

Liquid level sensing

Measuring liquid levels using Hall effect sensors

About this document

Scope and purpose

This application note is dedicated to liquid level sensing using non-contacting magnetic sensor technology. First, an overview of some liquid level sensor application requirements is given. Next, we will introduce some of the solutions that are employed today and are researched for future systems, including both contacting techniques as well as non-contacting methods. Magnetic sensing turns out to be a comparably easy and robust solution to tackle the problem and Infineon's linear Hall sensor portfolio is presented. Different design aspects of a magnetic liquid level sensor, including magnetic circuit designs, are discussed. The last section introduces some of Infineon's Hall effect sensors that are suitable for use in fuel level sensing.

Intended audience

The intended audiences for this document are design engineers, technicians, and developers of electronic systems.

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1 Liquid level sensor overview and requirements

Liquid level sensing is used in many different applications with varying requirements. This section deals with automotive, industrial as well as consumer applications.

1.1 Automotive applications

Every car, truck and motorcycle is equipped with a fuel level sensor to measure the amount of gasoline left in the fuel tank. Although these sensors have been in place for a long time already, there are still some evolutions ongoing and require manufacturers to consider new solutions in order to save space, weight and cost or to increase the reliability of these sensors and the fuel tanks. Among other, these requirements have led to more complex tank geometries and a reduction of the tank openings to reduce fuel leakage and permeation.

A fuel level sensor has to operate under very severe environmental conditions. Not only is it exposed to heavily varying temperatures and vibrations, but it also has to survive the fuel itself including ethanol, methanol, corrosive sulphur or fuel additives that can impact the reliability of the sensor. Car manufacturers still increase their reliability requirements, which can be explained by both quality as a selling point and the increasing repair cost for part failures due to the higher integration of fuel level sensor, tank and delivery module and more complex access paths.

There are many more liquids used in vehicles today, and some of them are also being sensed. Examples include engine oil, brake / power steering fluid, cooling water, windshield cleaning liquid or the AdBlue liquids used in SCR catalytic converters. Sensors used to detect those liquid levels often have to fulfill similar chemical resistance as fuel level sensors do. Space is more restricted as most tanks have considerably smaller volume than the fuel tanks. Many of these liquids are not continuously monitored, but it is sufficient to have an indicator once a certain low level is passed. A low-level indicator as presented in chapter 3.3 can be employed in that case.

1.2 Industrial and consumer applications

Liquids are present in a wealth of industrial and consumer applications: Industrial applications can include liquid level sensing in water treatment tanks, transport and storage tanks in the petrochemical industry for liquids such as petrol or various tanks in the agricultural / nutrition sector. The requirements vary heavily based on the environmental conditions, chemical composition of the liquid, accuracy requirements, available building space and measurement range to be covered, to name just a few. Accordingly, there is a big number of sensors based on different measurement principles available on the market as will be shown in the next section.

Consumer / household applications are also manifold and information about some liquid level may be required for devices such as automated coffee machines, water dispensers, juice squeezers, water evaporators, steamers, fridges and freezers, boilers, heating systems, dishwashers, washing machines, steam irons, etc. This application note can give some ideas on how to implement enduring level sensing solutions for these applications using magnetic sensors.

2 Measurement principles

The number of measurement principles is as wide as the number of application requirements. Here is a list of some of the principles that can be found for liquid level sensing:

- **Discrete resistor card:** This type of variable resistors is widely used in fuel level sensing. A wiper, connected to a lever arm with a float, sweeps across contacts connected by individual resistors, thereby changing the resistance seen between the two terminals. Only two wires are needed to connect to the resistor card, and the single resistor elements can be chosen to accommodate the nonlinearities of the tank form. The output is however discretized to the amount of resistor elements used and loss of contact can happen at the transition points between two contacts. Another major disadvantage of this solution is the contacting sensor principle, which is prone to wear.
- **Variable resistor cards:** Here, the resistors are not discrete but formed by a continuous resistive track using deposited resistive material and a wiper for sweeping. Both rotating lever and vertical float solutions can be designed. Some of the shortcomings of discrete resistor cards are solved that way, but the solution is still contact based and can wear out due to dithering movements around one position caused by slushing liquid.
- **Reed contacts:** An easy contactless solution uses reed contacts. Reed elements basically consist of ferrous metal contacts, situated in a sealed cavity, that are connecting to each other if a magnetic field is applied. They are found as proximity switches, low liquid level indicators or even contactless substitutes for discrete level liquid level sensors. Although simple and rather cheap, they may break under harsh conditions like vibrations.
- **Hall sensors:** Being a cheap, robust and well proven contactless solution for various position sensing applications, this type of sensors will be the focus of chapter 3.
- **Others:** There are many more techniques that we don't explain in more detail here: Capacitive measurement techniques, optical methods, ultrasonic measurements, magnetostrictive sensors or level estimation using intermediary variables such as pressure or force. The interested reader will find a lot of references about these particular methods in literature.

3 Magnetic fuel level sensors

This chapter elaborates on some fuel level sensor solutions based on Infineon's Hall effect devices. Both vertical float systems as well as lever-arm systems are considered. Finally, single switches for tank full and tank empty indications are shown.

3.1 Rotating lever sensor

A straightforward contactless solution of a fuel level sensor continues to use the same mechanical structure as used so far and only replaces the resistor card with a contactless magnetic sensor. The magnetic circuits depicted in Figure 1 can be used for an easy implementation. In the first arrangement, the linear Hall sensor is placed in the center of a diametrically magnetized ring magnet, surrounded by some soft iron ring to guide the magnetic flux. This implementation has the advantage that the magnetic field inside the ring is sufficiently homogeneous so that a small mechanical misplacement doesn't lead to big signal deviations. Additionally, the sensor is shielded by the soft iron ring and therefore better protected against external disturbances. Alternatively, one can also conceive even simpler magnetic circuits that only use two magnetic plates, also depicted in Figure 1. This solution offers a reasonable degree of accuracy while minimizing material cost. The circuit is a little bit less resistant against mechanical misalignments but is sufficient for many fuel level applications. Using a programmable sensor like the TLE4997 will allow a fast calibration and the flexibility to use the same sensor for a multitude of module designs.

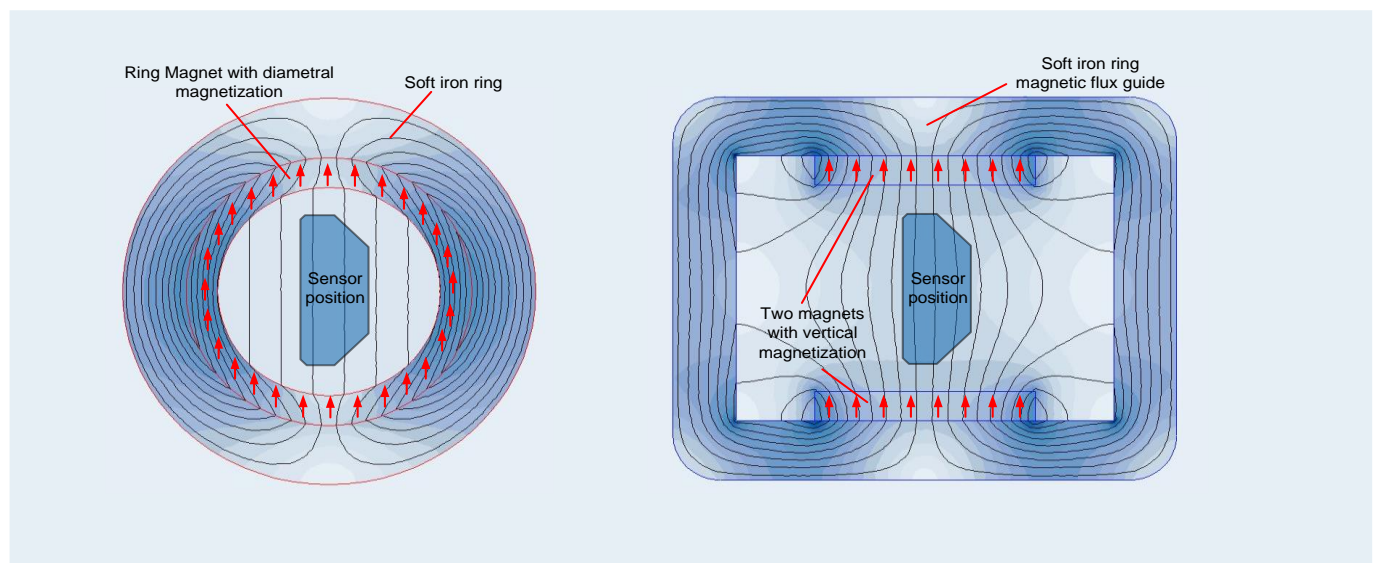


Figure 1 Two possible easy magnetic circuit designs leading to parallel magnetic field lines.

A linear Hall sensor measures only the vertical component of a magnetic field, so if we turn a magnet around the device, we will get an output signal $OUT \sim B_{\perp} = B_{max} \sin \beta$, where B_{\perp} is the perpendicular component of the measured magnetic field and B_{max} is the maximum field. The relationship between the angle of the lever β and the vertical distance h is given by $h = R \sin \beta$, where R is the distance between the articulation point and the floating device. We can now see that combining the two formulas, we obtain $OUT \sim B_{max}(h/R)$, revealing that the output signal OUT is proportional to liquid level h .

Figure 2 shows how such a sensor can be used to replace a traditional resistor card-based fuel level sensor. In order to have a similar sensitivity with respect to the measured variable throughout the measurement range, the sinusoidal shape of the linear Hall sensor output allows to follow the resistor card output within some limits. A comparison of a typical output characteristic of a resistor card fuel level sensor and a linear Hall based solution

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shown in Figure 3. The remaining error can be corrected in the microcontroller, taking into considerations nonlinear tank geometry.

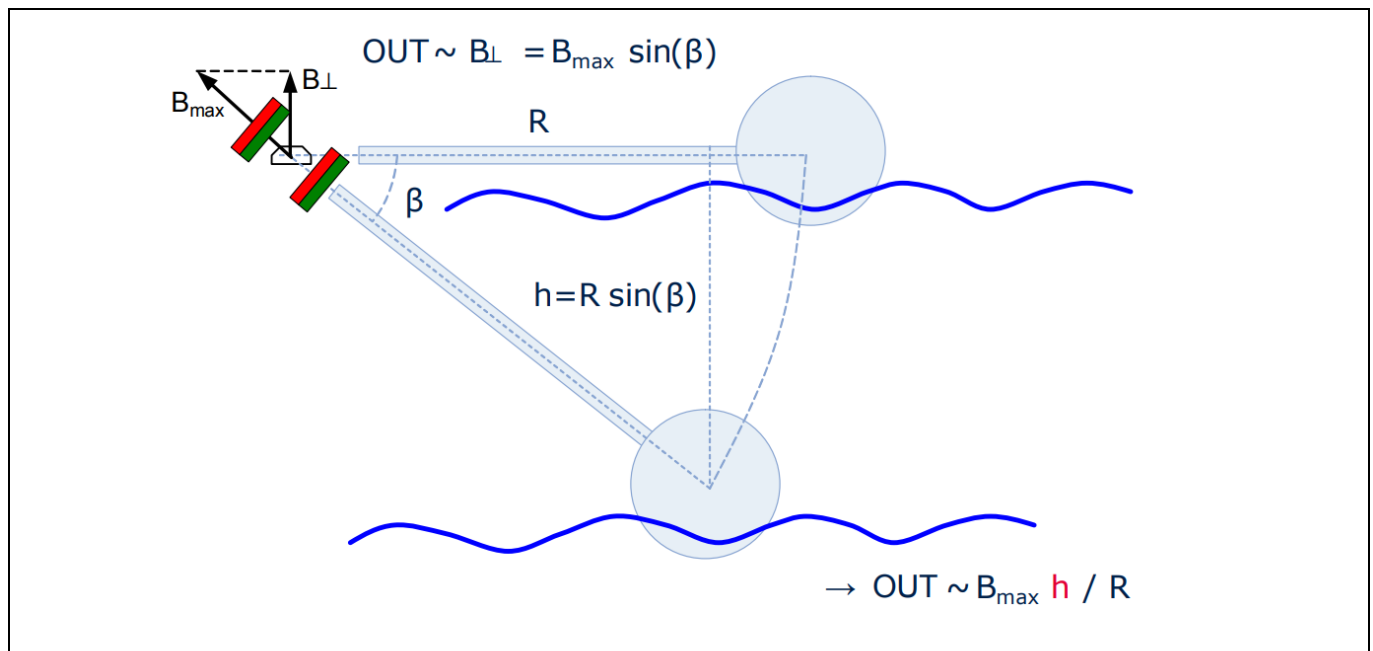


Figure 2 Principle of sinus cancellation in liquid level sensors using a linear Hall device.

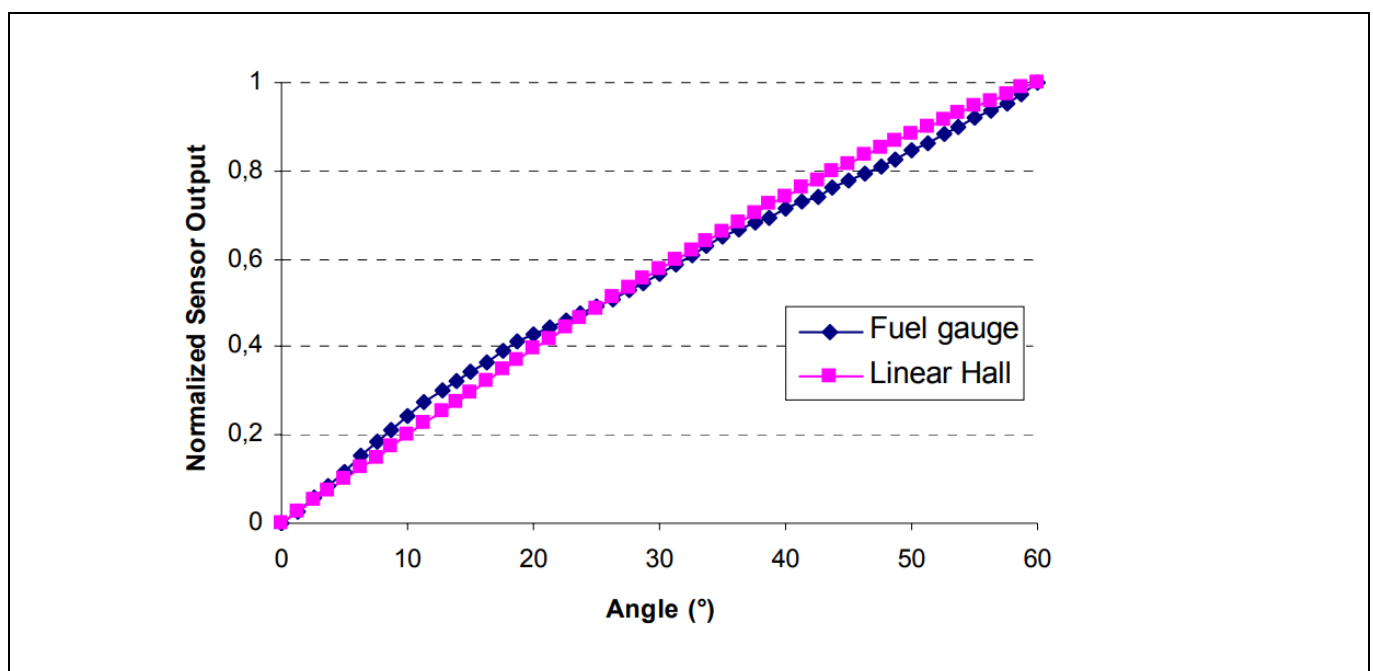


Figure 3 Comparison between resistor card fuel gauge output and a linear Hall sensor solution

Once such a mapping is feasible in the microcontroller, the main interest is not merely linearity, but stability of the output over temperature and lifetime. In the linear Hall sensors of Infineon, the temperature drifts of the application magnetic circuit can be compensated directly in the sensor. These products furthermore have a very good lifetime stability due to innovations in chip and package design, such as the active stress compensation in the TLE4998 and TLE4999.

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3.2 Vertical float systems

Another possible implementation of fuel level sensors use a vertically moving float. Depending on whether a continuous signal or only discrete levels are needed, solutions with magnetic sensors can be designed based on either linear Hall sensors or Hall switches. Figure 4 shows a possible implementation using an array of linear Hall sensors, utilizing two small magnets that are magnetized in opposite directions. By choosing the distance and size of the magnets properly, the horizontal field component turns out to be linear over a considerable range as can be seen in Figure 5. The distance between the linear Hall sensors then needs to be chosen in such a way that there is always at least one sensor in its linear range. From the outputs of the sensors, it is possible to decide which sensor output is to be taken.

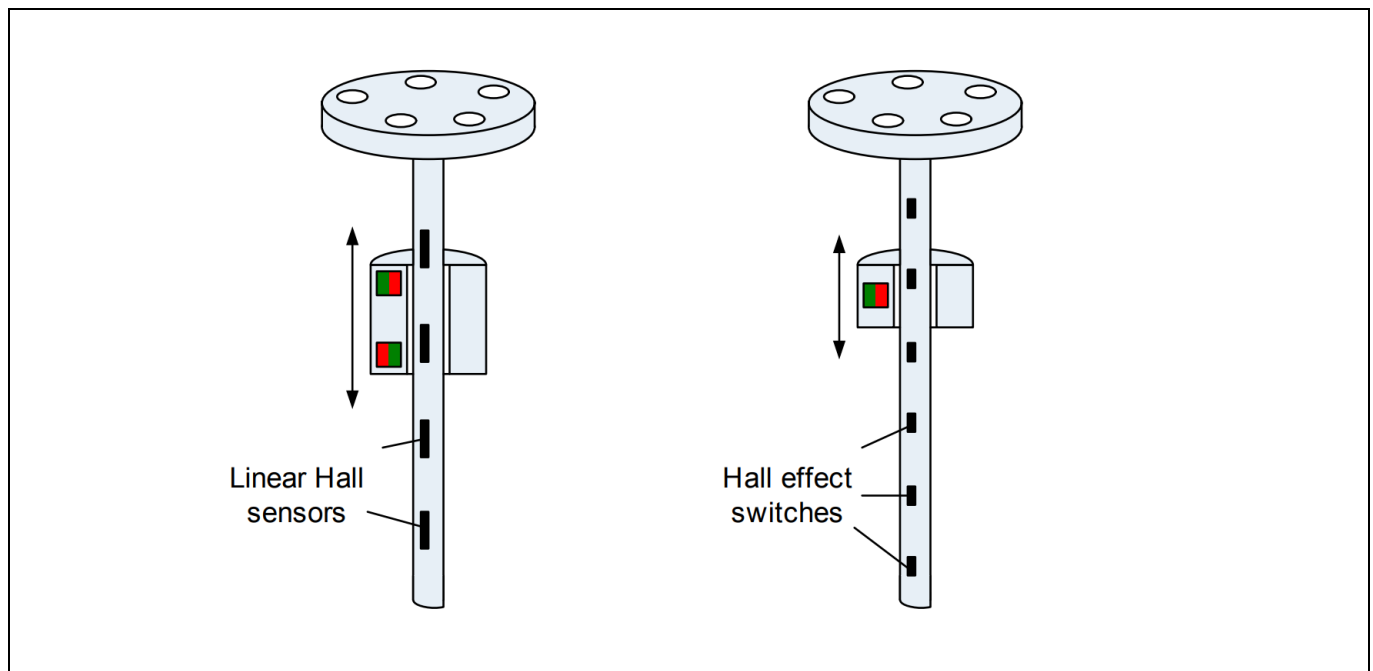


Figure 4 Vertical float based liquid level sensors using linear Hall sensors and Hall effect switches.

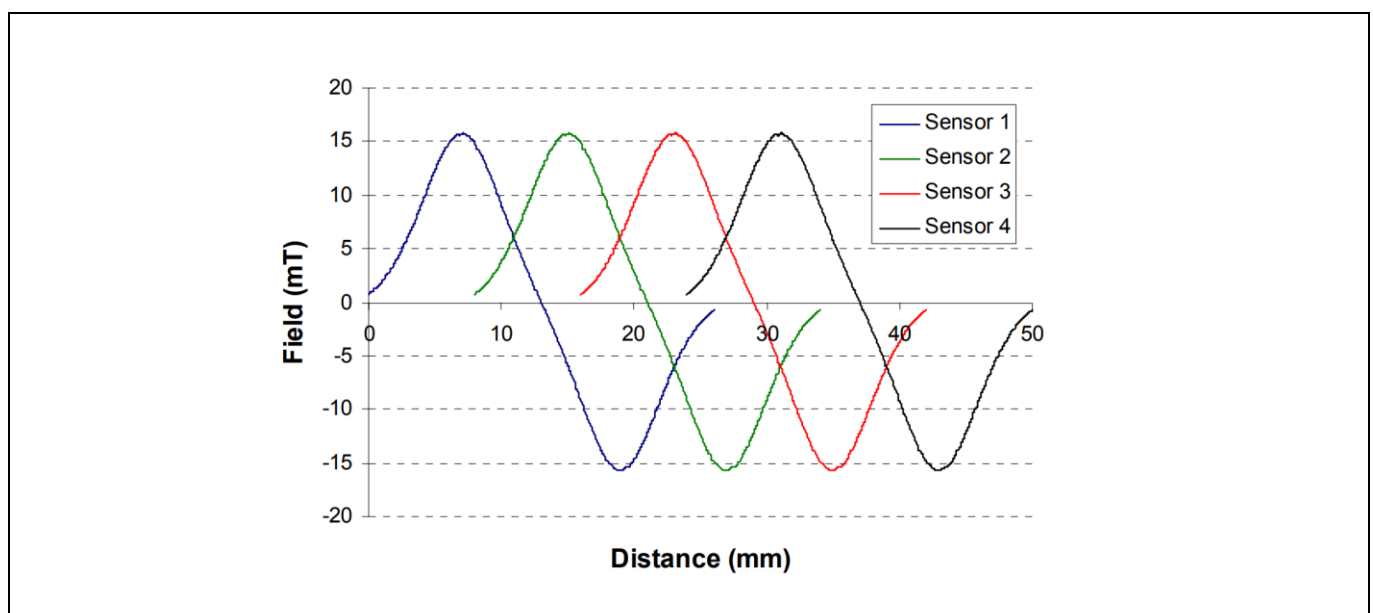


Figure 5 Possible output signals from an array of linear Hall sensors.

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If only discrete steps of the liquid level need to be known, Hall effect switches offer a cheaper and easier solution. Figure 4 shows such an implementation, using an array of Hall effect switches. Other than for the linear Hall sensors, one magnet is sufficient. One way of having an optimum tradeoff between resolution and covered distance is to make sure that during transitions there are always two sensors turned on. One possible decision matrix is shown in Table 1. With this scheme, it is possible to detect nine distinct positions with four Hall switches.

Table 1 Detecting 9 distinct levels using four Hall switches

Distance	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45
Switch 1	0	1	1	0	0	0	0	0	0
Switch 2	0	0	1	1	1	0	0	0	0
Switch 3	0	0	0	0	1	1	1	0	0
Switch 4	0	0	0	0	0	0	1	1	0

3.3 Low level switch

In some cases, a warning signal for low liquid levels is required. One can either use the signal generated by a continuous fuel level sensor or add a low-level indicator switch placed at the bottom of the liquid tank. Figure 6 depicts one possible implementation which uses a permanent magnet float and a Hall effect switch. Applications of such a switch also include many household appliances such as washing machines, coffee machines, steam irons or water dispensers.

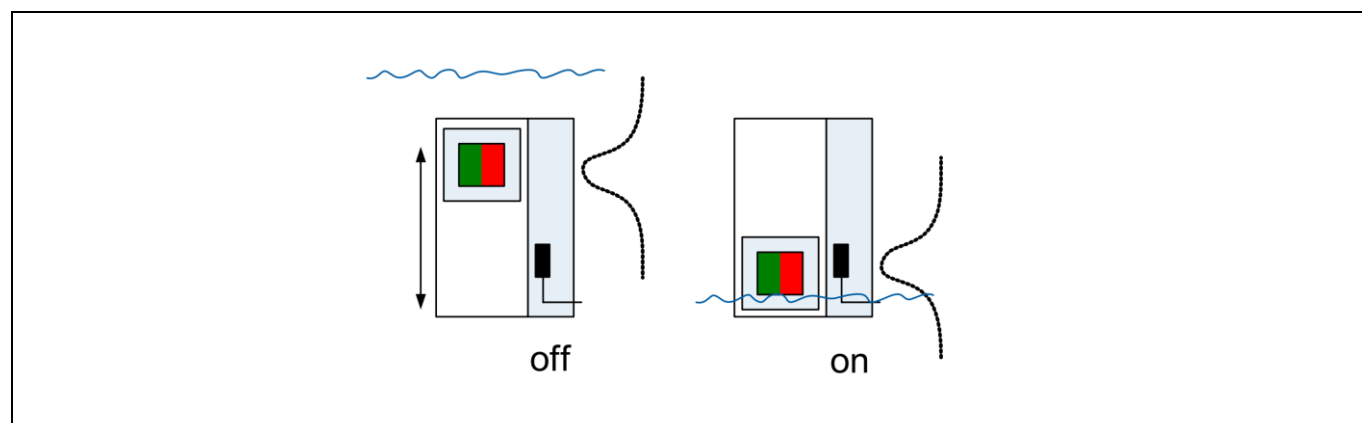


Figure 6 Low level switch example using a Hall effect switch

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Infineon's magnetic sensors for liquid level sensing

4 Infineon's magnetic sensors for liquid level sensing

Infineon offers a wide variety of magnetic sensors, including Hall effect devices and sensors based on the giant magnetoresistive (GMR) effect. As was shown in chapter 3, linear Hall sensors and Hall effect switches are most suitable for liquid level sensing and some representative devices are shown here.

4.1 Linear Hall sensors

Infineon offers a variety of linear Hall sensors with different programming, package and interface options. This section gives a general overview of our sensor portfolio. For more detailed information, please refer to the datasheets of each product.

Table 2 Overview of Infineon's linear Hall sensors useful for liquid level sensing

Product Type	Calibration	Package	Interface
TLE4997	2-point	PG-SSO-3-10 TDSO-8	Analog ratiometric
TLE4998	2-point	PG-SSO-3-10 PG-SSO-4-1 TDSO-8	PWM, SENT, SPC
TLE4999	2-point (TLE4999i3)	SSO-3-12	PSI5
	9-point (TLE4999C)	SSO-4-1 TDSO-8	SPC

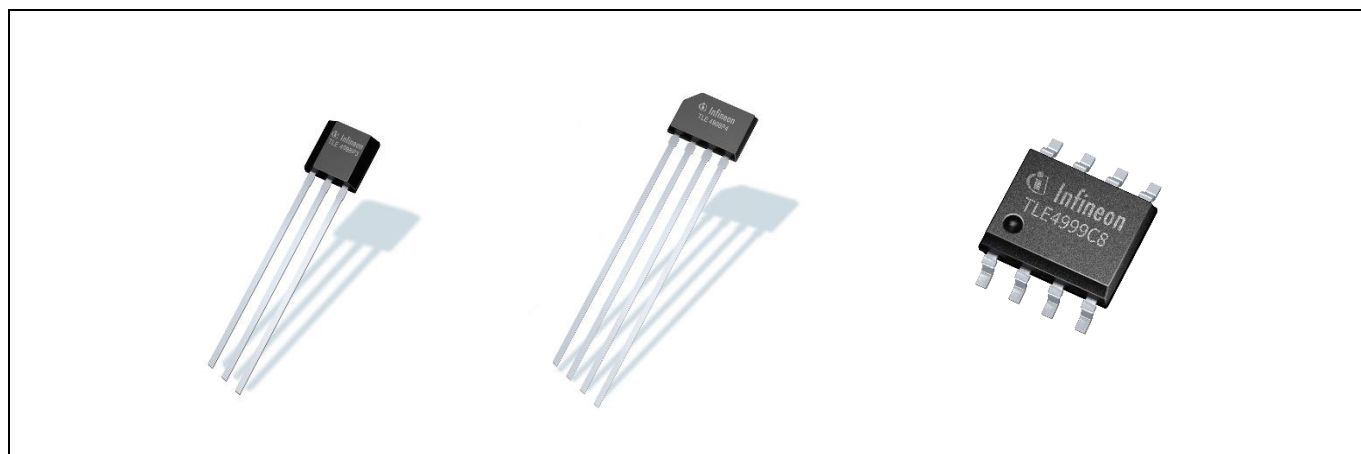


Figure 7 Leaded and SMD package variants of Infineon's linear Hall sensors: PG-SSO-3-10, PG-SSO-4-1 and PG-TDSO-8 (from left to right).

TLE4997

The TLE4997 has an analog, ratiometric output and can be used as a robust replacement for potentiometers. With the integrated EEPROM it is possible to program several parameters and adjust the sensor to application needs. For perfect fit parameters like sensitivity, offset or clamping can be set. The TLE4997 also offers independent and programmable parameters for both first and second order temperature coefficients of the application sensitivity. There are different leaded and SMD packages available therefore it is also suited for use in the limited space inside magnetic circuits such as the ones presented in magnetic circuit of Figure 1.

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TLE4998

The TLE4998 family is the successor of the TLE4997, providing innovations on the interface and lifetime stability side. The signal processing concept is based on the TLE4997 design, offering high-precision analog-to-digital signal conversion and a deterministic digital signal processing. An important innovation of the TLE4998 is a stress sensor that is integrated in the sensor and allows to constantly monitor the mechanical stress of the chip induced by sensor overmolding and environmental effects. The stress-induced changes in sensitivity of the sensor are then compensated in the DSP.

As the TLE4997, the TLE4998 is available in the 3-pin PG-SSO-3-10 package. Additionally, the sensor can be ordered in a slim 4-pin PG-SSO-4-1 package with a height of only 1mm.

Beside the leaded packages the TLE4998 is available in an 8 pin SMD package. Due to the pin count it is possible to have to sensor ICs in one package offering a dual die sensor in the same mounting space as a single die. With this approach it is possible to realize safety critical applications due to redundance sensing.

The TLE4998 is available with different interfaces. The PWM interface is very common and simple to integrate. But as kind of an analog transmission it is prone to disturbance and does not have any safety features. With the SENT and SPC interfaces are also two digital communication protocols available. These standardized protocols transmits measurement data and can also include additional data like sensor temperature in a communication frame.

TLE4999

The Infineon TLE4999 provides all means that are necessary to fulfill the state-of-the-art functional safety requirements on system level. It is developed in full compliance with ISO 26262. The device provides high redundancy on one chip by means of two sensor elements included within one monolithic silicon design. The two diverse Hall sensor elements („main” and „sub”) have internally separated signal paths within the chip. A plausibility check secures the high diagnostic coverage required for premium functional safety compliant systems up to ASIL D.

The sensor provides a digital SPC (Short PWM Code) protocol on the OUT pin that is based on the SENT (Single Edge Nibble Transmission) standard. As a second option a PSI5 current interface is available which is very robust and therefore suited for remote sensor integration. Configuration parameters can be programmed after assembly of the sensor in a module in an end-of-line calibration procedure using the serial inspection and configuration interface (SICI).

The sensor with SPC interface provides different output signal modes with 12bit, 14bit, or 16bit, protected by CRC and a rolling counter. The PSI5 communication interface supports a bitrate upto to 189 Kboud using the PSI5 v 2.1 protocol. In both cases the value of the main and sub sensing element is transmitted within one data frame resulting in low protocol overhead and high speed communication.

As a key feature the TLE4999C offers a 9-point calibration function. With this, non-linear input signals can be adjusted to deliver a constant linear output signal. To provide an optimal output, five calibration modes are available to compensate different non-linearity behaviors.

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4.2 Hall effect switches

Infineon offers a wide range of Hall effect switches, covering the whole range of unipolar and bipolar switching as well as latching devices. The TLE49x6 family has high switching point stability. If only discrete on/off information is needed, the TLE4906 unipolar Hall effect switch is a good choice, available in two packages: The TLE4906H in an SC59 SMD package as well as the TLE4906L in a leaded PG-SSO-3-2 package (c.f. Figure 8). The parts excel with

- Small switching point spread (Bop between 6.5 and 13.5 mT, Brp between -5.0 and 12 mT)
- Excellent Temperature compensation (set to -350 ppm/°C typical)
- Small delay time (typically 13µs)
- Low jitter (typically 1µs)

Additionally, all the basic requirements for sensors working in harsh environments are fulfilled by this part, including

- Broad operating supply voltage range (2.7 V to 18 V)
- High maximum supply voltage range including reverse polarity protection (-18 V to 26 V)
- High temperature range (-40 to 150 °C operating range, max rating up to 195 °C for short time)
- High immunity against ESD (6 kV)

All those features make the TLE4906H and the TLE4906L ideal choices for application in harsh environments. For details about this part, please refer to the corresponding datasheets.

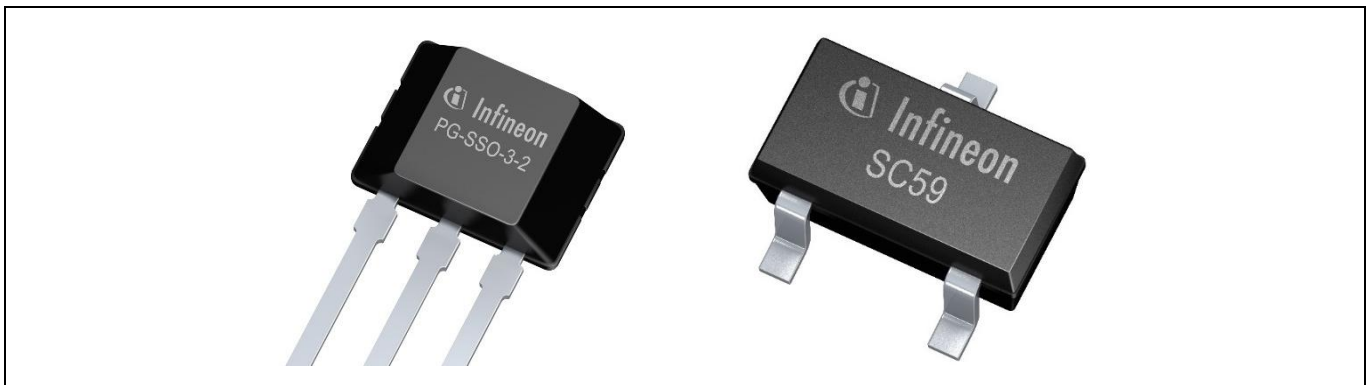


Figure 8 Infineon's Hall effect switches are available in the leaded PG-SSO-3-2 package (-L types) as well as in the small SC59 SMD package (-H, -K types).

5 Conclusion

Some possible implementations of contactless liquid level probes using Hall effect sensors have been presented. Well proven in many automotive applications such as ABS speed sensing or gas pedal position detection, Hall sensors are a robust and durable solution for high quality contactless sensing. Infineon offers a wide portfolio of Hall effect sensors, and linear Hall as well as Hall effect switches are a good choice for various position sensing applications. As could be shown, there exist easy and fast designs for liquid level sensing and Hall effect products can be effectively used in these applications.

Revision history

Document revision	Date	Description of changes
1.0	2009-02-12	Initial release
1.1	2025-02-28	<ul style="list-style-type: none">• Editorial changes to new template• Update product portfolio

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Edition 2025-02-28

Published by

Infineon Technologies AG

81726 Munich, Germany

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