Liquid Level Sensing

Measuring Liquid Levels Using Hall Effect Sensors

Application Note

Rev. 1.0, 2009-02-12

Sense & Control

Edition 2009-02-12

Published by
Infineon Technologies AG
81726 Munich, Germany

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Revision History: 2009-02-12, Rev. 1.0

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1 Introduction

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 are 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.

2 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.

2.1 Automotive Applications

Every car, truck and motorcycle is equiped 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 **Section 4.3** can be employed in that case.

2.2 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.

3 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 accomodate 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 **Section 4**.
- 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.

4 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.

4.1 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 diametrally 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.

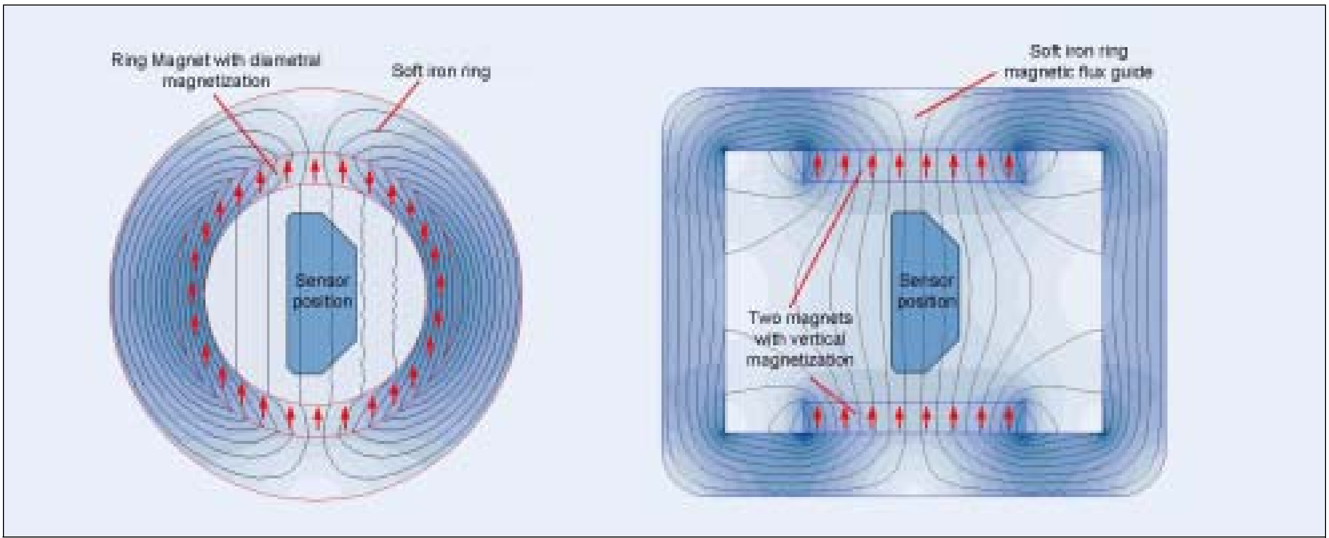

Figure 1 Two possible easy magnetic circuit designs leading to parallel magnetic field lines.

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 $OUT \sim B_{max}(h/R)$, reveiling 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 shown in Figure 3. The remaining error can be corrected in the microcontroller, taking into considerations nonlinear tank geometry.

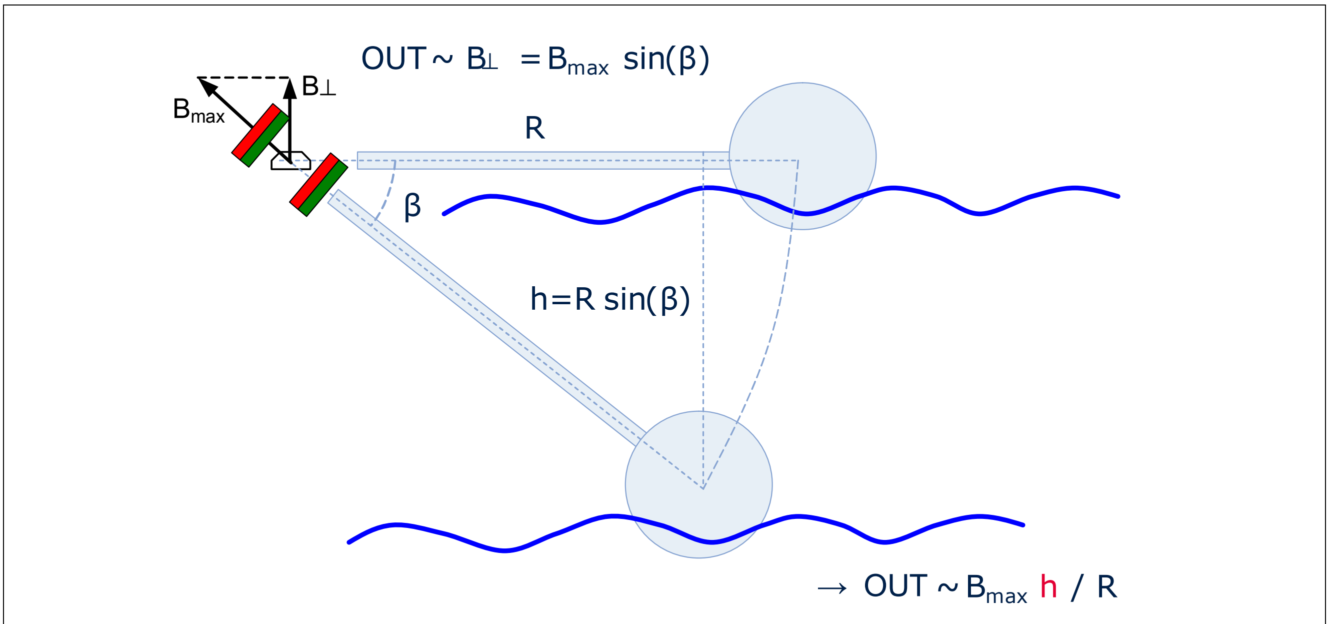

Figure 2 Principle of sinus cancellation in liquid level sensors using a linear Hall device.

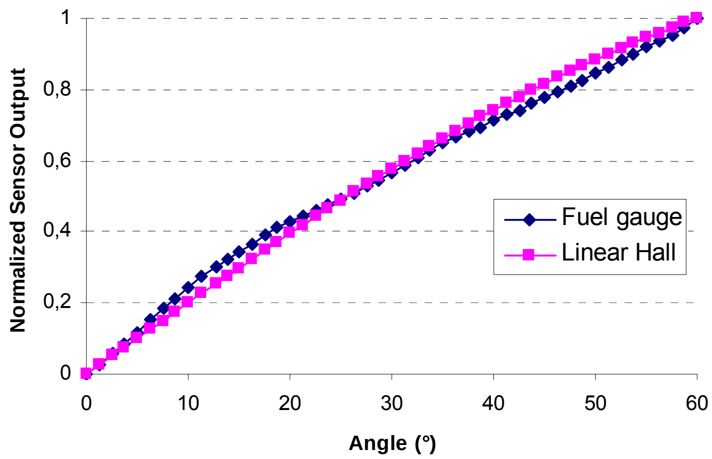

Figure 3 Comparison between resistor card fuel gauge output and a linear Hall sensor solution

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 TLE4997 and TLE4998, the temperature drifts of the application magnetic circuit can be compensated directly in the sensor. The products have a good lifetime stability due to innovations in chip and package design, such as the active stress compensation in the TLE4998.

4.2 Vertical float systems

Another possible implementation of fuel level sensors uses a vertically moving float. Depending on whether a continuous signal or only descrete 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 chosing 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.

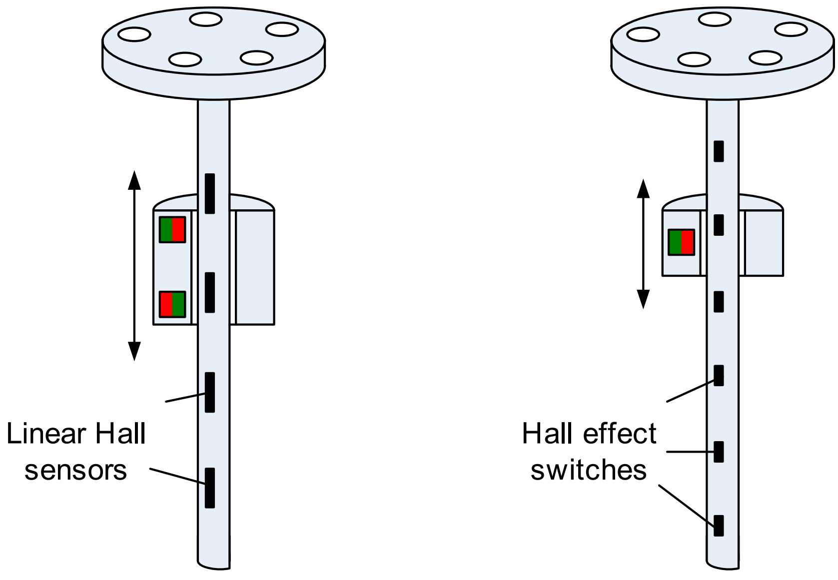

Figure 4 Vertical float based liquid level sensors using linear Hall sensors and Hall effect switches.

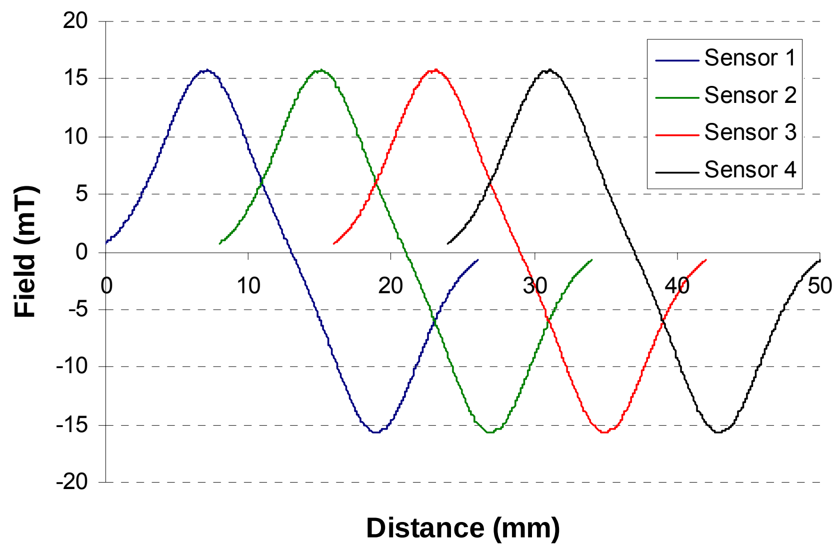

Figure 5 Possible output signals from an array of linear Hall sensors.

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

4.3 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.

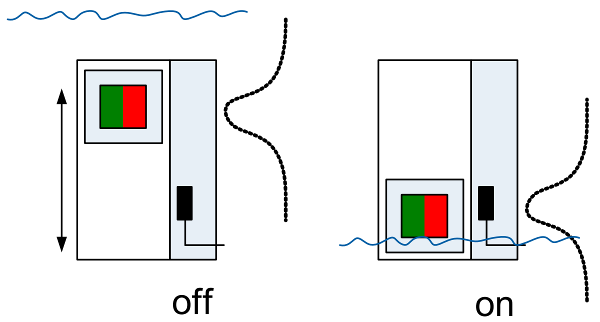

Figure 6 Low level switch example using a Hall effect switch

5 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 **Section 4**, linear Hall sensors and Hall effect switches are most suitable for liquid level sensing and some representative devices are shown here.

5.1 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	Programming	Package	Interface
TLE4990	Fuses	PG-SSO-4-1	Analog ratiometric
TLE4997	EEPROM	PG-SSO-3-10	Analog ratiometric
TLE4998P	EEPROM	PG-SSO-3-9 PG-SSO-3-10 PG-SSO-4-1	PWM

Figure 7 The three packages of Infineon's linear Hall sensors: PG-SSO-3-10, PG-SSO-3-9, PG-SSO-4-1 (from left to right).

TLE4990

The TLE4990 is Infineon's basic linear Hall sensor with analog signal processing and fuse programmability. The sensor is end-of-line programmable, meaning that its gain and sensitivity can be set in a two-point calibration in the module. Due to its thin PG-SSO-4-1 package, it fits in small air gaps. The TLE4990 has been field-proven in the last years and is well established for automotive applications such as gas pedal position sensing.

TLE4997

The TLE4997 has been designed to improve on some of the shortcomings of an analog compensation scheme as the one used in the TLE4990 and most competitor products, including offset and sensitivity drifts over temperature, range of the programmable parameters and accuracy. The signal processing of the TLE4997 is entirely shifted to the digital domain, making the influence of the programmed parameters completely deterministic. Temperature effects of the Hall probe can readily be compensated for using a pre-calibration in Infineon's fabrication. The TLE4997 is also the first sensor on the market that offers independent, programmable parameters for both first and second order temperature coefficients of the application sensitivity. The TLE4997 has an analog, ratiometric output and can be used as a robust replacement for potentiometers. It comes in a small 3-pin PG-SSO-3-10 package and is therefore suited for use in the limited space inside magnetic circuits such as the ones presented in magnetic circuit of **Figure 1**.

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. The TLE4998 is the first in class sensor that offers such a feature.

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. The third package option is the PG-SSO-3-9, a 3-pin package with two integrated capacitors on the lead frame between Vdd and Gnd and between Out and Gnd which enhances EMV and microbreak protection and helps to further reduce system cost.

The TLE4998P features a PWM interface, in which the duty cycle carries the Hall signal information. It offers 12-bit resolution on the output, and combined with an accurate detection on the microcontroller side, leads to a higher resolution than what is achievable by an analog interface. On a system level, the PWM interface offers cost saving advantages compared to analog solutions because the multiple signal conversion from digital to analog and back can be avoided. Other than for devices with ratiometric output, the devices can be directly connected to a 12V supply. The output consists of an open drain stage, so that a simple pull-up resistor can be used to connect the output to any voltage level suitable for the microcontroller input stage, achieving complete independence between microcontroller and sensor supply.

5.2 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 13us)
- Low jitter (typically 1us)

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).

6 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.

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