



Automotive Sensors

An exclusive collection featuring
top-tier articles, visionary experts,
and essential industry insights

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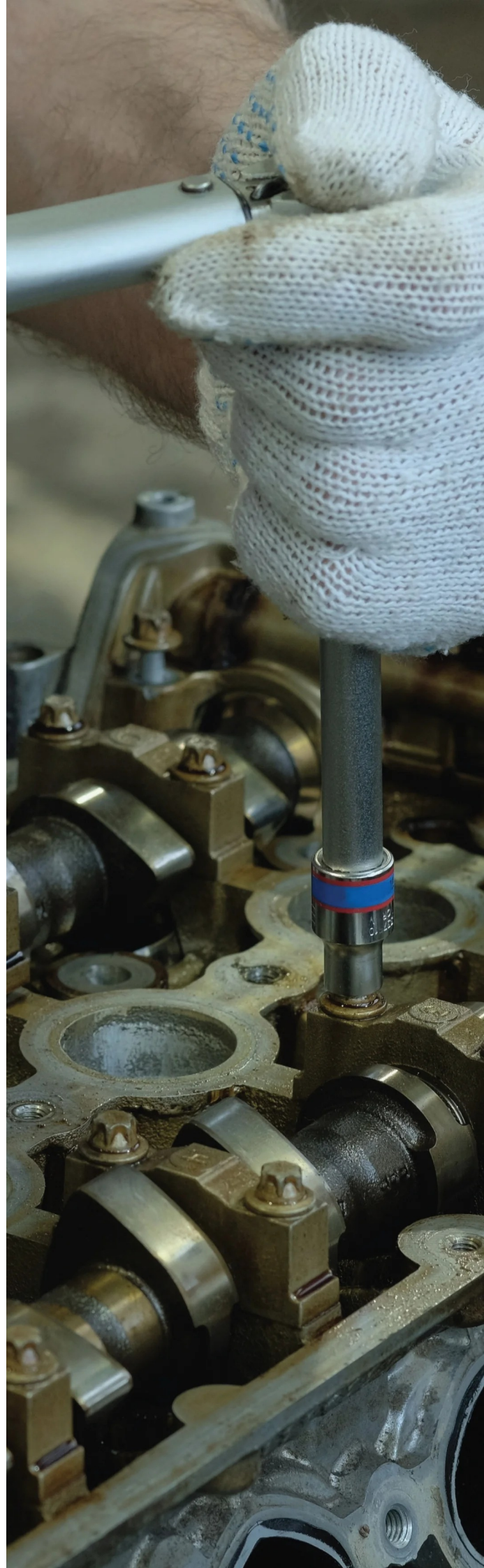
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Foreword

Welcome to the Automotive Sensors Editorial Focus eBook, where we spotlight the dynamic and increasingly essential world of automotive sensors. As vehicles become smarter, more efficient, and more sustainable, sensors are playing a critical role in shaping how we drive, maintain, and interact with our cars.

Modern automotive systems depend on a complex network of sensors to provide real-time data that enhances performance, boosts safety, and supports energy efficiency. From tire pressure monitoring and steering input to fuel level detection and engine diagnostics, sensors serve as the quiet but vital components that help vehicles operate smoothly and respond intelligently to their surroundings.

In this edition, you'll find expert insights into the technologies that define today's automotive sensor landscape. We cover foundational topics like what automotive sensors are and how they work, alongside a closer look at key sensors used in vehicles today. For those interested in specific applications, we explore fuel level sensors, tachometers, and steering sensors, highlighting how each one contributes to performance, safety, and driver experience.

As the industry continues its shift toward electrification and alternative propulsion,

sensing technologies are becoming even more critical. You'll find in-depth articles on electric vehicle cooling systems and the role of pressure sensors, as well as guidance on selecting sensors for the harsh environments found in fuel cell applications, all of which underscore how sensor innovation is supporting the move toward cleaner, more sustainable mobility.

We also take a closer look at MEMS piezoresistive pressure sensors, showcasing the advancements in compact, reliable, and precise sensor design for demanding automotive environments.

Whether you're an engineer, researcher, or industry enthusiast, this eBook offers a comprehensive look at the sensor technologies shaping the next generation of vehicles. We hope it supports your work and sparks a deeper appreciation for the technologies that keep us connected, safe, and in control on the road.

Electric Vehicle Cooling Systems and the Role of Pressure Sensors

The rise in popularity and uptake of electric vehicles cannot simply be put into words; one has to look at the data. Research carried out by the International Council on Clean Transportation (ICCT) in 2017 determined that global annual electric vehicle sales were increasing nearly at an exponential rate.¹



Image credit: Merit Sensor Systems

By the end of 2020, more than 10 million electric cars were navigating roads across the world.²

Electric vehicles are appealing to buyers for many reasons: they produce fewer emissions, can be operated at significantly lower costs and offer improved long-term prospects compared to gasoline-fueled cars.³⁻⁵

However, one of the greatest challenges in getting more people to convert to electric vehicles has long been the limited range that they can travel on a single charge.⁶ However, this obstacle is steadily being overcome.

Incremental improvements in battery technology are on the rise, and the maximum range of electric vehicles is extended with each advance, making electric vehicle ownership a more viable option for a future generation of drivers.

The Importance of Cooling Systems in Electric Vehicles

Attempts at improving battery capacity, however, can present certain challenges. The main question is related to cooling. Batteries generate heat when they charge and discharge. Therefore, the more energy a battery stores and the more quickly it charges or discharges, the more heat it will tend to create.

Vehicles that are entirely electric are equipped with a cooling system that maintains particular temperature limits in the vehicle's power electronics and battery packs. The main role of the cooling system is to ensure that the battery temperature remains within safe operating limits.

If the lithium-ion battery pack's temperature in any given cell gets too hot, it can provoke a chain reaction known as thermal runaway, in which the complete battery pack experiences catastrophic exothermic decomposition.⁷

Preventing overheating and thermal runaway is, of course, critical. The majority of EV cooling systems aim to keep battery packs at their optimum operating temperature most of the time.

Usually, this means a close-to-uniform temperature distribution in the 15 – 35 °C range.⁸ If temperatures are allowed to significantly vary throughout the pack or fall outside this particular range, then charging times and efficiency can be negatively affected resulting in a reduction in the service life of the battery.

EV Cooling Technologies

Electric vehicles employ various cooling technologies to manage the temperature of power systems: air, fins and liquid cooling.

Fin cooling is a simple and economical passive cooling mechanism that has been demonstrated to be successful in the world of electronics.

Effectively, building power-intensive components to feature fins and ridges as opposed to flat faces increases their surface area, thereby improving the rate at which they can dissipate heat to their surroundings.

However, fins have limited application in electric vehicles as they can increase the weight of power systems significantly.

Air cooling, the circulation of relatively cool air across the surface of a hot object, is another comparatively simple technology as it will cool it down more rapidly.

Air cooling is typically cost-effective and has been employed in some electric car models (including early models of the Nissan Leaf). However, this system can be relatively energy-intensive, and cars that are dependent on air cooling can run into trouble in hot weather.⁸

Liquid cooling is the most efficient way of controlling the temperature of batteries and power systems in electric vehicles.

Piping liquid coolant throughout power systems facilitates effective heat removal and while it is comparatively expensive and complex, it offers more precise temperature control of electronic systems and battery packs in electric vehicles.

As manufacturers are driving towards installing increasingly higher capacity battery packs in electric vehicles, the demands that these cooling systems must be able to cope with are also increasing.

Liquid cooling systems are becoming more crucial and complex as charging rates and battery capacity increase.^{9,10} Liquid cooling systems in today's electric vehicles may necessitate subdivision of the cooling system into several circuits and heat exchange between battery coolant and A/C system refrigerant.

The Role of Pressure Sensors in EV Cooling Systems

Pressure is a key parameter in an electric vehicle's liquid cooling system. Pressure sensors are vital components both for feedback for cooling system regulation and optimization as well as being able to detect pressure loss that could suggest a leak.

As liquid cooling systems grow in complexity, the demand for accurate and robust pressure sensors for [EV cooling systems](#) is now greater than any time before.

Merit Sensor Systems designs and manufactures a wide range of high-performance pressure sensors appropriate for demanding EV applications. The TR series sensors have been developed to offer precise pressure measurements in harsh media such as gases, oils and refrigerants.

TR series pressure sensors incorporate a hermetically sealed die that is able to take pressure measurements from the backside, where the media only comes into contact with the ceramic substrate, glass and gold-tin eutectic solder.

TR series sensors also offer accurate, dependable and robust pressure sensing in complex EV fluid system applications while rated for temperatures from -40°C to 150°C .

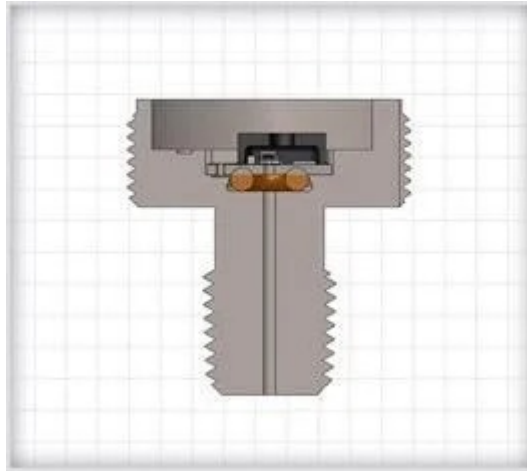


Figure 1. TR-Series face sealing integration (MeriTrek starter Kit) into metal/plastic housing. Image Credit: Merit Sensor

TVC series sensors have been optimized for measuring mid-to-high pressures in refrigerant gases up to 2,000 kPa.

Mounting the silicon die sensing element at the top of a ceramic pressure port means the TVC sensors have the capacity to measure backside pressure while separating the media from internal electronics, offering reliable and robust pressure (burst pressure 5x) measurements over a prolonged service life, even in harsh media.

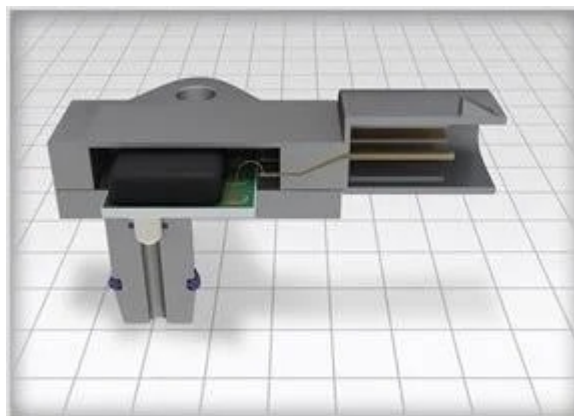


Figure 2. TVC-Series easy integration in metal/plastic housing with radial sealing (o-ring). Image Credit: Merit Sensor

With simple sealing and electrical connections, TR and TVC series pressure sensors have been engineered for seamless integration into complex fluid system pipelines and rapid connectors owing to reliable face and radial sealing.

To discover more, contact Merit Sensor Systems and find out how its pressure sensors offer a series of unparalleled advantages in EV systems.

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What Are Automotive Sensors and How Do They Work?

Automotive sensors are transforming how vehicles operate, making them safer, more efficient, and more comfortable to drive. But have you ever wondered how your car can sense when to deploy the airbag or adjust fuel levels for better performance? This article will explore the various types of automotive sensors, how they work, and why they are crucial to modern vehicle systems.



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Exploring Essential Types of Automotive Sensors

Automotive sensors vary by function and are categorized into types such as pressure, temperature, speed, and oxygen sensors. Each is designed to monitor specific parameters crucial for vehicle performance.

Oxygen sensors, for instance, are essential for monitoring the oxygen-fuel ratio within the exhaust system. By sending this data to the engine control unit (ECU), oxygen sensors enable precise fuel injection, improving combustion efficiency and helping reduce emissions—a vital

step toward cleaner, more efficient engines.¹

Pressure sensors, on the other hand, measure pressures in critical areas like the manifold, brake fluid, and tires. These readings play a key role in engine performance, braking power, and tire stability. Maintaining optimal pressure ensures that vehicles perform reliably, providing drivers with both safety and peace of mind.¹

Speed sensors are fundamental for calculating vehicle speed by measuring wheel rotations. This information supports essential safety systems like anti-lock braking (ABS) and electronic stability control (ESC). By preventing wheel lock-up and improving traction during sudden stops, speed sensors add a vital layer of control and stability to the driving experience.¹

Temperature sensors serve a dual purpose, monitoring both engine coolant levels and internal cabin temperatures. These sensors ensure that engines remain within safe operating temperatures while also adjusting cabin conditions for passenger comfort. By regulating these two areas, temperature sensors enhance both vehicle performance and the overall driving experience.¹

How Automotive Sensors Work

Automotive sensors are essential to the performance, safety, and efficiency of modern vehicles, using advanced technologies like micro-electro-mechanical systems ([MEMS](#)) and capacitive sensing to convert physical changes into actionable data. Designed to endure and accurately respond to the demands of the road, these sensors translate complex physical variations into reliable digital information.

Automotive sensors typically detect changes in resistance, capacitance, or electromagnetic fields, translating these into electrical signals essential for a range of vehicle functions.

- **MEMS Technology:** Many key sensors, such as accelerometers and gyroscopes, utilize MEMS technology. MEMS sensors are highly sensitive to slight shifts in pressure, force, and acceleration, translating these changes into data that support real-time vehicle stability and control. This sensitivity makes MEMS essential for features like traction control, rollover prevention, and enhanced vehicle handling.
- **Resistive, Capacitive, and Inductive Sensing:** Each type of sensor measures specific parameters. Resistive sensors detect variations in resistance as a reaction to physical changes, allowing them to measure factors like temperature and pressure. Capacitive sensors, by measuring capacitance shifts, accurately detect distance, thickness, or

pressure, proving useful in brake and suspension systems. Inductive sensors rely on electromagnetic induction to gauge proximity or detect speed changes, making them critical for anti-lock braking and speed monitoring.

- **Optoelectronic Components:** For advanced environmental mapping, [LiDAR \(light detection and ranging\) sensors](#) use laser-based technology to capture 3D spatial data and detect obstacles with exceptional accuracy. LiDAR sensors emit light pulses that reflect off nearby objects, allowing the system to calculate distance based on the return time. This capability supports high-precision applications like adaptive cruise control and autonomous navigation.²

Essential Components and Technologies

Beyond the sensor mechanisms themselves, key technologies such as analog-to-digital converters (ADCs), connectivity protocols, power management systems, and calibration techniques are essential for maintaining sensor performance under diverse and challenging conditions. These components enable efficient data processing, reliable connectivity, and sensor durability.

- **Signal Processing and Data Conversion:** Automotive sensors rely on microprocessors and ADCs to translate real-world physical inputs into precise digital data. Advanced sensors incorporate embedded processors that can handle initial data processing directly within the sensor, reducing strain on the central vehicle control system. This enables faster responses, particularly for safety-critical functions like collision detection and real-time vehicle adjustments.^{3,4}
- **Connectivity:** Automotive sensors work within interconnected networks, such as the controller area network (CAN) bus, facilitating real-time communication with other vehicle systems. High-speed technologies like Ethernet and FlexRay are employed for data-heavy or safety-critical applications, such as advanced driver assistance systems (ADAS). These connectivity solutions ensure reliable data transfer, supporting the vehicle's coordinated responses and system integrations.^{3,4}
- **Power Sources:** As automotive sensors must function under extreme temperatures and vibrations, their power requirements are carefully managed. Integrated power management systems support sensor longevity, while the energy-efficient designs of newer sensors help minimize overall power consumption without compromising performance.^{3,4}

- **Calibration:** Rigorous calibration is essential for ensuring the accuracy of automotive sensors, especially those integral to safety functions, like airbag deployment and ABS. With technological advances, self-calibrating sensors are also becoming more prevalent. These sensors automatically adjust to shifts in environmental conditions, providing consistent accuracy over time and reducing maintenance requirements.^{3,4}

Applications in Vehicle Systems

Automotive sensors are indispensable across vehicle systems, enhancing safety, efficiency, and driving experience in today's advanced automotive market.

In **safety systems**, sensors form the backbone of critical functions such as airbags, ABS, and ESC. For example, accelerometers monitor rapid deceleration to trigger airbag deployment instantly in the event of a collision, minimizing the impact on occupants. Likewise, speed and traction sensors continuously assess wheel activity, enabling ABS and ESC to adjust braking pressure and maintain traction. This enhances vehicle stability, particularly during sudden maneuvers or adverse conditions.^{1,2}

In **autonomous driving**, a suite of sensors—including LiDAR, radar, and cameras—works in unison to enable self-driving vehicles to interpret their surroundings. LiDAR creates 3D environmental maps, radar detects objects at various distances, and cameras analyze visual data such as traffic signs and lane markings. Together, these sensors provide the comprehensive situational awareness required for real-time decision-making, allowing autonomous systems to safely navigate roads, avoid obstacles, and interact intelligently with surrounding traffic.^{1,2}

Sensors also contribute significantly to **performance optimization** by monitoring key parameters within the engine, transmission, and fuel systems. By adjusting variables like the air-fuel mixture and engine temperature, these sensors ensure efficient operation and optimize fuel economy. This real-time data monitoring reduces wear on components, helping to extend the vehicle's lifespan and lower maintenance costs.

Emission control is another critical application, with oxygen and catalytic sensors playing a central role. These sensors help regulate the air-fuel ratio to ensure combustion efficiency and limit pollutant release, supporting adherence to environmental regulations and contributing to a reduced environmental footprint.^{1,2}

Comfort and convenience are also enhanced by sensors, particularly through climate control systems. Cabin temperature and humidity sensors inform the HVAC system, allowing it to

maintain an optimal climate that adapts to passenger preferences and external conditions. This ensures a comfortable environment for all occupants, regardless of external weather.

In terms of **collision avoidance** and **parking assistance**, ultrasonic and radar sensors help drivers by detecting nearby objects and providing real-time alerts. These sensors facilitate safe navigation through tight spaces, assist with parking, and reduce the risk of minor collisions, making for a more secure and user-friendly driving experience.^{1,2}

Optimizing Automotive Sensor Technology: Challenges and Breakthroughs

Despite their benefits, automotive sensors face challenges like environmental exposure, interference, and calibration demands. Meeting these challenges is crucial to ensure reliable and long-lasting performance.

Automotive sensors must operate under harsh conditions—exposed to heat, dust, moisture, and constant vibration—that can degrade durability and functionality over time. Ensuring sensors withstand these extremes is particularly critical for safety-focused applications.^{1,2}

Innovations in sensor materials and designs aim to enhance durability, such as the integration of 3D-printed, graphene-based strain sensors with flexible piezoelectric energy harvesters in smart tire technology. This system monitors tire-road interactions, speed, load, and pressure in real-time, demonstrating how advanced materials can improve resilience and self-sufficiency in challenging environments.⁵

In densely packed automotive systems, sensors often face electromagnetic interference (EMI) from other components, impacting their accuracy. Additionally, sensors can experience calibration drift due to fluctuating environmental conditions, necessitating frequent recalibrations. Novel approaches, like the fusion of 3D-LiDAR and camera data with Faster-RCNN technology, tackle these issues by enhancing object detection accuracy and depth perception, improving the reliability of sensors for real-time autonomous navigation. Such innovations are critical for maintaining precision and dependability in a dynamic driving environment.⁶

Power consumption is another key consideration, particularly for autonomous and electric vehicles, which rely heavily on multiple sensors. As more sensors are integrated, the demand for energy-efficient solutions rises. Higher power consumption can quickly deplete battery life in electric vehicles (EVs), making it imperative to develop sensors that balance performance with energy efficiency.^{1,2} Addressing this challenge, researchers are exploring low-power

sensors that optimize performance without compromising energy efficiency, helping extend battery life while supporting the high computational load of autonomous systems.

High-tech sensors, such as LiDAR, are integral to advanced driver-assistance systems but remain costly, limiting their inclusion in mid-range vehicles. Manufacturers face the challenge of integrating sophisticated sensor technologies without driving up production costs. Balancing innovation with affordability remains a primary focus, as the widespread adoption of autonomous features requires cost-effective solutions to make these technologies accessible across vehicle tiers.^{1,2}

Future Prospects and Conclusion

The future of automotive [sensor technology](#) lies in advancing autonomous driving and vehicle connectivity with a focused commitment to durability, efficiency, cost-effectiveness, and sustainability. As Artificial Intelligence (AI) and Machine Learning (ML) continue to evolve, they will play a key role in enhancing automotive sensor efficiency by enabling predictive diagnostics and improving object recognition. Additionally, innovations in [energy harvesting](#) and cost-reduction techniques promise to make these advanced sensor technologies accessible across all vehicle types.

In conclusion, automotive sensors have become central to modern vehicles, driving progress in safety, performance, and sustainability. Ongoing research and technological advancements are expected to produce even more intelligent, energy-efficient sensors, supporting the industry's transition toward fully autonomous and environmentally conscious vehicles. As the automotive sector continues to evolve, these sensors will not only elevate the driving experience but also contribute significantly to achieving the environmental goals of tomorrow.

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A Closer Look at Your Car's Essential Sensors

Modern vehicles are sophisticated machines equipped with a wide range of sensors designed to enhance safety, efficiency, and overall performance. These sensors function like the vehicle's "eyes and ears," constantly collecting data and relaying it to the Electronic Control Unit (ECU)—essentially the car's brain. The ECU processes this information to monitor engine performance, manage critical systems, and support advanced driver-assistance features (ADAS).

Sensors play a vital role in how today's cars are designed and how they operate. In this article, we'll take a closer look at the key sensors found in modern vehicles, what they do, and how they're helping shape the future of driving.



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Powertrain Sensors: The Heart of Engine Efficiency

The powertrain includes the engine, transmission, and drivetrain. It uses sensors to balance power output, fuel efficiency, and emissions.

Oxygen (O₂) Sensors

Oxygen sensors play a critical role in managing vehicle emissions. Positioned in the exhaust

system, these sensors monitor the oxygen levels in the exhaust gases to determine whether the engine is running with a rich (too much fuel) or lean (too much air) mixture.

This real-time data is sent to the ECU, which then adjusts the fuel injection accordingly to maintain optimal combustion. By fine-tuning the air-fuel ratio, oxygen sensors help improve fuel efficiency and significantly reduce harmful emissions such as nitrogen oxides (NOx).^{1,2}

Mass Airflow (MAF) Sensor

The MAF sensor measures how much air enters the engine and its density. It uses a heated wire or film to sense changes in airflow.

This information helps the ECU provide the right amount of fuel for combustion. If the MAF sensor is not working properly, it can cause rough idling, stalling, or poor acceleration.^{1,2}

Manifold Absolute Pressure (MAP) Sensor

The MAP sensor works with the MAF to measure the pressure in the intake manifold. This helps the ECU figure out how much load the engine is under.

By doing this, it can adjust the timing of the ignition and the fuel delivery. This is especially important for turbocharged engines, where it is crucial to control the boost pressure carefully.^{1,2}

Engine Knock Sensor

Knock sensors are designed to detect abnormal combustion events—commonly known as pre-ignition or “pinging”—which can damage engine components like pistons and cylinder walls.

These sensors rely on piezoelectric elements that convert engine vibrations into electrical signals. When unusual knocking is detected, the sensor alerts the ECU, which then adjusts the ignition timing to protect the engine and maintain smooth performance.¹

Coolant Temperature Sensor

The engine coolant temperature sensor tracks the temperature of the coolant to ensure the engine operates within a safe range. If the engine starts to overheat, the sensor alerts the ECU, which can trigger warning lights or reduce engine power to help prevent damage.

This sensor also plays a key role during cold starts, allowing the ECU to adjust the air-fuel mixture for better combustion and smoother performance in low temperatures.²

Safety and Stability Sensors

Modern safety systems use a variety of sensors to help prevent accidents and protect occupants.

Wheel Speed Sensors

Wheel speed sensors are a key component of the anti-lock braking system (ABS), continuously monitoring the rotational speed of each wheel. If a wheel begins to lock up during braking, the ABS uses data from these sensors to modulate the brake pressure, helping maintain traction and avoid skidding.

Beyond ABS, these sensors also support systems like traction control and electronic stability control (ESC) by detecting when a wheel is slipping, allowing the ECU to make real-time adjustments for safer handling and improved vehicle stability.^{1,3}

Yaw Rate and Accelerometer Sensors

Yaw rate sensors measure how much the vehicle is rotating around its vertical axis—essentially tracking its side-to-side motion during turns. Alongside accelerometers, which detect lateral and longitudinal forces, these sensors provide critical data for Electronic Stability Control (ESC) systems.

When the ESC detects a risk of skidding or loss of control, it can respond by adjusting engine power or applying brake pressure to specific wheels, helping the driver maintain stability and stay on course.¹

Tire Pressure Monitoring System (TPMS)

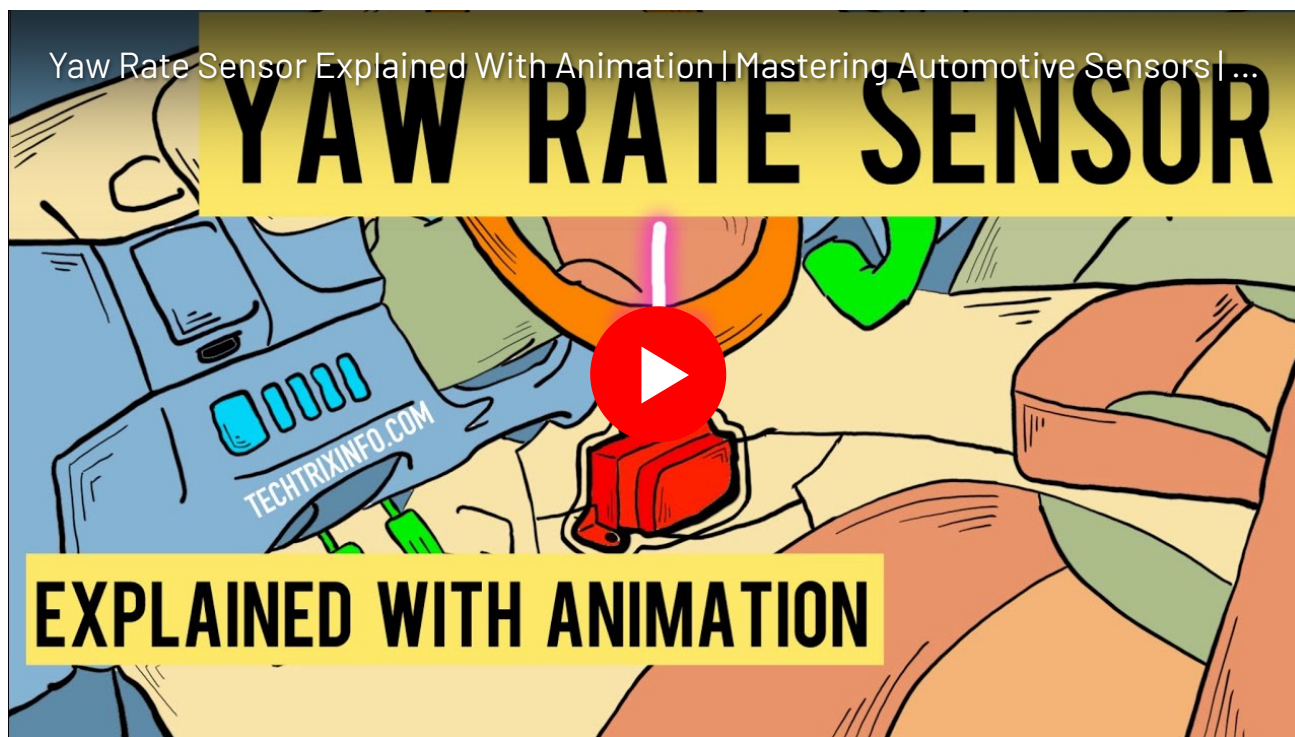
Tire Pressure Monitoring System (TPMS) sensors, typically mounted on the wheel rims, monitor both tire pressure and temperature. When pressure drops below a safe threshold, the system triggers a dashboard warning to alert the driver.

Maintaining proper tire pressure not only enhances safety but also helps improve fuel efficiency and extend tire life. Most modern TPMS setups use wireless transmitters to send real-time data to the ECU, ensuring timely alerts and accurate monitoring.^{1,4}

Airbag Impact Sensors

Accelerometers and pressure sensors are crucial for detecting sudden deceleration during a collision—responding in just milliseconds.

Once an impact is sensed, they send immediate signals to the airbag control unit, triggering airbag deployment and activating seatbelt pre-tensioners. This rapid chain of events is vital for reducing the risk of injury and ensuring maximum protection for occupants in the event of a crash.³



Driver-Assistance Sensors

Advanced Driver-Assistance Systems (ADAS) rely on a network of sensors—such as cameras, radar, and lidar—to improve both safety and driving convenience.

These systems support features like adaptive cruise control, lane-keeping assistance, and automatic emergency braking. By continuously monitoring the vehicle's surroundings and responding to potential hazards, ADAS not only help prevent accidents but also serve as a foundational step toward fully autonomous driving.^{1,5}

Ultrasonic Sensors

Ultrasonic sensors are commonly used in vehicles to assist with parking. These sensors emit high-frequency sound waves that bounce off nearby objects, helping the vehicle detect its surroundings.

When an obstacle is detected, the system alerts the driver with visual or audible warnings, making it easier and safer to maneuver in tight spaces. They're especially useful for low-speed situations like parallel parking or navigating close quarters.^{1,5}

Radar Sensors

Radar systems use radio waves to detect objects at distances of up to 200 meters, making them a key component in advanced safety features. They're crucial for systems like adaptive cruise control (ACC) and automatic emergency braking (AEB), which rely on radar data to monitor the distance and speed of vehicles ahead.

This allows the car to automatically adjust its speed to maintain a safe following distance or apply the brakes if a collision risk is detected—enhancing both safety and driver comfort in dynamic traffic conditions.⁵

LiDAR Sensors

Light Detection and Ranging (LiDAR) sensors use laser pulses to generate detailed 3D maps of the vehicle's surroundings. While they're currently more expensive and bulkier than other sensor types, LiDAR offers highly accurate spatial data, making it especially valuable for self-driving technology. These sensors can detect pedestrians, cyclists, vehicles, and road markings—even in low-light conditions—providing the precision needed for safe autonomous navigation.⁵

Cameras

Forward-facing cameras play a key role in keeping vehicles centered in their lanes and recognizing traffic signs, helping drivers stay aware of their surroundings. Surround-view cameras offer a 360-degree perspective around the car, making parking and low-speed maneuvers safer and more manageable.

Some vehicles also use infrared cameras to enhance night vision by detecting heat signatures from objects, such as pedestrians or animals, improving visibility in dark or low-light conditions.⁵

Comfort and Convenience Sensors

Sensors also contribute significantly to passenger comfort and overall vehicle usability. Rain sensors, which use infrared or optical elements to detect moisture on the windshield, automatically activate the wipers and adjust their speed based on the intensity of the rainfall.

Ambient light sensors help reduce driver fatigue and improve visibility by automatically adjusting headlight brightness and interior lighting according to surrounding light conditions.^{1,4}

Inside the cabin, temperature and humidity sensors are essential for maintaining a comfortable environment. They work with the climate control system to regulate airflow and temperature while also helping to prevent window fogging.

Additionally, advanced gesture and voice control sensors integrated into infotainment systems allow drivers to adjust settings without taking their hands off the wheel, reducing distractions and enhancing the driving experience.⁴

Emerging Trends and Future Innovations

The automotive sensor market is projected to grow at a strong compound annual growth rate (CAGR) of 10.1%, driven largely by advancements in vehicle electrification and autonomous technologies.

One of the most important developments in this space is [sensor fusion](#)—the integration of data from multiple sources like cameras, radar, and LiDAR to improve object detection and situational awareness. For instance, while LiDAR excels at creating detailed 3D maps, radar performs more reliably in poor weather, offering a valuable layer of redundancy and safety.^{4,5}

Microelectromechanical systems ([MEMS](#)) are also making smaller, more reliable sensors possible, helping to reduce manufacturing costs and expand the use of sensors throughout the vehicle.

Looking ahead, we may see biometric sensors incorporated into vehicles to monitor driver health metrics like heart rate or signs of drowsiness, enabling real-time adjustments for improved safety.

Additionally, vehicle-to-everything (V2X) communication is on the horizon, allowing cars to exchange data with each other and with infrastructure. This capability has the potential to enhance traffic flow, prevent collisions, and support the broader move toward connected and autonomous mobility systems.⁴⁻⁶

Conclusion

Sensors are at the heart of today's vehicles, enabling everything from better fuel efficiency to advanced driver-assistance and self-driving capabilities. As automotive technology continues to evolve, sensors will become even more essential—making cars safer, more efficient, and more intuitive to operate.

Gaining a basic understanding of these components not only sheds light on how modern vehicles function but also underscores the impressive engineering shaping the future of mobility.

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Choosing the Right Sensor for Harsh Environments in Fuel Cell Technology

Electric vehicles (EVs) have recently gained a huge amount of attention in the evolving transportation landscape.

According to the latest statistics, an estimated 14 million EVs are projected to be sold in 2023, reflecting a 35% year-on-year increase.¹ [Fuel cell EVs](#) have also attracted attention from major players in the auto industry, including Toyota, Honda, and BMW.^{2,3,4}

However, manufacturing fuel cell EVs poses significant challenges. Their reputation for being clean and eco-friendly, a remedy for our polluted past, is hard-earned.

This article will elaborate on the various internal components of a fuel cell EV, which must maintain different pressures to ensure optimal performance and safety. The pressure sensors, situated amidst these components, play a crucial role in monitoring the system.

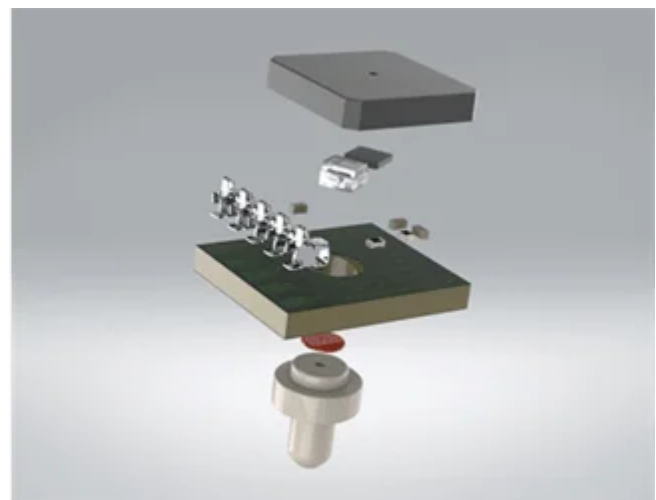
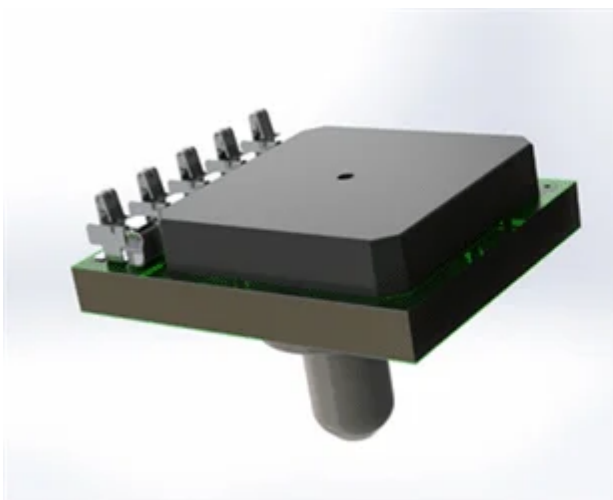


Image Credit: Merit Sensor

Understanding Hydrogen Fuel Cells

Hydrogen fuel cells represent pioneering technology in sustainable energy. These cells harness the power of hydrogen, combining it with oxygen from the air to produce electricity, with only water vapor as the emission.

Currently, hydrogen's use as an energy carrier is mainly for road vehicles. As of June 2021, over 40,000 fuel cell EVs were operational globally, with nearly 90% concentrated in four countries:

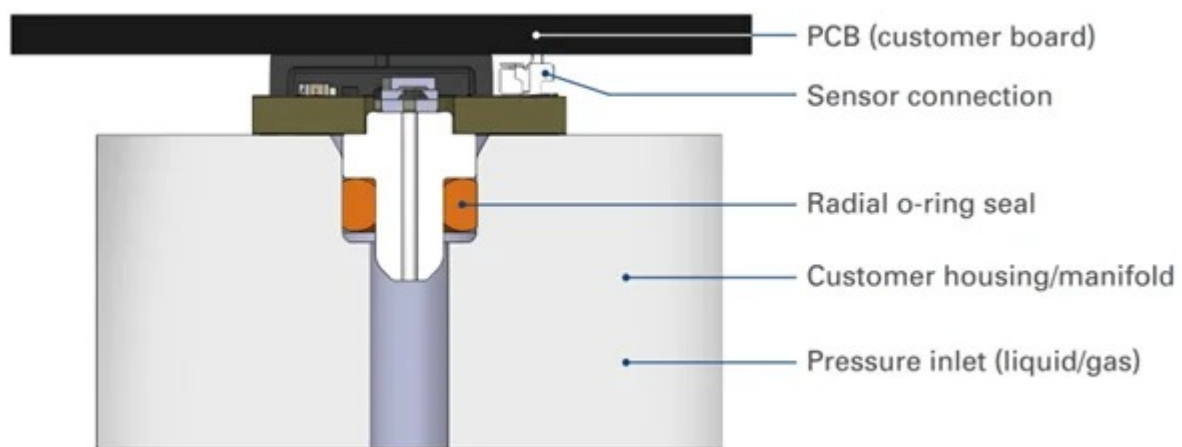
Japan, Korea, China, and the United States.⁵

The utilization of hydrogen fuel cells is expected to grow, with CEM H2I leading the efforts to promote fuel cell technologies worldwide through collaboration with governments and partners.⁶

The Vital Role of Decompressing Hydrogen

In a typical hydrogen fuel cell EV, hydrogen is stored in a high-pressure container. However, because the fuel cell stack operates optimally at significantly lower pressure, a decompression procedure is necessary to bridge the gap between the high-pressure hydrogen tank and the fuel cell stack.

The decompression of hydrogen is crucial for the fuel cell to function effectively.⁷ Hydrogen, being the smallest particle, does not affect the absolute TRVC function, making radial sealing critical in design due to TRVC and plug geometry.



TRVF Series in plastic housing. Image Credit: Merit Sensor

Significance of Heat Management Systems in EVs

Heat management, such as efficient cooling systems, plays a key role in the performance and lifespan of fuel cells.⁸

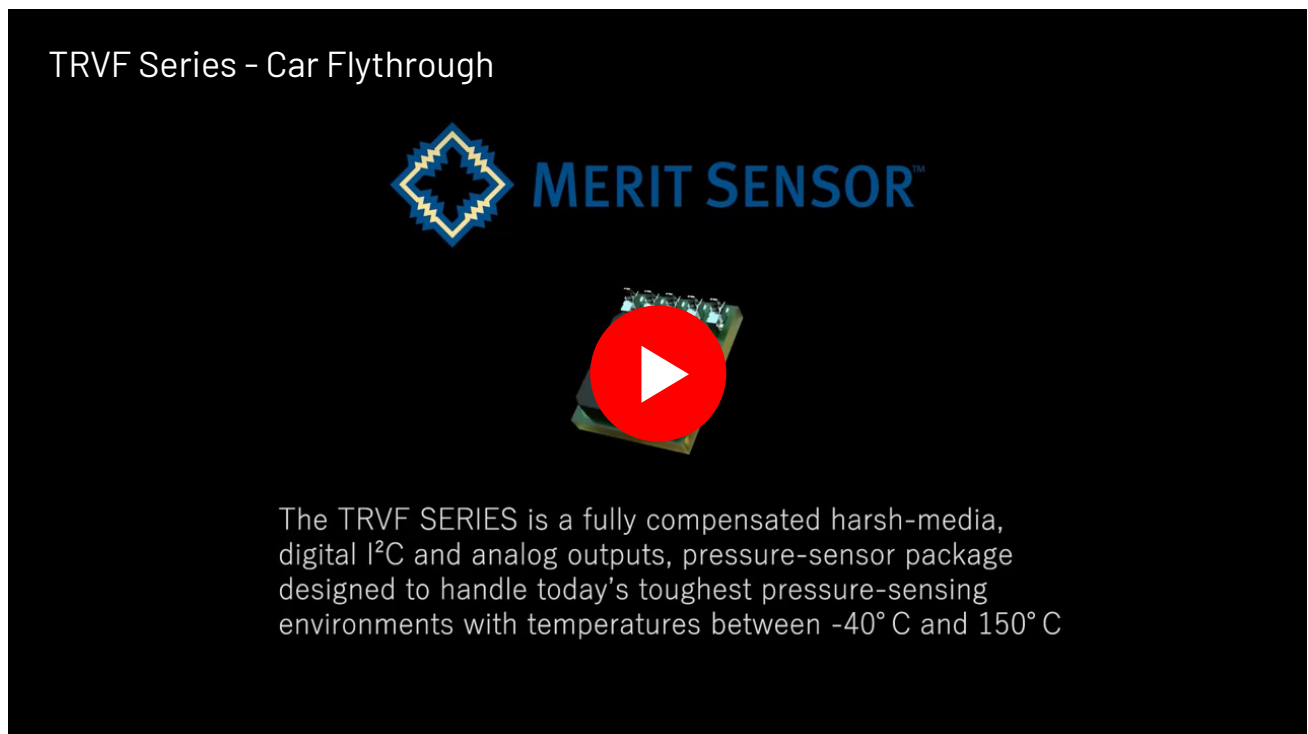
Making sure heat dissipates effectively is essential to keep critical parts like the battery and electronic systems within the required temperature limits. For batteries, this often means using a dedicated battery thermal management system (BTMS).

Keeping the right pressure in cooling systems specific to each EV is vital to prevent coolant leaks and potential damage to components.⁹

Importance of Pressure Sensors in Fuel Cell Technology

Precise pressure measurement is essential during energy generation and heat management. Accurate pressure sensors are necessary to monitor gas flow in pipelines and maintain proper coolant levels in the cooling system.

Sensors face challenges in harsh environments with corrosive substances, temperature changes, and high-pressure fluctuations. Thus, pressure sensors deployed in these settings must be designed to endure harsh conditions.



TRVF Series - Car Flythrough. Video Credit: Merit Sensor

Introducing Merit Sensor's TRVF-Series of Pressure Sensors

Merit Sensor, a top player in [piezoresistive pressure sensors](#), crafted the TRVF-Series to meet industry needs. These sensors seamlessly integrate into fuel cell systems' hydrogen supply and coolant circuits, ensuring top-notch stability.

Capable of handling temperatures from -40 °C to 150 °C, the TRVF-Series boasts exceptional

durability thanks to its trio of materials – silicon, glass, and ceramic. These sensors are built to endure the harsh conditions within fuel cell environments.

The aforementioned materials also guarantee compatibility with various liquids, vapors, and gases, from fuel to water, ensuring longevity and reliability in challenging operational settings.

Covering a pressure range of 2–15 bar, the TRVF-Series offers precise measurements and accurate analog voltage output, enabling effective monitoring of gas and liquid pressures for optimized energy generation and improved heat management processes.¹⁰

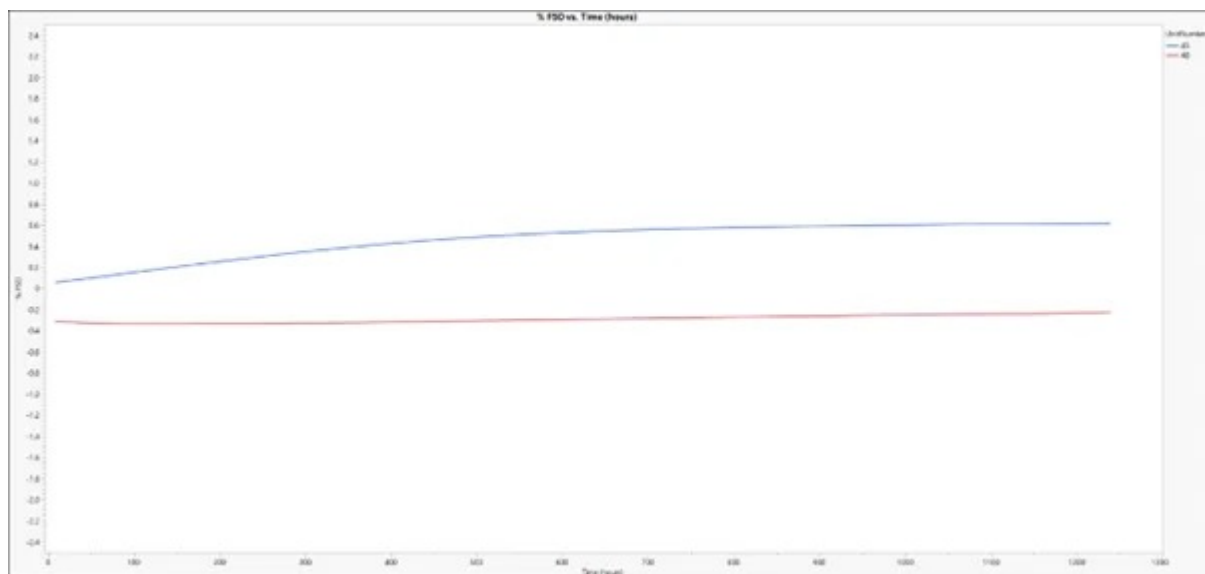


Image Credit: Merit Sensor

The graph illustrates the stability results of the TRVF Series measured at 150 °C for 1300 hours.

Enhanced Reliability in Coolant Circuit Measurements

TRVF sensors have been designed to collect pressure measurements from its posterior surface. This is achieved by hermetically sealing the MEMS silicon die on top of a ceramic port, ensuring that the media only touches the desired wetted materials.

This functionality allows the sensor to consistently provide dependable readings within the coolant system, ensuring efficient coolant control and contributing to the overall effectiveness and performance of the fuel cell system.¹⁰

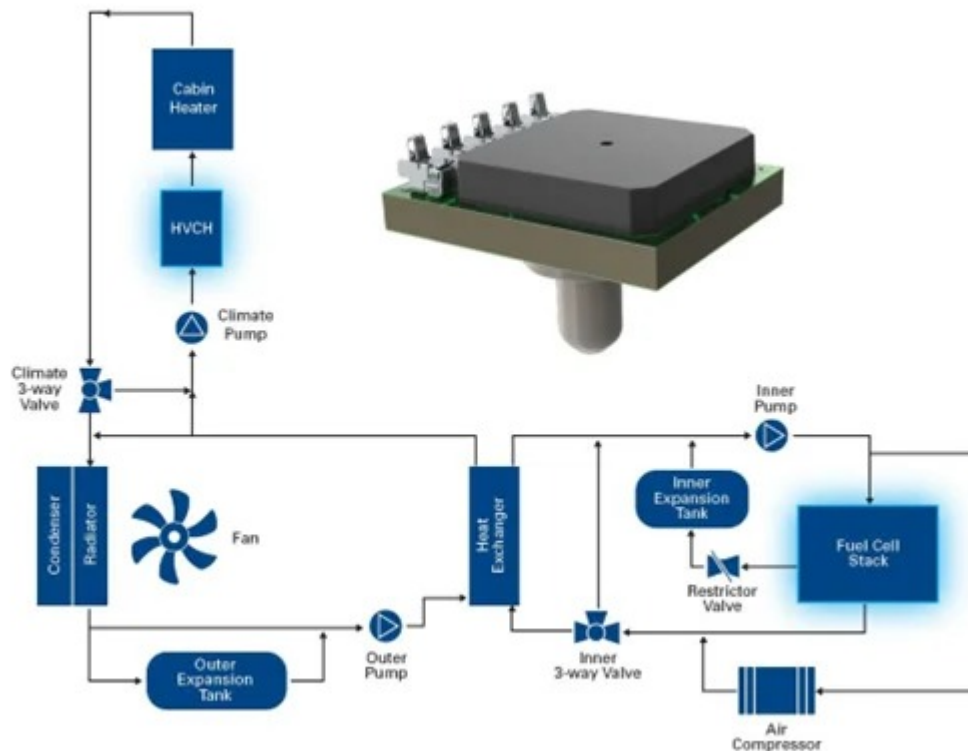


Image Credit: Merit Sensor

Measured Under Pressure: Serving Fuel Cell Technology with the TRVF-Series

The introduction of Merit Sensor's [TRVF-Series](#) marks a significant advancement in fuel cell technology, addressing the crucial need for durable and accurate sensors capable of enduring the tough conditions within fuel cell systems.

With its sturdy build and dependable performance, the TRVF-Series is positioned to have a significant impact on driving the advancement of sustainable transportation and energy solutions, establishing a new standard of excellence in sensing technology for harsh fuel cell environments.

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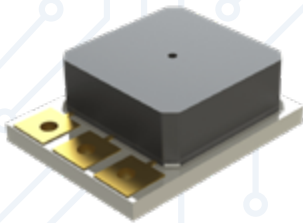
Pressure Measurement in Automotive Applications

Automotive pressure sensors perform many functions. For example, fuel-pressure sensors improve fuel efficiency. Oil-pressure sensors help keep the automobile's engine safe and long lasting. Pressure sensors for diesel-particulate filters (DPFs) and EVAP systems help to control harmful emissions.

One common factor in automotive applications is harsh media, such as fuel, oil, and fuel vapor. Another important factor is temperature, which can fluctuate between extremely cold and very hot. We know our automotive customers want pressure sensors that have been temperature compensated and packaged to withstand harsh media, and that's what we provide. Some of our pressure sensors can provide accuracy of $\pm 1.0\%$ between -40 to $150\text{ }^{\circ}\text{C}$.

HTS SERIES

The HTS Series is a surface-mountable pressure sensor that offers you a choice between an analog or digital output. But the HTS Series is not just your typical surface-mount device. Due to its backside-pressure-measurement design, the sensor's electronics are isolated, making the HTS Series compatible with wet, corrosive media. Learn [more](#).



TR SERIES

Whether you need to measure fuel vapor at low pressures or refrigerant gas at higher pressures, you can rely on the TVC Series. It was designed to provide a stable output, even at temperatures up to $150\text{ }^{\circ}\text{C}$. One of two possible MEMS silicon dies, the HM Series or J Series, is mounted at the top of the ceramic pressure port, allowing backside pressure. This configuration isolates the media to the ceramic, silicon, and die-bond material. Another advantage of the die bond on top of the ceramic pressure port is the option of customization based on the two different MEMS dies.



TR SERIES

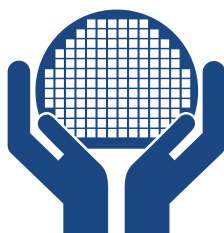
Do you need to measure the pressure of gas, oil, refrigerant, or other harsh media? If these materials penetrate the sensor's packaging, they can lead to reliability issues, costly maintenance, and even recalls. Our solution? The TR Series. Its hermetically sealed die measures pressure from the backside, where media contacts nothing more than the ceramic substrate, glass, and gold-tin eutectic solder. With the TR Series you can count on accurate and reliable pressure measurement.

Why Choose Merit Sensor?

**Designed &
Manufactured
in the USA**



**In-House
Wafer Fab &
Production**



**Worldwide
Distribution
& Direct Sales**



**History of
Customized
Solutions**



Fuel Level Sensors: How Your Car Measures Fuel Accurately

Sensors are integral vehicle and aircraft components, monitoring and analyzing critical data points and feeding them back to onboard ECUs, which act depending on the input. This article will look at one of the crucial sensors in use in vehicles: the fuel level sensor.



Image Credit: kckate16/Shutterstock.com

What is a Fuel Level Sensor?

Fuel level sensors allow vehicle operators to monitor fuel consumption and determine when to refill the tank. A fuel level sensor consists of two main components: the sensing system itself (also known as the sender) and the indicator (also commonly referred to as the gauge).

Fuel level sensors work by measuring the voltage across a variable resistor within the sensing system to determine the amount of fuel in the vehicle, which is then relayed to the driver or pilot via the indicating system.

Several components work within the sensing system, enabling it to detect how much fuel is in

a tank, including the float switch, a variable resistor, and a wiper. The fuel level sensor system is relatively simple compared to other sensors currently produced, although newer fuel sensor systems utilize microprocessors.

The fuel level sensor is located in the fuel tank and consists of a foam float, an actuating metal rod, and a variable resistor. The variable resistor is usually composed of a resistive material, with one end attached to the tank. A small wiper moves over the resistive material as the float moves.

A voltage change is induced when the wiper moves across the wiper. This is caused by the float moving when the fuel level changes. Due to the wiper's orientation, the highest resistance is experienced by the resistor when the tank is empty. The change in current is sent to an indicator, which changes the reading.

How Accurate Are Fuel Level Sensors?

Fuel level sensors in automobiles can often be inaccurate, especially when driving with a full tank. In this scenario, the float will rise to the top of the tank, with the wiper returning to the ground end of the resistor, resulting in a small resistance and a high current passing through the sensor.

As the fuel level drops, the sensor's resistance changes, but the fuel level sensor gauge will often remain on 'full' for a period. This is due to the tank blocking the float, meaning the float cannot position itself correctly on the top of the fuel.

Another factor that limits the accuracy of a fuel level sensor when the tank is full or nearly full is the actuating rod's reach. This causes the float to become submerged when the tank is full.

These factors cause inaccurate readings when the tank is full of fuel. When the fuel drops to a level where the float can sit on top, the resistance is allowed to change, leading to a more accurate reading.

Similarly, when the fuel level is low, the rod often does not extend to the end of the tank, causing the gauge to indicate an empty tank when, in fact, some fuel remains in the tank.



Image Credit: Nadezda Murmakova/Shutterstock.com

Aircraft Fuel Level Sensors

Some smaller aircraft use the same fuel level sensor mechanisms as automobiles. However, larger aircraft use more complex systems incorporating several sensors due to the increased size of the fuel tanks. Aircraft fuel sensors need to be much more accurate than automobiles.

This is due to the increased dangers associated with fuel loss in aircraft, which can have catastrophic consequences. Additionally, fuel level sensors in aircraft must be able to cope with changes in altitude. Therefore, sensor systems are much more sophisticated than their counterparts in the automotive industry.

Large commercial and military aircraft typically use fuel level sensor systems based on capacitance and ultrasound technologies.

In capacitance sensors, the fuel passes through special vents when it is consumed, causing a change in capacitance. In an ultrasonic fuel level sensor, ultrasonic signals are transmitted through the fuel to a sensor at the far end of the tank. Information on fuel levels is then passed to the pilots via the onboard computer.

A recently proposed novel fuel level sensor for use in aircraft is based on TIR point sensor arrays. This optical sensing technology is suitable for any type of common jet fuel and can work even with condensed water on the surface of the sensor.

In Summary

A fuel level sensor is an integral part of a vehicle, whether it is an automobile, commercial truck, or airplane. Current automobile fuel sensors do, however, suffer from a degree of inaccuracy, which is why these types of sensors are not used in large aircraft, which instead utilize more accurate capacitance or ultrasound sensors.

Research is ongoing into novel fuel level sensors for use in the aerospace and automotive industries to improve accuracy and reliability. The dangers of low fuel levels are well known in aircraft (and, in some scenarios, too much fuel), which makes research into more accurate systems crucial for the industry.

[See More: What Are the Common Contaminants Found in Marine Fuel?](#)

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How Tire Sensors Enhance Safety, Performance, and Efficiency in Modern Vehicles

Tire Pressure Monitoring Systems (TPMS) are a game-changer for modern vehicles, helping drivers stay safe while improving performance and efficiency. By keeping tabs on things like tire pressure, temperature, and wear, these systems provide real-time insights that prevent accidents, enhance handling, and even boost fuel economy.^{1,2}



Image Credit: Tetrisme/Shutterstock.com

TPMS are more than just a safety feature—they're a key component in optimizing vehicle performance and efficiency. In this article, we'll cover:

- **Why Tire Sensors Matter** – The impact of tire pressure and wear on vehicle safety and handling.
- **How TPMS Works** – The technology behind tire sensors and their role in monitoring tire health.
- **Different Types of Tire Sensors** – A breakdown of optical, strain, accelerometer, and PVDF sensors.
- **Applications of TPMS** – How these systems enhance vehicle stability, predictive maintenance, and autonomous driving.
- **The Future of Smart TPMS** – Innovations that go beyond pressure monitoring, integrating temperature and wheel alignment tracking.
- **Key Industry Players** – The companies leading the charge in tire sensor technology.

Why Tire Sensors are Important?

Tire problems like low pressure and blowouts are a leading cause of accidents worldwide. If your tires aren't performing properly, you're at a higher risk of losing control, especially in tricky driving conditions. Since tires are the only point of contact between your car and the road, they directly impact braking, cornering, and acceleration.^{1,2}

Modern TPMS go beyond just monitoring pressure—they improve safety systems like anti-lock braking systems (ABS), electronic stability control, collision mitigation, and adaptive cruise control. In self-driving cars, they're even more critical, providing data on road conditions and tire-road interactions to refine vehicle responses.¹

These systems also enable communication between vehicles and infrastructure, helping drivers and traffic systems anticipate and respond to potential hazards. On top of that, they provide valuable data for researchers working to design better, more durable tires.^{1,2}

How Tire Pressure Sensors Work

So, how do these systems actually work? Most tire sensor systems consist of a power unit, sensing unit, signal processing unit, auxiliary unit, and transmission unit. They directly measure tire states like acceleration, deformation, temperature, strain, and inflation pressure. This data helps estimators assess vehicle states for control systems.¹

Friction potential, tire forces, contact patch characteristics, and contact patch dynamics could be estimated by measuring the operational states.¹

Key types of tire pressure sensors include:

- [Optical sensors](#)
- Accelerometers
- Strain sensors
- Polyvinylidene fluoride (PVDF) sensors

Each type of sensor has unique advantages and challenges, making them better suited for different applications. Which type is best? That depends on the vehicle and the specific driving conditions.

Types of Tire Pressure Monitoring Systems

PVDF Sensor

PVDF sensors are widely used due to their flexibility, high sensitivity, and affordability. They generate voltage when pressure is applied, allowing for accurate measurement of tire strain

and deformation.

By integrating PVDF sensors with friction force models, engineers can estimate slip angles and lateral forces, helping improve traction control. However, they have some limitations—distinguishing between different directional strain signals and compensating for temperature variations remain challenges.¹

Strain Sensor

Strain sensors, typically made with high-elongation foil strain gauges, are attached inside the tire to measure lateral and circumferential strain. Newer versions use ultra-flexible materials to enable wireless monitoring.

However, strain sensors come with their own set of challenges. Stress concentration at the sensor-tire interface can impact longevity, and temperature fluctuations can introduce inaccuracies. Researchers are continuously working on making them more flexible and resistant to environmental factors.¹

Optical Sensor

Curious about how optical sensors work? They use lasers, cameras, and position-sensitive detectors to provide highly accurate, real-time data about tire deformation and structural integrity. Since they are mounted on the wheel rim and not in direct contact with the tire, they don't interfere with tire mechanics.

The enclosed environment of the tire cavity protects optical sensors from dust and debris, but they require additional light sources for precise measurement. While they offer exceptional accuracy, their high cost, power consumption, and complex calibration processes limit widespread use.¹

Accelerometer

Accelerometers are a well-established technology in TPMS. They are small, lightweight, and affordable, making them ideal for mass production. By detecting rapid changes in tire deformation, they help estimate the contact patch length (where the tire touches the road).

Most TPMS use triaxial accelerometers mounted inside the tire. These sensors track vibrations in great detail, but they can be sensitive to outside disturbances, leading to noise in the data. Additionally, alignment errors between the sensor and wheel frame can introduce measurement inaccuracies.¹

Where Tire Pressure Sensors Are Used

Tire Pressure Monitoring Systems (TPMS) play a crucial role in multiple aspects of vehicle performance, safety, and maintenance. But where do they have the biggest impact? Let's

break it down:

1. **Vehicle Stability Control** – TPMS contribute significantly to vehicle stability by working alongside ABS, traction control, and electronic stability management systems. By continuously monitoring tire pressure and temperature, these sensors help prevent issues like underinflation, which can compromise grip and handling. Maintaining optimal tire pressure ensures that braking, acceleration, and cornering remain predictable and stable.
2. **Performance Tracking** – Racing teams and performance car manufacturers rely on TPMS to gain real-time feedback on handling, braking efficiency, and fuel consumption. By analyzing pressure fluctuations during high-speed maneuvers, drivers and engineers can fine-tune tire performance for optimal results. In commercial vehicles, TPMS help fleet managers optimize tire longevity and fuel efficiency, reducing operational costs.
3. **Predictive Maintenance** – TPMS aren't just about immediate alerts; they also play a key role in long-term vehicle maintenance. By detecting early signs of uneven tire wear, gradual pressure loss, or heat buildup, these sensors allow for proactive tire servicing before problems escalate. This reduces the risk of tire blowouts, which can lead to costly repairs and accidents. For fleet vehicles, predictive TPMS data helps companies schedule maintenance efficiently, reducing downtime and extending tire lifespan.
4. **Autonomous Driving** – In self-driving and highly automated vehicles, TPMS are essential for ensuring that the vehicle can safely interact with the road. These systems provide real-time tire-road interaction data, allowing autonomous driving algorithms to adjust braking and steering dynamically. Without accurate tire data, autonomous vehicles may struggle to adapt to sudden road changes, such as wet or icy conditions. As autonomous technology advances, TPMS will become even more integrated into AI-driven vehicle control systems.

In short, TPMS are more than just a simple safety feature—they're an essential component in modern vehicle intelligence, offering benefits across performance, safety, and cost efficiency.^{1,2}

Smarter Tire Pressure Monitoring Systems

Most current TPMS only alert drivers when tire pressure drops below a safe level. But a study published in the IOP Conference Series: Materials Science and Engineering suggests an upgraded TPMS that does much more. This enhanced system not only monitors tire pressure but also tracks temperature and wheel alignment, giving drivers a more complete picture of their tire health and overall safety.^{2,3,4}

The system uses an electronic unit attached to each tire, which sends real-time data to an in-vehicle display. It's equipped with sensors, microcontrollers, a radio frequency transmitter,

and a battery, all working together to alert the driver when tire conditions go beyond safe limits.

Here's how it works:

- Sensors collect data on tire pressure, temperature, and alignment.
- A microcontroller processes this information.
- An accelerometer checks if the car is properly aligned.
- A temperature sensor monitors heat buildup from friction.
- The system uses amplitude shift keying to transmit data wirelessly.
- The receiving unit inside the vehicle, powered by an Arduino UNO, processes the incoming data and displays it on an LCD screen. A potentiometer allows the driver to adjust the screen's brightness for better visibility.

Successful experiments have shown that this smarter TPMS effectively helps drivers maintain their tires, improving both safety and driving comfort. With more comprehensive monitoring, drivers can catch potential issues early—before they turn into major problems.^{2,4}

Key Players

Leading companies in the tire sensor market include [Continental AG](#), [Sensata Technologies](#), [Denso Corporation](#), [NXP Semiconductors](#), and [Sumitomo Rubber](#). These industry leaders are actively pursuing strategic collaborations to strengthen their market presence and drive profitability.

Continental AG is at the forefront of tire sensor innovation, developing advanced solutions such as ContiSense™ and ContiPressureCheck™. These systems go beyond traditional tire pressure monitoring by providing real-time data on tread depth,

temperature, and road conditions. In India, the company is introducing cost-effective intelligent technologies, including the ContiPressureCheck system for CombineMaster tires, which continuously monitors both tire pressure and temperature.

Sensata Technologies and Denso Corporation are also major players, focusing on cutting-edge sensor technologies that enhance vehicle safety and performance. Meanwhile, NXP Semiconductors N.V. plays a crucial role as a leading provider of automotive semiconductors, including those used in tire pressure monitoring systems.

Sumitomo Rubber has launched proof-of-concept testing for a new Tire Pressure Monitoring System (TPMS) service designed to enable remote tire condition monitoring. This innovation has the potential to transform fleet management and vehicle maintenance by providing real-time insights.

Collectively, these key players are shaping the future of the tire sensor market, prioritizing safety, fuel efficiency, and comprehensive tire health data for vehicle operators and fleet managers.

Want to Learn More?

As tire sensor technology continues to evolve, its impact on vehicle safety, efficiency, and maintenance is becoming more significant. Whether you're an industry professional, fleet manager, or automotive enthusiast, staying informed about the latest advancements can help you make better decisions.

For further insights, explore topics such as:

- [How Pressure Mapping Advancements Will Change the Face of the Tire Industry](#)
- [What Are Automotive Sensors and How Do They Work?](#)
- [The Tire Industry Project: Addressing the Environmental Impacts of Tires](#)

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Understanding the Use and Function of MEMS Piezoresistive Pressure Sensors

insights from industry

Scott Sidwell
Engineering Manager
Merit Sensor Systems



In this interview, AZoSensors talks to Scott Sidwell, Engineering Manager at Merit Sensor Systems, about MEMS piezoresistive pressure sensors, silicon dies, and how these are all utilized across a range of industries.

Could you provide us with some background information on pressure sensors and their significance in various industries?

Pressure sensors are vital components that play a crucial role in various industries. The pressure sensor market is projected to see remarkable growth, as indicated by recent research, and it is expected to reach nearly 24.5 billion dollars by 2028.

They find applications in automotive, industrial automation and process control, consumer products like diving, e-bikes, and, importantly, in the medical field.

Pressure sensors work based on the principle of the force of a fluid divided by area. To put it into perspective, consider a syringe – a smaller one can generate more pressure than a larger one with the same force applied. Understanding this concept is crucial when dealing with pressure sensors.

Atmospheric pressure is a term we often hear. Could you explain what it is and its relevance in the context of pressure sensors?

Atmospheric pressure is essentially the weight of the air pressing down on us. As you ascend in an airplane or spacecraft, the air becomes less dense, with fewer molecules and less

oxygen. It is important to consider atmospheric pressure when measuring the pressure in your application, because it will determine the type of pressure sensor needed.

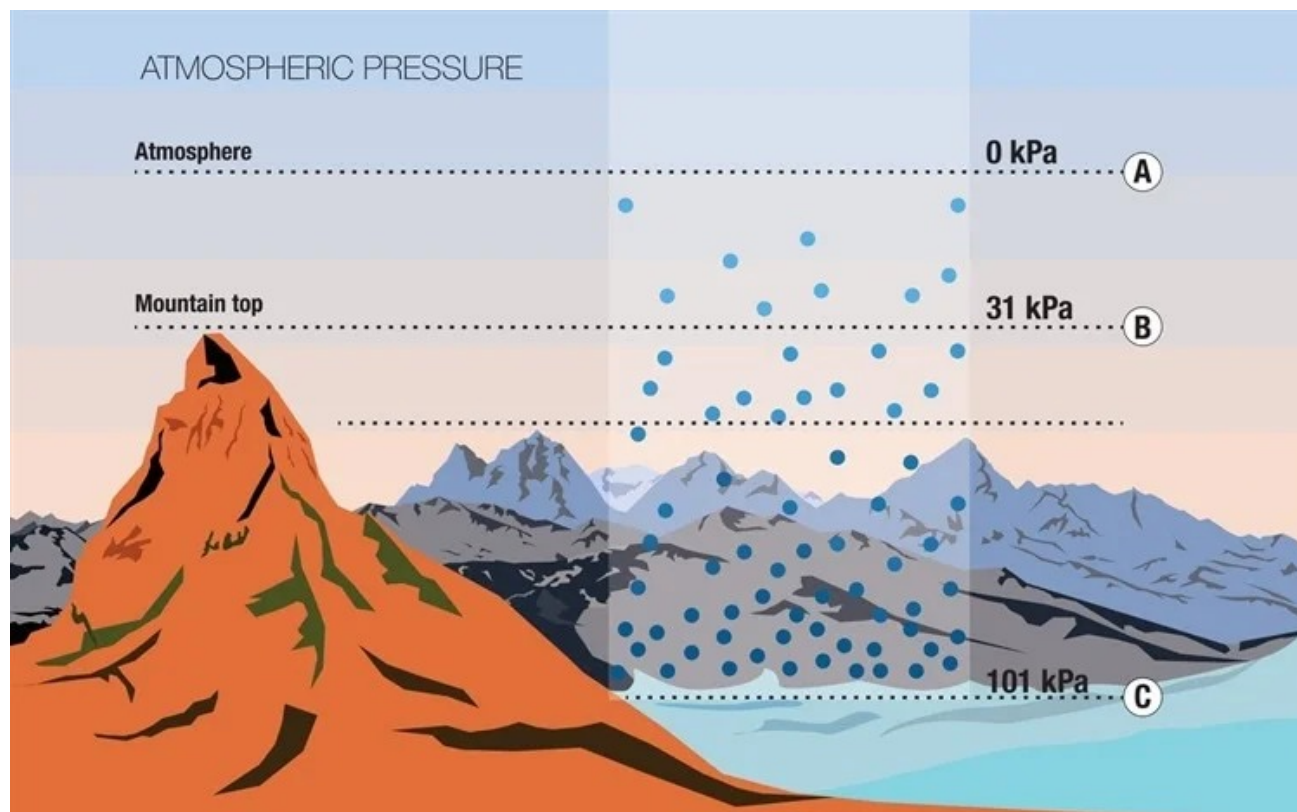


Image Credit: Mi Sketch/Shutterstock.com

What other applications besides the automotive industry benefit from pressure sensors, and how are they used?

Pressure sensors find applications across a diverse spectrum of industries, expanding far beyond their traditional use in the automotive sector. One of the sectors where pressure sensors play a critical role is the diving industry. In this field, pressure sensors are employed to monitor the depth of divers underwater, enabling them to calculate ascent and descent times accurately. The hostile underwater environment necessitates reliable pressure measurements to ensure diver safety.

Pressure sensors have made their way into the consumer product market. For instance, in the realm of bicycles, especially the emerging category of e-bikes, pressure sensors are integrated into various components. These sensors may be utilized on bike shocks, tires, and other critical parts to enhance the overall performance and user experience.

We will help you handle the pressure, whether your application is inside a hospital room or a turbine engine.

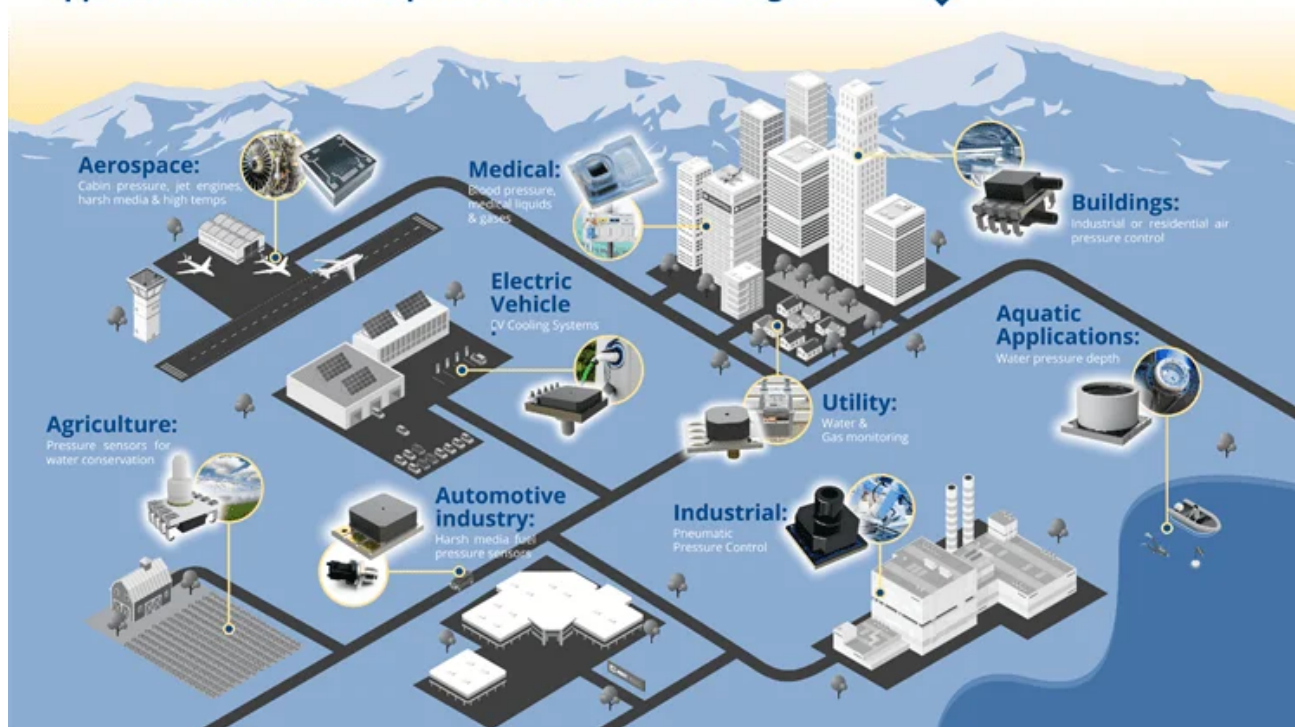


Image Credit: Merit Sensor

What are the typical applications of piezoresistive pressure sensors, and how do they work?

Piezoresistive pressure sensors are a subtype of pressure sensors known for their versatility and use in various applications. Piezoresistive sensors function on a principle involving doped, semiconductor silicon crystal, which allows them to measure pressure more repeatably than other technologies.

To understand their typical applications, it is worth highlighting that piezoresistive pressure sensors are not constrained to a single field. They are used in an array of industries, including the medical sector. In medical procedures like angioplasty, where surgeons inflate balloons inside arteries, pressure sensors play a crucial role. In these procedures, the pressure sensor's output helps the surgeon monitor the level of inflation inside the balloon, and assess the overall status of the procedure.

Can you explain what MEMS technology is and its advantages in the context of pressure sensors?

MEMS stands for Micro-Electrical-Mechanical Systems, and there are many different types of MEMS. The deposition, ion implantation, and diffusion steps are all fundamental to semiconductor manufacturing, as well as the photolithography and etching of MEMS pressure sensors. MEMS pressure sensors feature an elastic silicon diaphragm, which means they are free from hysteresis and creep.

This elasticity benefits the sensor because it allows it to undergo repeated pressure cycling without altering its properties. When things tend to creep or change, it is almost always a result of how they are packaged, not necessarily the silicon chip itself. Putting thousands of pressure sensors onto one wafer also significantly helps to reduce costs.

Merit Sensor has its wafer fab in Utah. There are many advantages to working with a vendor that has its wafer fab. When it comes to developing a new product, having your wafer fab is a huge advantage, as it allows you to control the supply chain. Keeping the design in-house is often considered the key to the successful development and launch of any product.



Can you give us a basic understanding of the MEMS pressure sensor?

The key design characteristic of a MEMS pressure sensor is the Wheatstone bridge diffused into the silicon diaphragm. The change in output from this bridge corresponds to a change in applied pressure. When a customer needs a higher pressure range, the sensor requires a thicker diaphragm to handle the increased pressure. Conversely, for measuring low pressures, like inches of water or low pascals, a thin diaphragm suffices.

After the manufacturing process, the silicon is bonded to a piece of glass. The glass may have a hole to create a vent for various pressure applications, or it can be sealed without a hole. In the latter case, the glass and silicon are bonded together in a vacuum.

When there is no hole in the glass, it is known as an absolute sensor because the space between the silicon and glass represents zero pressure absolute.

There are two types of absolute sensors made from MEMS dies. The traditional type has no hole in the back glass, creating a sealed vacuum reference for absolute pressure. However, this design requires protection for the circuitry on the top side to prevent corrosion and shorts from humidity or moisture.

Alternatively, there is the absolute sensor with backside pressure. In this design, a piece of glass is added to the top of the silicon, creating a sealed vacuum reference on the top side and allowing for backside pressure on the MEMS element. This type is commonly used in automotive and high-temperature applications, as well as with liquids.

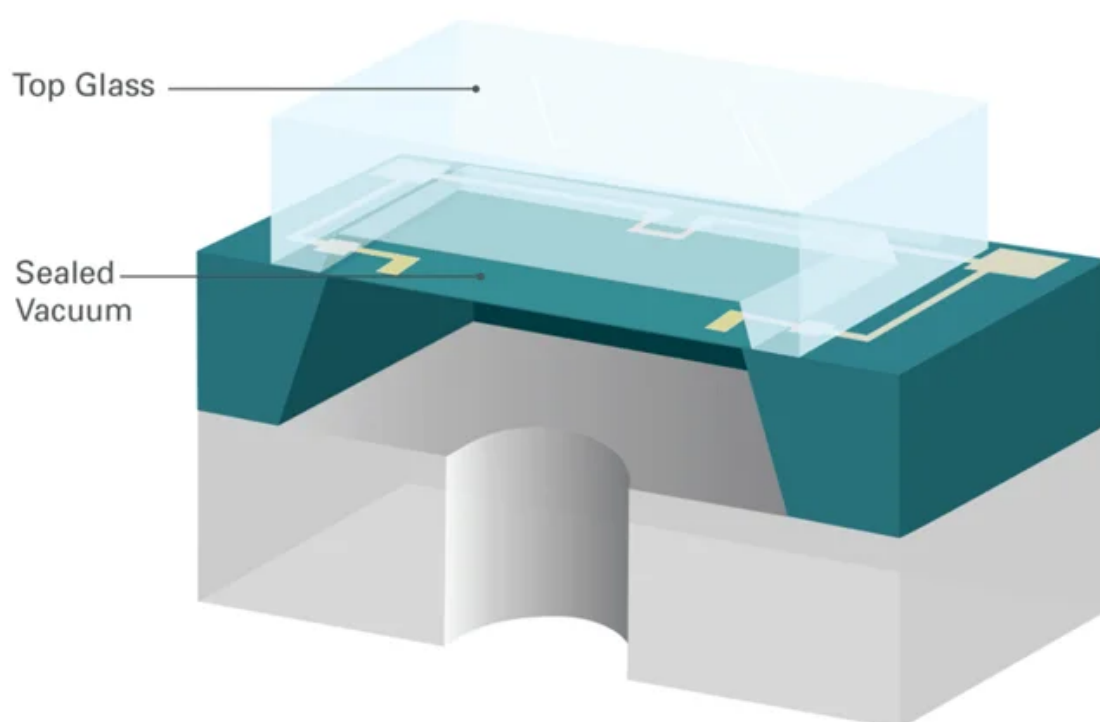


Image Credit: Merit Sensor

Can you tell us more about offset pressure and other factors like pressure non-linearity and hysteresis?

Offset pressure is the zero pressure measurement at room temperature. Pressure non-linearity measures how linear or nonlinear the sensor's output is from zero pressure to full-scale pressure, and hysteresis reflects the difference between the initial zero and return zero, when pressure is applied and then relieved. The MEMS sensing element is designed to minimize these sources of error.

How do temperature-related factors, such as TCR and TCS, influence the behavior of pressure sensors?

It is possible to use the TCR, the Temperature Coefficient of Resistance, in conjunction with the pressure sensing to determine the temperature, because the TCR changes significantly with temperature. The Temperature Coefficient of Span/Sensitivity, or TCS, is important to take into account, especially in applications for wide operating temperature ranges. The TCS is negative, and when using the MEMS piezoresistive pressure sensor, the sensitivity or span decreases as the temperature rises.

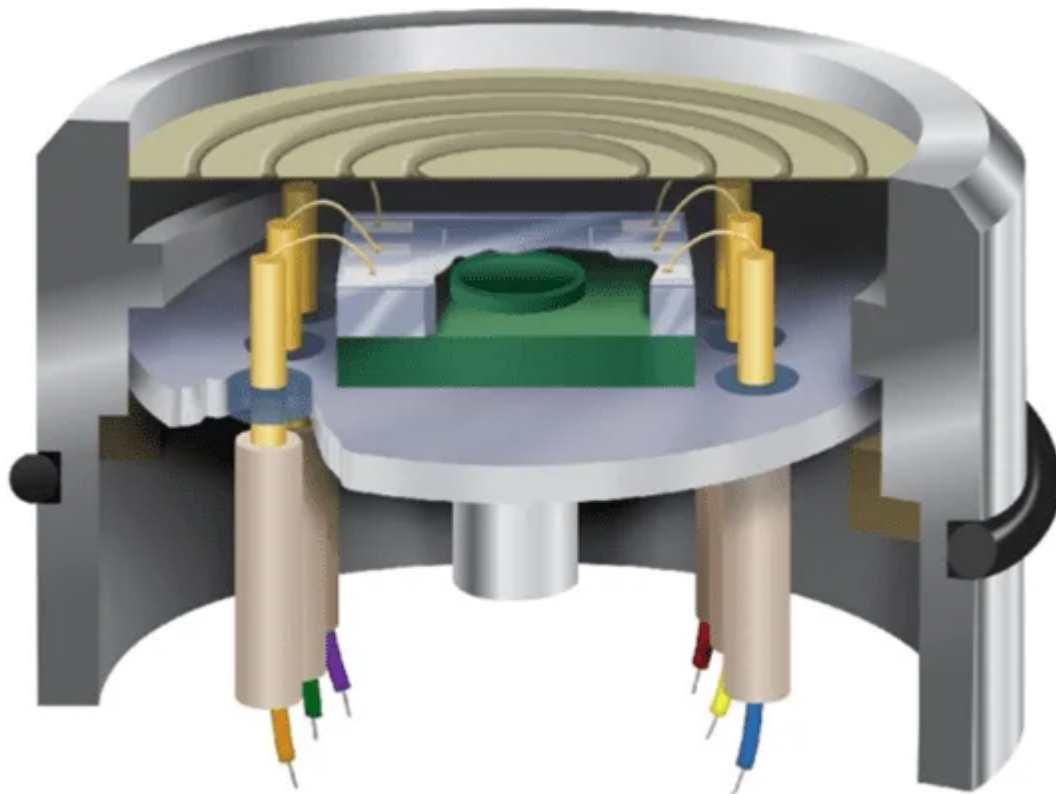
Can you explain the importance of accuracy in pressure sensors and how it can be achieved?

Accuracy in pressure sensors is often measured as the total error band, which includes errors related to temperature and pressure. Achieving accuracy involves calibration, and fully compensated sensors with onboard ASICs simplify this process and provide higher accuracy. Accuracy is vital, especially in applications where precise measurements are critical.

How do stress and other external influences impact pressure sensors?

We take great pride in understanding and characterizing the sources of error that our customers can't compensate for: thermal hysteresis and long-term stability. The last thing our customers want is a part failure in their hands, which can occur due to long-term stability issues.

It's important to keep in mind, that the MEMS sensing element is also a good stress sensor. For example, a torque, or bending moment on the MEMS element will change the output of the Wheatstone bridge. Stress can be induced during packaging and assembly processes, impacting sensor performance. Over time, any package-related stresses will relieve themselves and come back to equilibrium. This stress-relief will manifest as a change in the offset of the sensor, in other words, offset drift and long-term stability. Careful handling and packaging are essential to maintain sensor stability.



Could you explain how MEMS dies are suitable for a wide range of applications, both specific and general, and what factors should customers consider when selecting a pressure sensor?

MEMS dies are common in pressure transducer or pressure transmitter applications where the MEMS die is on a header. The header gets welded into a stainless-steel housing with a stainless-steel diaphragm. Stainless steel is an excellent choice since it is very media-friendly, and most people are usually very familiar with stainless steel's capabilities. This package is suitable for many industrial applications.

After welding the stainless-steel diaphragm and package together, there's a back-filling of oil into this housing. A clean silicon oil surrounds the MEMS die, transmitting pressure between the stainless-steel diaphragm and the silicon diaphragm of the MEMS element.

In the HVAC industry, the MEMS die can be purchased separately or packaged into our LP series and placed on a control board. These control boards are found in large buildings, either atop the building near the air intake or in the building's utility room, where heat exchangers and air airflow systems are located.

Another common application is in transportation. Pressure sensors are widely used in various types of automobiles. This area continues to grow as legislation drives the demand for higher efficiency and cleaner emissions.



To learn more, watch the full webinar below:



[Understanding MEMS Piezoresistive Pressure Sensors: A Close Look at a Silicon Die](#) from [Merit Medical](#) on [Vimeo](#).

About the interviewee

Scott joined Merit Sensor in September of 2003. Before joining Merit Sensor, he worked in a variety of engineering roles with semiconductor companies, such as ON Semiconductor and Motorola. In his current role he works closely with customers to provide pressure-sensing solutions and technical support.

Scott received a chemical-engineering degree and MBA from Brigham Young University. He speaks Spanish and enjoys volunteering his time.



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What is a Tachometer?

A tachometer measures the rotational speed of an engine or motor, typically expressed in revolutions per minute (RPM). These devices, available in both analog and digital formats, are commonly found in automobiles and aircraft.



Image Credit: Panuwatccn/Shutterstock.com

In this article, we will explore the different types of tachometers, their working principles, applications across various industries, and recent advancements in tachometer technology.

What is a Tachometer?

A tachometer is a device that measures rotational speed—typically tracking how fast an engine's crankshaft or a motor's rotor is spinning. It works by generating a signal that corresponds to the rotation speed, usually displaying the measurement in revolutions per minute (RPM). If you've ever noticed a gauge in a car with a needle moving as you press the gas, that's the tachometer. It usually features a dial, a needle, and markings that indicate safe and potentially damaging speed ranges.

Most modern vehicles now use digital tachometers integrated into the dashboard, but the core function remains the same. Depending on the method of measurement, tachometers either determine speed by counting the frequency of pulses generated by the rotating shaft or by measuring the time between each pulse.

The term “tachometer” comes from the Greek words *tachos* (speed) and *metron* (measure). Early mechanical versions worked using centrifugal force—the outward push experienced by objects in a spinning system. By the early 19th century, these devices were adapted for measuring machine speed, and by the 1840s, they became a standard feature in locomotives and other vehicles.

Beyond engines, tachometers also have specialized applications. In medicine, for example, a *haematachometer* can be placed inside an artery or vein to estimate blood flow based on the speed of a tiny spinning turbine. This helps diagnose circulation issues, such as arterial blockages.¹⁻³

Understanding Tachometer Types and Their Principles

Not all tachometers are the same. They come in different designs, each suited for specific uses. Let’s take a closer look at how they’re classified based on their working principles, data collection methods, and measuring techniques.

Tachometer Classification Based on Working Principle

Analog Tachometers

Analog tachometers have a classic needle-and-dial design, displaying RPM in a straightforward way. They rely on mechanical or electromechanical systems to turn rotational movement into an electrical signal. Many use a frequency-to-voltage converter to translate speed into voltage, which is then displayed on an analog meter.

These tachometers are simple and reliable but lack modern features like data storage and precise deviation calculations. They’re commonly found in older vehicles and machinery where basic real-time speed monitoring is enough.³

Digital Tachometers

Digital tachometers take mechanical speed and convert it into digital signals, offering real-time, highly accurate readings. These models detect shaft rotation and display RPM on an LCD or LED screen. For example, an infrared module can detect interruptions in a beam caused by the rotating shaft, producing pulses that are counted to determine speed.

Unlike their analog counterparts, digital tachometers provide clear, easy-to-read numerical displays and often include memory storage for data analysis. They’re widely used in cars, planes, and medical equipment. However, they can be sensitive to slight positional changes, and rapidly fluctuating speeds can make it tricky to get a stable reading.^{2,4}

How Tachometers Collect Data: Contact vs. Non-contact

Now that we’ve explored how tachometers display and process speed readings, let’s look at

how they collect data—whether through direct contact with a rotating object or using non-contact methods.⁴

Contact Tachometers

As the name suggests, contact tachometers must physically touch the rotating shaft to measure speed. They typically use optical encoders or magnetic sensors to detect motion, converting mechanical movement into RPM readings. These devices work best when direct interaction with the rotating part is feasible and when precise measurements are required. They usually measure speeds between 0.5 and 10,000 RPM and often feature five-digit LCD displays.⁴

Non-Contact Tachometers

Non-contact tachometers measure rotational speed without touching the object, making them ideal for high-speed applications. These devices use lasers or optical disks to detect motion and are commonly found in vehicles such as buses, trains, and airplanes.

They work by detecting pulses from a shaft encoder. When a reflective surface on the shaft interrupts a light beam, pulses are generated and counted by an electronic circuit to determine speed. These tachometers are highly accurate, particularly at high speeds, and are essential when physical contact could interfere with performance.⁵

How Tachometers Measure Speed: Time vs. Frequency

Now that we've looked at how tachometers collect data, let's see how they interpret that data to determine speed. Depending on the approach, they can measure speed based on either time intervals or frequency calculations.

Time Measuring Tachometers

Time-based tachometers measure speed by calculating the time between incoming pulses. These are especially useful for low-speed applications, as they maintain reliable resolution regardless of the speed.

Frequency Measuring Tachometers

These tachometers determine speed by measuring the frequency of incoming pulses, making them ideal for high-speed applications. Many use red LED displays and operate across a frequency range of 1Hz to 12 kHz. They're known for being both cost-effective and efficient.

Where Tachometers Are Used

Tachometers are found in nearly every industry that involves rotating machinery. Some of the most common applications include:¹⁻⁵

- **Automobiles, airplanes, trucks, tractors, and trains** – for monitoring engine and wheel

speeds.

- **Laser instruments and medical devices** – ensuring precision in specialized applications.
- **Analog audio recording** – maintaining consistent speeds for playback and recording.
- **Industrial machinery** – preventing wear and tear by keeping speeds within optimal ranges.

What's New in Tachometer Technology?

Tachometer technology has made huge strides, moving from simple mechanical designs to sophisticated digital systems that deliver high levels of precision. One exciting example comes from a recent study in the *Journal of Language and Linguistic Studies*, which introduced a digital tachometer capable of measuring speeds up to 800 RPM using a PSoC5LP microcontroller. This system integrates an alphanumeric LCD, an optical sensor, and a DC motor, showing just how much microcontrollers can boost the accuracy and versatility of tachometers.

What makes this study stand out is its use of PSoC5LP interrupts to measure motor speed and update the display every three seconds. This not only showcases the advancements in digital tachometers for industrial and mechanical applications but also highlights their growing importance in education.

By incorporating hands-on microcontroller-based speed measurement, students and engineers alike can gain a deeper understanding of real-world applications. This reflects a broader trend—tachometers are no longer just passive measurement tools; they are becoming smarter, more interactive, and more valuable across different fields.⁶

The Future of Tachometers

Tachometers are getting smarter, more precise, and a whole lot more automated. Thanks to advancements in [sensor technology](#) and microcontrollers, we're seeing wireless, high-efficiency speed measurement systems that can adapt to various industries. Whether it's keeping tabs on engine performance in cars or monitoring industrial machinery, these innovations are making tachometers more accurate and versatile than ever.

Looking ahead, tachometers will continue to be a go-to tool in engineering and mechanics. No matter the industry—automotive, aerospace, or manufacturing—these devices will play a crucial role in keeping things running smoothly.

Whether you opt for an analog or digital model or decide between contact and non-contact options, the goal remains the same: reliable and precise speed monitoring. As technology advances, tachometers will likely become even more integrated into smart systems, solidifying their place in modern diagnostics and automation.

Want to Learn More?

For more insights into automotive technology and applications, why not check out the following articles:

- [What's Next for the Automotive Market in 2025?](#)
- [Vapor Tachometer from MX South](#)
- [Understanding Quality Testing for Automotive Chain Drive Components](#)
- [Automotive Semiconductor Manufacturing: Industry Leaders](#)

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Steering Sensors: How They Improve Vehicle Handling and Safety

Steering a car might seem like a simple task—but behind the scenes, a lot is happening to keep things smooth, stable, and safe. At the heart of that hidden complexity are steering sensors, quietly working to enhance everything from precision handling to crash prevention.



Image Credit: oatzpenz studio/Shutterstock.com

Today's vehicles are less mechanical and more like rolling computers. Packed with sensors and software, they rely on real-time data to adjust and react faster than any human could. And while features like lane keeping and automated parking get all the attention, steering sensors are often the unsung heroes making it all possible.

In this article, we'll take a closer look at how steering sensors work, why they're crucial to modern driving, and how they're shaping the next generation of smart vehicles.

So... What Exactly Are Steering Sensors?

At their core, steering sensors translate your input—how you move the wheel—into digital signals your car's systems can understand. But that's just scratching the surface.

Back in the day, steering was all mechanical. Systems based on principles like Ackerman geometry helped align the wheels during turns, and that was enough for basic driving. But those setups couldn't adapt to changing road conditions like ice, rain, or a sudden obstacle.

The game changed with electric power steering (EPS). Swapping out hydraulic components for electric motors opened the door to smarter, sensor-based steering. With sensors tracking wheel angles, steering torque, and speed, the vehicle's electronic control units (ECUs) could respond almost instantly.^{1,2}

Today's steering systems typically measure things like:

- How hard you're turning the wheel (torque)
- The exact position of the wheel (angle)
- How fast the car is rotating or sliding sideways (yaw/lateral acceleration)
- How fast each wheel is spinning (wheel speed)

All of this helps the vehicle react precisely—not just to you, but to the road, weather, and even nearby objects.

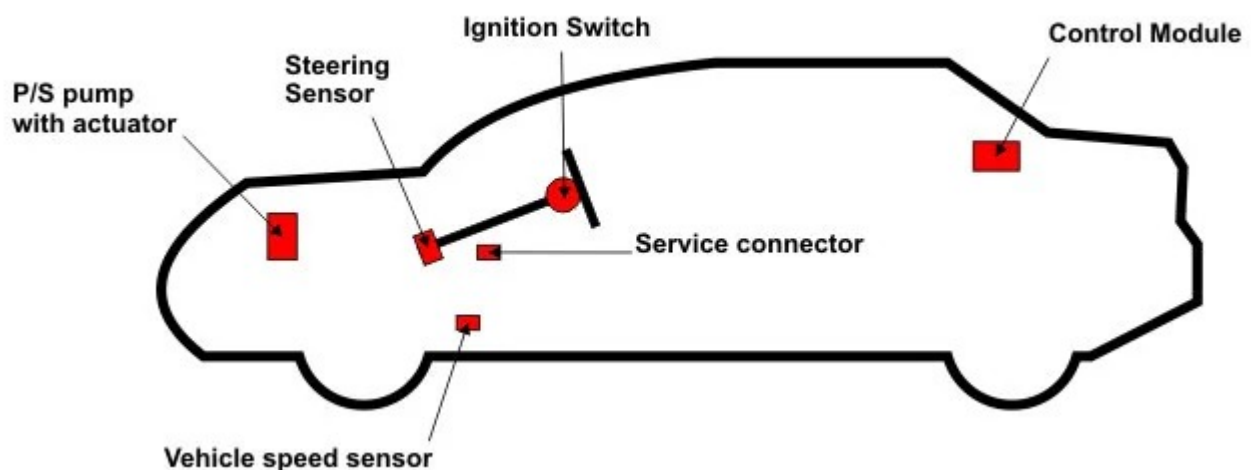


Figure 1. A schematic drawing of the steering components of a car. Image Credit: Knowles D. (2003). *Today's Technician: Automotive Suspension and Steering Systems*. USA, New York: Delmar Learning, a division of Thomas Learning, Inc.

Steering Sensors: The Silent Force Behind Safer, Smarter Driving

Modern vehicles are no longer just mechanical systems. They're responsive, data-driven machines that sense, think, and adapt in real time—and steering sensors are a key part of how that happens. While they rarely get the spotlight, these sensors do a surprising amount of heavy lifting, from keeping your car stable on ice to helping you avoid a crash before you even know it's coming.

Here's a closer look at how steering sensors quietly shape the driving experience—and where they're headed next.

1. Translating Driver Input into Motion

At the most fundamental level, steering sensors convert physical actions into digital instructions. When you turn the wheel, you're not just moving a mechanical linkage anymore. You're generating torque, angle, and rotational data that gets processed by the vehicle's control systems.

Modern steering sensors measure the force applied to the steering wheel (torque sensors), its position (angle sensors), and the rotational motion of the vehicle itself (via yaw rate and lateral acceleration sensors). Together, this data tells the car: "Here's what the driver wants," and lets the electronic control units (ECUs) translate that intent into precise, calculated motion.

This real-time interpretation is what enables vehicles to respond with precision, even in complex or high-speed scenarios.

2. Path Tracking and Cornering Control

One of the key performance gains from steering sensors is in how accurately a vehicle can stay on its intended path, particularly during turns.

Model predictive control (MPC) is a technique that uses steering sensor data to forecast the vehicle's trajectory and make continuous adjustments to stay on course. This becomes especially important during high-speed cornering or quick evasive maneuvers, where the margin for error is slim.

Studies have shown that vehicles using MPC in combination with steering sensors can cut lateral path deviation by up to 50 % compared to systems without it.² It's not just about sharper turns—it's about ensuring the car reacts predictably and smoothly to both driver input and road

geometry.

3. Skid Prevention and Stability on Low-Traction Surfaces

On wet, icy, or uneven roads, steering sensors work with the stability control system to reduce the risk of skidding. The sensors monitor how the vehicle is rotating (yaw) and moving sideways (lateral acceleration), and compare that to the direction the wheels are pointed.

If the car starts to slide or rotate unexpectedly—say, in a tight turn on a slick road—the system recognizes the mismatch and responds in real-time. It might apply selective braking to individual wheels or adjust steering torque to help the vehicle regain its intended trajectory.

One study found that sensor-assisted stability control systems could help maintain directional control even on roads with a friction coefficient as low as 0.7, where traditional systems struggled.²

4. Context-Aware Steering: Adapting to Speed and Conditions

Not all driving situations are created equal. Highway cruising, city traffic, and parallel parking each require a different kind of steering feel. That's where context-aware systems powered by steering torque sensors come in.

These sensors allow the vehicle to adapt its response based on driving conditions. At higher speeds, the system may dampen sensitivity to create a more stable feel and reduce driver fatigue. In slower, low-speed situations—like parking—it can increase responsiveness to make tight maneuvers easier.

This adaptability is driven by algorithms that factor in vehicle speed, road surface data, and torque inputs from the driver. All in all, the user gains a steering experience that feels tailored, even when it's largely happening behind the scenes.

5. Emergency Steering and Collision Avoidance

When a collision is imminent, every millisecond counts, and sometimes braking alone isn't enough. That's where autonomous emergency steering (AES) systems step in, using steering sensor data to make real-time decisions about evasive maneuvers.

These systems combine steering angle, wheel speed, and object detection inputs to calculate a safe trajectory around obstacles. Using predictive models, they can determine how the vehicle will behave under sudden input, and adjust accordingly to keep it under control.

In simulation tests, AES systems powered by steering-sensor data and MPC algorithms successfully avoided collisions at speeds up to 60 km/hour, executing smooth and stable maneuvers with a 95 % success rate. Crucially, they did this without sacrificing passenger comfort or inducing new risks.²

6. Driver Behavior Monitoring Through Steering Patterns

Steering sensors aren't just looking at what the car is doing, they're also watching the driver. Irregular steering behavior, such as sudden corrections, erratic movement, or prolonged inactivity, can signal distraction, fatigue, or even medical issues.

By tracking patterns over time, modern systems can flag abnormal inputs and prompt alerts when necessary. Some advanced implementations go further, using machine learning to classify driving styles—such as aggressive versus cautious—with high levels of accuracy. In one study, this approach reached a 93 % accuracy rate using in-vehicle sensor data.⁵

This kind of passive monitoring adds another layer of safety—it is subtle, noninvasive, and always on in the background.

7. ADAS Integration: Lane-Keeping, Shared Control, and Parking

Steering sensors are core enablers of many advanced driver assistance system (ADAS) features we now take for granted.

Lane-Keeping Assistance (LKA) uses steering angle data and camera inputs to detect unintentional lane departure. If the car begins to drift without a turn signal, the system applies corrective torque to guide it back. These systems have been shown to reduce lane-departure-related crashes by up to 21 %. But for them to be effective, their response has to feel natural—too aggressive, and drivers often disable them.

Shared control systems, like lane-centering assist, rely on torque sensors to detect whether the driver is actively steering. If a potential hazard is detected and the driver doesn't respond, the system can take over momentarily to steer away from danger, blending human and machine control.

In autonomous parking scenarios, steering sensors coordinate with LiDAR and ultrasonic sensors to position the vehicle accurately, even in tight spots. This can reduce minor parking collisions by around 30 %, especially in urban environments where space is limited.¹

Challenges: Environmental Noise, Data Processing, and Driver Overreliance

As effective as steering sensors are, they still have limitations that can affect performance, especially in real-world driving conditions.

Environmental factors are a constant challenge. Optical systems like cameras can struggle with heavy rain, fog, snow, or dirt buildup. Electromagnetic interference, meanwhile, can throw off torque sensors, leading to inaccurate readings. On poorly marked roads—especially in rural or unpaved areas—some steering systems simply don't have enough reliable input to work correctly.¹

Then there's the computational side. Many of these systems rely on heavy real-time data processing, particularly when predictive models like LSTM (Long Short-Term Memory) networks are involved. These models are powerful but demand substantial training data and high-performance onboard computing, something not every vehicle is optimized for.

Perhaps most critically, overreliance on automation is becoming a human factor risk. Some studies have shown that when drivers grow too comfortable with advanced driver assistance systems—especially automated steering—they're slower to respond to sudden hazards. In one survey, nearly 38 % of participants failed to react promptly when an emergency required manual intervention.^{2,6} That's not a tech issue, it's a trust-and-attention issue.

What's Next: AI Prediction Models and Multi-Sensor Fusion

To overcome these limitations, the next wave of steering systems will be even smarter and more intuitive.

Artificial intelligence is already playing a major role. LSTM-based prediction models are being trained on historical driving data to anticipate future vehicle states: how a car might react to sharp turns, where slippage might occur based on surface data, and even when a rollover risk is emerging. These predictions don't just react to the present—they adjust steering parameters proactively before the situation unfolds.

Another major leap is happening in [sensor fusion](#). By combining input from multiple data sources—LiDAR for depth and distance, radar for velocity tracking, and cameras for lane and object recognition—future steering systems will be able to cross-verify environmental information and reduce uncertainty. This redundancy is key to navigating complex urban settings, where fast-moving traffic, pedestrians, and cyclists create constant unpredictability.

Some emerging systems are even starting to anticipate pedestrian behavior—not just recognizing a person crossing, but estimating whether they’ll continue walking, pause, or step back. That kind of real-time interpretation mirrors the intuition of experienced drivers—and that’s exactly where this technology is headed.⁷

The Expanding Role of Steering Sensors in Safer Driving

Steering sensors may not be the centerpiece of flashy automotive marketing, but they’re quietly doing the work that makes modern driving feel safer, smoother, and more responsive. They take your input, interpret road conditions, and power systems that keep you in your lane, out of skids, and sometimes, out of harm’s way entirely.

As vehicles evolve, steering systems will continue to blend human control with machine intelligence—not to replace the driver, but to support them in smarter and more intuitive ways.

Want to explore more on automotive tech and intelligent control systems? Why not check out some of the below topics?

- [What Are Automotive Sensors and How Do They Work?](#)
- [A Closer Look at Your Car’s Essential Sensors](#)
- [Then vs. Now: How Automotive Sensor Technology Has Evolved](#)
- [How Coolant Temperature Sensors Regulate Antifreeze for Effective Engine Cooling](#)
- [Understanding Tire Pressure Sensors: How They Keep You Safe](#)

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