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Data Sheet, V 2.08, September 2008

TLE4997

Programmable Linear Hall Sensor

Sensors

Never stop thinking.

Edition 2008-09

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Revision History: **2008-09** V 2.08

Previous Version: V 2.07, July 2008

Page	Subjects (major changes since last revision)
12	*Table 2: ESD specification (HBM) changed from 2kV to 4kV*
general	*spelling and typing errors*

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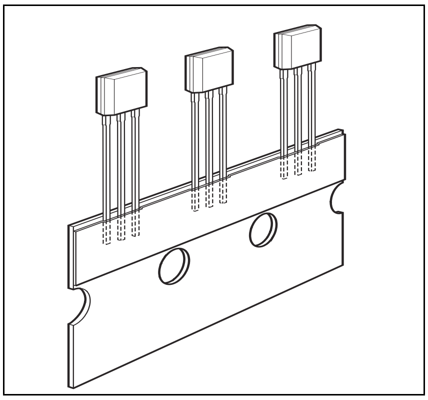

1.1 Features

- High linear and ratiometric push-pull rail-to-rail output signal
- 20-bit Digital Signal Processing
- Digital temperature compensation
- 12-bit overall resolution
- Operates from -40°C up to 150°C
- Low drift of output signal over temperature and lifetime
- Programmable parameters stored in EEPROM with single bit error correction:
  - magnetic range and magnetic sensitivity (gain)
  - zero field voltage (offset)
  - bandwidth
  - polarity of the output slope
  - clamping option
  - temperature coefficient for all common magnets
  - memory lock
- Re-programmable until memory lock
- Single supply voltage 4.5 - 5.5 V (4 - 7 V in extended range)
- Operation between -200 mT and +200 mT within three ranges
- Slim 3-pin package (Green)
- Reverse polarity and overvoltage protection for all pins
- Output short circuit protection
- On-board diagnostics (wire breakage detection, undervoltage, overvoltage)
- Digital readout of internal temperature and magnetic field values in calibration mode.
- Individual programming and operation of multiple sensors with common power supply
- Two-point calibration of magnetic transfer function
- Precise calibration without iteration steps
- High immunity against mechanical stress, EMC, ESD

Type	Marking	Ordering Code	Package
TLE4997	4997E2	SP000235288	PG-SSO-3-10

1.2 Target Applications

- Robust replacement of potentiometers
  - No mechanical abrasion
  - Resistant to humidity, temperature, pollution and vibration
- Linear and angular position sensing in automotive applications like pedal position, suspension control, valve or throttle position, headlight levelling and steering angle
- High current sensing for battery management, motor control, and electronic fuse

1.3 Pin Configuration

Figure 1 shows the location of the Hall element in the chip and the distance between the Hall probe and the surface of the package.

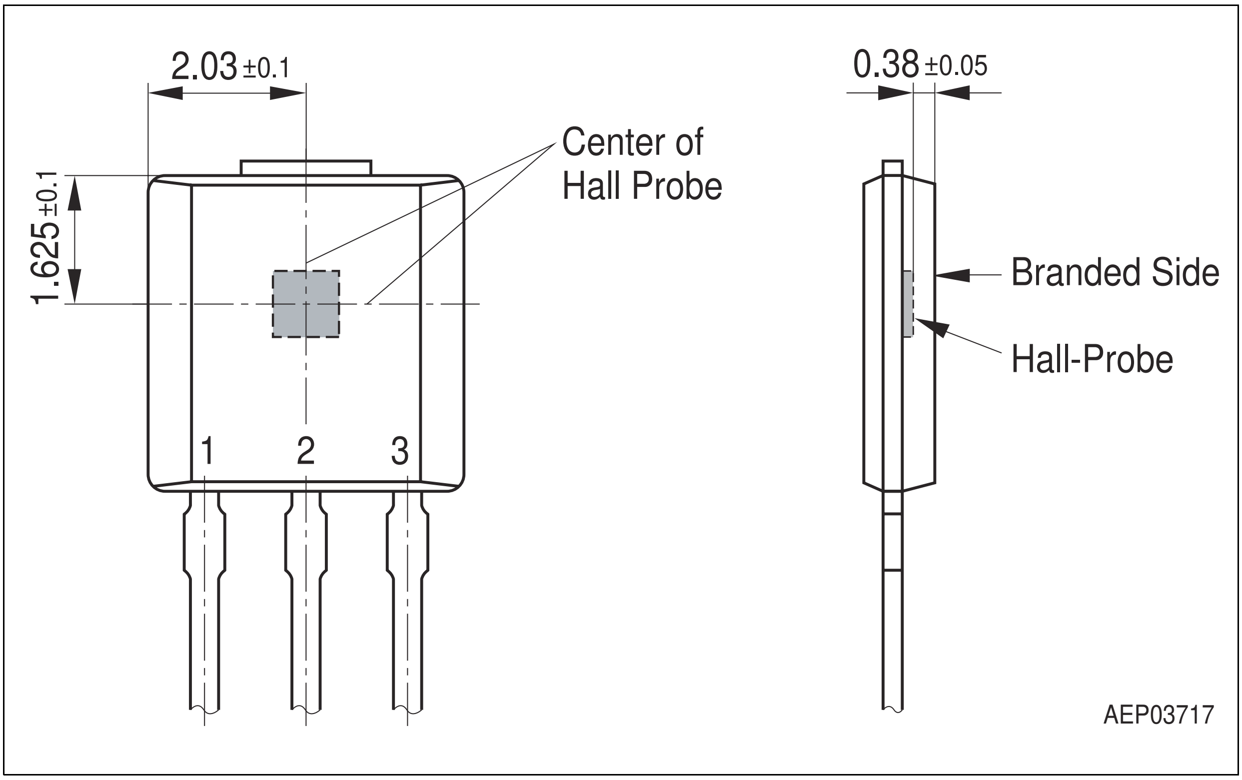

Figure 1 Pin Configuration and Hall Cell Location

Table 1 Pin Definitions and Functions

Pin No.	Symbol	Function
1	V_{DD}	Supply voltage / programming interface
2	GND	Ground
3	OUT	Output voltage / programming interface

2 General

2.1 Block Diagram

Figure 2 shows a simplified block diagram.

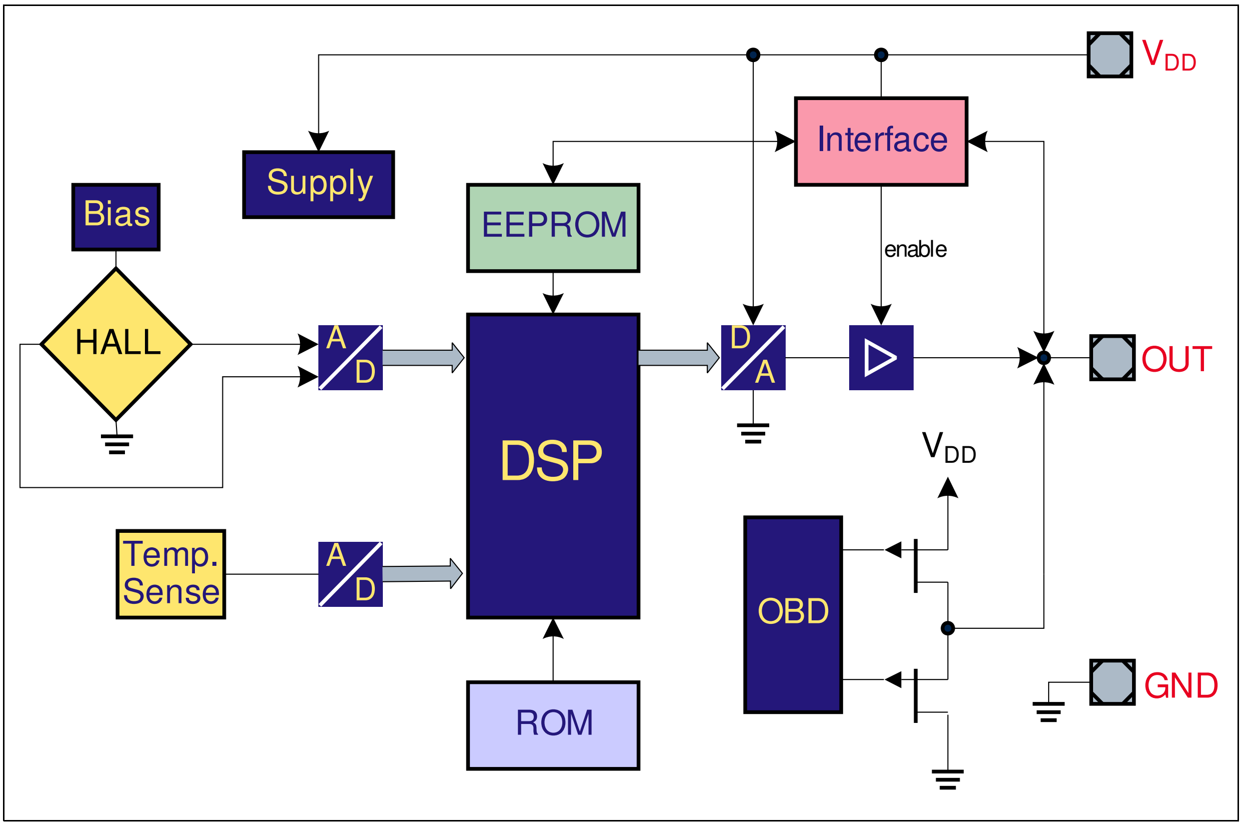

Figure 2 Block Diagram

2.2 Functional Description

The linear Hall IC TLE4997has been designed specifically to meet the demands of highly accurate rotation and position detection, as well as for current measurement applications.

The sensor provides a ratiometric analog output voltage, which is ideally suited to Analog-to-Digital (A/D) conversion with the supply voltage as a reference.

The IC is produced in BiCMOS technology with high voltage capability and also provides reverse polarity protection.

Digital signal processing using a 16-bit DSP architecture and digital temperature compensation guarantees excellent stability over a long period of time.

The minimum overall resolution is 12 bits. Nevertheless, some internal stages work with resolutions up to 20 bits.

2.3 Principle of Operation

- A magnetic flux is measured by a Hall-effect cell.
- The output signal from the Hall-effect cell is converted from Analog to Digital signals.
- The chopped Hall-effect cell and continuous-time A to D conversion provide very low and stable magnetic offset.
- A programmable Low-Pass filter reduces the noise.
- The temperature is measured and A to D converted.
- Temperature compensation is processed digitally using a second order function.
- Digital processing of output voltage is based on zero field and sensitivity value.
- The output voltage range can be clamped by digital limiters.
- The final output value is D to A converted.
- The output voltage is proportional to the supply voltage (ratiometric DAC).
- An On-Board-Diagnostics (OBD) circuit connects the output to V_{DD} or GND in case of errors.

2.4 Further Notes

Product qualification is based on “AEC Q100 Rev. G” (Automotive Electronics Council - Stress test qualification for integrated circuits).

2.5 Transfer Functions

The examples in **Figure 3** show how easily different magnetic field ranges can be mapped to the output voltage.

- Polarity Mode:
  - **Unipolar**: Only North- or South-oriented magnetic fields are measured.
  - **Bipolar**: Magnetic fields can be measured in both orientations.
    The limit points must not be symmetric to the zero field point.
- Inversion: The gain values can be set positive or negative.

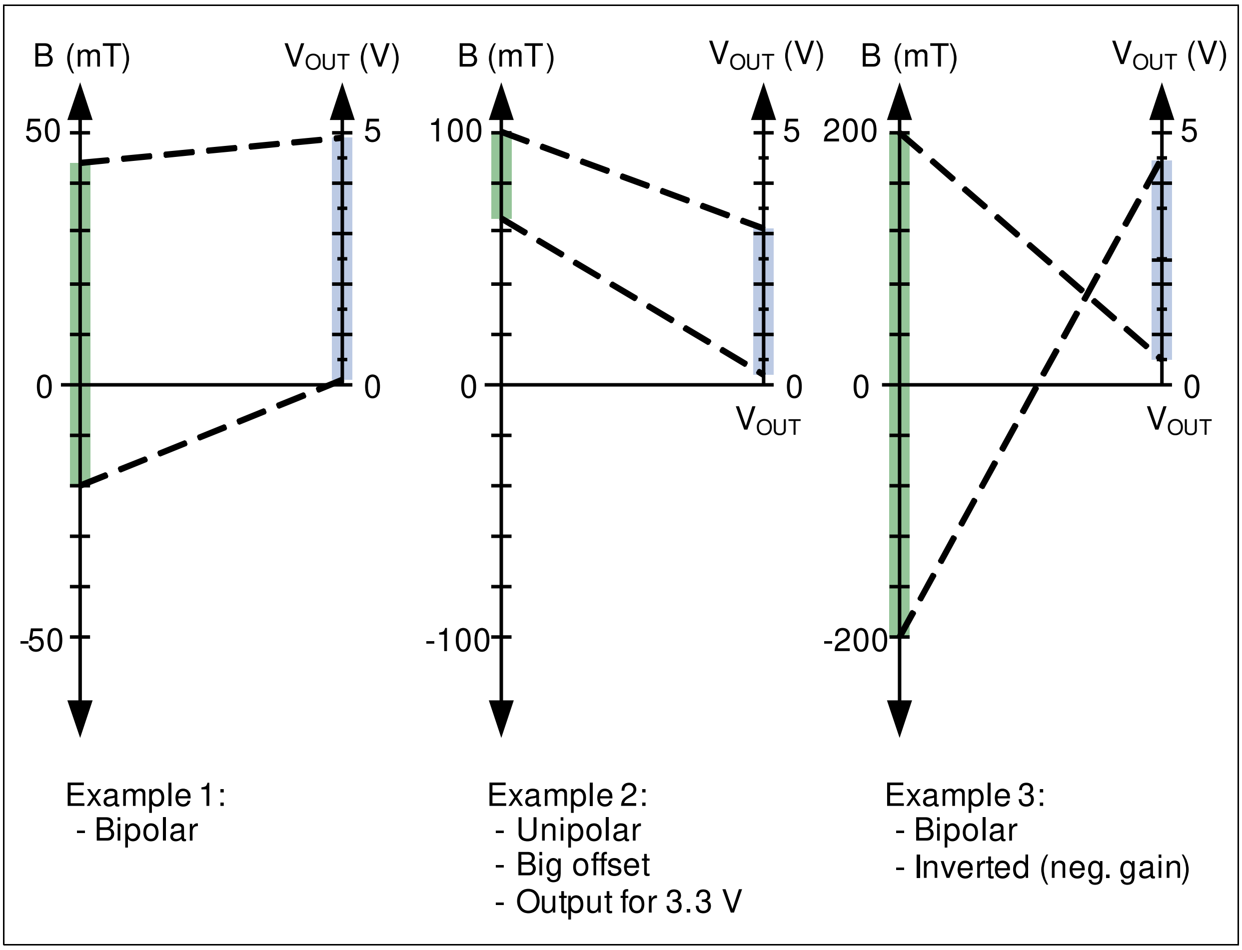

Figure 3 Examples of Operation

Note: Due to the ratiometry, voltage drops at the V_{DD} *line are imaged in the output signal.*

3 Maximum Ratings

Table 2 Absolute Maximum Ratings

Parameter	Symbol	Limit Values		Unit	Notes
		min.	max.		
Storage temperature	T_{ST}	-40	150	°C	
Junction temperature	T_J	-40	170	°C	For 96h [1]
Voltage on V_{DD} pins with respect to ground (V_{SS})	V_{DD}	-20 [2]	20 [3]	V	[4] $R_{THja} \leq 150$ K/W
Supply current @ overvoltage	I_{DDov}	-	52	mA	
Supply current @ reverse voltage	I_{DDrev}	- 75	-	mA	
Voltage on output pin with respect to ground (V_{SS})	V_{OUTov}	-16 [5]	16 [3]	V	$R_{THja} \leq 150$ K/W V_{out} may be > V_{DD}
Magnetic field	B_{MAX}	-	unlimited	T	
ESD protection	V_{ESD}	-	4.0	kV	According HBM JESD22-A114-B [6]

[1] For limited time only. Depends on customer temperature lifetime cycles. Please ask for support by Infineon.

[2] max 24 h @ -50°C $\leq T_a < 30$°C
max 10 min. @ 30°C $\leq T_a < 80$°C
max 30 sec. @ 80°C $\leq T_a < 125$°C
max 15 sec. @ 125°C $\leq T_a \leq 150$°C.

[3] max. 24 h @ $T_J < 80$°C.

[4] Guaranteed by laboratory characterization, tested at ±18V.

[5] Max. 1 ms @ $T_J < 30$°C; -8.5 V for 100 h @ $T_J < 80$°C.

[6] 100 pF and 1.5 kΩ

Note: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Furthermore, only single error cases are assumed. More than one stress/error case may also damage the device.

Exposure to absolute maximum rating conditions for extended periods may affect device reliability. During absolute maximum rating overload conditions ($V_{IN} > V_{DD}$ or $V_{IN} < V_{SS}$) the voltage on V_{DD} pins with respect to ground (V_{SS}) must not exceed the values defined by the absolute maximum ratings.

4 Operating Range

The following operating conditions must not be exceeded in order to ensure correct operation of the TLE4997. All parameters specified in the following sections of this document refer to these operating conditions, unless otherwise indicated.

Table 3 Operating Range

Parameter	Symbol	Limit Values		Unit	Notes
		min.	max.		
Supply voltage	V_{DD}	4.5	5.5	V	
		4	7	V	Extended range [1]
Output current	I_{OUT}	-1	1	mA	[2]
Load resistance	R_L	10 10	- -	kΩ	Pull-down to *GND* Pull-up to V_{DD}
Load capacitance	C_L	0	210	nF	
Junction temperature [3]	T_J	-40	125 150	°C	For 5000h For 1000h[4] [5]
Useful lifetime	t_{Live}	-	16	years	

[1] For reduced output accuracy.

[2] For V_{OUT} within the range of 5% ... 95% of V_{DD}.

[3] $R_{THja} \leq 150$ K/W.

[4] For reduced magnetic accuracy.

[5] Not additive.

Note: Keeping signal levels within the limits specified in this table ensures operation without overload conditions.

5 Electrical and Magnetic Parameters

Table 4 Electrical Characteristics

Parameter	Symbol	Limit Values			Unit	Notes
		min.	typ.	max.		
Output voltage range	V_{OUT}	5 6	-	95 94	% of V_{DD}	For $T_A \le 120$°C For $T_A > 120$°C
Supply current	I_{DD}	3	7.5	10	mA	[1]
Output current @ OUT shorted to supply lines	I_{OUTsh}	-30	-	30	mA	For operating supply voltage range only
Zero field voltage	V_{ZERO}	-100	-	100	%	Of V_{DD} [2]
Zero field voltage drift	ΔV_{ZERO}	-10	-	10	mV	In lifetime [3]
		-10	-	10	mV	Error band ov. temp.[4]
Ratiometry error	E_{RAT}	-0.25	-	+0.25	%	Of V_{DD}[4][5]
Thermal resistance	R_{thJA}	-	-	219	K/W	Junction to air
	R_{thJC}	-	-	47	K/W	Junction to case
Power on time	t_{Pon}	-	-	1 10	ms	$\Delta V_{OUT} \le \pm 5\%$ of V_{DD} $\Delta V_{OUT} \le \pm 1\%$ of V_{DD}
Power On Reset level	V_{DDpon}	2	-	4	V	
Output DAC quantization	ΔV_{OUT}	1.22			mV	@ $V_{DD} = 5$ V
Output DAC resolution	-	12			bit	
Output DAC bandwidth	f_{DAC}	-	3.2	-	kHz	Interpolation filter [6]
Output noise	V_{noise}	-	-	4.68	mV_{pp}	5% exceeded [7][8]
Differential non-linearity	DNL	-1	-	1	LSB	Of output DAC
Signal delay	t_{DS}	-	-	250	µs	@ 100 Hz [9]

---

[1] Also in extended V_{DD} range. For V_{OUT} within the range of 5%... 95% of V_{DD}, I_{OUT}= 0mA.

[2] Programmable in steps of 1.22 mV (@ $V_{DD} = 5$V).

[3] For Sensitivity $S \le 25$ mV/mT. For higher sensitivities the magnetic offset drift is dominant. This means that for the precalibrated (typical) 60mV/mT sensitivity the typical output drift might be given due to the allowed magnetic offset tolerence up to ±0.4mT x 60 mV/mT = ±24 mV.

[4] For $4.5\text{ V} \le V_{DD} \le 5.5$ V and within nominal V_{OUT} range; see **"Ratiometry" on Page 15** for details on E_{RAT}.

[5] For the maximum error in the extended voltage range, see **"Ratiometry" on Page 15**.

[6] More information, see **"DAC Input Interpolation Filter" on Page 22**.

[7] 100 mT range, sensitivity 60 mV/mT, LP-filter 244 Hz, 160 Hz external RC low pass filter as application circuit.

[8] '5% exceeded' means that 5 of 100 continuously measured V_{OUT} samples are out of limit.

[9] A sinusoidal magnetic field is applied, V_{OUT} shows amplitude of 20% of V_{DD}, no LP filter is selected.

Ratiometry

The linear Hall sensor works like a potentiometer. The output voltage is proportional to the supply voltage. The division factor depends on the magnetic field strength. This behavior is called “ratiometric”.

The supply voltage V_{DD} should be used as the reference for the A/D Converter of the microcontroller. In this case, variations of V_{DD} are compensated.

The ratiometry error is defined as follows:

$$E_{RAT} = \left(\frac{V_{OUT}(V_{DD})}{V_{DD}} - \frac{V_{OUT}(5\text{V})}{5\text{V}} \right) \times 100\ \%$$

The ratiometry error band displays as a “Butterfly Curve”.

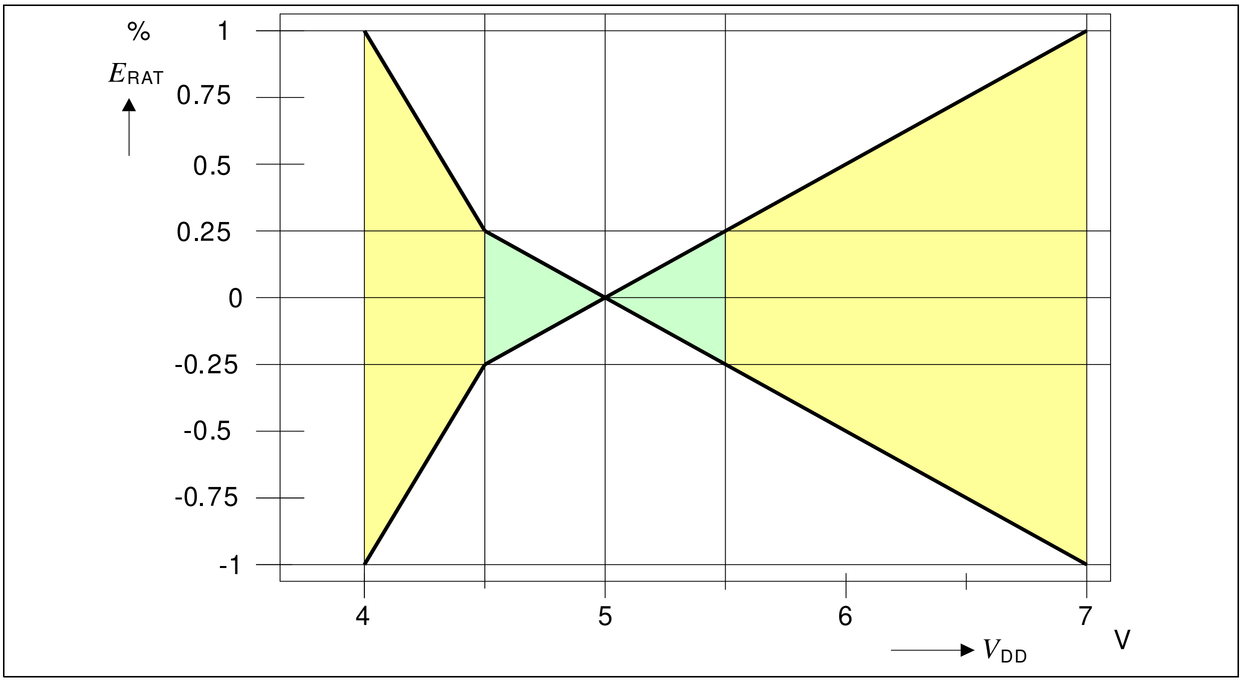

Figure 4 Ratiometry Error Band

Note: Take care of possible voltage drops on the V_{DD} and V_{OUT} line degrading the result. Ideally, both values are acquired and their ratio is calculated to gain the highest accuracy. This method should be used especially during calibration.

Calculation of the Junction Temperature

The total power dissipation P_{TOT} of the chip increases its temperature above the ambient temperature.

The power multiplied with the total thermal resistance R_{thJA} (Junction to Ambient) leads to the final junction temperature. R_{thJA} is the sum of the addition of the values of the two components *Junction to Case* and *Case to Ambient*.

$$R_{thJA} = R_{thJC} + R_{thCA}$$

$$T_J = T_A + \Delta T$$

$$\Delta T = R_{thJA} \times P_{TOT} = R_{thJA} \times (V_{DD} \times I_{DD} + V_{OUT} \times I_{OUT}) \qquad I_{DD}, I_{OUT} > 0, \textit{ if direction is into IC}$$

Example (assuming no noticeable load on Vout):

- $V_{DD} = 5$ V
- $I_{DD} = 10$ mA
- $\Delta T = 219$ [K/W] x (5 [V] x 0.01 [A] + 0 [VA]) = 11 K

For moulded sensors, the calculation with R_{thJC} is more adequate.

Magnetic Parameters

Table 5 Magnetic Characteristics

Parameter	Symbol	Limit Values			Unit	Notes
		min.	typ.	max.		
Sensitivity	S	± 12.5	-	± 300	mV/mT	[1] [2]
Magnetic field range	MFR	± 50	± 100[3]	± 200	mT	Programmable [4]
Integral nonlinearity	INL	-15	-	15	mV	= ± 0.3% of V_{DD}[5]
Magnetic offset	B_{OS}	-400	-	400	µT	[6] [7] [8]
Magnetic offset drift	ΔB_{OS}	- 5	-	5	µT / °C	Error band [7]

[1] Programmable in steps of 0.024%.

[2] @ $V_{DD} = 5$ V and $T_J = 25$°C

[3] This range is also used for temperature and offset pre-calibration of the IC.

[4] Depending on the Offset and Gain settings, the output may saturate at lower fields.

[5] INL = $V_{out} - V_{out,lse}$ with $V_{out,lse}$ = least square error fit of V_{out}.
Valid in the range (5% of V_{DD}) < V_{OUT} < (95% of V_{DD}) for $T_J \le 120$°C
and (6% of V_{DD}) < V_{OUT} < (94% of V_{DD}) for 120°C < $T_J \le 150$°C

[6] In operating temperature range and over lifetime.

[7] For Sensitivity $S > 25$ mV / mT. For lower sensitivities, the zero field voltage drift is dominant.

[8] Measured at ± 100 mT range.

6 Signal Processing

The flow diagram in **Figure 5** shows the data processing algorithm.

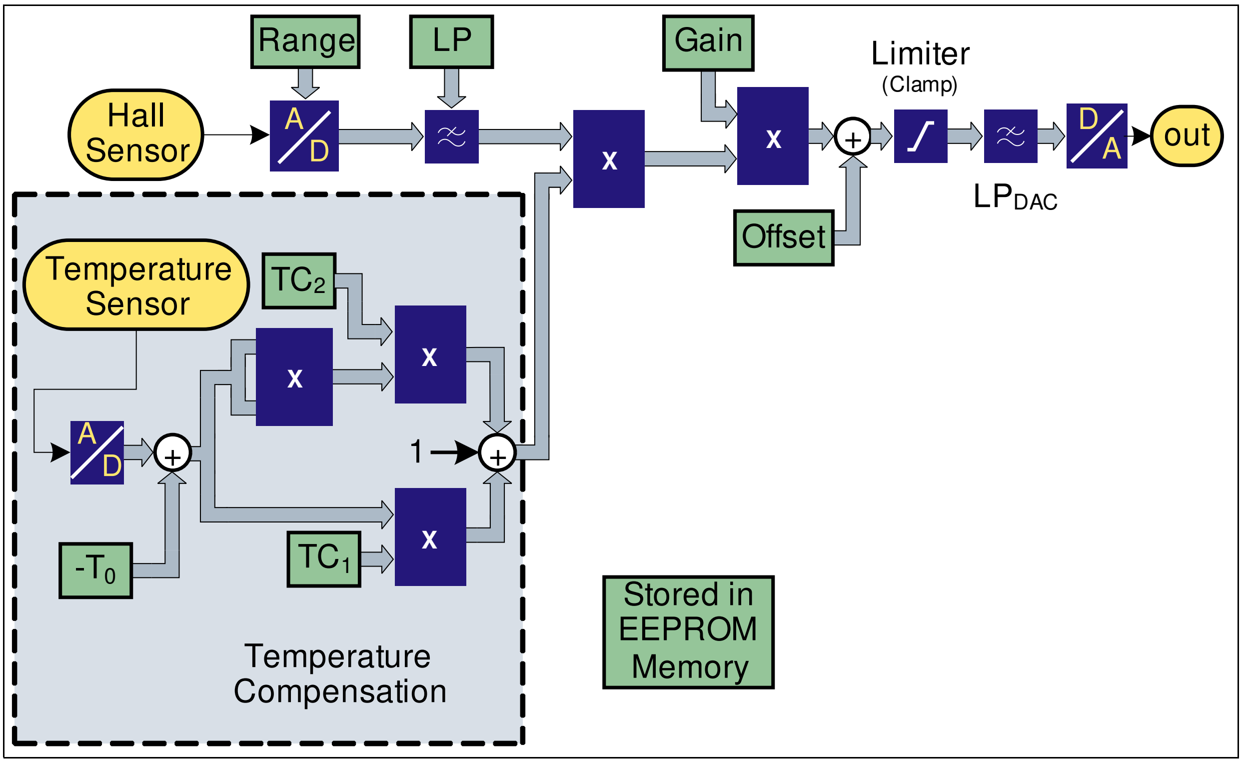

Figure 5 Signal Processing Flow

Magnetic Field Path

- The analog output signal of the chopped Hall cell is converted in the continuous-time A/D Converter. The range of the chopped A/D Converter can bet set in several steps (see **Table 6**). This assures a suitable level for the A/D Converter.
- After the A/D conversion, a digital low pass filter reduces the bandwidth (**Table 10**).
- A multiplier amplifies the value according to the gain setting (see **Table 8**) plus temperature compensation.
- The offset value is added (see **Table 9**).
- A limiter reduces the resulting signal to 12 bits and feeds the D/A converter.

Temperature Compensation

(Details are listed in **Chapter 8**)

- The output signal of the temperature cell is also A/D converted.
- The temperature is normalized by subtraction of the T_0 value (zero point of the quadratic function).
- The linear path is multiplied with the TC_1 value.

- In the quadratic path, the difference temperature is squared and multiplied with the TC_2 value.
- Both path outputs are added together to the gain value from the EEPROM.

6.1 Magnetic Field Ranges

The working range of the magnetic field defines the input range of the A/D Converter. It is always symmetric to the zero field point. Any two points in the magnetic range can be selected to be the end points of the output curve. The output voltage represents the range between the two points.

In the case of fields higher than the range values, the output signal may be distorted.

The range must be set before the calibration of offset and gain.

Table 6 Range Setting

Range	Range in mT	Parameter R
Low	± 50	3
Mid	± 100	1
High	± 200	0

Table 7 Range

Parameter	Symbol	Limit Values		Unit	Notes
		min.	max.		
Register size	R	2		bit	1)

---

1) Ranges do not have a guaranteed absolute accuracy. The temperature pre-calibration is performed in the mid range (100 mT).

6.2 Gain Setting

The sensitivity is defined by the range and the gain setting. The output of the A/D Converter is multiplied with the gain value.

Table 8 Gain

Parameter	Symbol	Limit Values		Unit	Notes
		min.	max.		
Register size	G	15		bit	Unsigned integer value
Gain range	$Gain$	- 4.0	3.9998	-	[1][2]
Gain quantization steps	$\Delta Gain$	244.14		ppm	Corresponds to $1/4096$

[1] For gain values between - 0.5 and + 0.5, the numeric accuracy decreases.
To obtain a flatter output curve, it is recommended to select a higher range setting.

[2] A gain value of +1.0 corresponds to a typical 40 mV/mT sensitivity (100 mT range, not guaranteed). Infineon pre-calibrates the samples to 60mV/mT (100mT range) in the final test, but does not guarantee the accuracy of this calibration. It is crucial to do a final calibration of each IC within the application using the Gain/V_{OS} value.

The gain value can be calculated by

$$Gain = \frac{(G - 16384)}{4096}$$

6.3 Offset Setting

The offset voltage corresponds to an output voltage with zero field at the sensor.

Table 9 Offset

Parameter	Symbol	Limit Values		Unit	Notes
		min.	max.		
Register size	OS	15		bit	Unsigned integer value
Offset range	V_{OS}	-400	399	% V_{DD}	[1]
Offset quantization steps	ΔV_{OS}	1.22		mV	@ V_{DD} = 5 V generally V_{DD} / 4095

[1] Infineon pre-calibrates the samples at zero field to 50% of V_{DD} (100mT range) in the final test, but does not guarantee the accuracy of this calibration. It is crucial to do a final calibration of each IC within the application using the Gain/V_{OS} value.

The offset value can be calculated by:

$$V_{OS} = \frac{(OS - 16384)}{4096} \times V_{DD}$$

6.4 DSP Input Low Pass Filter

A digital Low Pass Filter is placed between the Hall A/D Converter and the DSP to reduce the noise level. The Low Pass filter has a constant DC amplification of 0 dB (this is exactly a gain of 1), which means that its setting has no influence on the internal Hall A/D Converter value.

The bandwidth can be set in 8 steps.

Table 10 Low Pass Filter Setting

Parameter LP	**Cutoff frequency in Hz (at 3dB attenuation)**[1]
0	78
1	244
2	421
3	615
4	826
5	1060
6	1320
7	off [2]

[1] As this is a digital filter running with an RC-based oscillator, the cutoff frequency may vary within ±25%.

[2] The output low pass-interpolation filter behavior remains as main component in the signal path.

Table 11 Low Pass Filter

Parameter	**Symbol**	**Limit Values**		**Unit**	**Notes**
		min.	**max.**		
Register size	LP	3		bit	
Corner frequency variation	Δf	- 25	+ 25	%	

Note: In Low Pass filter setting 7 (filter off), the output noise increases. Because of higher DSP load, the current consumption also rises slightly.

Figure 6 shows the characteristic of the filter as a magnitude plot (the highest setting is marked). The “off” position would be a flat 0 dB line. In this case, the output decimation filter limits the bandwidth of the sensor. The update rate after the Low Pass filter is 16 kHz.

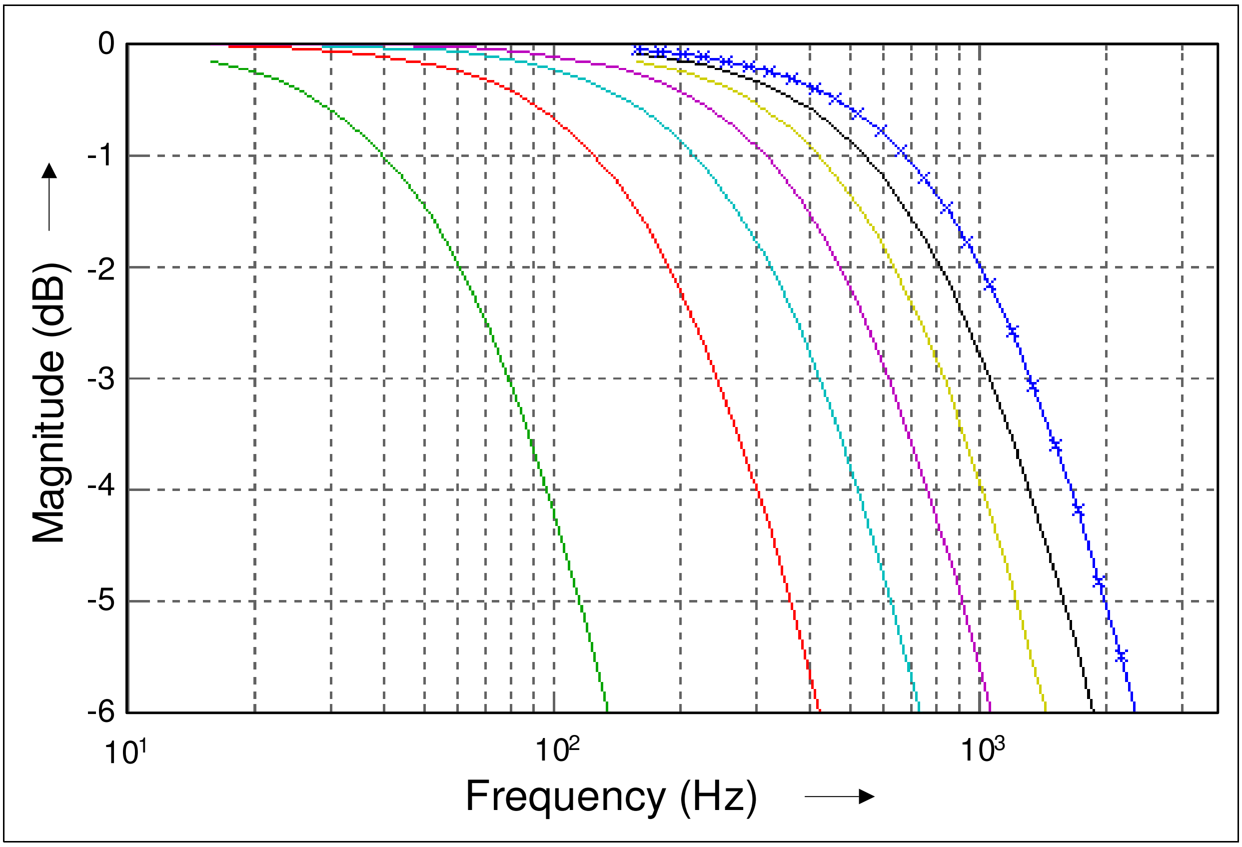

Figure 6 DSP Input Filter (Magnitude Plot)

6.5 DAC Input Interpolation Filter

An interpolation filter is placed between the DSP and the output DAC. It cannot be switched off. This filter limits the frequency behavior of the complete system if the DSP input filter is disabled. The update rate after the interpolation filter is 256 kHz.

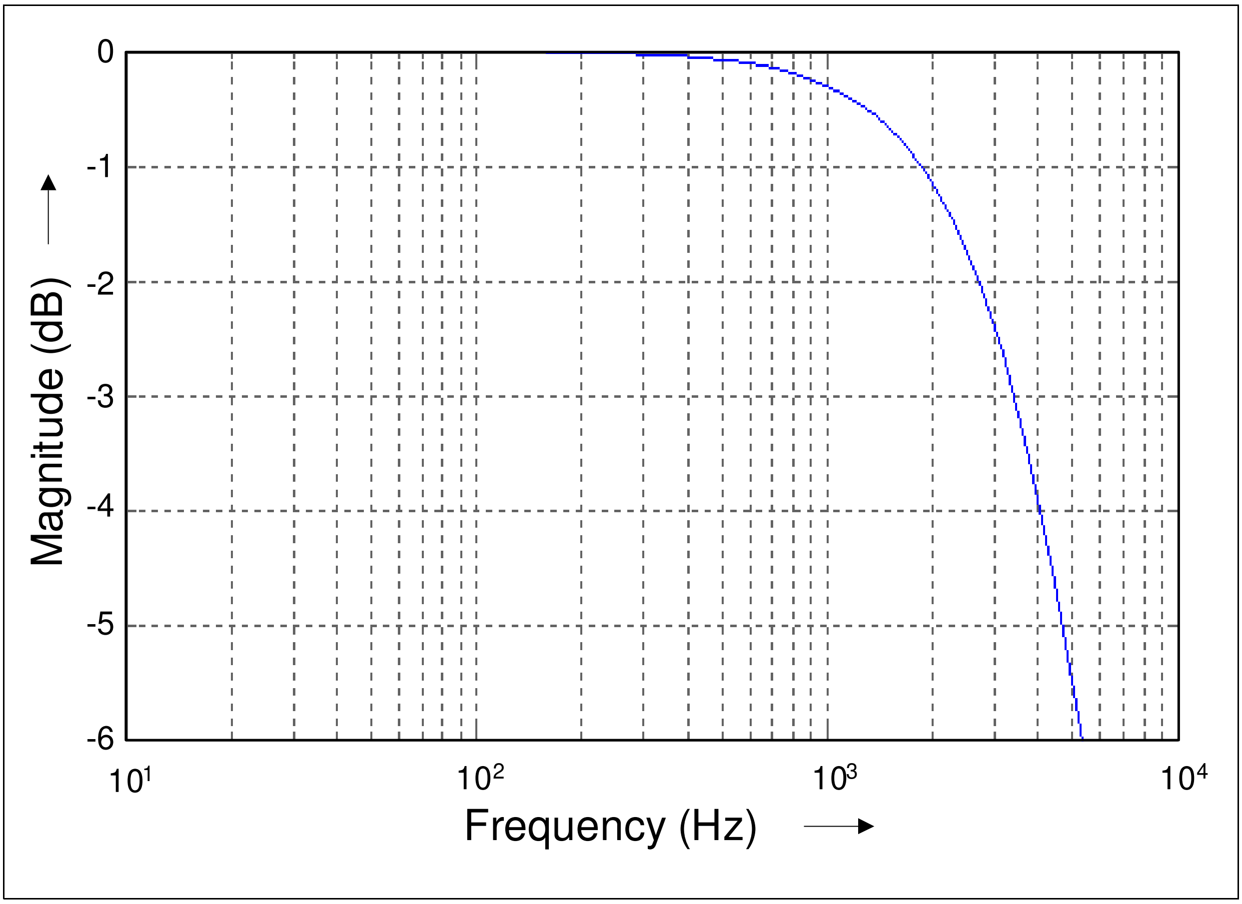

Figure 7 DAC Input Filter (Magnitude Plot)

Note: As this is a digital filter running with an RC-based oscillator, the cutoff frequency may vary within ±25%.

6.6 Clamping

The clamping function is useful for splitting the output voltage into the operating range and error ranges. If the magnetic field is outside the selected measurement range, the output voltage V_{out} is limited to the clamping values.

Table 12 Clamping

Parameter	Symbol	Limit Values		Unit	Notes
		min.	max.		
Register size	CL, CH	2 x 12		bit	
Clamping voltage low	V_{CLL}	0	99.98	% V_{DD}	[1]
Clamping voltage high	V_{CLH}	0	99.98	% V_{DD}	[1]
Clamping quantization steps	ΔV_{CLQ}	1.22		mV	@ $V_{\mathrm{DD}} = 5$ V
Clamping voltage drift	ΔV_{CL}	-15	15	mV	in lifetime[2]
		-15	15		over temperature[2]

[1] If clamping is set, it must be within the allowed output voltage range to be effective.

[2] Valid in the range (5% of V_{DD}) < V_{OUT} < (95% of V_{DD}) for $T_J \leq 120°C$
and (6% of V_{DD}) < V_{OUT} < (94% of V_{DD}) for $120°C < T_J \leq 150°C$

The clamping values are calculated by:

Clamping low voltage:

$$V_{\mathrm{CLL}} = \frac{\mathrm{CL}}{4096} \times V_{\mathrm{DD}}$$

Clamping high voltage:

$$V_{\mathrm{CLH}} = \frac{\mathrm{CH}}{4096} \times V_{\mathrm{DD}}$$

Note: For an exact setup, the register value may be re-adjusted due to the actual output voltage in the clamping condition. The output voltage range itself has electrical limits. See the ***Electrical Characteristics*** *of* v_{out}.

Figure 8 shows an example in which the magnetic field range between B_{min} and B_{max} is mapped to voltages between 0.8 V and 4.2 V.

If it is not necessary to signal errors, the maximum output voltage range between 0.3 V and 4.7 V can be used.

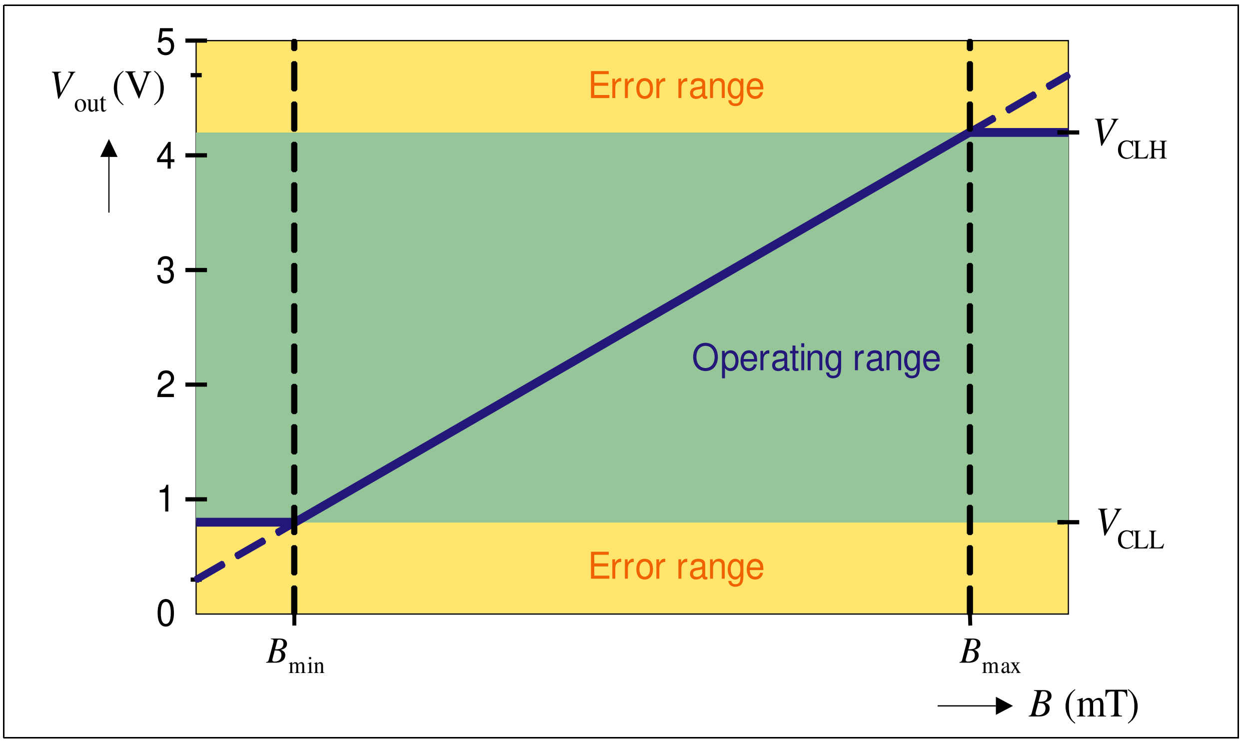

Figure 8 Clamping Example

Note: The high value must be above the low value.
If V_{CLL} is set to a higher value than V_{CLH}, the V_{CLH} value is dominating. This would lead to a constant output voltage independent of the magnetic field strength.

7 Error Detection

Different error cases can be detected by the On-Board-Diagnostics (OBD) and reported to the microcontroller. The OBD is useful only when the clamping function is enabled. It is important to set the clamping threshold values inside the error voltage values shown in **Table 13** and **Table 14** to ensure that it is possible to distinguish between correct output voltages and error signals.

7.1 Voltages Outside the Operating Range

The output signals error conditions, if V_{DD} lies

- inside the ratings specified in **Table 2 "Absolute Maximum Ratings" on Page 12**
- outside the range specified in **Table 3 "Operating Range" on Page 13**.

Table 13 Undervoltage and Overvoltage (All values with $R_L \geq 10k$)

Parameter	**Symbol**	**Limit Values**		**Unit**	**Notes**
		min.	**max.**		
Undervoltage threshold	V_{DDuv}	3	4	V	
Overvoltage threshold	V_{DDov}	7	8.3	V	
Output voltage @ undervoltage	V_{OUTuv}	0.95 x V_{DD}	-	V	$3V \leq V_{DD} \leq V_{DDuv}$
Output voltage @ overvoltage	V_{OUTov}	0.97 x V_{DD}	-	V	$V_{DDov} < V_{DD} \leq 16$ V
Supply current [1]	I_{DDuv}	-	10	mA	@ undervoltage

[1] For overvoltage and reverse voltage, see **Table 2 "Absolute Maximum Ratings" on Page 12**.

7.2 Open Circuit of Supply Lines

In the case of interrupted supply lines, the data acquisition device can alert the user. If two sensors are placed in parallel, the output of the remaining working sensor may be still used for an emergency operation.

Table 14 Open Circuit (OBD Parameters) [1]

Parameter	**Symbol**	**Limit Values**		**Unit**	**Notes**
		min.	**max.**		
Output voltage @ open V_{DD} line	V_{OUT}	0	0.18 0.2	V	$T_J \leq 120$°C 120°C $< T_J \leq$ 150°C
Output voltage @ open GND line	V_{OUT}	4.82 4.8	5	V	$T_J \leq 120$°C 120°C $< T_J \leq$ 150°C

[1] With V_{DD} = 5 V and $R_L \geq$ 10 kΩ pull-down or $R_L \geq$ 20 kΩ pull-up.