalanche ruggedness and SOA (safe operating area). Avalanching occurs when a load puts power back into the MOSFET itself, for example a solenoid coil. When the device is powered on the energy enters the coil, and when the MOSFET is turned off the magnetic energy in the coil is discharged back into the MOSFET itself, creating an avalanche mode condition. This may happen only once or twice during the MOSFET lifetime or may be designed to occur billions of times in repetitive cascade applications such as fuel injectors.

The super-junction approach and superior thermal capabilities enable Nexperia's silicon to take on more energy, allowing their MOSFETs to navigate occasional impulses or even repetitive avalanches.

Nexperia's MOSFET structure also offers a superior safe operating area (SOA), enabling it to take on more current for more time through the die. These design considerations give Nexperia's MOSFETs up to 2X the avalanche capabilities and 3.5X SOA capabilities compared to competitors.

Fault condition tolerance. Fault conditions are within all module designs in case a problem arises in the automobile, such as motor stall or short circuit. Fault conditions typically occur from five to 50 times over a module's lifetime, and the MOSFET needs to be able to repeatedly absorb extra energy without destroying itself. The thermal ability of Nexperia's silicon and package allows its MOSFETs to overcome these fault conditions more often and be more robust when an issue arises.

From a mechanical point of view, the unique gull wings on Nexperia's package allow for thermal expansion in a heated environment as the part expands and shrinks. Competitors often use a leadless package design, leaving no room for thermal expansion. The gull wing design approach further contributes to advanced avalanche ruggedness and superior AEC Q101 testability — the LFPACK88 tests for 15X the automotive specification, making it the most robust MOSFET application in the automotive marketplace.

Automotive ASFETs

Within the automotive marketplace, some unique applications require more capabilities than a standard MOSFET can offer. These application-specific FETs (ASFETs) feature MOSFETs with

optimized parameters that focus on individual applications. Nexperia's ASFET portfolio includes repeated avalanche, half-bridge and airbag modules.

Repeated avalanche. Normal MOSFETs are designed to handle one or two avalanches, but the repetitive avalanche application MOSFET is built to be in continuous avalanche mode and withstand billions of repeated avalanches. Fuel injectors, engine management, transmission where solenoids are being switched on and off, and ABS or electric powered steering are all conditions where an inductive load creates an avalanche condition.

There are a number of ways the industry traditionally solves for avalanche conditions, including boost circuits, free-wheel circuits, and active clamps. Designing for a MOSFET that can support avalanche mode is the simplest circuit design and does not require a complex module. A boost circuit — the most common application — is made up of three FETs and the DC-to-DC converter where any package can be used, including a DPAK. An avalanche circuit solution offers the exact same functionality by putting the part into continuous avalanche mode and building the device to tolerate that. By removing a large amount of circuitry from the boost circuit application and putting them into the avalanche mode along with the LFPAK88 instead of a D2PAK, Nexperia creates a more simple yet robust solution.

This ASFET is a modern trench alternative to older planar technologies. Applications include three-phase motor control in automotive powertrains, DC-to-DC applications, and actuator and auxiliary loads. There are anywhere from 30 to 100 standard FETs in an automobile that could be replaced by repetitive avalanche FETs.

Half-bridges. A half-bridge device connects two FETs together inside a single package. Instead of using two separate packages, the half-bridge MOSFET is more efficient and space-saving.

The half-bridge is a common building block inside a car and is designed for a variety of applications, including motor drives and DC-to-DC converters. The half-bridge MOSFET is footprint-compatible with Nexperia's dual MOSFET, making it easier to switch from one device to another. Switching from dual FET devices to a half-bridge offers the advantage of not having to worry about plating through the hole or the external conductance, capacitance and resistance of the wire connecting the two FETs together.

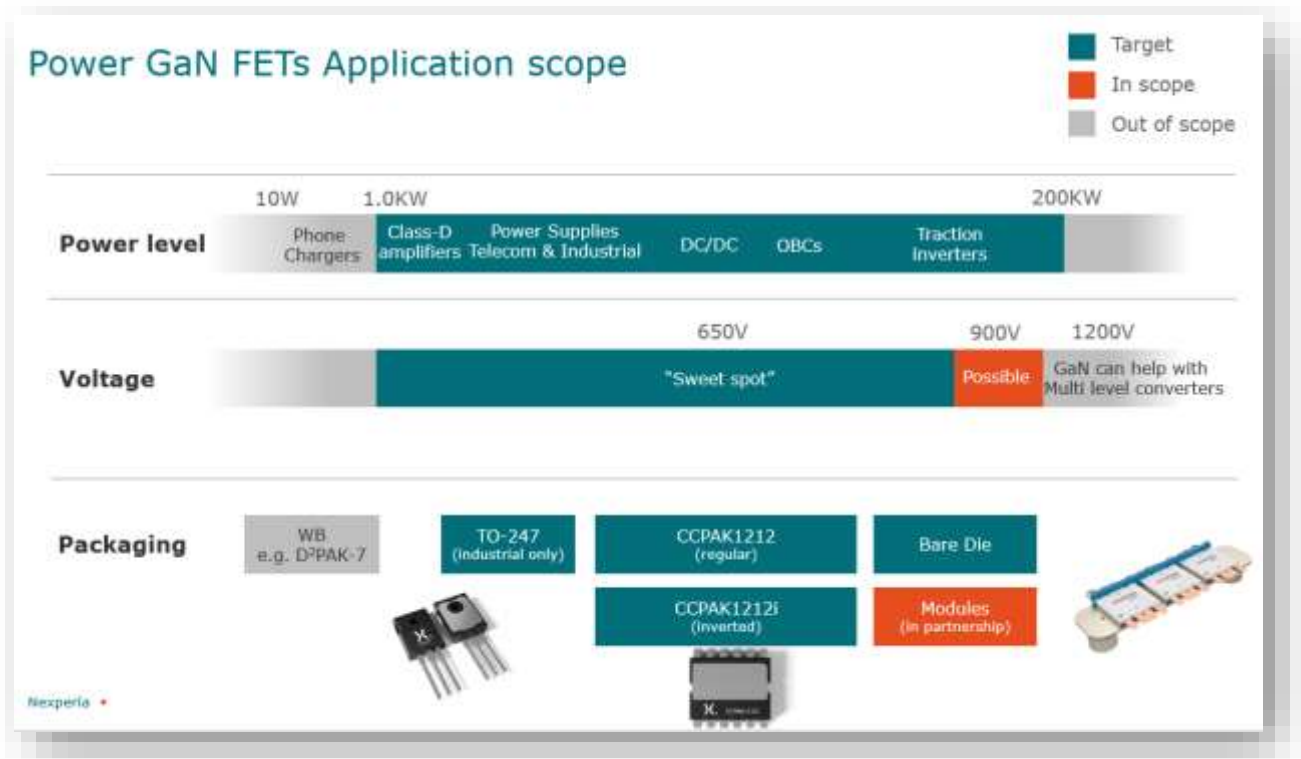
Airbag devices. The number of airbags installed inside automobiles continues to grow. A standard MOSFET used to deploy an airbag needs less than a one millisecond pulse to fire and requires about 15 amps at 15 volts. The MOSFETs needed to meet SOA requirements can be met by the LFPAK56 or LFPAK33.

Nexperia ASFETs are smaller, lighter, and offer better system performance while meeting all technical requirements for automotive uses.

Gallium Nitride in Automotive Applications

As the electric vehicle market grows, designers are turning to power semiconductor technologies, including silicon carbide and gallium nitride (GaN), to build more efficient and powerful circuits. Each material offers unique benefits.

In a sample performance test, a silicon carbide-powered device requires more power to turn it off and on than a GaN-powered device. The power to drive the silicon carbide FET is almost twice what it takes to drive the GaN Cascode FET, which also has the benefit of running a higher frequency.



GaN consumes up to 46% less power in the gate circuit and 25% less power in power losses running an average 11kW application compared to silicon carbide. GaN also offers almost a percent more efficiency than silicon carbide — that’s tens of kilowatts of energy that don’t have to be cooled or moved out of the battery. Even a small amount of efficiency gain by switching to GaN noticeably improves battery life and the overall efficiency of the system.

GaN semiconductor solutions are built for 1 to 200 kW applications, which include Class D audio amplifiers, power suppliers, DC-to-DC converters, onboard chargers, traction inverters.

In terms of voltage, GaN is suited best for 650V but will work at the 900V range if needed. Once an application reaches the 1200V range, a single GaN is no longer enough.

Nexperia GaN Solutions

Nexperia's cascode GaN solution is a device that includes the GaN device, a depletion mode HEMT (High Electronic Mobility Transistor) device and a MOSFET that serves as an onboard driver that offers reliability while protecting the gate of the D-mode HEMT itself from the outside. The cascode GaN meets industry standard requirements and is inherently safe against parasitic turn-ons. The GaN device is hidden behind a silicon MOSFET, creating superior conduction and switching losses.

A regular GaN doesn't have a path for flow and reverse current, so the body diode onboard the silicon MOSFET itself provides a conduction path when the device is being operated. This solution offers the advantage of high frequency, high speed, low RDSon operation along with the ability to conduct in reverse via the alternate path of the body diode of the silicon MOSFET. GaN also offers reduced system cost, particularly compared to silicon carbide and IGBTs, and a reduced footprint.

Overall, GaN is more efficient in terms of board space and system design because all magnetics, board sizes and cooling are smaller due to high frequency operation possible with GaN. Cascode GaN goes a step further because the gate driver solution is lowered.

There are a wide variety of applications available across the different voltages and packages. Nexperia's CCPAK1212 takes copper-clip packaging and applies it to GaN technology. This module has the option of both top-side and bottom-side cooling depending on the application. This solution is 12mm x 12mm — a large footprint that offers more cooling capabilities than the largest silicon MOSFET. Although the CCPAK1212 was originally developed for GaN devices, it is being developed for silicon MOSFETs, too, where it can easily exceed 500 amps of current through a single package.

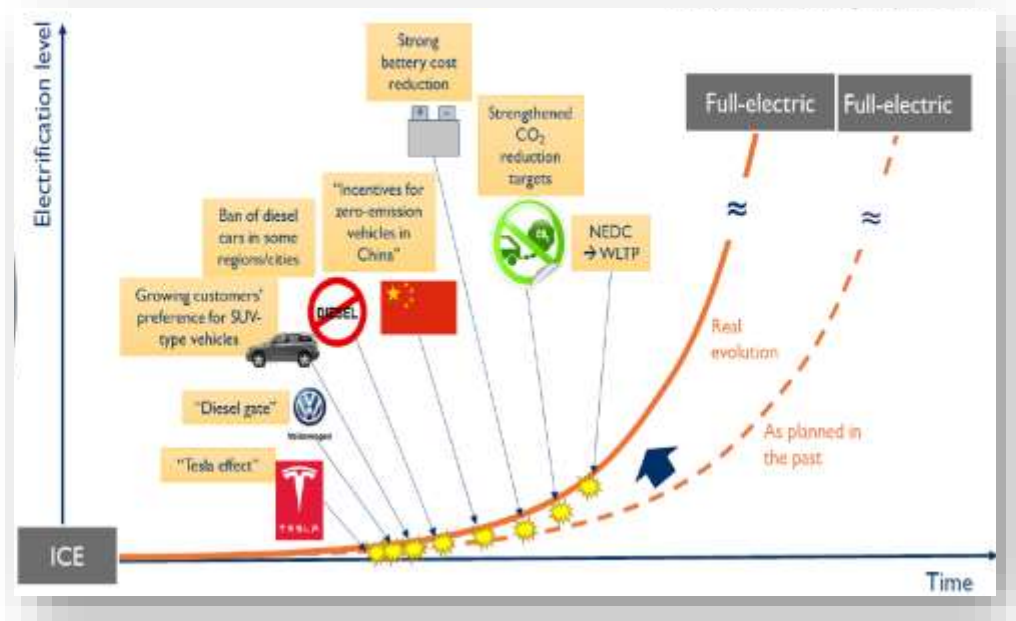
Nexperia is also partnering with KYOCERA AVX to build a complete module with Nexperia's 650V cascode GaN devices. These are built and fully rated for automotive applications and allow engineers to build entire solutions instead of having to design from the main board up to build a complete application.

This solution will be used primarily for three-phase traction inverters with a liquid cooler on board that is easily connected to the cooling solution. It uses a bare die built into a half-bridge module, offering the ability to use a GaN device without having to design a module from scratch.

Although the market seems to be aiming at higher performance, Nexperia's cascode GaN at 650V is well-suited for today's plug-in electric vehicles and hybrid vehicles. This automotive-optimized solution offers the efficiencies that come with using gallium nitride, including high-frequency switching, low RDS(on), and the ability to build it on a silicon substrate which keeps the price low.

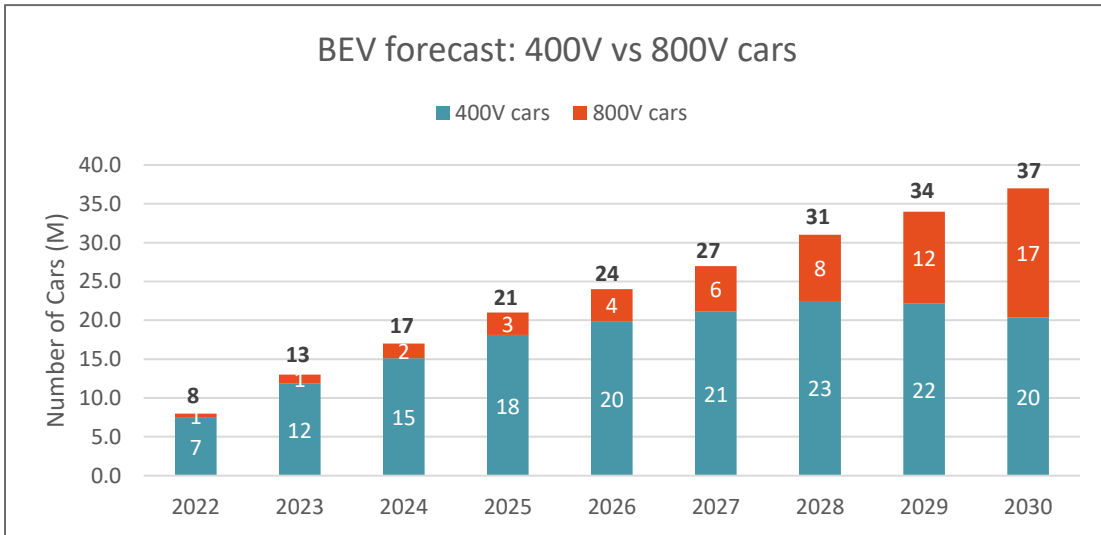
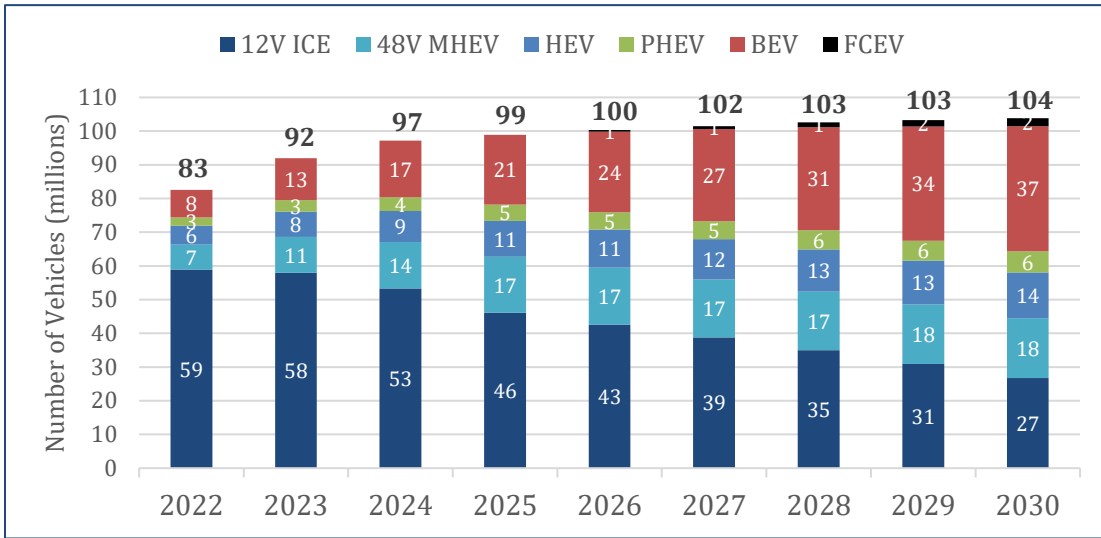
Automotive Market Trends

Many thought it would take a long time for electric vehicles to be able to saturate the market, but advances in technology are speeding up adoption. Battery-only electric vehicles are going to come online faster than expected — the performance is increasing and the new batteries are built as major OEMs invest in electrification. This trend is apparent in data, too — there will now be an estimated 2X the volume of battery electric vehicles in the market by 2030 compared to previous estimations.



Meanwhile, the market for mild hybrid electric vehicles, which run on 48V systems, is expected to grow rapidly through 2025 and then stagnate toward 2030 as fully electric vehicles become more readily available.

Another emerging trend includes a shift to 800V systems for luxury electric vehicles. This approach will result in more power, lower current and less copper, lower conduction losses and faster charging. However, insulation costs will rise, circuits will need to be redesigned to account for the additional voltage on board, frequency limitations will need to be considered, and there will be an increased rate of harmonic distortion. These design costs and challenges likely mean it will take a while for 800V electric vehicle systems to become mainstream.



Indeed, the market is forecast to use 400V platforms for a while yet. In foreign markets, small- and medium-sized cars use 400V; Tesla, Toyota and NIO announced that they would keep building 400V vehicles; a significant portion of the battery electric vehicle market share is predicted to be 400V until 2030; and HEVs and PHEVs will remain 400V and below. There is still plenty of marketplace available for 650V GaN devices in the 400V battery space.

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