



## Innovations Shaping the Future of Automotive Electronics

The recent surge in electric vehicle (EV) production has ignited a profound transformation in the automotive industry, especially within automotive electronics. This shift has prompted the emergence of key trends reshaping vehicle technology. Let us delve into these trends and their impacts on the automotive landscape.

### Emerging Trends

The industry is undergoing a technological revolution, with automotive

electronics at the forefront of innovation. Looking ahead to 2024, numerous trends continue to shape vehicle technology's trajectory.

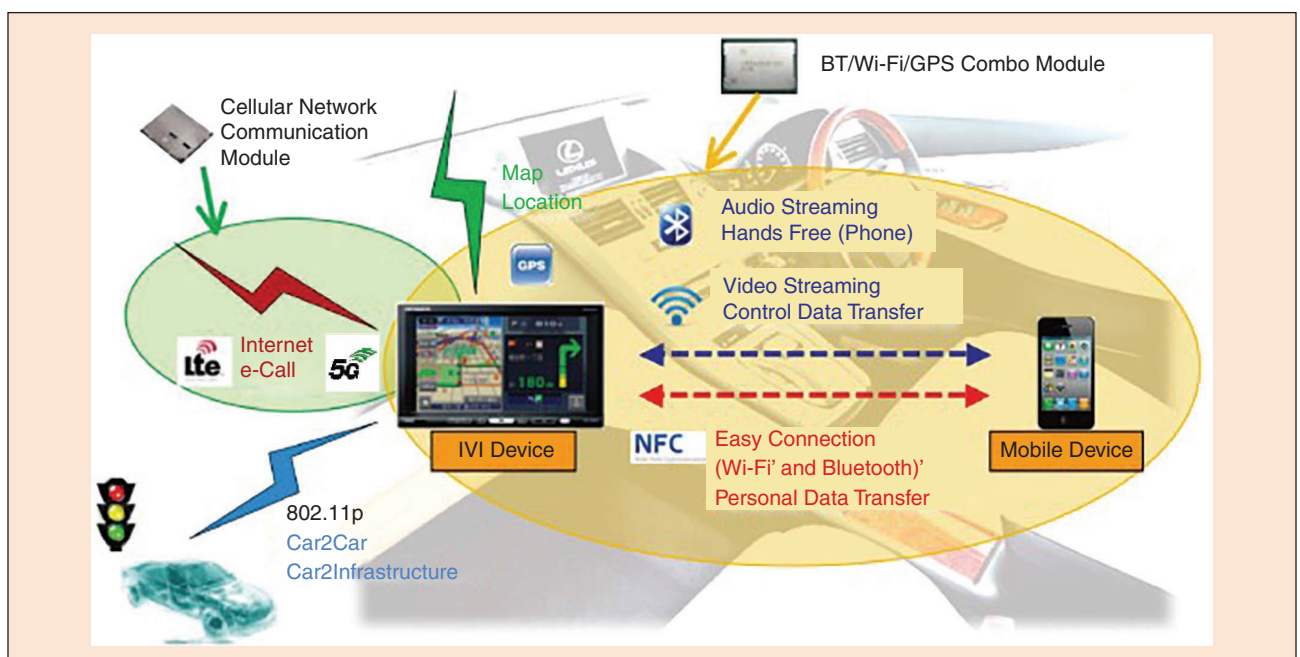
### Connectivity Modules

As automotive electronics continue to evolve, one of the most prominent trends emerges: "the integration of connectivity modules in vehicles." These modules facilitate seamless communication among vehicles and external devices, heralding the era of smart and connected vehicles (Figure 1). With functionalities such as vehicle-to-vehicle communication,

over-the-air updates, and remote diagnostics, connectivity modules are revolutionizing the driving experience, enhancing safety, convenience, and entertainment options for drivers. Let us explore some examples of these transformative connectivity modules.

- **WLAN System and Bluetooth Modules:** Modules that combine Bluetooth, WLAN, and GPS functionalities for car navigation and audio systems, enhancing connectivity options in vehicles. For instance, connecting mobile phones and/or mobile music players wirelessly via Bluetooth

Digital Object Identifier 10.1109/MVT.2024.3387248  
Date of current version: 4 June 2024



**FIGURE 1** Wireless connectivity in automotive systems by Murata [1]. (Source: <https://corporate.murata.com/>; used with permission.)

to facilitate hands-free communication and music streaming in vehicles [1].

- *Gateway modules:* These modules translate messages among different bus protocols within the vehicle's electronic systems, facilitating communication among various components [2].
- *Wireless communication modules:* These modules include Bluetooth modules for infotainment systems and tire pressure monitoring systems, enhancing connectivity features in modern vehicles [2].
- *Smart car access modules:* These modules provide security features through advanced access control systems for vehicles, ensuring secure and convenient vehicle access [3].

These examples showcase the diverse range of connectivity modules integrated into automotive electronics to enhance safety, convenience, and entertainment options for drivers and passengers in modern vehicles.

### Advanced Power Electronics

The advent of EVs has propelled advancements in power electronics within the automotive sector. These systems play a crucial role in managing energy distribution within vehicles, especially in electric and hybrid models. Advanced power electronics ensure efficient power delivery to various components, optimizing energy usage and contributing to overall sustainability. By leveraging technologies such as regenerative braking and power inverters, carmakers are enhancing the efficiency and performance of EVs while reducing their environmental impact.

Some examples of advanced power electronics in the automotive sector, particularly in EVs, include the following.

### Regenerative Braking Systems

Regenerative braking systems (Figure 2) capture and store energy typically lost during braking, converting it into usable *electricity* to enhance

## BY LEVERAGING TECHNOLOGIES SUCH AS REGENERATIVE BRAKING AND POWER INVERTERS, CARMAKERS ARE ENHANCING THE EFFICIENCY AND PERFORMANCE OF EVs WHILE REDUCING THEIR ENVIRONMENTAL IMPACT.

the vehicle's overall efficiency and reduce energy wastage [4].

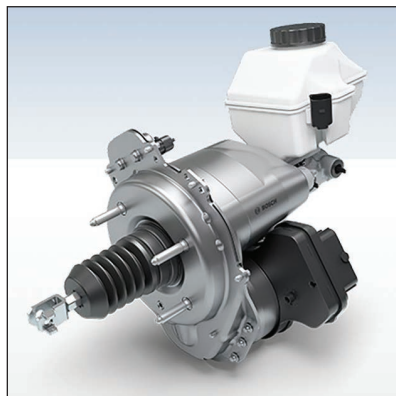
Advancements in automotive electronics components and software pertaining to regenerative braking systems have led to significant improvements in efficiency and effectiveness. These advancements include the development of advanced power electronics that efficiently manage the conversion of kinetic energy into electrical energy during braking, optimizing the energy transfer process for maximum efficiency in capturing and storing energy. Integration of advanced sensors plays a crucial role in accurately detecting braking conditions, facilitating seamless energy recovery and conversion by monitoring the vehicle speed, wheel rotation, and braking force. Additionally, the implementation of advanced control systems and algorithms regulates the operation of regenerative braking systems, ensuring smooth coordination among braking mechanisms, power electronics components, and energy storage units to maximize energy recovery and minimize wastage. Furthermore,

sophisticated software solutions enable real-time monitoring, analysis, and optimization of regenerative braking performance, enhancing overall efficiency by fine-tuning energy conversion processes based on driving conditions and user behavior. These advancements contribute to enhanced vehicle performance, reduced energy consumption, and increased sustainability in electric and hybrid vehicles.

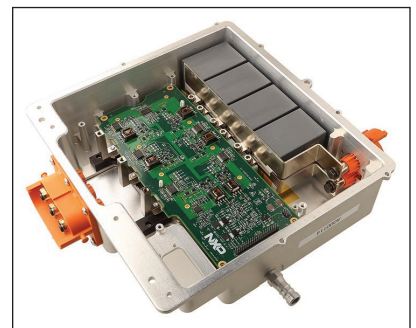
### Power Inverters

Advanced power inverters (Figure 3) are crucial components in EVs, converting dc power from the battery into ac power to drive the electric motor, ensuring optimal performance and efficiency [5].

Hardware advancements in automotive electronics related to power inverters have significantly improved EV performance and efficiency. First, efficiency improvements in power inverters have led to reduced energy losses during the conversion process from dc to ac power, enhancing overall energy utilization and extending driving range. Second, modern power inverters feature compact designs, resulting in lighter and smaller units that save space within vehicles



**FIGURE 2** An iBooster vacuum-independent, electromechanical brake booster. (Source: <https://www.bosch-mobility.com/>; used with permission.)



**FIGURE 3** EV power inverter control reference design Gen 3 isometric view. (Source: <https://www.nxp.com/>; used with permission.)

and improve vehicle dynamics. Enhanced cooling systems in power inverters effectively manage heat dissipation, ensuring optimal operating temperatures and prolonging component life spans. Integration with vehicle control systems allows for real-time monitoring and adjustment of power delivery to the electric motor, enhancing vehicle performance and efficiency. Furthermore, some advanced power inverters possess regenerative capabilities, capturing and storing energy during deceleration or braking phases to recycle kinetic energy and enhance overall energy efficiency. These hardware advancements underscore the ongoing innovation in automotive electronics, driving EVs toward higher performance, efficiency, and sustainability in the transportation sector.

### Electric Traction Drive Thermal Management

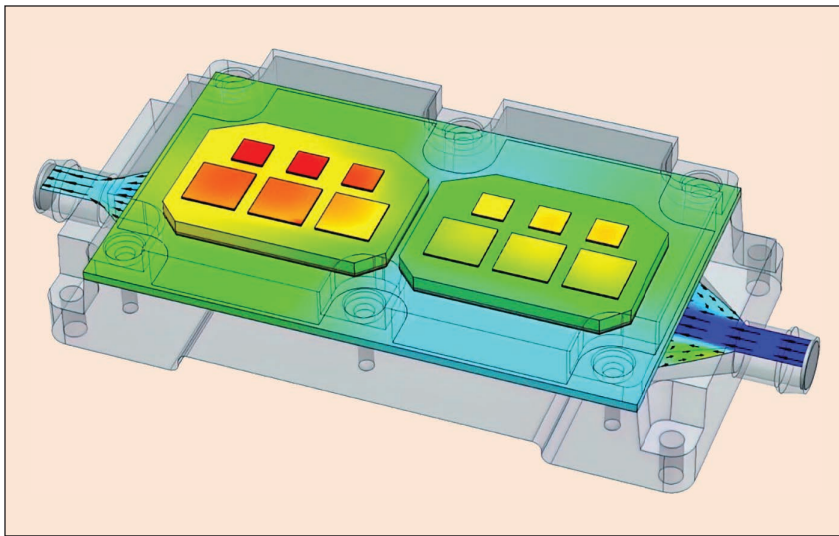
These systems manage the heat generated by electric traction drives, ensuring efficient operation and longevity of the vehicle's power electronics components [6].

Advancements in both hardware and software within electric traction drive thermal management have greatly improved the efficiency and durability of vehicle power electronics components. In terms of hardware, key advancements include the development of enhanced cooling systems utilizing compact heat exchangers, microthermoelectric coolers, and phase change materials to efficiently dissipate heat, thereby maintaining optimal operating temperatures and ensuring component longevity.

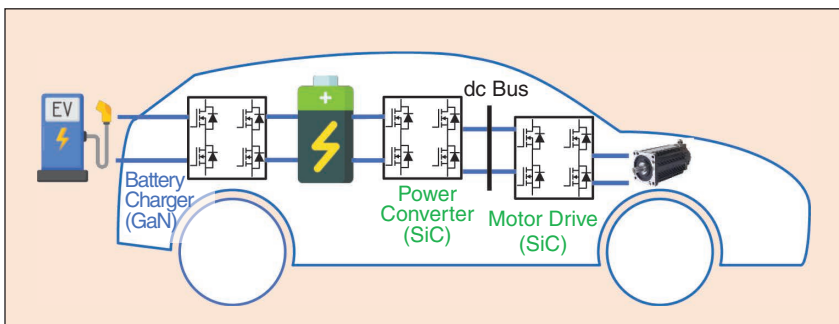
Innovative heat dissipation techniques such as cold plate cooling and impingement cooling with fluids like automatic transmission fluid have also been introduced, reducing thermal resistance and enhancing overall system efficiency. Additionally, the integration of high-power density components like GaN power FETs in integrated motor drive designs has increased power efficiency and performance while enabling compact and efficient systems that further improve thermal management.

On the software front, advancements enable real-time monitoring and control of thermal conditions within electric traction drives, utilizing data from sensors to adjust cooling mechanisms and optimize heat dissipation. Computational fluid dynamics (CFD) simulation software aids in replicating extreme operating conditions, optimizing thermal management strategies, and ensuring component reliability under varying thermal stresses. Integrated diagnostic systems provide diagnostic capabilities to monitor the health and performance of power electronics components, facilitating early issue identification and proactive maintenance, thereby enhancing the system longevity (Figure 4).

These combined hardware and software advancements in electric traction drive thermal management significantly enhance the efficiency, reliability, and performance of vehicle power electronics components, contributing to the overall advancement of EV technology.



**FIGURE 4** Simcenter FLOEFD support multiphysics simulations for full 3D CFD outputs. (Source: <https://plm.sw.siemens.com/>; used with permission.)



**FIGURE 5** Wide bandgap device application in EVs. (Source: e-TEC Lab, used with permission.)

### Semiconductor Power Electronics

- These technologies (Figure 5) are fundamental in controlling the flow of electricity among powertrain components in EVs, optimizing energy distribution and enhancing the overall system efficiency [7].

Significant strides in automotive electronics have propelled semiconductor power electronics to the

forefront of EV innovation, revolutionizing energy management and system efficiency. The continuous evolution of power semiconductor devices, exemplified by silicon carbide (SiC) and gallium nitride (GaN) transistors, has ushered in a new era of efficiency and performance. These advanced materials offer enhanced switching speeds, diminished losses, and superior thermal management capabilities, fostering improved energy distribution and overall system efficiency. Moreover, the integration of wide bandgap semiconductors like SiC and GaN has facilitated higher operating temperatures, reduced switching losses, and increased power density, resulting in more compact and efficient powertrain components that extend driving range and optimize energy utilization [8].

The integration of smart inverter technology, featuring advanced control algorithms and real-time monitoring, alongside innovations in thermal management systems, has significantly enhanced the efficiency and performance of semiconductor power electronics in EVs. These intelligent inverters dynamically adjust power delivery according to driving conditions, battery status, and motor requirements, ensuring optimal energy distribution and system efficiency. Moreover, sophisticated cooling solutions such as liquid cooling and phase change materials maintain ideal operating temperatures for power electronics components, prolonging their life span and elevating overall system efficiency. Coupled with precise software regulation of energy flow, these advancements represent a pivotal shift toward greater EV efficiency, performance, and sustainability, reshaping the future of driving. These developments underscore how advanced power electronics technologies are revolutionizing the automotive sector, particularly in EVs, by optimizing energy distribution, enhancing efficiency, and minimizing environmental impact.

## FROM COLLISION AVOIDANCE SYSTEMS TO ADAPTIVE CRUISE CONTROL, SENSOR CHIPS PLAY A VITAL ROLE IN ENHANCING DRIVER ASSISTANCE FEATURES AND OVERALL VEHICLE SAFETY.

### Sensor Chips

Sensor chips have become indispensable components in modern vehicles, enabling crucial functions related to safety, efficiency, and automation. These chips serve as the eyes and ears of a vehicle, allowing it to perceive its surroundings and react accordingly. From collision avoidance systems to adaptive cruise control (ACC), sensor chips play a vital role in enhancing driver assistance features and overall vehicle safety. As EVs continue to gain popularity, sensor chips will be instrumental in enabling advanced autonomous driving capabilities and enhancing overall driving experiences [9].

Examples of sensor chips in modern vehicles that play a crucial role in enhancing safety, efficiency, and automation include the following.

### Collision Avoidance Systems

Sensor chips are integrated into vehicles to detect obstacles and potential collisions, enabling advanced

safety features that help prevent accidents and protect both drivers and passengers [10].

Collision avoidance systems signify a pivotal advancement in automotive safety technology, employing sensor chips to detect obstacles and potential collisions. One significant development lies in the integration of multiple sensors, including radar, lidar, cameras, and ultrasonic sensors, to offer comprehensive coverage around the vehicle. This fusion of sensors enhances detection accuracy and reduces false alarms, thereby bolstering overall system reliability. Moreover, sophisticated algorithms, encompassing artificial intelligence and machine learning, empower collision avoidance systems to analyze sensor data in real time and predict collision risks. These algorithms enable proactive responses to imminent dangers, thereby contributing to improved road safety.

Furthermore, collision avoidance systems often incorporate autonomous



**FIGURE 6** How do collision avoidance systems work? (Source: <https://medium.com/>; used with permission.)

emergency braking (AEB) technology, automatically applying brakes to prevent or mitigate collisions if the driver fails to react promptly (Figure 6). AEB systems utilize sensor data to assess collision risks and initiate braking interventions to minimize accident severity. Additionally, advanced systems include features for pedestrian and cyclist detection, utilizing sensor chips to identify individuals in the vehicle's path and trigger alerts or emergency braking. Integration of vehicle-to-everything communication technology further enhances collision avoidance systems, enabling real-time data exchange with other vehicles and infrastructure to anticipate and prevent collisions. Moreover, as collision avoidance systems integrate with autonomous driving systems, vehicles gain the capability to autonomously take evasive actions to prevent accidents, with sensor chips providing crucial input for autonomous decision-making. These developments underscore the continuous evolution of automotive safety technology, leveraging sensor chips to enhance detection capabilities, prevent accidents, and safeguard both drivers and passengers on the road.

## ACC

Sensor chips are utilized to monitor the distance between vehicles and

adjust the vehicle's speed accordingly, enhancing driving comfort and safety by automatically maintaining a safe following distance [11].

ACC stands as a notable advancement in automotive technology, leveraging sensor chips to monitor intervehicle distances and adjust speeds, thereby enhancing driving comfort and safety. These systems integrate long-range radar sensors to accurately detect vehicles ahead, providing real-time data on relative speed and position to enable precise speed adjustments for maintaining safe following distances. Complementing radar sensors, camera systems are often integrated into ACC setups to bolster object recognition capabilities. These cameras identify lane markings, traffic signs, and road conditions, enhancing the system's ability to adapt speed and respond effectively to dynamic traffic scenarios.

Some ACC systems incorporate traffic jam assist functionality, facilitating automatic following of traffic flow in congested conditions. Continuously monitoring surrounding vehicles, sensor chips enable seamless speed adjustments, reducing driver fatigue during stop-and-go traffic. Additionally, advanced ACC systems utilize predictive algorithms to anticipate traffic flow changes, optimizing speed control for smoother accelera-

tion and deceleration. Furthermore, ACC systems may include emergency brake assist, wherein sensor chips assess collision risks and initiate braking interventions to prevent accidents or mitigate their severity, thereby enhancing overall road safety.

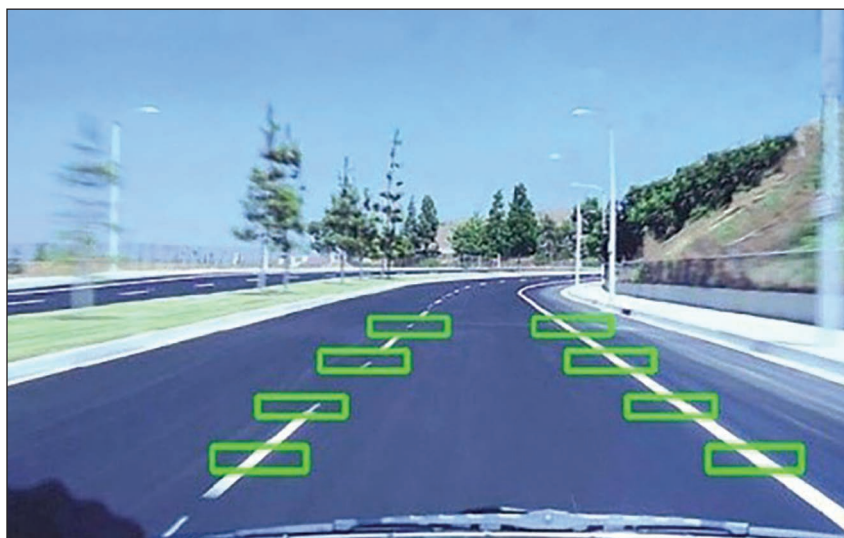
Customizable following distance settings offer drivers flexibility in ACC systems, allowing them to tailor following distances based on preferences or driving conditions. Sensor chips continuously monitor intervehicle distances and adjust speeds accordingly, providing drivers with enhanced control and comfort. These advancements underscore how sensor chips enhance driving comfort, safety, and convenience in ACC systems, maintaining safe following distances, dynamically adapting speeds, and elevating the overall driving experience.

## Lane Departure Warning Systems

These systems use sensor chips to detect lane markings and alert drivers if the vehicle unintentionally drifts out of its lane, contributing to improved road safety and accident prevention [11].

Lane departure warning systems (LDWSs) serve as vital tools in bolstering road safety, harnessing sensor chips to detect lane markings and alert drivers to inadvertent lane deviations. Modern vehicles often deploy camera based LDWSs, leveraging image processing algorithms to discern lane markings in real time. These systems analyze camera data to ascertain the vehicle's lane position and issue visual or audible alerts upon detecting a lane departure (Figure 7). Moreover, certain LDWSs incorporate steering wheel vibration alerts, providing tactile feedback to prompt corrective action when the vehicle veers out of its lane without signalling.

Advanced LDWSs may encompass lane keeping assist functionality, actively intervening to guide the vehicle back into its lane if necessary. Continuously monitoring lane markings



**FIGURE 7** An LDWS. (Source: Francis & Sons; used with permission.)

and vehicle position, sensor chips enable automated steering corrections to avert unintended lane departures, thereby enhancing driving safety. Additionally, some LDWSs extend their capabilities to include road edge detection, identifying road boundaries or shoulders to prevent unintentional veering off the road. Sensor chips analyze road parameters and issue warnings or corrective actions to maintain the vehicle within safe driving boundaries.

Further advancements include adaptive LDWSs, which adjust alert thresholds based on contextual factors such as vehicle speed or turn signal usage. This adaptive approach minimizes false alarms, rendering warnings more accurate and tailored to specific driving scenarios. Integration with driver monitoring systems is also notable, enabling LDWSs to track driver behavior and attention levels. In the event of detected drowsiness or distraction, LDWSs can escalate alerts or activate additional safety features, mitigating potential risks associated with lane departure incidents. These examples underscore how LDWSs leverage sensor chips to fortify road safety, avert accidents, and assist drivers in upholding proper lane discipline for a safer and more secure driving experience.

### Blind Spot Detection

Sensor chips are employed to monitor blind spots around the vehicle and alert drivers of approaching vehicles or objects, enhancing driver awareness and reducing the risk of accidents during lane changes [11].

Blind spot detection systems are instrumental in augmenting driver awareness and mitigating accident risks during lane changes, leveraging sensor chips to monitor blind spots around vehicles. Various implementations and functionalities of this technology serve to enhance safety and provide crucial alerts to drivers.

Radar-based blind spot monitoring utilizes radar sensors integrated into the system to detect vehicles ap-

proaching from adjacent lanes that might be in the driver's blind spot. Upon detecting a vehicle entering the blind spot zone, the system issues visual or audible warnings, prompting caution during lane changes.

Some blind spot detection systems employ ultrasonic sensor technology to monitor the proximity of vehicles in adjacent lanes. These sensors detect objects, including vehicles or obstacles, in blind spots and alert the driver to prevent potential collisions during lane changes or merging maneuvers (Figure 8).

Indicator lights on side mirrors serve as visual cues in many vehicles equipped with blind spot detection. These lights illuminate when a vehicle is detected in the blind spot, signalling to the driver the presence of a vehicle in the adjacent lane and prompting increased caution before changing lanes.

Advanced systems may incorporate haptic feedback alerts, such as vibrating seat or steering wheel mechanisms, to notify drivers of vehicles in their blind spots. This tactile feedback provides an additional sensory cue, enhancing driver awareness and reducing the likelihood of blind-spot-related accidents.

Integration with lane change assist functionality enhances some blind spot detection systems, assisting drivers in safely changing lanes

by providing warnings and guidance when vehicles are detected in blind spots. These integrated systems offer comprehensive assistance during lane change maneuvers, bolstering safety and convenience for drivers.

Moreover, blind spot detection systems may include cross-traffic alert functionality, which warns drivers of approaching vehicles when reversing out of parking spaces or driveways. By monitoring surrounding traffic using sensor chips, these systems enhance driver awareness and prevent potential collisions in parking lots or congested areas.

In essence, these examples underscore how blind spot detection systems leverage sensor chips to improve driver awareness, enhance safety, and reduce accident risks by diligently monitoring blind spots and alerting drivers to potential hazards during various maneuvers.

### Parking Assistance Systems

Sensor chips enable parking sensors that assist drivers in maneuvering into parking spaces by detecting obstacles around the vehicle, making parking safer and more convenient [11].

Parking assistance systems, powered by sensor chips, revolutionize parking maneuvers by detecting obstacles around the vehicle, thereby enhancing safety and convenience. Here is an overview of the technology.



**FIGURE 8** Blind spot detection in vehicles. (Source: <https://www.extremeaudio.org/>; used with permission.)

**IN THE WAKE OF THE MASS PRODUCTION OF EVs, A SURGE OF INNOVATION IS SWEEPING THROUGH AUTOMOTIVE ELECTRONICS, RESHAPING THE INDUSTRY AS WE KNOW IT.**

Ultrasonic parking sensors are integral components of parking assistance systems, utilizing sound waves to detect nearby obstacles. These sensors alert the driver to object proximity, facilitating precise parking maneuvers and collision avoidance.

Some systems incorporate 360-degree camera systems, providing a comprehensive view of the vehicle's surroundings. Coupled with sensor chips, these cameras offer real-time footage of obstacles, aiding drivers in accurate parking maneuvers for enhanced precision (Figure 9).

Advanced iterations may feature automated parking assist functionality, enabling autonomous steering into parking spaces with minimal driver intervention. Sensor chips detect space dimensions and obstacles, guiding the vehicle into parallel or perpendicular spots safely and efficiently.

Dynamic parking guidelines, displayed on the infotainment screen, assist drivers in aligning the vehicle during parking. These guidelines, adjusted based on steering input and obstacle proximity, ensure accurate parking and collision prevention.

Parking assistance systems issue obstacle detection alerts, either audibly or visually, when obstacles are detected nearby during parking. Sensor chips monitor surroundings, alerting drivers to potential hazards and promoting cautious maneuvering in tight spaces.

Moreover, some systems offer parallel parking assistance, guiding drivers through parallel parking steps with instructions and alerts. Sensor chips detect available spaces and obstacles, simplifying parallel parking for enhanced convenience and precision.

These examples underscore how parking assistance systems leverage sensor chips to enhance driver assistance, bolster parking safety, and streamline parking maneuvers by detecting obstacles and providing guidance throughout the process.

These examples illustrate how sensor chips are essential components in modern vehicles, enabling advanced driver assistance features, enhancing safety measures, and paving the way for autonomous driving capabilities in the automotive industry.

In the wake of the mass production of EVs, a surge of innovation is sweeping through automotive electronics, reshaping the industry as we know it. The trends highlighted here offer just a glimpse into the transformative journey underway. With automakers embracing electrification and connectivity at an unprecedented pace, we stand on the brink of even more remarkable advancements that will redefine the very essence of transportation. By leading the charge in these trends, stakeholders within the automotive ecosystem can spearhead progress toward a future that is not just sustainable and efficient but intricately connected, promising a driving experience like never before.

As we venture into 2024, the automotive industry is poised on the cusp of a monumental transformation, fueled by groundbreaking trends that are revolutionizing automotive electronics. Here is a snapshot of the key developments shaping the landscape.

The electrifying rise of EVs continues to gain momentum, with consumers eagerly embracing these eco-friendly alternatives. This surge drives innovations in EV technology, infrastructure, and battery efficiency as the industry rallies behind sustainability and carbon emission reduction.

In parallel, sustainability in automotive manufacturing takes center stage, with manufacturers doubling down on eco-conscious practices. From waste reduction to energy efficiency, the industry's commitment to greener manufacturing underscores a pivotal shift toward environmental stewardship.

As the automotive ecosystem evolves, expect to witness the integration of new players injecting fresh perspectives and cutting-edge technologies into the mix. These newcomers are set to spark competition and innovation, propelling the industry into uncharted territory.

Simultaneously, vehicle ownership trends are undergoing a dramatic



**FIGURE 9** The PARK4U automated parking system. (Source: <https://www.valeo.com/>; used with permission.)

overhaul, with shared mobility, subscription-based services, and autonomous vehicle fleets reshaping consumer preferences. These shifts reflect a seismic change in how we view ownership and mobility in the digital age.

The horizon of 2024 promises to usher in unprecedented advancements in electrification and automation technologies. From electric powertrains to autonomous driving systems, these breakthroughs herald a new era of safer, smarter, and more efficient vehicles poised to revolutionize our roads.

In summary, these trends offer a clear glimpse into the dynamic and innovative world of the automotive industry in 2024. With sustainability, technological integration, and shifting consumer behaviors leading the way, automotive electronics are paving the road toward a future that is not just interconnected and efficient but fundamentally transformative in its impact on the environment and driving experience.

### The 2024 IEEE 100th Vehicular Technology Conference and the 2024 IEEE Vehicle Power and Propulsion Conference

The convergence of two prestigious conferences, the 2024 IEEE 100th Vehicular Technology Conference (VTC 2024-Fall; <https://events.vtsociety.org/vtc2024-fall/>) and the 2024 IEEE Vehicle Power and Propulsion Conference (VPPC 2024; <https://events.vtsociety.org/vppc2024/>) (Figure 10), both scheduled from 7 to 10 October 2024 in Washington, DC, USA, marks a monumental occasion in the realm of vehicular technology. As the semiannual flagship conference of the IEEE Vehicular Technology Society (VTS), VTC 2024-Fall will serve as a gathering point for esteemed individuals from academia, government, and industry, fostering vibrant discussions and knowledge exchange in the fields of wireless, mobile, and vehicular technology. Simultaneously,

### THE CORE FOCUS OF THIS SUMMER SCHOOL WAS ON EMR, A GRAPHICAL FORMALISM DESIGNED TO MODEL ENERGY CONVERSION SYSTEMS WITH MULTIPLE SUBSYSTEMS.

VPPC 2024 will assemble practicing engineers, researchers, and professionals to delve into the intricacies of electrified vehicle power and propulsion, aligning with the global objective of advancing green e-motion. By hosting these conferences concurrently, Washington, DC, will become the epicenter of cutting-edge innovation and interdisciplinary collaboration, catalyzing advancements in both wireless communication and electric propulsion technologies.

Attendees of both conferences can anticipate a rich program encompassing keynote presentations by authoritative speakers, technical sessions exploring the latest research findings, tutorial sessions offering in-depth insights, and engaging exhibitions showcasing state-of-the-art technologies. Moreover, the inclusion of special and invited sessions, poster presentations, and industry tracks will provide attendees with ample opportunities to explore diverse perspectives and forge valuable connections within the vibrant ecosystem of vehicular technology. With proposals for special sessions welcomed and accepted papers slated for inclusion into IEEE *Xplore*, these concurrent confer-

ences promise to not only celebrate the rich legacy of VTS's centennial milestone but also chart a visionary path forward toward a more sustainable and technologically advanced future in transportation.

### The 2024 Energetic Macroscopic Representation International Summer School

The 16th Energetic Macroscopic Representation (EMR) International Summer School, held from 26 to 28 March 2024, was a collaborative effort between Amity University (India) and the University of Lille (France), hosted at the Noida campus (a suburb of Delhi, India) in a hybrid format. EMR 2024 featured six lectures on foundational concepts, 19 lectures on practical applications, and three simulation sessions, including one face-to-face and two online sessions. The event drew 64 attendees from 11 countries, both in person and online, representing a diverse international community (Figure 11).

EMR 2024 was supported by the scientific organizations VTS, MEGEVH, CUMIN, Lab of Electrical Engineering and Power Electronics (L2EP), and Amity Institute of Technology and received industrial support from i-FEVA and Mini-Cooper. Notably, the event kicked off with a special industry session comprising two panel discussions on EVs, which captivated over 70 in-person attendees. Additionally, a supplementary simulation session was organized on 30 March specifically for in-person attendees from India.

The core focus of this summer school was on EMR, a graphical formalism designed to model energy conversion systems with multiple subsystems. This approach facilitates a comprehensive analysis of system behavior and systematic



FIGURE 10 The VPPC 2024 logo. (Source: IEEE Vehicular Technology Society; used with permission.)





**FIGURE 11** The 2024 EMR International Summer School. (Source: <https://l2ep.univ-lille.fr/>; used with permission.)

deduction of control organization. Attendees explored a wide array of applications, ranging from electric/hybrid vehicles to renewable energy conversion systems, including fuel cell systems, electrical grids, piezo-electric actuators, and more.

Originating in 2000 from the control team at L2EP at the University of Lille, EMR has gained traction worldwide, being taught in over nine countries and increasingly adopted by industry leaders such as Alstom, Renault Group, Stellantis, Siemens Mobility, Siemens Software, Valeo, and SNCF, and is the core of the PANDA H2020 European Project.

The EMR summer school was spearheaded by Prof. Alain Bouscayrol (L2EP, University of Lille) in 2006, evolving over the years to become an annual event, alternating between Lille (France) and various international locations. Notably, since 2011, master's and Ph.D. students have been eligible to receive credits from the University of Lille and/or partner institutions for their participation.

Looking ahead, the 2025 EMR International Summer School is slated to take place at the University of Lille, France, in June 2025, under the leadership of Dr. Clement Mayet as general chair. The upcoming program will encompass fundamental sessions, applied tracks, and an industrial exhibition. Further details will be available in the coming months at <https://emr-website.univ-lille.fr/>.

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