

Hall Effect Position Sensors and Their Use in Automotive Applications

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The demand for compact, accurate position sensors in automotive applications is projected to grow substantially to \$1.6bn by 2026. This growth is largely being driven by electrification (Figure 1), not only of the traction system but also of auxiliary functions such as power steering and the clutch. As the number of applications for motors in automobiles continues to grow, it is necessary to have some way to accurately track the position and speed of the rotors they contain.

In this white paper, we review legacy approaches to how proximity and position detection was performed, and the drawbacks associated with them. We consider the operation and advantages of using magnetic proximity and position sensors based on the Hall effect for this purpose and explain some of the factors which have limited their use in automotive applications to date.

Finally, we present a series of Hall sensor switches/latches that have been specially designed to enable automotive systems to achieve the highest levels of automotive safety certification – ISO 26262.



Figure 1: ELECTRIFICATION OF AUTOMOBILES IS DRIVING THE DEMAND FOR POSITION AND PROXIMITY SENSORS





The Hall Effect

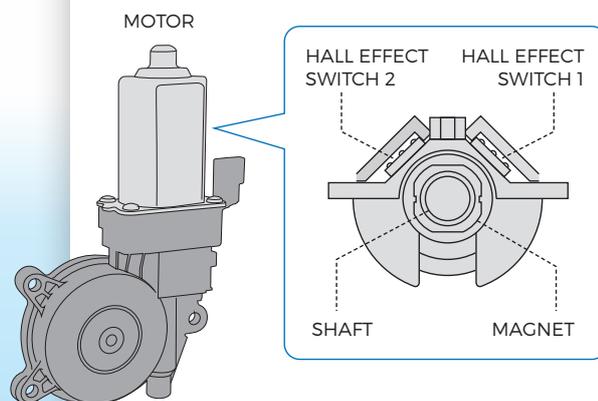
The Hall effect, named after American physicist Edwin Hall (who discovered it in 1879), is the potential difference (voltage) that occurs across a current-carrying conductor when a magnetic field is applied perpendicular to the current.

The size of the voltage depends on the material from which the conductor is made, the current flow, and the strength of the magnetic field. The Hall effect is well understood, and mathematical models are readily available for use in the design of magnetic detection switches and position sensors.

A Hall effect sensor typically includes one or more embedded magnetic elements. When an external magnetic field comes into the proximity of the sensor, it alters the polarity and strength of the embedded magnetic field. As the magnetic field changes, so does the potential difference across the sensor, enabling it to detect the presence of the external magnetic field. This is used in simple magnetic switches to detect the opening and closing of a window or door, for example (Figure 2):

These applications require a Hall effect sensor and a magnet on either side of the locking mechanism.

Figure 2: HALL EFFECT SENSORS CONTROLLING A MOTOR TO OPEN/CLOSE A CAR WINDOW



Over time, Hall effect sensor technology has evolved to enable extremely precise and accurate measurement of linear and rotary positioning in a multitude of applications.

A rotary position sensing application may be implemented using a simple assembly that consists of a fixed sensor board mounted perpendicular to a rotating magnet mounted on-axis on the shaft of the rotor.

Magnetic position sensors are small, light, and lower cost than alternative sensor technologies. Device manufacturers have developed the capability to produce Hall effect magnetic sensors in an integrated circuit (IC) on a standard complementary metal-oxide semiconductor (CMOS) fabrication process. These allow Hall sensors to be manufactured cost effectively in high volumes. To fully appreciate the benefits of using magnetic encoders for proximity and sensing applications, it is first useful to understand how these functions were performed in legacy applications. The three most widely used technologies were potentiometers, optical encoders, and resolvers.

A potentiometer uses a physical contacting method to measure rotary motion and consists of a resistive element, a sliding contact (wiper) that moves along the element, electrical terminals at each end of the element, and a rotor mechanism that moves the wiper from one end of the element to the other. As the wiper moves along the element, the resistance of the element changes. By measuring this resistance change, the potentiometer can be used to measure position. However, because the potentiometer involves physical contact, it is subject to mechanical wear and tear caused by friction and its performance can be affected by shock or vibration. In addition, contamination of the resistive element by foreign substances, such as dirt, dust, moisture, or grease, can impair performance and even cause premature failure. Carefully designed housings can be used to seal the potentiometer and prevent contamination, but these make the sensor more expensive.

In contrast with potentiometers, magnetic sensing technology does not require bulky and expensive housing because it is contactless and therefore less vulnerable to such contamination. As a result, magnetic sensor systems tend to be smaller, more economical, and more reliable than potentiometers, which have fallen out of favor in many automotive applications.

Optical encoders measure position by detecting alternating areas of light and dark as a disk with cut-out holes (often referred to as a code-wheel) rotates between an LED light source and a photodiode sensor. The alternate pulses of light and dark allow the rotor position to be accurately measured even at high speeds. Like magnetic sensors, optical encoders are also contactless meaning they do not suffer the effects of mechanical wear and tear. However, they are vulnerable to contamination, which can interfere with the light source and detector. For automotive applications, where reliability is important, this can be a cause for concern. Furthermore, optical systems are bulky and must be assembled precisely to have very low tolerances.

A resolver can also measure position accurately at high rotational speeds, however, their large size and heavy weight increase cost in automotive applications. Hall effect magnetic sensors are popular in consumer and industrial applications due to their long life, small size, and low cost. These features make them appealing for use in automotive applications, but commodity versions of these devices are unsuitable for use in the demanding operating conditions experienced in vehicles.

Automotive Requirements for the Use of Hall Switches

Using electronic rather than mechanical or hydraulic actuation of control functions such as steering and gear change improves performance, increases reliability, and reduces size and weight.

Automotive applications for Hall sensor technology in which these attributes are particularly important include:

- Motor position in electric power steering
- Chassis position
- Motor position in dual-clutch transmission
- Traction motor position in hybrid electric and fully electric vehicles
- Steering angle

In these applications, the Hall effect magnetic sensor has become the dominant technology. The lower weight of a Hall sensor solution also assists car manufacturers in their efforts to reduce fuel consumption while the smaller size improves mechanical design flexibility. High volume CMOS production also helps to lower costs compared to alternative technologies such as the resolver.

While the appeal of using Hall effect magnetic sensor technology in the design of automotive applications is obvious, the automotive industry has specific requirements in relation to quality, reliability, and safety for safety-critical functions, which prohibit the use of the commodity and general-purpose Hall effect sensors.

These cover the areas of:

- **Quality:** Exacting requirements for repeatability, traceability, and production quality are specified in safety certifications and in the Automotive Engineering Council's series of standards. These apply not just to individual components but also to the complete sensor system assembly.
- **Reliability:** Devices used in critical automotive applications are expected to operate in a wider temperature range than that expected for consumer or industrial devices and are also specified to operate over a minimum lifetime of ten years.
- **Safety:** ISO 26262 functional safety standard (which applies to electronics systems in vehicles) has significantly increased the focus of OEMs on safety in the design and performance of electronic systems, including that of position sensing systems that use Hall effect devices.

Under each of these headings, general-purpose Hall sensors do not conform to the automotive sector's typical performance specifications meaning they could potentially expose automotive OEMs to an elevated risk of failure. Some magnetic position sensors installed in production vehicles have presented reliability issues and safety concerns for vehicle manufacturers, with the main cause of problems being external magnetic interference. A Hall effect sensor operates by detecting and measuring changes in the magnetic field induced at the surface of the sensor IC by the movement of a small, weak magnet in its immediate proximity. In an electrically quiet operating environment (free from the influence of external electrical and magnetic fields), the voltage signal generated by changes in the magnetic field of the IC is due only to the movement of the paired magnet. However, automobiles are very electrically noisy environments with many stray magnetic fields that can interfere with the operation of a magnetic sensor. Components such as motors, solenoids, and high-voltage cables generate strong magnetic fields, and if these operate close to a sensor, they can distort the signal sensed by the IC. This can lead to measurement errors and negatively impact the accuracy of the sensor's position readings. In an EV traction motor, for example, this could lead to a severe reduction in or even complete loss of torque or unpredictable wheel rotation.

The use of magnetic sensors in automotive motors has also put an increased focus on the repeatability of the assembly construction in production. All Hall effect position sensors measure position relative to a paired magnet. In a motor, for example, the paired magnet mounted on the shaft of the motor rotates relative to a static sensor.



Each sensor will have a specified tolerance for the variation in the air gap between the sensor and the magnet, and for any misalignment between the center point of the magnet and the center point of the sensor. Some automotive manufacturers have faced production quality problems due to a mismatch between the assembly tolerance achievable in a production setting and the tolerance specified by the sensor IC. The use of magnetic position sensors has also been reviewed following the adoption of the ISO 26262 functional safety standard.

Compliance with ISO 26262 requires a rigorous *Failure Modes Effects and Diagnostic Analysis* (FMEDA) to be performed at the system level,

and for adequate safety countermeasures to be put in place to combat the risks associated with known failure mechanisms. In magnetic sensor-based position measurement systems, this FMEDA highlights the requirement to guarantee fault detection in the sensor, and for integrated safety procedures that can ensure continued operation or safe shutdown if a fault is detected. Commodity magnetic position sensors do not have the diagnostic, monitoring, and fail-safe features required to guarantee system safety in the event of a device failure. They are also not supported by ISO 26262-compliant development, and production processes and documentation.

Hall Effect Switches/Latches by Diodes Incorporated

The AH32xxQ series of Hall unipolar switches and latches by Diodes Incorporated are based on an advanced design that enables automotive manufacturers to achieve ISO 26262 compliance for their position and proximity sensing systems. Some of the main features of this family of devices (Table 1) include:

- Automotive-compliant with AEC-Q100 qualification, manufactured in IATF 16949 certified sites, and supporting PPAP documentation
- Integrated diagnostics (AH324xQ/328xQ) to support ISO 26262 ASIL-compliant systems
- High sensitivity (AH3270Q/71Q and AH3280Q/81Q)
- Wide operating voltage range
- Chopper stabilized for accuracy and stable B_{OP}/B_{RP}
- High 8kV ESD withstand capability for robustness & reliability

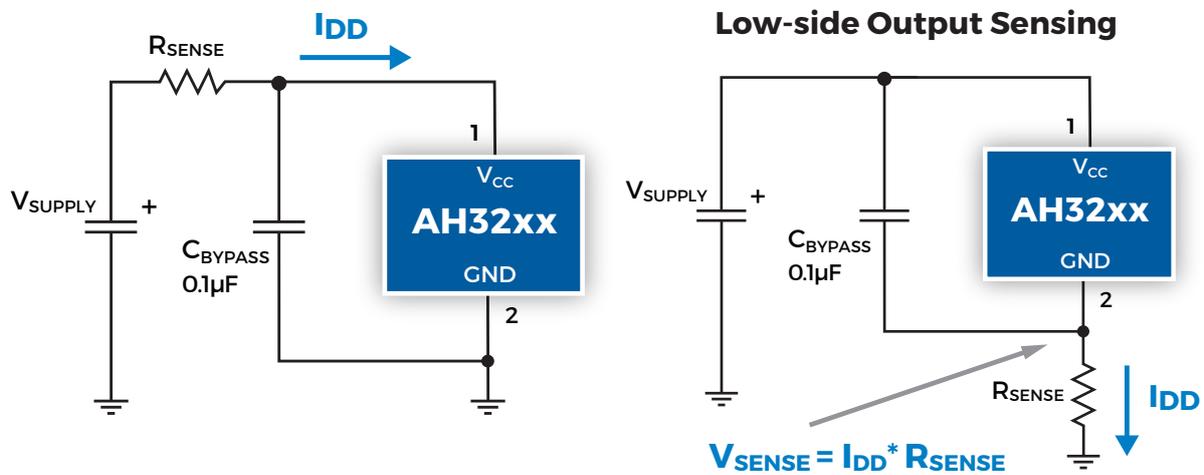
Table 1: SUMMARY OF FEATURES IN THE AH32XX FAMILY OF HALL SWITCHES/LATCHES BY DIODES INCORPORATED

Part Number		Active Pole	Type	Operating Voltage (V)	Supply Current		Operating Point B _{OP} (Gauss)			Release Point B _{RP} (Gauss)			Ambient Temp °C	Packages
No Diagnostics	Built-in Diagnostics (Support for ISO 26262)				"On" (mA)	"Off" (mA)	Min	Typ	Max	Min	Typ	Max		
AH3270Q	AH3280Q	Direct South	Latch	2.7 to 27	14.5	3.3	3	18	33	-33	-18	-3	-40 to +150	SC59, SIP3
AH3271Q	AH3281Q	Direct South	Latch	2.7 to 27	14.5	6	3	18	33	-33	-18	-3		
AH3272Q	AH3282Q	Direct South	Latch	2.7 to 27	14.5	3.3	10	30	50	-50	-30	-10		
AH3231Q	AH3241Q	Inverted South	Unipolar	2.7 to 27	14.5	6	55	90	135	35	70	115		
AH3232Q	AH3242Q	Direct South	Unipolar	2.7 to 27	14.5	6	30	60	90	10	40	70		
AH3233Q	AH3243Q	Direct South	Unipolar	2.7 to 27	14.5	6	20	45	70	3	28	53		
AH3234Q	AH3244Q	Inverted South	Unipolar	2.7 to 27	14.5	6	20	45	70	3	28	53		

The fact that these sensor ICs require only two wires for operation helps to reduce overall system cost, especially when the wire harness is long length. Unlike most Hall effect sensor switches that have a voltage output, these provide a current output which is

more resilient than voltage in the presence of noise spikes (Figure 3). The devices in the series also have a wider operating voltage range (2.7V to 27V) and are supplied in the industry-standard SC59 and SIP-3 packages.

Figure 3: A CURRENT OUTPUT IS MORE RESILIENT THAN VOLTAGE IN THE PRESENCE OF NOISE SPIKES



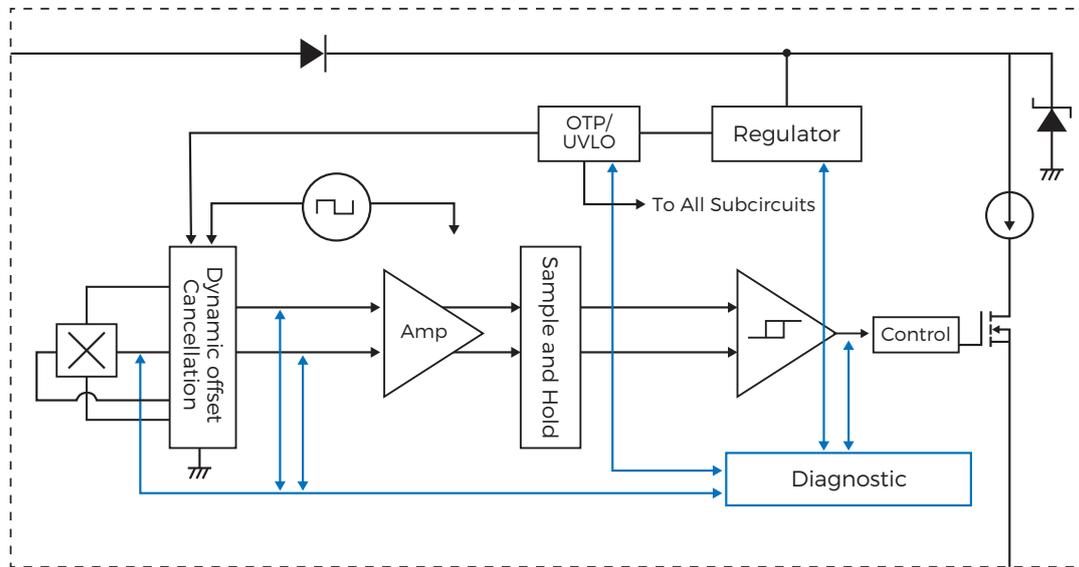
The AH324xQ and AH328xQ also include integrated self-diagnostic functions that make them well suited for use in systems requiring high levels of functional safety (Figure 4).

These self-diagnostic features operate automatically in the background without the need for external activation. If an error is detected, the device enters a “safe mode” of operation where the output (supply) current drops to 1mA, thereby acting as a warning flag to the system.

The integrated self-diagnostics monitor the following device characteristics:

- V_{DD} undervoltage
- Overtemperature
- Self-test of major functional blocks

Figure 4: FUNCTIONAL DIAGRAM OF THE AH324XQ/AH328XQ SHOWING SELF-DIAGNOSTIC FEATURES



Conclusion

Vehicle electrification is a major driver behind the growth in the number of motors in automobiles, which in turn is creating the requirement for a small, lightweight, reliable, and low-cost sensor to track their speed and position.

Magnetic position and proximity sensors based on the Hall effect offer such a solution, but commodity versions are unsuitable for use in automotive applications because they do not allow position sensing systems to meet safety critical standards like ISO 26262.

The AH32xx range of Hall switches/latches by Diodes Incorporated has been specially designed to have a wide operating voltage range to increase their sensitivity and current output signaling to improve robustness in the presence of voltage spikes.

Some members of this family also include self-diagnostic features that enable sensor subsystems to achieve the safety certifications required for their use in automotive applications.