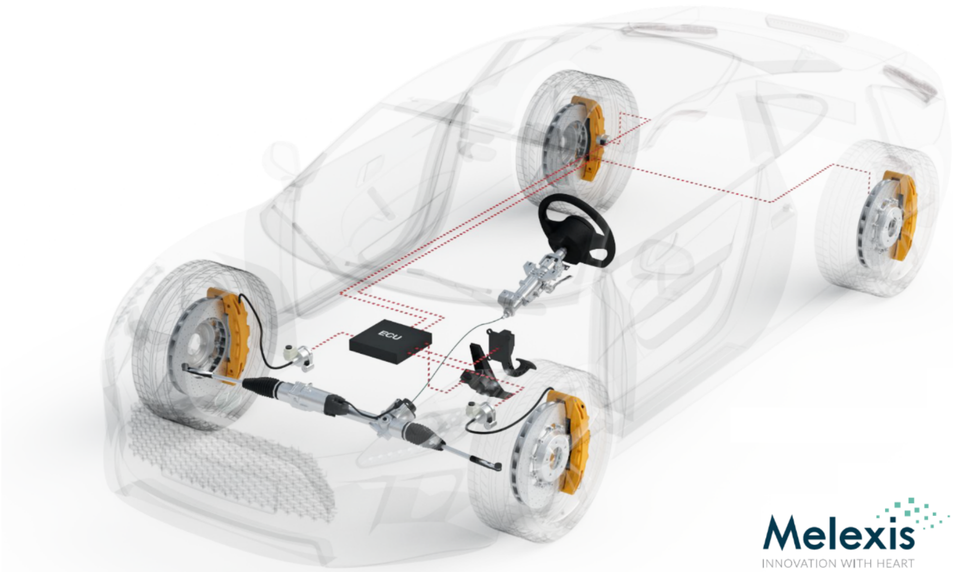
Key Technologies Enabling Automotive By-Wire Systems

Carlos Velásquez, Chassis Systems Expert at Melexis

July 2025



The automotive industry has long been dominated by mechanical and hydraulic engineering. From suspension and cooling to the engine and controls, the overwhelming majority of vehicle systems feature mechanical and hydraulic control and operation. While electronic components have been incorporated into vehicles since the 1930s, mainly in the form of engine starters, lighting, and optional radios, the overall mechanical nature of vehicles persisted.

Yet in recent decades, the scope and application of electronic systems in vehicles have expanded. Countless mechanical pumps and vacuum-controlled systems have been replaced with solenoids, solid-state relays, and piezoceramics. Likewise, electronic sensors and displays have long superseded feedback systems, such as mechanical gauges. However, despite this shift, core functions like steering and braking have remained predominantly mechanical and hydraulic, with electronic components playing only a secondary role.

That is beginning to change. The convergence of automotive intelligence, electrification, and tighter emissions regulations is now pushing designers to re-engineer these critical systems as fully electromechanical. By doing so, they can enhance safety and precision, simplify integration, reduce overall complexity, and lower both emissions and energy consumption. This is driving the rise of next-generation “by-wire” architectures, which can support emerging vehicle functions in ways traditional mechanical-hydraulic designs cannot.

The Shift Towards By-Wire Systems

A by-wire system replaces traditional mechanical linkages with electronic control mechanisms. This represents a significant shift in vehicle design, as essential functions, such as throttle, braking, and steering, no longer rely on physical connections like steering columns, cables, or hydraulic lines. Instead, these functions are managed by sensors, motorized actuators, and electronic control units (ECUs).

Throttle-by-wire, for example, replaces the mechanical connection between the accelerator pedal and the throttle valve with position sensors that relay pedal input to the engine control module (ECM) for precise electronic power adjustment. While the absence of a physical linkage can raise concerns, the concept has a long and proven track record. The Concorde, introduced in 1969, was the first commercial airliner to use fly-by-wire technology [1], and throttle-by-wire entered the automotive market in the mid-1980s with BMW's 7 series [2]. Today, it is standard in virtually all modern vehicles.

By-wire systems deliver finer control, greater efficiency, enhanced safety features, and compatibility with emerging technologies such as autonomous driving. They also present challenges, including built-in redundancy to meet safety-critical standards and the advanced integration with other systems like steering or powertrain.

Brake-by-Wire and Steer-by-Wire

While electronic control has become common in systems like throttles, engines, and gearboxes, the transition has been slower for two key systems – braking and steering. That is now rapidly changing.

Brake-by-Wire

Brake-by-wire systems use sensors to monitor brake pedal position or pressure and control the braking force either by driving electro-hydraulic or electromechanical actuators at the calipers. These solutions enable the seamless integration of autonomous driver-assistance systems (ADAS) and autonomous driving capabilities [5], and also facilitate the implementation of regenerative braking in electric vehicles (EVs). In this process, the powertrain motors generate braking force, which reverses the current flow and recharges the battery during deceleration.

Steer-by-wire

Steer-by-wire systems remove the mechanical steering column that directly links the steering wheel to the wheels. Electronic sensors detect steering inputs and transmit them to actuators that adjust wheel angle. This architecture simplifies the integration of advanced functions such as lane-keeping assistance, collision avoidance, and variable steering ratios, while supporting the next generation of autonomous vehicles. Furthermore, steer-by-wire technology helps to resolve packaging problems, supporting the easier implementation of in-wheel motors (which are difficult to connect to a typical steering rack), and allows for novel vehicle interiors by freeing up the area previously occupied by the steering column.

Historically, the complexity and cost of these systems kept them mechanical. However, the advent of vehicle automation, electrification, and advanced sensing and actuation technologies has removed many barriers – positioning brake-by-wire and steer-by-wire as key enablers for the next generation of EVs.

Emissions reduction

Hydraulic systems are affected by fluid contamination and leakage; therefore, they require regular maintenance and fluid replacement to ensure safe operation. Brake-by-wire and steer-by-wire in combination with the implementation of purely electromechanical actuators, allow the complete removal of hydraulic systems. This represents a new paradigm in the car industry and enables “dry” braking and steering systems, which reduce the amount of fluids in the car, eliminating the associated emissions and maintenance requirements.

There is also an additional dimension to worldwide emissions. With the implementation of emissions regulations and the introduction of EVs, the exhaust emissions of fine particulate matter PM10 and PM2.5 (smaller than 10μm and 2.5μm, respectively) have sig-

[1] https://www.heritageconcorde.com/fly-by-wire
[2] https://www.pistonheads.com/news/ph-features/ph-origins-electronic-throttle-control/38098

nificantly dropped in the last two decades.

However, the emissions due to brake and tire wear have slowly but continuously increased, and they have become the main source for vehicle particulate matter emissions. Figure 1 shows an estimation from the Air Quality Expert Group of the evolution of fine dust emissions (PM10) in the United Kingdom from 2000 to 2030 [2].

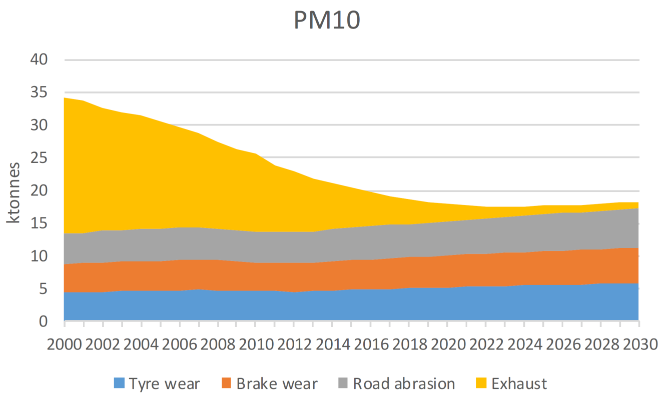


Figure 1 – UK emissions of PM10 from road transport (Source: Air Quality Expert Group UK [2])

The current emission rates require improvement, as the latest Euro 7 regulation has introduced constraints to the brake particle emissions and aims to define limitations for tire abrasion [1].

Brake-by-wire technology can provide a faster application and release of braking torque, which, in combination with precise speed sensors and automotive intelligence, enables the minimization of brake and tire wear emissions in several ways. These include maximizing regenerative braking, optimizing braking torque to reduce tire wear, and avoiding the concurrent application of throttle and brakes due to brake release lag.

Sensor Requirements

In safety-critical systems, electronic components must adhere to several essential technical requirements. These components need to feature inherent precision, reliability, and the ability to withstand the challenging conditions found in vehicles, such as vibration, temperature fluctuations, and electromagnetic interference (EMI). Moreover, the sensors must be simple to integrate and able to work alongside other sensor types, as heterogeneous redundancy is a core element of the functional safety architecture that governs by-wire systems and ensures failsafe operation [4].

In comparison to a conventional braking system, a brake-by-wire system requires both more areas of sensing and higher redundancy at each point in the system, as it lacks the mechanical backup (Figure 2). To guarantee safe operation, it is common to deploy several sensing channels, making sensor integration and flexibility a key design consideration for engineers. System control and feedback are gathered through brake pedal position and force sensors, along with additional sensors installed on the calipers and brake fluid circuits. Due to the temperature ranges, vibration, and EMI associated with these areas of a vehicle, sensor accuracy and reliability are key at each point in the system, demanding the deployment of redundant high-quality sensors.

In a steer-by-wire system, supplementary sensors are necessary to track the position of the rack and verify that the movement aligns with the indicated demand from the steering angle sensor (Figure 4). Once again, reliability is crucial, and multiple sensing technologies must be deployed to enable heterogeneous redundant system operation.

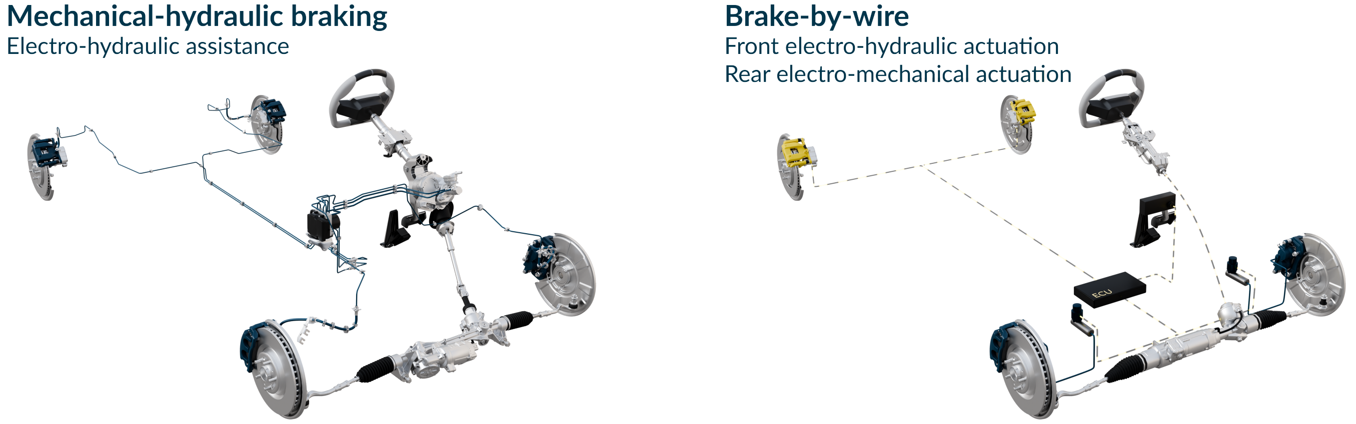


Figure 2 – Evolution from mechanical-hydraulic to brake-by-wire braking systems (Source: Melexis)

Melexis Sensors for By-Wire Systems

With a longstanding association with the automotive industry, Melexis has supplied a wide range of sensing technologies across multiple vehicle systems. Its current portfolio includes advanced magnetic and inductive sensors developed specifically for next-generation by-wire systems.

Magnetic Sensors

Melexis magnetic sensors such as the MLX90423, MLX90424, and MLX90427 leverage Melexis proprietary Triaxis® technology, designed for demanding brake-by-wire and steer-by-wire applications. Unlike conventional Hall sensors, which detect only the magnetic flux density perpendicular to the Hall element, Triaxis® sensors detect all three magnetic flux components using an integrated magnetic concentrator (IMC). This technology enables the sensor to accurately decode the absolute position of any moving magnet, whether it is moving in a rotary or linear displacement (Figure 3).

Triaxis® sensors such as the MLX90423 and MLX90427 are ISO 26262 ASIL-C qualified [4] and can withstand stray fields up to 5mT, which makes them an excellent choice for EVs or systems in close proximity to other magnetic or inductive sensors. They are also available in TSSOP-16 Dual-Die packaging, providing additional built-in redundancy and enabling the implementation of ASIL-D systems. A product like the MLX90424 integrates two Triaxis® MLX90423 sensors and one MLX92292 low-power latch and switch wake-up sensor in a single package, providing the ultimate sensing solution for brake-by-wire applications.

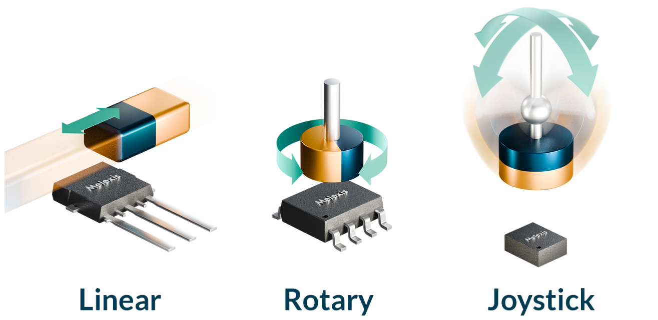


Figure 3 – Triaxis® solutions can be used to detect linear, rotational or "joystick" movement (Source: Melexis)

Beyond the sensing elements, the Triaxis® ICs provide a number of key features designed to further simplify the development of advanced by-wire systems. The multiple output modes (Analog, SPI, PWM and SENT, including SPC capability) in ICs such as the MLX90377 and MLX90376, support applications with a multi-sensor bus architecture and ensure compatibility with different system configurations, enabling smooth integration into various automotive platforms.

Furthermore, by including a gateway (input pin) in ICs such as the MLX90372, the sensor can measure external signals from sources like pressure sensors, force-sensitive resistors, or NTC temperature sensors. This feature enhances integration possibilities, reducing wire count and simplifying system design.

Figure 4 – Evolution from mechanical to steer-by-wire steering systems (Source: Melexis)

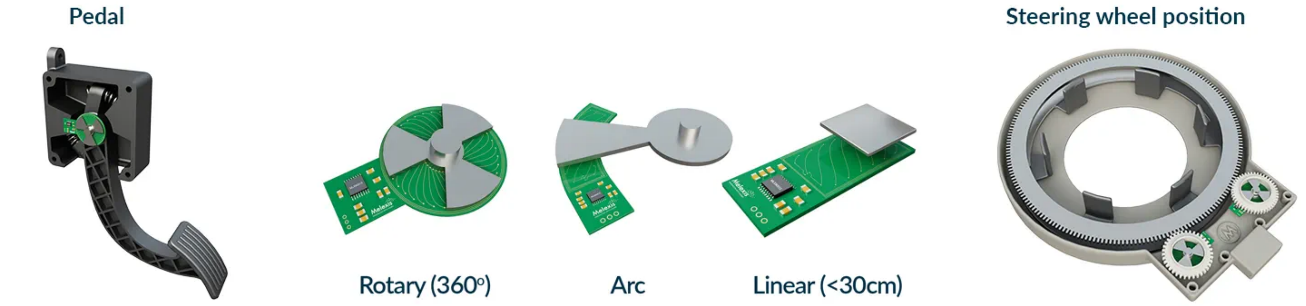


Figure 5 – MLX90513 three movement types (central) accompanied by a brake-by-wire pedal (left) and a steering wheel position application (right) (Source: Melexis)

Inductive Sensors

Alongside its innovative magnetic sensing ICs, Melexis offers a range of inductive solutions, such as the MLX90513, that are immune to magnetic stray fields (ISO 11452-8 [3]), enabling deployment in environments with high EMI and combination with magnetic sensors such as the MLX90423 or MLX90427. This makes them ideal for the heterogeneous setups required in safety-critical by-wire systems.

Designed for automotive and industrial applications, drawing on more than 15 years of inductive sensors experience at Melexis, the MLX90513 is a robust interface for sensing absolute rotary and linear motion or position (Figure 5). The device operates using inductive coupling between a transmitting coil, the metallic target (rotor), and three receiver coils. When the on-chip LC oscillator generates an electromagnetic field through the transmitting coil, it induces a rotor-angle-dependent voltage in the three receiving coils.

The MLX90513's internal signal processing units capture and process the three signals, delivering precise positional information with a maximum error of $\pm 0.1\%$ full scale. The receiving coils are positioned relative to each other according to the number of poles on the rotor. Typically, these coils are implemented as tracks on a printed circuit board, allowing for simple custom design and elegant integration into brake-by-wire and steer-by-wire systems.

Similar to its magnetic counterparts, the MLX90513 is ISO 26262 ASIL-C qualified [4] and offers four output modes (SENT/SPC, PWM and Analog) to support multi-sensor bus setups and integrate easily into automotive platforms.

Conclusion

The automotive landscape is undergoing a profound transformation, with steer-by-wire and brake-by-wire technologies emerging as cornerstones for the next generation of vehicles. These safety-critical systems offer distinct advantages over traditional mechanical and hydraulic setups, enabling enhanced functionality, superior control, and significant progress towards a more sustainable, clean, and intelligent mobility future.

However, the successful implementation of these advanced systems relies on highly precise, reliable, and intelligently integrated sensing solutions. This is where Melexis excels with a portfolio of cutting-edge, robust Triaxis® magnetic sensors and stray-field-immune inductive sensors, specifically engineered to meet the stringent demands of automotive by-wire applications. Melexis sensors deliver exceptional precision, a wide operational temperature range (40°C to 160°C), and outstanding immunity to electromagnetic interference and stray fields, ensuring reliable performance in the most challenging automotive environments.

Beyond their technical capabilities, Melexis solutions are designed to simplify complex system architectures through features such as built-in redundancy (e.g., TSSOP-16 Dual-Die packaging for ASIL-D systems), multiple output modes (Analog, SPI, PWM, SENT, SPC), and the ability to integrate external signals via input pins. This holistic approach empowers automotive OEMs and Tier 1s to streamline development cycles and reduce overall system complexity and cost.

As the industry accelerates towards electrification and higher levels of autonomous driving, the functionality and safety provided by advanced by-wire systems will be paramount to winning consumer confidence. High-quality position sensors are not merely components – they are critical enablers that support the safety, performance, and innovative design of the vehicles of tomorrow.

References

[1] *Euro 7 REGULATION (EU) 2024/1257*. European Union, May 2024. URL: https://eur-lex.europa.eu/eli/reg/2024/1257/oj.

[2] Air Quality Expert Group. *Non-Exhaust Emissions from Road Traffic*. Tech. rep. PB14581. United Kingdom: Department for Environment, Food and Rural Affairs et al., July 2019. URL: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf.

[3] *ISO 11451 Vehicle electromagnetic immunity*. International Organization for Standardization (ISO), June 2025. URL: https://www.iso.org/publication/PUB200114.html.

[4] *ISO 26262 Road vehicles functional safety*. International Organization for Standardization (ISO), Dec. 2018. URL: https://www.iso.org/publication/PUB200262.html.

[5] *SAE J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*. Society of Automobile Engineers (SAE), Apr. 2021. DOI: https://doi.org/10.4271/J3016_202104. URL: https://www.sae.org/standards/content/j3016_202104.