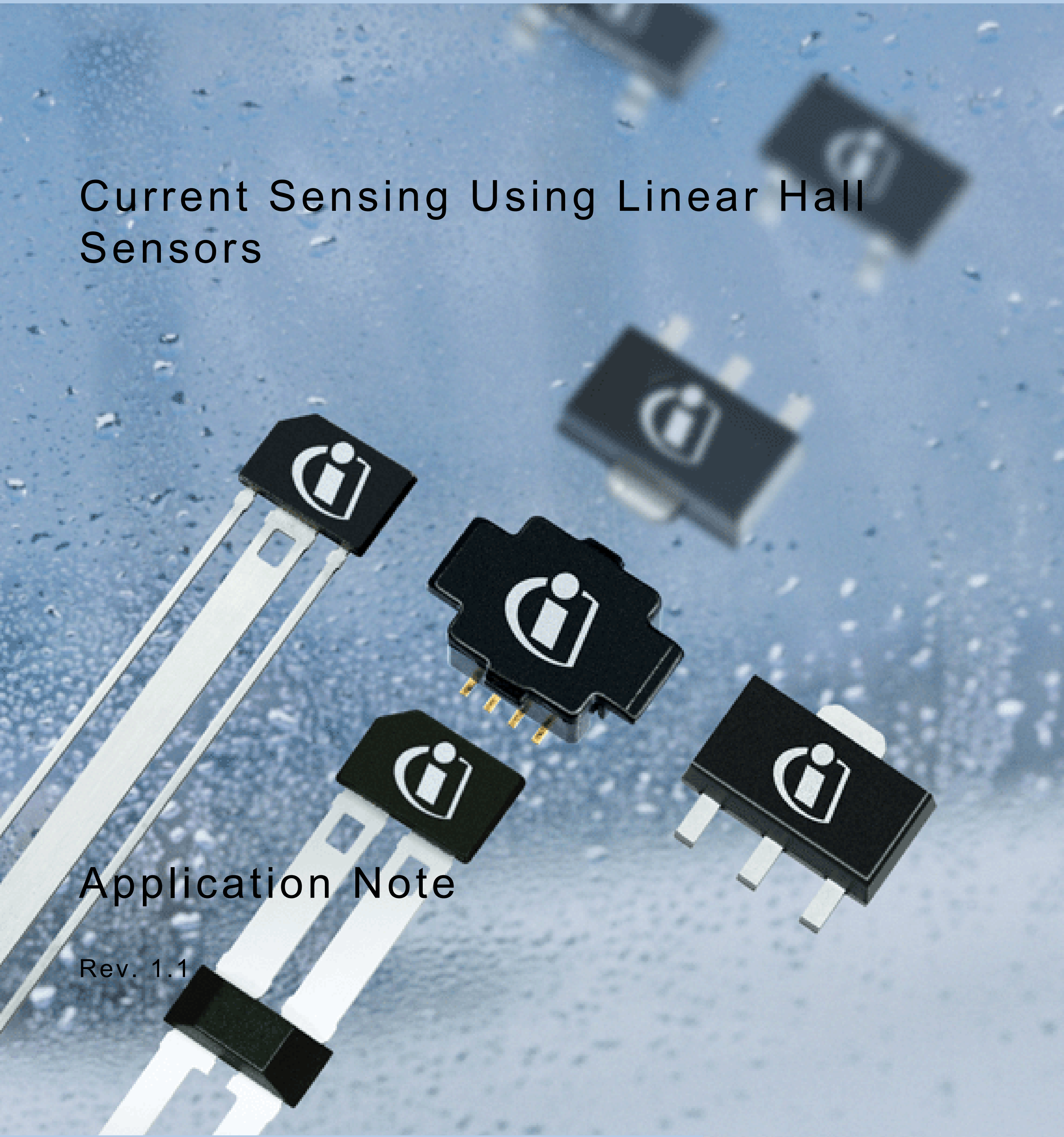
February 2009

Current Sensing Using Linear Hall Sensors



Application Note

Rev. 1.1

Sense & Control

Never stop thinking

Edition 2009-02-03

Published by
Infineon Technologies AG
81726 Munich, Germany

Information

For further information on technology, delivery terms and conditions and prices, please contact the nearest Infineon Technologies Office (**www.infineon.com**).

Warnings

Due to technical requirements, components may contain dangerous substances. For information on the types in question, please contact the nearest Infineon Technologies Office.

Infineon Technologies components may be used in life-support devices or systems only with the express written approval of Infineon Technologies, if a failure of such components can reasonably be expected to cause the failure of that life-support device or system or to affect the safety or effectiveness of that device or system. Life support devices or systems are intended to be implanted in the human body or to support and/or maintain and sustain and/or protect human life. If they fail, it is reasonable to assume that the health of the user or other persons may be endangered.

Current Sensing Using Linear Hall Sensors

Revision History: 2009-02-03, Rev. 1.1

Previous Version: 1.0

Page	Subjects (major changes since last revision)
General	Ported to new layout
General	Reworked all sections, added new products TLE4998 and application examples

Table of Contents

1 Introduction

This application note is dedicated to current sensing using Hall effect sensors. Electric current is an important physical quantity and its measurement is required in many applications, be it in industrial, automotive or household fields. Different technical solutions to measure currents are known and are found on the market. We are trying to give an overview of important measurement techniques and show their respective advantages and disadvantages. It turns out that due to galvanic isolation between the sensed circuit and the measuring circuitry, current sensing using Hall effect ICs is a good choice for many applications. Accordingly, we present in more detail Infineon's linear Hall sensor products suitable for current sensing modules. The next section looks into some design aspects for current sensor designs with Hall effect sensors, including choices of flux concentrator types, designs and materials. An open-loop current sensor example is presented in **Section 5** using the TLE4998S. The TLE4998C linear Hall sensors are finally the focus of **Section 6**, highlighting the advantages of this sensor for some current measurement applications requiring high dynamic range readings.

2 Principles of Current Measurement

This section looks into some solutions of how to measure electric current. Included are sections about different shunt measurement solutions as well as the focus technique of this application note, current sensing using Hall effect devices.

2.1 Shunt Resistor Solution

The well known formula of Georg Simon Ohm reads:

$$U_2 - U_1 = R_{shunt} \cdot I, \tag{1}$$

where R_{shunt} is a shunt resistor through which flows a current I, and the difference $U_2 - U_1$ is the voltage difference reading on the two terminals of the shunt resistor. This voltage drop can subsequently be processed in different ways. One possibility is to amplify the voltage and feed it into an analog to digital converter (ADC). The output of this configuration is a digital value proportional to the current. We can distinguish between two possible insertion points of this resistor, the first being as low-side, the second as high-side shunt.

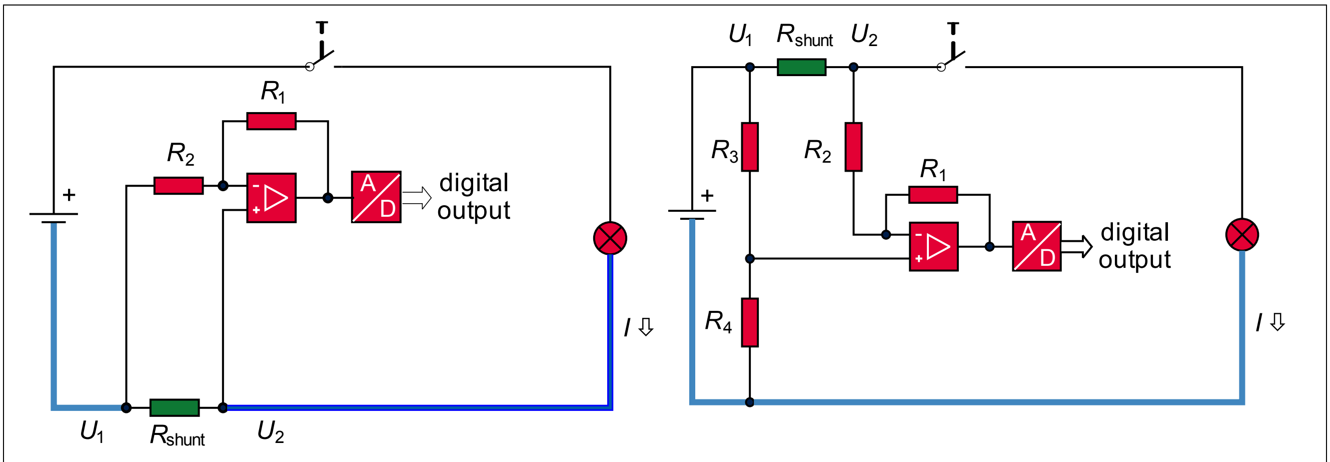


Figure 1 Current measurement using low-side shunt (left) and high-side shunt resistor (right).

Low-Side Current Shunt Resistor

As shown in **Figure 1**, a low-side shunt resistor has one terminal connected to the battery ground (U_1), the other one connected to the load. An opamp setup is used with two resistors R_1 and R_2 to amplify the voltage drop accross the shunt resistor. Since the voltage U_2 is slightly higher than the battery ground U_1, the load has to be connected using two wires and the common ground (e.g. car chassis) cannot be used.

High-Side Shunt Resistor

The use of a high-side shunt simplifies the wiring since now the load can be connected directly to the common battery ground, which is often available locally, for example in the form of the car chassis in automotive applications. Accordingly, one wire can be saved. The measurement circuit however requires additional two resistors R_3 and R_4 as voltage dividers. The most critical item of this solution is the offset adjustment and the relation between the 4 resistors R_1 to R_4 has to be adjusted carefully.

Although being simple, the shunt solution has several problems:

- **Voltage drop for measurement**: For a good resolution and an acceptable signal-to-noise ratio (SNR) a voltage drop in the range of 100 mV for full load is recommended. This is already 2 % in a 5 V application.
- **Voltage drop at the connectors of the shunt**: For higher currents, the shunt resistor is usually connected with screws. This gives an additional unspecified resistance added to the shunt value. A solution of this problem is the use of more expensive four pole resistors - two for the big current and two for the measurement voltage.
- **Power dissipation in the shunt resistor**: A simple example: R = 1 mΩ, I = 100 A. Consequently, U = 100 mV and the dissipated power is P = 10 W!

Table 1 Assessment: Current measurement with shunt resistor

Pros	Cons
Easy to implement	No galvanic isolation
DC and AC measurements	Voltage drop
	Power dissipation in the shunt resistor

Reference [2] gives a good overview about the state of the art in high current shunt measurements in modern power electronic modules.

2.2 Hall Effect Solution

An electric current generates a magnetic field around a conductor. The direction can be determined with the “right hand rule”. The field strength H, given in A/m, is directly proportional to the current I and decreases linearly with higher distances r according to

$$H = \frac{I}{2\pi r}. \qquad (2)$$

Using $B = \mu_0\mu_r H$, the flux density B can then be expressed as

$$B = \frac{\mu_0\mu_r I}{2\pi r}, \qquad (3)$$

where the material permeability μ_r is nearly unity for air and the free space permeability $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am is a constant. The flux density B can conveniently be measured using an integrated Hall effect IC.

Other than for the shunt solution, for current measurements using the Hall effect there is no resistor immersed into the primary circuit and accordingly no voltage drop happens nor is there any power lost. The measuring circuit is completely independent and galvanically separated, the only power consumed is the one from the Hall measurement device.

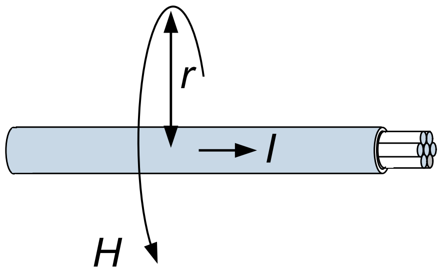


Figure 2 Magnetic field created around a conductor

Since we are interested in obtaining a continous signal that is proportional to the current, the devices to be used are so called linear Hall sensors. These devices deliver an output signal which is a linear function of the magnetic flux density passing perpendicularly through its Hall plate. In modern linear Hall ICs such as Infineon's TLE499x family, a Hall plate is integrated together with high precision readout and compensation circuitry on a single piece of silicon. Infineon's linear Hall ICs and their respective performance indicators are discussed in **Section 3**.

Although the direct measurement of the magnetic field of a conductor is possible, in practice it is advisable to use a field concentrator to both concentrate and boost the magnetic flux. Additionally, this soft magnetic concentrator helps to make the setup less prone to mechanical misalignments. Some design aspects regarding concentrators, including feedback structures for so-called closed-loop measurements will be discussed in **Section 4**.

Table 2 **Assessment: Hall Effect**

Pros	**Cons**
Galvanic isolation	Costs of field concentrator
DC and AC measurement	
No voltage loss	

3 Infineon's Portfolio of linear Hall ICs

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

Table 3 **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
TLE4998S	EEPROM	PG-SSO-3-9 PG-SSO-3-10 PG-SSO-4-1	SENT
TLE4998C	EEPROM	PG-SSO-3-9 PG-SSO-3-10 PG-SSO-4-1	SPC

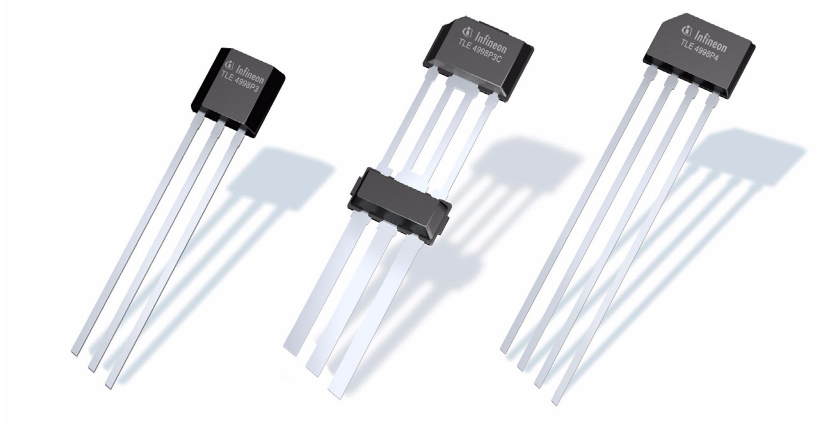


Figure 3 The three packages of Infineon's linear Hall sensors: PG-SSO-3-10, PG-SSO-3-9, PG-SSO-4-1 (from left to right).

3.1 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 comes in a small 3-pin PG-SSO-3-10 package.

3.2 TLE4998

The TLE4998 family is the successor of the TLE4997, providing innovations on the interface and lifetime stability side. The signal processing concept is basically 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 also 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 1 mm. The third package option is the PG-SSO-3-9, another 1 mm thick 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 because the multiple signal conversion from digital to analog and back can be avoided.

The TLE4998S is equivalent to the TLE4998P except for the interface, which is implemented as SAE's Single Edge Nibble Transmission (SENT) standard. SENT offers a low cost alternative to CAN and LIN, but still incorporates a coded digital signal transmission with a Cyclic Redundancy Check (CRC) to check the validity of a transmission. Apart from an industry-leading 16-bit Hall value, the transmitted SENT frame includes 8-bit temperature information and a 4-bit sensor status information. The temperature information can be used for plausibility checks. The transmission of status information finally allows for an improvement of overall system safety.

The TLE4998C features a Short PWM Code (SPC) Protocol, which is an extension to the standard SENT protocol and therefore offers all the advantages already present in the TLE4998S such as high resolution, status, temperature and CRC information. The sensor does however not send out the measured values indefinitely, but only after being triggered by the ECU. This functionality allows a synchronized transmission of data. The protocol additionally incorporates the possibility to select out of up to four sensors, which are connected to a single bus line. The benefits of this solution for current sensing are further outlined in **Section 6**.

4 Field Concentrators

Field concentrators basically consist of a soft magnetic material (high permeability and low remanence) surrounding the conductor. They are used for these main reasons:

- **Boost the Flux density**: The Flux density is increased with the effective permeability μ_r of the core. This leads to a typical amplification between a factor 20 and 70.
- **Positioning**: Without concentrator, the position of the sensor versus the conductor is highly dependent on the distance. Using a soft magnetic material toroid will effectively collect all the flux and concentrate it (therefore its name). Therefore, using such a core, the wire can be moved inside the aperture without a remarkable influence on the output voltage of the sensor.
- **Enabling Closed-Loop Systems**: Using a field concentrator, it becomes possible to impose a counteracting feedback-current on the same concentrator, allowing accurate closed-loop systems to be built.

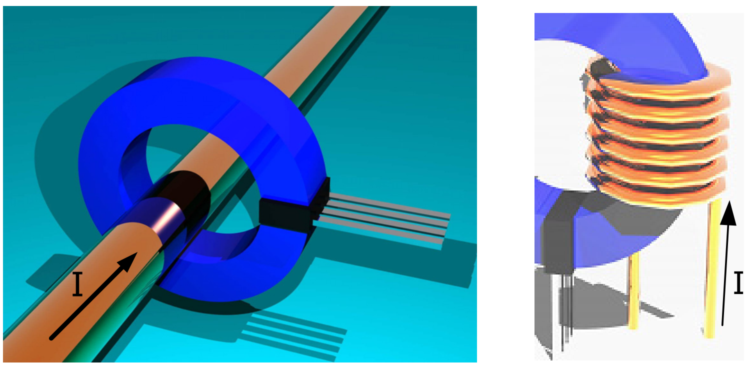


Figure 4 Flux concentrator (blue) surrounding the conductor. A Hall sensor is inserted in the air gap (left). The flux can further be boosted by using multiple windings of the principal conductor (right).

4.1 Open Loop Configuration

In the open loop configuration, there is no feedback path implemented. **Figure 4** schematically shows how field concentrators can be arranged around a conductor in an open loop configuration. The cross section of the concentrator core has to be at least the size of the Hall cell to minimize the sensitivity to effects like mechanical misplacement or external magnetic fields. Experience tells that the core area should be double the size of the sensor chip. In such an arrangement the magnetic flux through the sensor can be written using Ampere's law as

$$B = \frac{\mu_0 \mu_r I}{2\pi(r-d) + d\mu_r}, \tag{4}$$

and comparing this to **Equation (3)**, we can put it into the same form

$$B = \frac{\mu_0 \mu_e I}{2\pi r}, \tag{5}$$

where we have introduced the effective permeability of the toroid/air gap assembly μ_e given as

$$\mu_e = \frac{\mu_r}{1 + \frac{\mu_r d}{2\pi r} - \frac{d}{r}}, \tag{6}$$

In most practical cases $\mu_r d \gg 2\pi r$ and the effective permeability (e.g. the flux boosting strength) is approximately given by the ratio of the circumference $2\pi r$ of the toroid to the airgap d. With an airgap of 1 mm (as required e.g. for the PG-SSO-4-1 package) and a toroid diameter of 15 mm, the boosting factor is found to be about 50. As long as this approximation holds, the flux density becomes independent of the concentrator radius and can be written as

$$B = \frac{\mu_0 I}{d}. \tag{7}$$

Usually it is sufficient to lead the conductor wire straight through a toroid concentrator to get a sufficiently high magnetic field strength. Depending on the material, the minimal full range still reasonably achievable is in the area of 10 A. For lower currents, the wire can be wound in more turns around the toroidal concentrator whereby the reachable field is directly proportional to the number of turns. **Figure 4** shows an example for a ring core with one wire through the center as well as a PCB mountable version with 6 turns. For the latter case, the measured magnetic flux density is multiplied by the number of conductor windings and can be expressed as

$$B = \frac{N\mu_0 I}{d}, \tag{8}$$

where N is the number of windings. The linear Hall sensors detect this flux density and the sensor output is programmable in the form

$$OUT = S \cdot B + OS = \frac{SN\mu_0 I}{d} + OS, \tag{9}$$

where S is the sensor's sensitivity and OS is the offset. Both these parameters are programmable, meaning that any first order transfer function can be chosen (within the parameter range limits) to adapt to the required measurement range. It is in particular possible to program either uni- or bipolar behaviour. **Section 5** will give an example of a TLE4998S-based open loop current sensor, elaborating more on the meaning of **Equation (9)**.

4.2 Closed-Loop Configuration

In the open loop configuration, most errors arise when high currents exhibit relatively large magnetic flux densities in the concentrator. The concentrator material has the best properties around 0 mT (best linearity and temperature behaviour), and the Hall sensor accuracy is also higher because multiplicative sensitivity errors are decreased and only the comparably small additive offset errors remain. To avoid these high magnetic fields, a closed loop circuit topology can be chosen in which a counteracting drive-current creates an opposing magnetic flux. Both primary and feedback conductors need to act on the same magnetic concentrator as shown in **Figure 5**.

Using an appropriate control circuit, this current can be scaled in such a way that the resulting magnetic flux in the measurement gap becomes zero, deviations from which are sensed by a linear Hall effect sensor inserted in the field concentrator gap. A possible electronic setup for such a closed-loop configuration is also shown in **Figure 5**. The negative feedback loop, through supplying the appropriate amount of compensation current, always tends to drive the sensor output towards Vdd/2 (assuming it is programmed to have a mid-rail output at 0 mT). The secondary current can then be measured using a small sense resistor R_{sens}. Ideally, the secondary conductor has many windings, therefore multiplying its flux generating ability. This way, the amount of compensation current can be significantly reduced. A module with a 1000 turn coil provides an output of 1 mA per Ampere in the primary circuit.

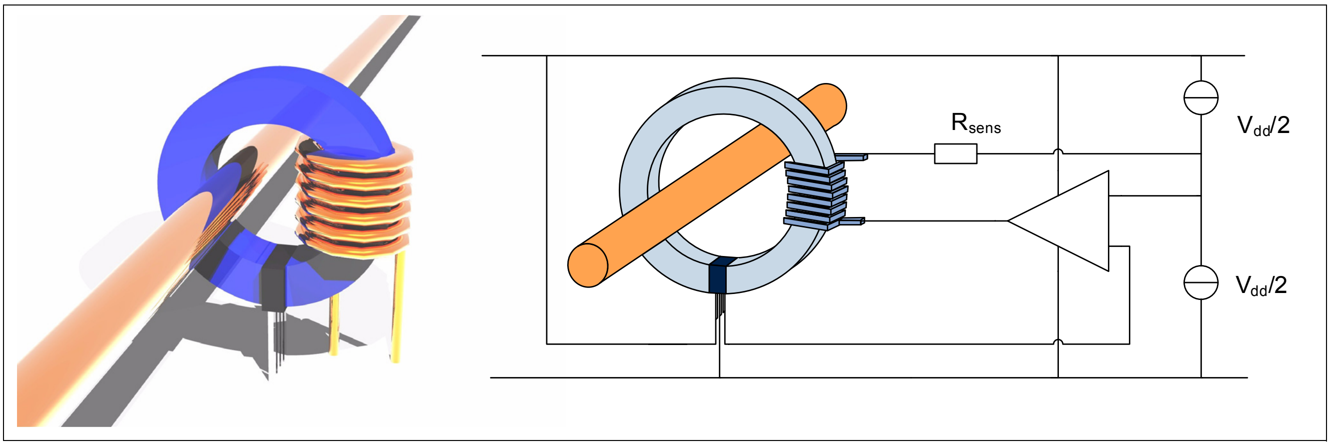


Figure 5 **Closed-loop configuration including primary conductor as well as feedback windings and a possible driving circuit**

On the downside, a closed loop current sensor draws substantially higher supply current and the measurement range may as well be reduced by the driving capability limitation of the chosen amplifier. The electric design is more complex and aspects like stability have to be addressed. The setup also requires more circuit components as well as additional wires / windings, leading to a higher price tag than the comparably simple open-loop configuration.

4.3 Concentrator Materials

There are different materials available to create field concentrator cores. The selection is determined according to criteria such as material performance (μ_r, remanence), current measurement range requirements, mechanical shape and cost. Some common materials for field concentrators are listed and described subsequently.

Ferrite

Ferrites are the cheapest material. Their main disadvantage is the high remanence. To keep the remanence low, it is important to have a high initial permeability μ_i. After the application of a higher current, the core preserves a rest of the magnetic field, leading to an offset error. This remaining field can be erased with a current in the other direction. The best protection against ending up with remanent fields is to avoid high current spikes.

Iron Powder

Iron powder cores can be used for the measurement of higher currents. As their μ_e is about 50% lower compared to ferrites, it can be used for current values above 200 A. The lower μ_e allows the use of smaller air gaps as well, leading to a better shielding of the sensor against external fields.

Alloys

Materials like $NiFe_{15}Mo$ are available in the form of thin tapes. They can be punched into the form of E-cores.

Amorphous Soft Magnetic Material

Materials like $Fe_{73}Cu_1Nb_3Si_{16}B_7$ have extremely low remanence values. Their saturation lies between 0.6 and 1 T. Their μ_r is in the same range as the one of ferrites. The sophisticated production process however leads to a price about three times higher compared to ferrite materials. Amorphous materials are produced as extremely thin foils and it is possible to wind them into ring cores. After soaking in a thin fluid epoxy glue, the hardened (yet still brittle) core can be mechanically postprocessed and an air gap can be sawed in it accordingly.

5 Application Example: Open-Loop Current Sensor Using TLE4998S

The TLE4998S, as described above, has a 16bit output, producing digital values between 0 and 65535 digits (LSB, least significant bits). The sensitivity is programmable between ±131.2 LSB/mT and ±3920 LSB/mT. In order to avoid distortions, the maximum field however needs to be limited to ±200 mT (given the appropriate ±200 mT range is chosen). This means that 400 mT are mapped on 65535 LSB, leading to the minimum practicable sensitivity of 65535 / 400 = 164 LSB/mT.

Maximum Current

Equation (8) can be used to derive the maximum possible measurement current range. The following maximum current can be measured in a single-winding setup using a 1 mm airgap:

$$I_{max} = \frac{B_{max} d}{\mu_0 N} = \frac{\pm 200 \times 10^{-3} \cdot 1 \times 10^{-3}}{4\pi \times 10^{-7} \cdot 1} = \pm 159\,\text{A}. \tag{10}$$

If even higher currents need to be measured, larger airgaps d are the most suitable possibility (e.g. 1.5mm for the PG-SSO-3-10 package). Please note that the sensor IC is not destroyed at higher currents, but that the Hall sensor would simply saturate.

Accuracy

We will only focus on Hall-IC related errors and not go into detail about the core-related deviations which depend heavily on the chosen material as discussed in **Section 4.3**. The major sources of error for linear Hall ICs are offset and sensitivity errors. We will now look into the achievable accuracy of a current sensor based on the TLE4998S designed for a ±100 A range. Using **Equation (9)**, the programmed sensitivity is found to be 261 LSB/mT.

Offset errors are additive, meaning that their contribution is the same regardless of whether the sensor sees 0 mT or 100 mT (see **Figure 6**). Offset errors can result due to production spread, temperature and mechanical stress variations or lifetime effects. Infineon's linear Hall sensors are programmable and therefore allow to calibrate out any spreads due to production spread. The remaining errors are specified to be ±400 uT over temperature and lifetime for the TLE4998S. Referred to the input using **Equation (7)**, this corresponds to a maximum offset error of ±0.32 A. If the sensor is used in a smaller temperature window, the typical performance will be much better than this worst case performance.

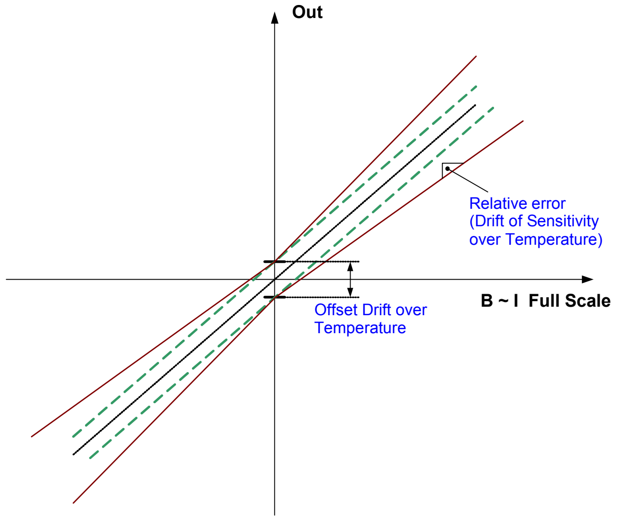


Figure 6 Additive offset errors and multiplicative sensitivity errors

Sensitivity errors are multiplicative, meaning that their contribution scales with the applied magnetic field: They vanish at 0 mT but become important at large fields. For the TLE4998S, the sensitivity drift is specified to be below ±150 ppm/°C. As an example, between 25°C and 85°C, the sensitivity could drift by ±150 ppm/°C x 60°C = ±0.9%. In the worst case for the discussed ±100 A current sensor, this corresponds to a drift of ±100 A x 0.9 % = ±0.9 A. As the error scales with applied current, the error is less important for lower currents. As an example, at ±20 A current it reduces to ±20 A x 0.9% = ±0.18 A. Again, the typical measurements are better than this worst case performance.

The linearity of the linear Hall sensors are usually very good: For the TLE4998S, the integral nonlinearity (INL) is specified to be below 0.1% of the magnetic field range.

Errors due to hysteresis are important to be considered on the module level, for the Hall IC itself, there is however no need to worry. The linear Hall ICs inherently have a very low hysteresis of some uT, which is negligible compared to the other error contributions. To summarize, **Table 4** gives an overview of the discussed Hall IC related contributions affecting the accuracy of a current sensor.

Table 4 Overview: Hall sensor IC relative error contributions for a 100 A current sensor

Contribution	Effect at 0 A	Effect at 20 A	Effect at 100 A
Offset errors	medium	medium	medium
Sensitivity errors	none	medium	large
Linearity errors	small	small	small
Hysteresis errors	negligible	negligible	negligible

Resolution and Noise

One big advantage of the TLE4998S is its resolution. While common analog interfaces are limited in resolution, the digital SENT interface now allows the transmission of a 16 bit value. For a ±100 A sensor, this corresponds to 3 mA steps. The high resolution is only achievable if the sensor output is averaged over several samples as there is an rms noise of about 16 LSB (typical) present at the sensor output. A digital programmable low pass filter implemented in the sensor allows a trade-off between speed and effective resolution.

Speed

The response time of a current sensor is an important aspect. The SENT protocol has a transmission time that is dependent on the chosen SENT unit time as well as on the data content, but is smaller than 1ms, allowing a data update frequency of about 1 kHz. If higher speeds are needed, the TLE4998C with the SPC protocol is a possible choice, which allows to shorten the number of transmitted nibbles and thus increases the update frequency. Analog sensors such as the TLE4990 or the TLE4997 are another choice, the cut-off frequency of the TLE4997 being at 3.2 kHz.

Sensor Design

As an example design, the CCS T4610 from Epcos is shown in **Figure 7**, which uses the TLE4998S4[1]. A permalloy field concentrator is placed horizontally with the TLE4998S inserted into a thin airgap. The device can easily be integrated on a PCB and the primary measurement current of up to ±100 A is directed through the center mounting hole.

1) For further information, please contact Epcos AG, IN TCF PMD, Anzinger Str. 13, 81671 Munich, Germany

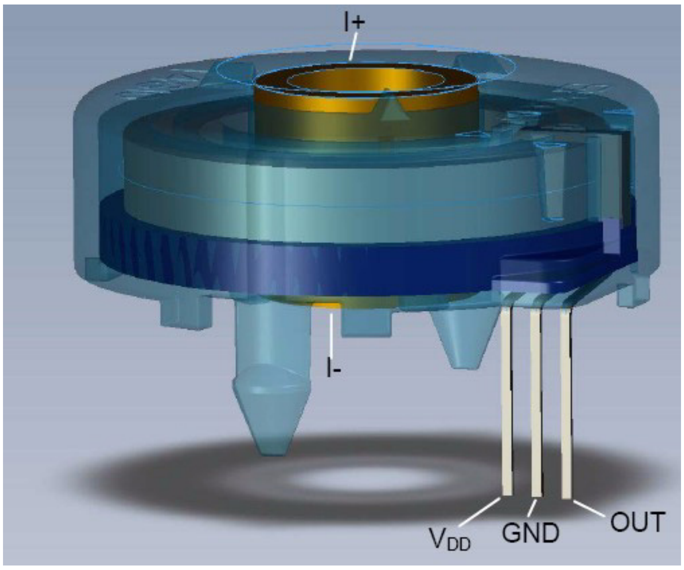


Figure 7 Epcos CCS T4610 open-loop current sensor using the TLE4998S4

6 Application Example: Current Sensor Using TLE4998C in Range Selection Mode

The TLE4998C features the digital SPC protocol, which is derived from the SENT protocol used in the TLE4998S and also allows the same 16-bit high resolution transmission. Other than SENT, SPC however allows for a synchronous transmission of the data after the master requests it. One mode allows to dynamically select the measurement range of the sensor as either ±50, ±100 and ±200 mT by the master. This feature is particularly interesting for current sensing as it allows the measurement accuracy at smaller currents to be improved up to a factor of four all by maintaining the high maximum range to be covered. **Figure 8** shows how a master trigger pulse of varying length is used to set the sensor into the desired range. The whole synchronous transmission is possible on only one wire owing to the open drain output stage of the sensor (for more details on SPC specifics, please refer to the TLE4998C datasheet.

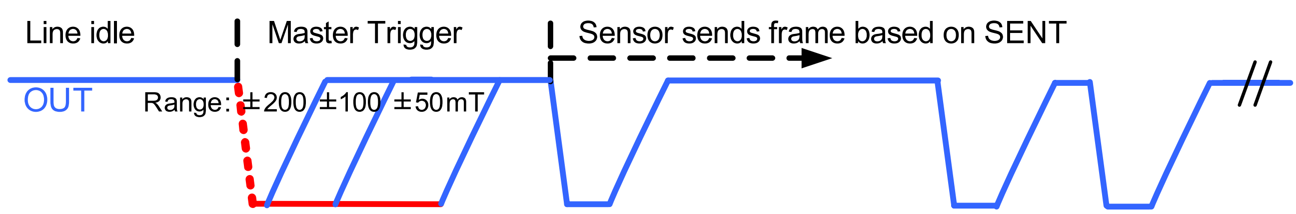


Figure 8 Range selection feature of the SPC protocol implemented in the TLE4998C

Data On Request

With SPC, it is possible for the master to gather sensor data only on request and leave the line idle otherwise. This way it is also possible to know exactly at what point the data is sampled.

Resolution Improvements

The dynamic range selection allows the master to set the current sensor into the appropriate range according to the present current level. For example, one could distinguish between high start-up current, medium operation currents and low idle currents and get the best resolution out of every operating range. The full range of the Hall sensor is better used and the resolution can be improved up to a factor of four for the smaller current ranges.

7 Conclusion

This application note has introduced some aspects of current sensor designs. From the different presented sensing solutions, Hall-effect based current sensors have the big advantage of allowing galvanically isolated measurements without voltage losses on the primary circuit. It was shown how Infineon's linear Hall effect sensors help to design programmable, high accuracy, high resolution current sensors for many different applications. Finally, the given explanations on field concentrator design and concrete examples based on the TLE4998S and TLE4998C help the reader to understand the possibilities and advantages offered by current sensors based on Infineon's linear Hall ICs.

References

[1] "CCS T4610 Hall Effect-based Directly Mapping Digital Current Sensor", Preliminary Data Sheet, Rev. 1.5, Epcos AG, December 2008.

[2] "A Progressive Way to Integrate Current Measurement into Modern Power Electronic Systems", Martin Schulz, Infineon Technologies AG, PCIM Europe, June 2008.

Terminology

AC	Alternate Current
ADC	Analog to Digital Converter
CAN	Controller Area Network
CRC	Cyclic Redundancy Check
DC	Direct Current
DSP	Digital Signal Processor
ECU	Electronic Control Unit
IC	Integrated Circuit
INL	Integral Nonlinearity
LIN	Local Interconnect Network
LSB	Least Significant Bit
PCB	Printed Circuit Board
ppm	Parts Per Million
PWM	Pulse Width Modulation
SAE	Society of Automotive Engineers
SENT	Single Edge Nibble Transmission (Protocol)
SPC	Short PWM Codes Protocol

w w w . i n f i n e o n . c o m

Published by Infineon Technologies AG