Harsh automotive environments call for Hall effect position sensing

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Magnetism is a powerful force that enables a wide range of technologies, making a huge difference in the world; for example, without magnetism there would be no electric motors. One area where the properties of magnetism are fully exploitable is contactless position sensing. As all sectors continue along the march to modernisation, automation and electrification, contactless position sensors are a reliable and versatile approach to control, making this technology extremely influential in our world today.

Contactless position sensing is particularly beneficial in industrial and automotive applications, where the control mechanisms used can be exposed to repetitive actions under harsh conditions. Of the many ways to implement contactless sensing, the Hall effect has established itself and is now a well-understood practice. By coupling this proven principle to advanced integrated circuitry, it is possible to develop sophisticated sensing solutions that meet the needs of a wide array of applications.

Hall effect in demanding settings

Whilst at its core the Hall effect is robust, in order to develop a practical implementation of it, it's important to understand and control all the factors that may cause perturbations. This includes ambient temperature variations, the potential influence of any local parasitic magnetic fields, and sources of vibration.

As shown in Figure 1, Hall-effect sensors are now found in many applications in and around a vehicle. This includes under the hood, where conditions can be most demanding, as well as in the vehicle's cabin. Powertrain and chassis applications face challenges from the harsh operating environment, where high temperatures and external contamination like saltwater and dirt are common. Such environments are highly tasking on any sensor, which not only face space and orientation constraints but must also comply with the most stringent requirements in terms of reliability and electromagnetic compatibility, whilst doing the required job.

Inside the Hall-effect sensor

The Hall effect describes the disturbance to the flow of charge carriers in a conductor, caused by the presence of a magnetic field perpendicular to its base. The redistribution results in a potential difference across the conducting material, known as the Hall voltage, which can be detected.

The potential difference is proportional to the orientation and strength of the magnetic field; it is this change that enables the Hall voltage to be used in sensing applications. The effect is reliable and, under the right conditions, predictable. This means that the theory can be applied in any application involving the relative movement between two objects, by equipping one with a magnet and the other with a Hall sensor IC.

Whilst a standard planar Hall element can only sense the field perceived in its Z axis, the use of proprietary hardware and advanced algorithms can render three-dimensional measurements, useful in almost any orientation; see Figure 3. Incorporating this technology with one or

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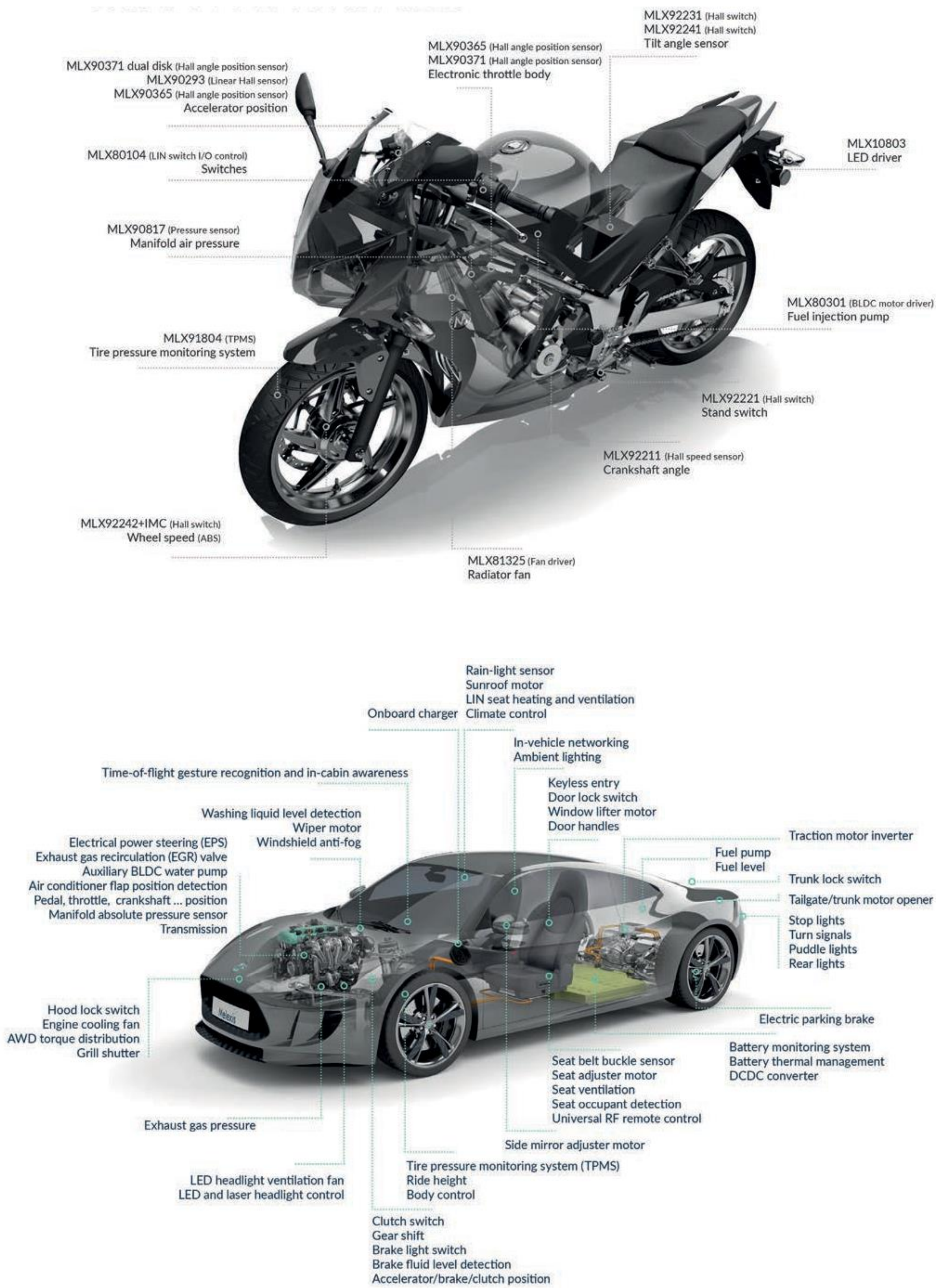

Figure 1: Position sensing is fundamental to modern motorcycles and automobiles

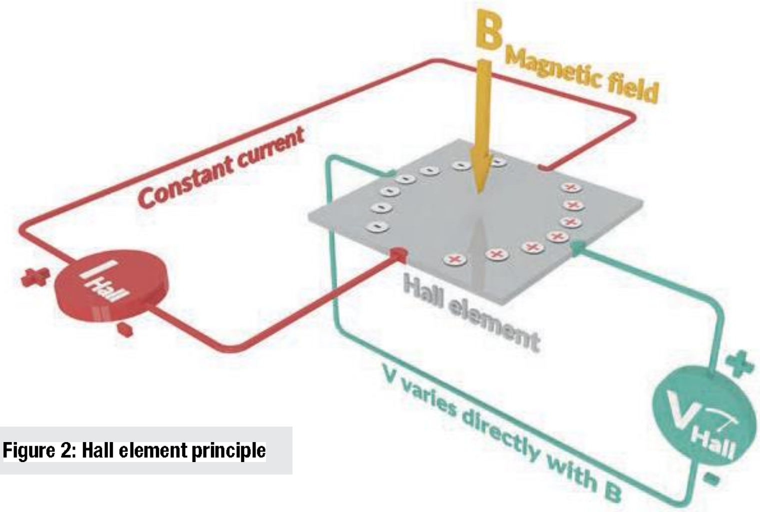

Figure 2: Hall element principle

more Hall elements has resulted in Melexis's Triaxis technology.

This three-axes measurement is enabled by the Integrated Magnetic Concentrator, or IMC. Developed by Melexis, the IMC enables a Hall effect sensor to simultaneously determine flux field strengths flowing in the X, Y and Z axes. The IMC bends the field lines of the X and Y directions, such that the planar Hall element can perceive and measure those fields. It is therefore possible to sense the three magnetic flux components B_x, B_y and B_z with planar Hall elements.

The signal chain for a Hall-effect sensor will typically include a programmable element that applies compensation and linearisation based on the application; some solutions now integrate these elements into a single device. For rotary sensors such as those attached to motors, the output may be an encoded representation of the angle. For other sensors, the output may simply be a basic measurement for post-processing by a host device. What is important in all cases is the ability to tune the solution.

To develop a useful signal, the first stage is the Triaxis sensing element, formed through coupling the Hall element (see Figure 3, left) with the IMC (Figure 3, centre). Together, this translates the absolute position of a magnet – moving linearly or through angular rotation – into a very low Hall voltage, around several µV.

As the sensing element responds to magnetic flux density in three axes, converting it to a single voltage creates what we can now consider our "signal".

The signal at this level is weak and can easily be confused with noise and other parasitic elements. To make the signal useful, it is fed into an amplifying stage (Figure 4), subsequently to be adapted and scaled to the application. Through this signal chain, a stronger and more robust signal is generated.

It should be noted that this step is crucial and must meet the application's requirements regarding the minimum and maximum fields that can be perceived by the sensor IC. If the signal is too small or too large at the source, it would likely be outside the functional limits of the amplifying stage.

Going further, the amplified signal now forms the input to the analogue-to-digital converter (ADC) stage, where it goes into the digital domain, allowing the signal to be further tuned for the application.

From here, the digital representation of the sensor's output passes to the digital signal processor (DSP), running algorithms stored in the on-chip memory. This allows further processing, such as linearisation and temperature compensation. The DSP can also perform digital filtering to remove the effects of system noise, as well as process diagnostic results.

Digital signal processing

Digital signal processing is a critical technology in this regard, since it allows complex algorithms to become part of the overall system. Deeply embedded within the sensor chip itself, it makes it much simpler to develop robust sensing solutions that are stable under all predicted operating conditions and with excellent linearity. Whilst digital signal processing can introduce some latency, it is useful in the majority of applications, so it should to be included at some point in the overall signal chain. However, for those that do not require this feature, options are also available without it to avoid any associated processing latencies.

The inclusion of DSP technology allows digital filtering to be applied at the source, whilst still offering a step response time of around 500µs to 2ms. Further benefits of an integrated DSP include non-linear compensation, a primary method for tuning a sensor to a specific application. It also enables the sensing element to be calibrated to match the characteristics of the magnet; this is a powerful and valuable feature, as it allows the use of virtually any type of magnet, from a variety of shapes to different chemistries such as ferrite or rare earth magnets.

Essentially, calibration involves taking a series of measurements at a number of points on the possible excursions for a position

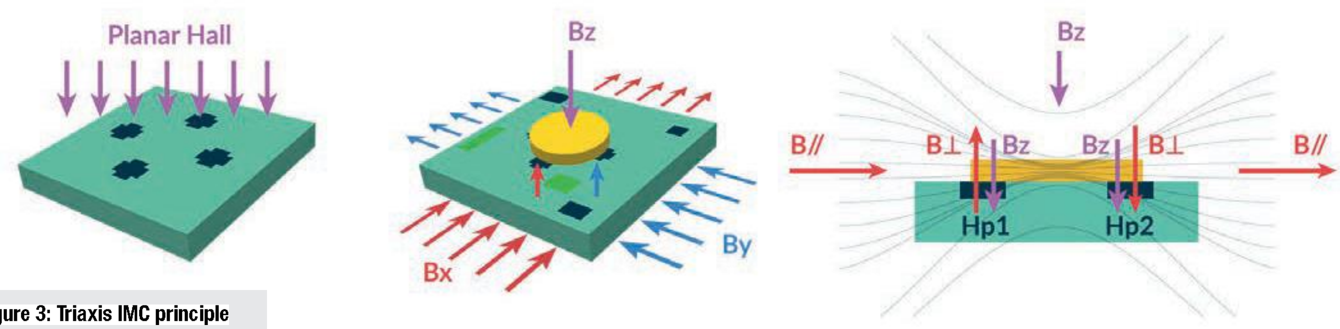

Figure 3: Triaxis IMC principle

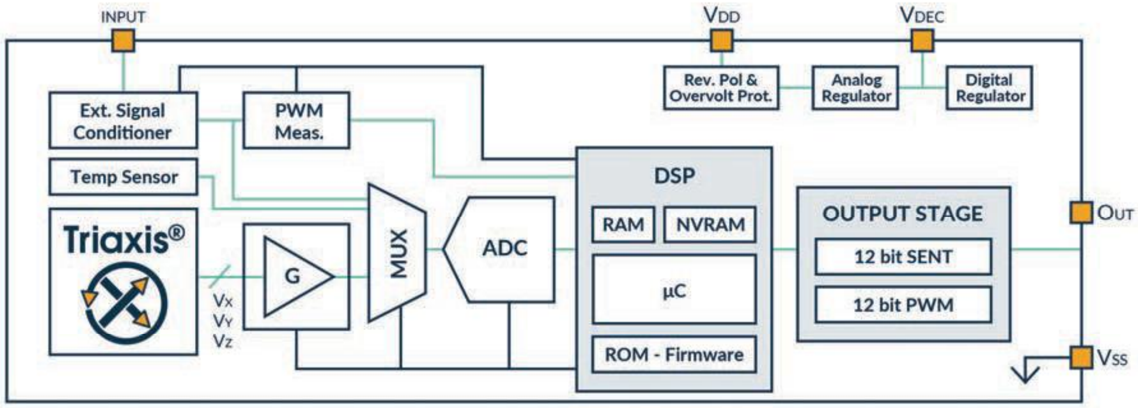

Figure 4: Example of functional block diagram of a magnetic sensor, the Melexis MLX90372, a Triaxis Hall-effect position sensor

sensor, and using these to interpolate the output of the sensor for any possible position. As the operation of a Hall sensor is dependent on the magnet and mechanical setup, the output is unlikely to be linear in nature. By building a profile of the application, the sensor signal chain can compensate for these non-linearities in the output that comes from mechanical errors like misalignment of the magnet.

Back at our sensor, finally, the output stage formats the signal into the required protocol.

The way these sensors interface to the rest of the system is also evolving with the support for industry standard protocols such as SENT (SAE J2716) and PSI5, as well as generic formats such as PWM, SPI, I^2C or analogue voltage.

Fit for harsh environment

On top of enabling a measurement in three axes with only one integrated circuit (IC), another major benefit of the Triaxis is that it allows smaller and lower cost magnets to be used, which can be mounted in almost any orientation.

The addition of the IMC delivers high accuracy even when using low-cost magnets, as it allows the sensor to be less sensitive to unwanted artefacts such as variations in flux density strength that can result from temperature changes, proximity and even mechanical wear. These benefits extend to the output transfer characteristics, through linearity compensation using multi-point or multi-segment calibration. This can be carried out after production, allowing assembly errors to be corrected, such as tilt, off-axis or magnetic strength variation.

New challenges

Challenges to Hall effect sensing such as stray field immunity, the package and functional safety are also addressed, as follows:

The IMC technology provides greater immunity to stray magnetic fields, per the ISO 11452-8 specification (up to 4kA/m or 5mT). This feature allows sensors to be tuned to specific applications in accordance with the working environment.

As vehicles become increasingly electrified, the potential for stray fields increases. Any inductive load will generate a parasitic magnetic field, but so too can the increasingly high electrical currents and voltages used in hybrid and full-electric powertrains. This only puts more pressure on sensor manufacturers to add greater levels of stray-field immunity.

When it comes to packaging, many manufacturers are now looking to integrate as much as possible into a single device. This reduces the amount of peripheral components required by the sensors, partly due to the need to fulfill specific EMC requirements. For example, an electrically-adjusted seat with three motors may require as many as nine sensors, positioned close to the motors. Each sensor would typically require its own printed circuit board, along with connectors and passive components such as capacitors, all of which take up valuable space. Adopting sensors that integrate the necessary passive components and are supplied in packages that support PCB-less mounting can drastically reduce the space required to add position sensors, as well as simplify the manufacturing process.

When it comes to functional safety, ISO26262 is the latest standard to support the development for safety-critical automotive applications.

As automotive and industrial systems become more autonomous and automated, sensing is a key enabler. EW

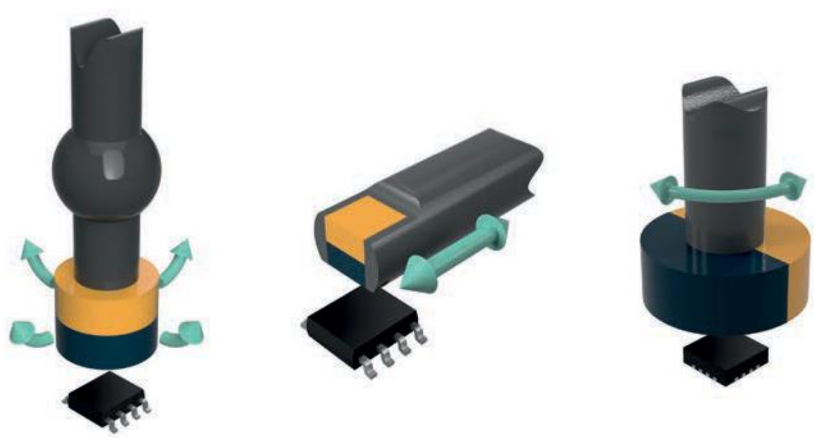

Figure 5: Illustration of the flexibility offered by Triaxis