6.3 Principles of Operation of Integrated Hall ICs

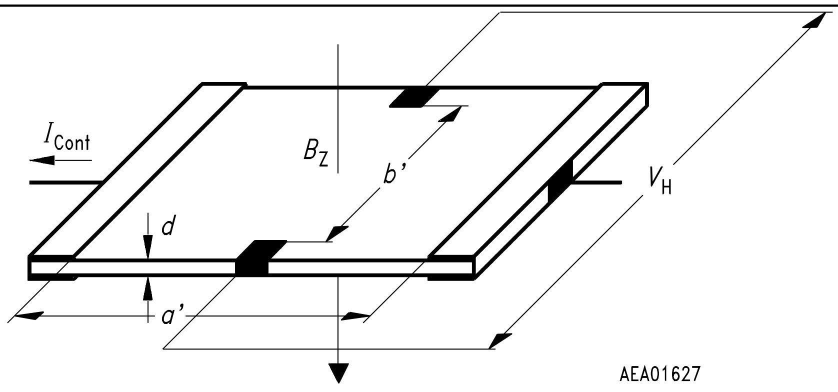
Automotive manufacturers and industry in general are placing ever increasing demands on accurate sensor systems for wheel speed sensing systems, engine and transmission management as well as power steering. In addition such systems are also required for onboard instrumentation, fuel consumption and for the accurate calculation of any kind of positional and rotational position sensing.

Contactless, magnetically actuated Integrated Hall Effect Circuits are subject to stringent performance and reliability requirements in automotive applications. The Hall Effect Sensor is virtually immune to environmental contaminants and is suitable for use under severe conditions. The IC is very sensitive and provides a reliable, reproducible operation in close tolerance applications with temperatures in excess of 150 °C.

Silicon Hall Effect ICs have found increasing use in the past ten years. By using standard bipolar IC technologies it is possible to create and process integrated Hall Effect Sensors resulting in very cost effective solutions to a wide variety of sensing tasks.

Solid State Hall Effect Sensors

The integrated Hall Effect Sensor is based on the Hall effect, named after its discoverer Edwin Hall in 1879. A Hall element (a square shaped semiconductor layer, for example) is supplied by a constant current. When applying a magnetic field perpendicular to the current flow, the charge carriers are deflected due to the Lorentz force. This deflection can be measured as the so-called Hall voltage, which is perpendicular to both the magnetic field and the current flow. The Hall voltage is directly proportional to the magnetic field (**figure 28**).



I_{Cont} = control current
B_Z = magnetic induction
d = thickness of the conductor lamina
R_H = material constant (Hall constant)
V_H = $R_H \times I_{Cont} \times B_Z / d$

Figure 28

Hall Effect Principle

Silicon Hall Effect IC Sensors have experienced a rapidly growing demand in the past years. Merging the silicon based monolithic Hall element with standard bipolar IC fabrication and assembly technologies allows the development and production of small and reliable Hall ICs in large volumes at competitive prices, resulting in attractive solutions for many sensing applications.

Signal Processing

There are three basic configurations for integrated signal processing of magnetic sensors:

- Linear Hall ICs with analog output
- Switching Hall ICs with digital output
- Switching Hall ICs with digital output using two Hall elements in a differential configuration

All these configurations share some basic circuitry. One of the most important components is the differential amplifier. The signal levels of silicon based Hall elements are very low. By using a low noise, high impedance differential amplifier (OTA), the basic signal is amplified and adapted for further processing. Another important feature is the Hall voltage generator that provides a constant supply current to the Hall element.

Additional circuit cells for protection purposes are required. Clamping structures protect input and output against overvoltages. These structures consist of arrays of zener diodes that cut voltage peaks. Diodes at the input and output protect against accidental polarity reversal. Finally, EMI structures minimize the influence of electromagnetic radiation. All the forementioned protection structures are integrated on-chip.

Packaging

One important benefit of Integrated Hall Effect Sensors is their small size. This allows for new concepts in sensing applications such as the integration of the sensor into sealed bearings (in-bearing sensor). The operating temperature range of Siemens Hall Effect Sensors is – 40 … + 150 °C junction temperature, but temperatures of + 170 °C, for some of the ICs even up to + 210 °C, are possible.

An important aspect for the package is the thickness. A thin package where the IC surface is close to the package surface increases the usable working air gap between the sensor and the magnet.

Linear Hall ICs with Analog Output

For linear Hall Effect ICs the output of the differential amplifier is converted into a ground-referenced signal and boosted by an operational amplifier, producing a stable analog output signal (**figure 29**).

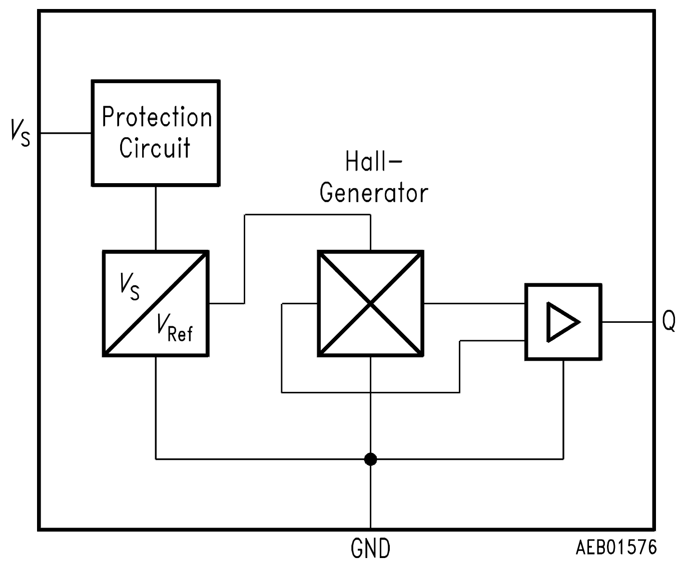


Figure 29
Block Diagram of a Linear Hall IC

This sensor is used to detect motion, position, angle or directly the field magnitude of a electromagnet, permanent magnet or a ferromagnetic material with applied magnetic bias. Automotive applications concentrate on throttle position, pressure and liquid level measurement.

Switching Hall ICs with Digital Output

The Hall Effect switch includes a Schmitt trigger with built-in hysteresis for realizing a non contact, magnetically controlled switching function. Some hysteresis is required for minimizing undefined switching or oscillation and ensures that the output remains unaffected by mechanical vibration.

The output stage is an open collector (current sink) transistor (**figure 30**).

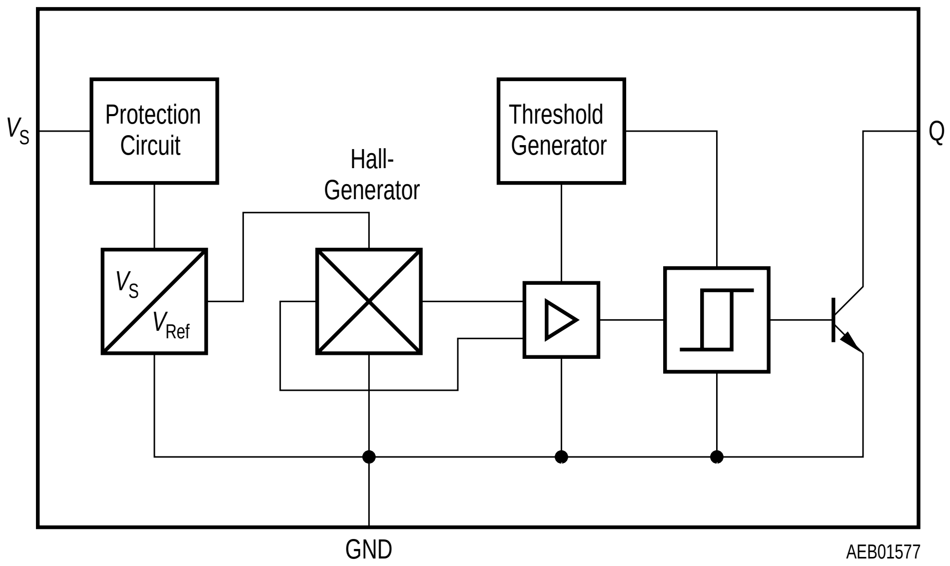


Figure 30
Block Diagram of a Switching Hall IC

The magnetic characteristics, i.e. the thresholds of the Schmitt trigger, are specified in terms of magnetic flux density (Tesla, 1 mT = 10 Gauss). Maximum, minimum and typical operating (switch on) and release (switch off) points as well as the hysteresis are specified.

Switching Hall ICs are divided into two categories:

– Unipolar Switches
– Bipolar Switches

The output transistor of an unipolar switch conducts when exposed to a magnetic south pole (operate point or B_{OP}). If the flux density is reduced by removing the south pole, the output becomes non-conducting (release point or B_{RP}) (**figure 31a**). By definition the field of a magnetic south (north) pole is represented by a positive (negative) sign.

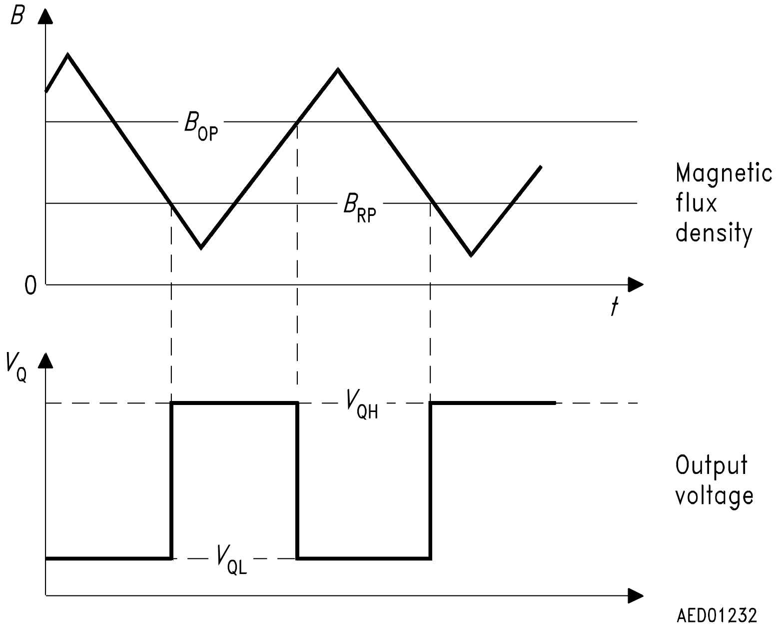


Figure 31a
Unipolar Hall IC, Switching Characteristics

The bipolar or latching switches are designed to operate (switch ON) when exposed to a magnetic south pole. However the switch remains on after the south pole has been removed. To reach the release point (switch OFF), the switch must be exposed to a magnetic north pole (**figure 31b**). A symmetrical and cyclical south to north alternation will produce a frequency output with a duty cycle of 50%.

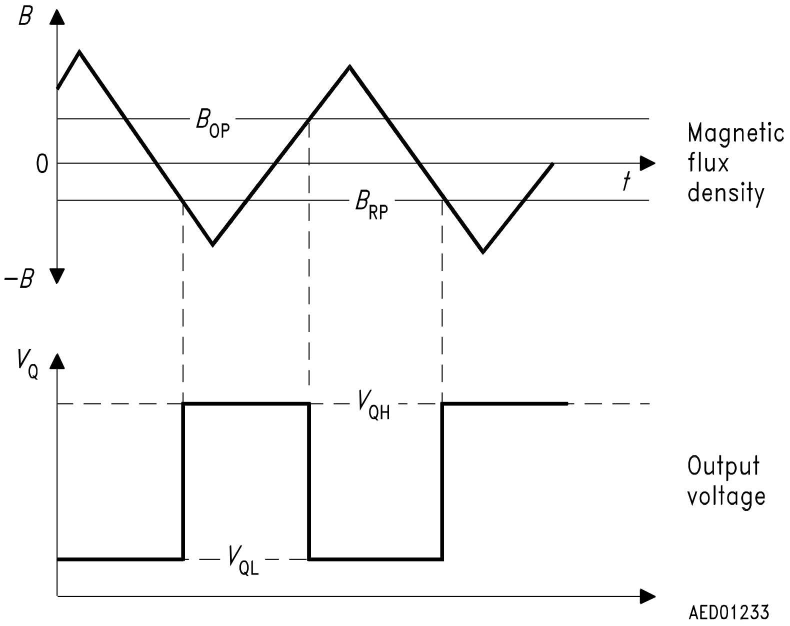


Figure 31b
Bipolar Hall IC, Switching Characteristics

For achieving stable and precise thresholds over the whole operating temperature range, a temperature compensation has to be integrated. The Hall element is electrically compensated to minimize piezoresistive effects (shifts of the switching points due to mechanical stresses in the chip).

Hall IC switches are used in a wide range of applications in industry, consumer and automotive. Position recognition, detection of rotational speed, e.g. for measuring liquid volumes and noncontact commutation of DC motors are just some examples.

Differential Hall ICs with Digital Output

For rotation or position sensing of magnetically permeable materials (i.e. ferromagnetic gear wheels, slotted crankshafts, etc.) the Hall IC must be placed between a backbiasing magnet and the target wheel (**figure 32a**).

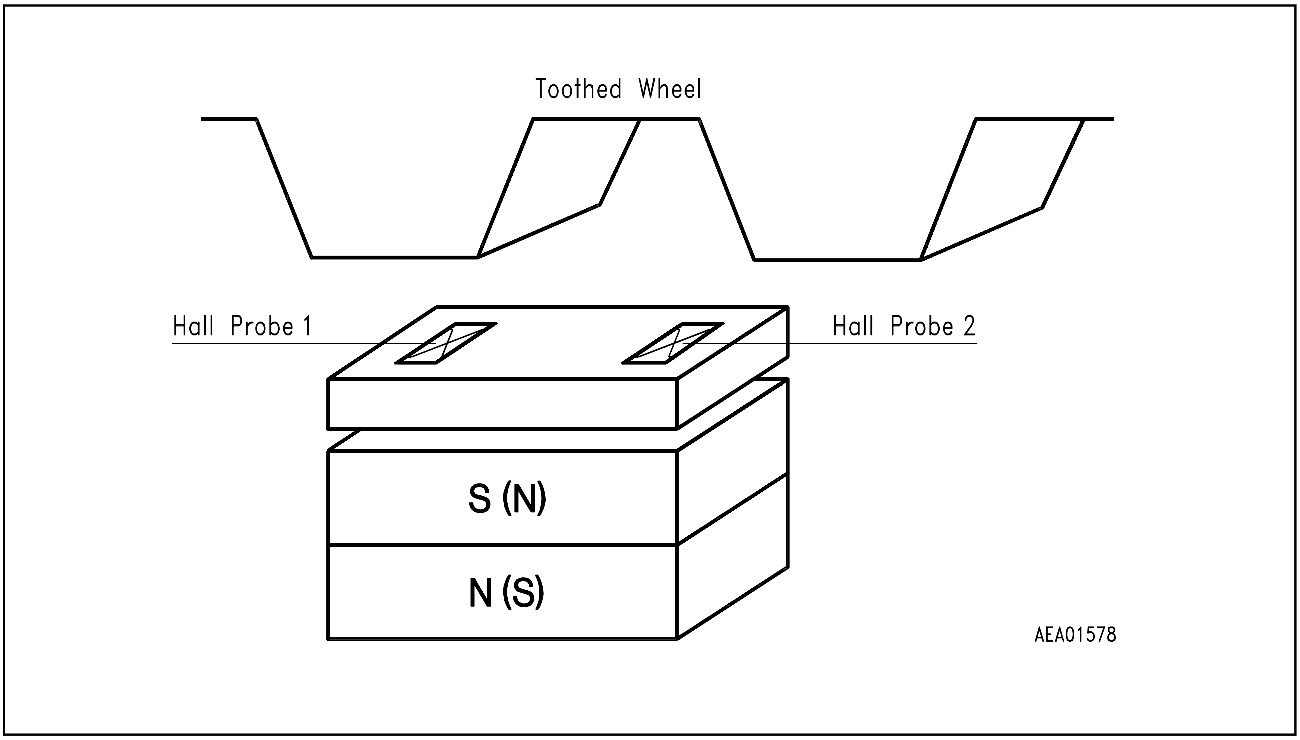


Figure 32a
Differential Hall IC, Toothed Wheel Application

The sensor is magnetically biased by the magnet and the rotating target wheel modulates the flux density through the Hall cells. A tooth acts as a flux concentrator that increases the absolute value of the magnetic field while a gap decreases it. The separation between the tooth and the gap of the gear wheel corresponds approximately to the one of the Hall elements. In this way, the output signals of the elements are shifted by 180°. When the differential signal of both element outputs is formed by subtraction in a differential amplifier, the constant magnetic bias is eliminated and the sensitivity is doubled (**figure 32b**). In addition noise signals or disturbances, which can be caused by system offsets or by bearing clearances of the wheel and which act equally on both Hall elements, are eliminated. The benefits of the differential principle are the intrinsically high sensitivity and the high stability.

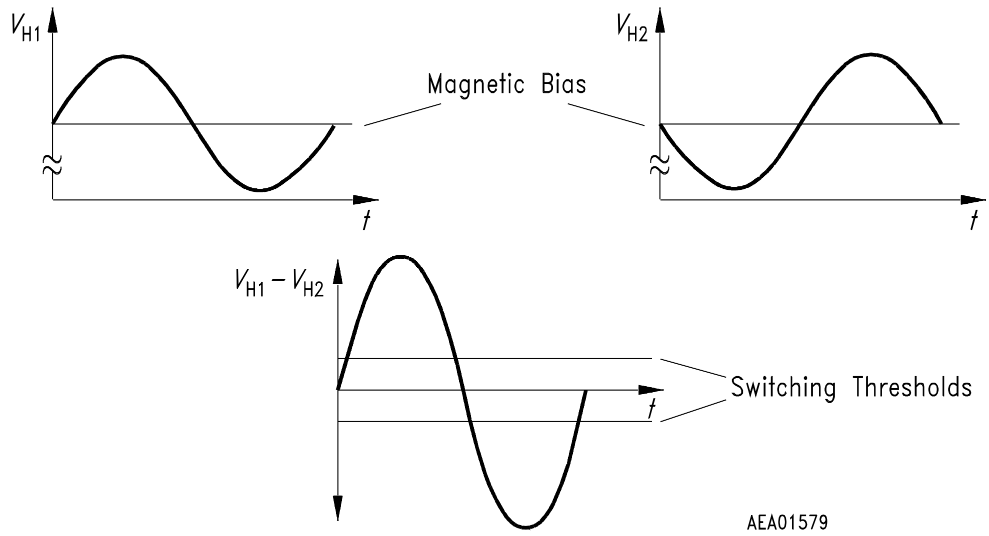


Figure 32b
Differential Mode Principle

Each Hall element consists of several Hall cells with different orientation for compensation of piezoresistive effects. The statistical spread of the individual cell offset is also averaged by the differential amplifier so that the resulting offset is minimized.

The achievable airgap depends primarily upon the ratio of Hall signal amplitude to residual Hall element offset. For improving this ratio, the offset can be reduced by an integrated trimming circuit.

The differential signal is conditioned by a Schmitt trigger with hysteresis.

The sensor provides a frequency proportional the rotational speed of the target. Over the total operating air gap range the signal is unaffected by radial vibration of the target wheel due to bearing clearances or by positioning tolerances.

Dynamic Differential Hall Effect Sensors

Large airgaps for differential sensors can be achieved if they are operated in the dynamic mode. This mode of operation employs a highpass filter with an external capacitor between the differential amplifier and the Schmitt trigger (**figure 33**).

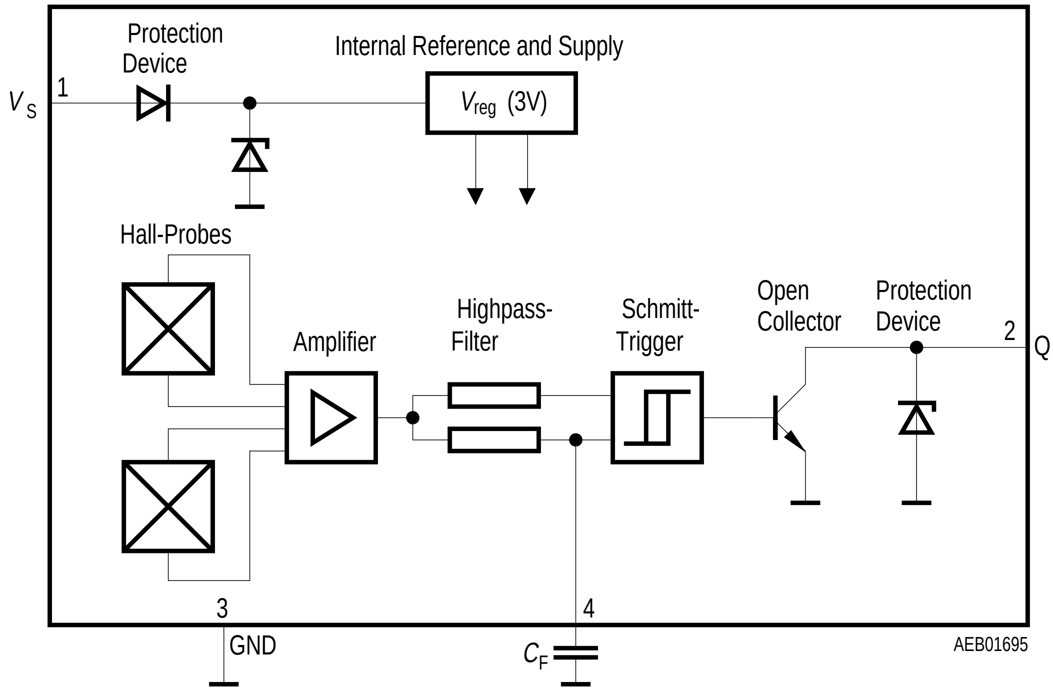


Figure 33
Block Diagram of a Dynamic Differential Hall IC

In this case, spurious low frequent effects are filtered and the hysteresis can be kept very small. This allows for a high sensitivity and a large working air gap. Also here, symmetrical switching points lead to a duty cycle approaching 50%.

Applications for differential Hall ICs are in industry and automotive such as for timing control in engines, speed control in gearboxes and general speed/position control of mechanical shafts.

Differential Hall ICs with a current interface allow true two-wire operation. In this case the supply current is modulated in order to transmit the output state of the IC. Two-wire operation is preferred in cases using long wire distances and for applications with high safety requirements, i.e. detection of “broken wire”.

An important two-wire application is for AWSS (Active Wheel Speed System) where the distance to the controller is large.