# Datasheet: I3D MAGNETIC FIELD TRANSDUCERS

*Very Low-Noise & Low-Offset Fluctuations Magnetic Transducers with Integrated 3-axis Hall Probe*

*** Replacement of the model I3C Magnetic Field Transducer ***

## DESCRIPTION:

The **I3D** denotes a range of SENIS Magnetic Field-to-Voltage Transducers magnetic field to voltage transducer with integrated 3-axis Hall probe that measures all three components (Bx, By, Bz) of an applied magnetic field.

The Hall Probe contains a CMOS integrated circuit, which incorporates three groups of mutually orthogonal Hall elements and a temperature sensor. The integrated Hall element occupies very small area (100 µm x 100 µm), which provides very high spatial resolution of the probe.

The Hall probe is connected with an electronic box (module E in Fig. 1). The Module E provides power to the Hall probe by using the spinning-current technique, which reduces offset, low frequency noise and the planar Hall effect. The additional conditioning of the Hall probe output signals in the electronic box includes Hall signal amplification, high linearization, compensation of temperature variations, and limitation of the frequency bandwidth.

The outputs of the I3D magnetic field transducer are available at the connector CoS of the Module E:

- 3 (three) high-level differential voltages proportional to all three measured components (Bx, By, Bz) of the magnetic flux density, and
- ground-referred voltage proportional with the actual local temperature of the Hall sensor.

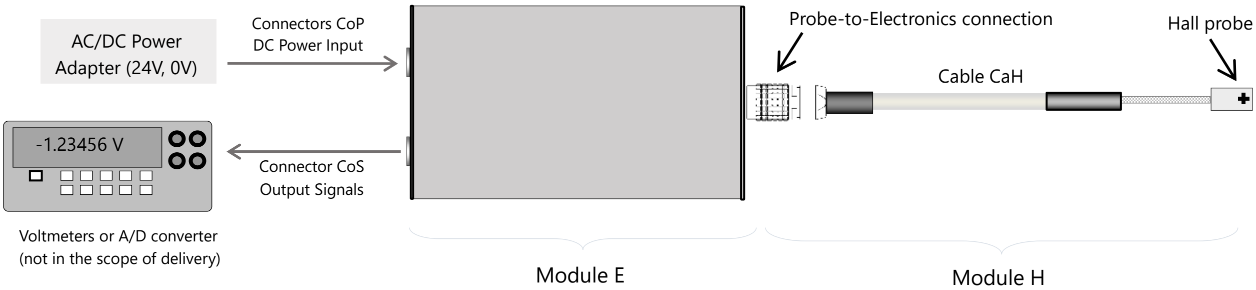



**Figure 1:** Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with integrated 3-axis Hall Probe (Module H) and Electronic (Module E)

## KEY FEATURES:

- Integrated CMOS 3-axis Hall Probe (Bx, By, Bz), of which one, two or three channels are used
- Low-noise & low-offset fluctuation magnetic field transducer, allowing very high-resolution measurements
- Very high linearity
- Magnetic transducer based on much improved offset and noise reduction technique
- Very low planar Hall voltage
- Temperature sensor in the probe for temperature compensation
- Negligible inductive loops on the probe

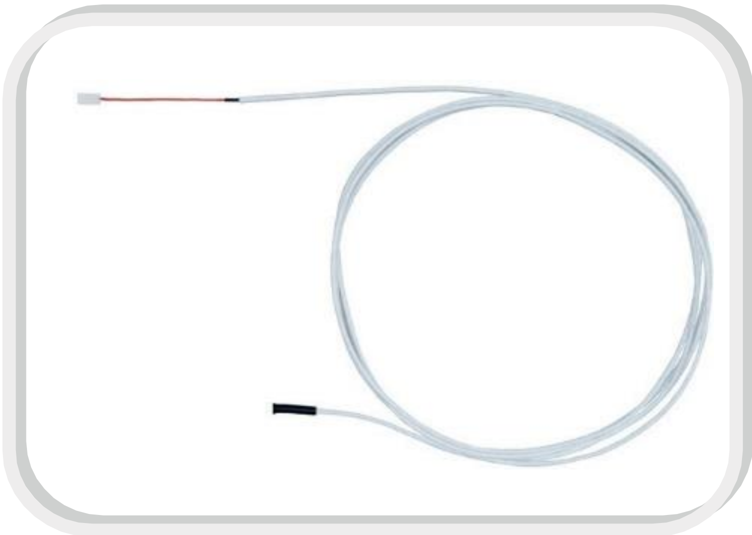



**Figure 2:** Photo of 3-axis magnetic field transducers I3D with integrated 3-axis Hall Probe. Only one probe cable variant is available - flexible shielded white cable, OD 2.7 mm.

## TYPICAL APPLICATIONS:

- Mapping magnetic fields
- Characterization of undulator systems
- Current sensing
- Application in laboratories and in production lines
- Quality control and monitoring of magnet systems (generators, motors, etc.).

## MAGNETIC AND ELECTRICAL PERFORMANCES:

***NOTE:*** *Unless otherwise noted, please allow for 30 minutes warm up time to achieve optimal performances.*
*The listed specifications apply for all three measurement channels at room temperature (23 ± 1) °C.*

| Parameter | Value | | | Remarks |
|---|---|---|---|---|
| Standard measurement range ($\pm B_{FS}$) * | ±0.2 T | ±2 T | ±5 T | *No saturation of the outputs. Other measurement ranges* |
| Linear range of magnetic flux density ($\pm B_{LR}$) | ±0.2 T | ±2 T | ±2 T | *Optimal, fully in-Laboratory calibrated measurement range* |
| Measurement DC accuracy @ $B < \pm B_{LR}$ | < ±0.1 % | < ±0.1 % | < ±0.1 % | *Measured at DC fields as % of full scale. See note 1* |
| Output voltages | Differential (±10 V @ $\pm B_{FS}$) | | | *See note 2* |
| Magnetic sensitivity (S) | 50 V/T | 5 V/T | 2 V/T | *Measured at DC fields. Differential outputs. See note 3* |
| Tolerance of sensitivity ($S_{err}$) @ $B < \pm B_{LR}$ | < 0.02 % | < 0.03 % | < 0.05 % | *See notes 3 and 4* |
| Nonlinearity (NL) @ $B < \pm B_{LR}$ | < 0.03 % | < 0.05 % | < 0.05 % | *See note 4* |
| Planar Hall voltage ($V_{planar}$) @ $B < \pm B_{LR}$ | < 0.01 % of $V_{normal}$ | | | *See note 5* |
| Temperature Coefficient of Sensitivity | < ±100 ppm/°C (0.01 %/°C) | | | *@ Temperature range (25 ± 10) °C* |
| Long-term instability of Sensitivity | < 1 % over 10 years | | | |
| Offset (@ B = 0 T) | <±5 mT | < ±6 mT | < ±10 mT | *@ Temperature range (25 ± 5) °C* |
| Temperature Coefficient of the Offset | < ±10 μT/°C | < ±20 μT/°C | < ±40 μT/°C | |
| Offset fluctuation & drift (@ 0.01-10 Hz, eg., Δt=0.05 s, t=100 s) | < 2 μT | < 4 μT | < 5 μT | *Peak-to-peak values. See note 6* |
| **Output Noise:** | | | | |
| Noise Spectral Density @ f = 1 Hz | < 0.2 $\mu T/Hz^{1/2}$ | < 0.14 $\mu T/Hz^{1/2}$ | < 0.4 $\mu T/Hz^{1/2}$ | *Region of 1/f noise* |
| Corner frequency ($f_C$) | ~10 Hz | | | *Where 1/f noise = white noise* |
| Noise Spectral Density @ $f > f_C$ | < 0.1 $\mu T/Hz^{1/2}$ | < 0.1 $\mu T/Hz^{1/2}$ | < 0.25 $\mu T/Hz^{1/2}$ | *Region of white noise* |
| Broad-band Noise (@ $f > f_C$) | Depends on the adjusted Frequency Bandwidth (Bw) | | | *RMS noise. Peak-to-peak noise is ~5-6 times higher. See note 7* |
| Resolution | | | | *See notes 6 - 10* |
| **Typical frequency response:** | | | | |
| Frequency Bandwidth (Bw) | 0.5 kHz<br>1 kHz | | | *Sensitivity attenuation is -3 dB. See note 11* |
| Output resistance | < 1 kΩ, short circuit proof | | | |
| **Temperature output:** | | | | |
| Voltage-to-ground (Vth) | $V_{TH}[mV] = T_H[°C] \times K_{TH}[mV/°C] + V_{TH}(0)$ | | | *$T_H$ being the actual local temp. of the Hall sensor. See note 13* |
| **Magnetic Flux Density (B) units: tesla (T) – gauss (G):** | | | | |
| 1 T = 10 kG    1mT = 10 G    1 μT = 10 mG | | | | |

*** The device provides only one measurement range – a subject prior to ordering.**

## HALL PROBE AND CABLE – MECHANICAL SPECIFICATIONS:


**Figure 3:** Dimensions of the Hall probe-to-transducer Cable CaH

The I3D magnetic field transducers apply a number of different geometries/dimensions of Hall probes available that fulfil a wide range of application requirements:

| Hall Probe Type: | External Dimensions:<br>L x W x H (mm) | Magnetic Field Sensitive Volume<br>MFSV (µm³) |
|---|---|---|
| **Type C** [1)]<br> | 8.0 x 4.0 x 0.9 | ***Bx, Bz:*** 100 x 10 x 100<br>***By:*** 30 x 5 x 30 |
| **Type H** [2)]<br> | **L:** 71.0 x 2.0 x 0.75<br>**M:** 47.0 x 2.0 x 0.75<br>**S:** 8.0 x 2.0 x 0.75 | |

The Hall sensor chip is embedded in the probe package and connected to the CaH cable.

**REMARKS:**

1) Standard, robust, very compact package.
2) Narrow and thin package with mechanically protected chip. It comes in 3 lengths: very long (L), medium (M) and short (S).

## OUTLINE DIMENSIONS:

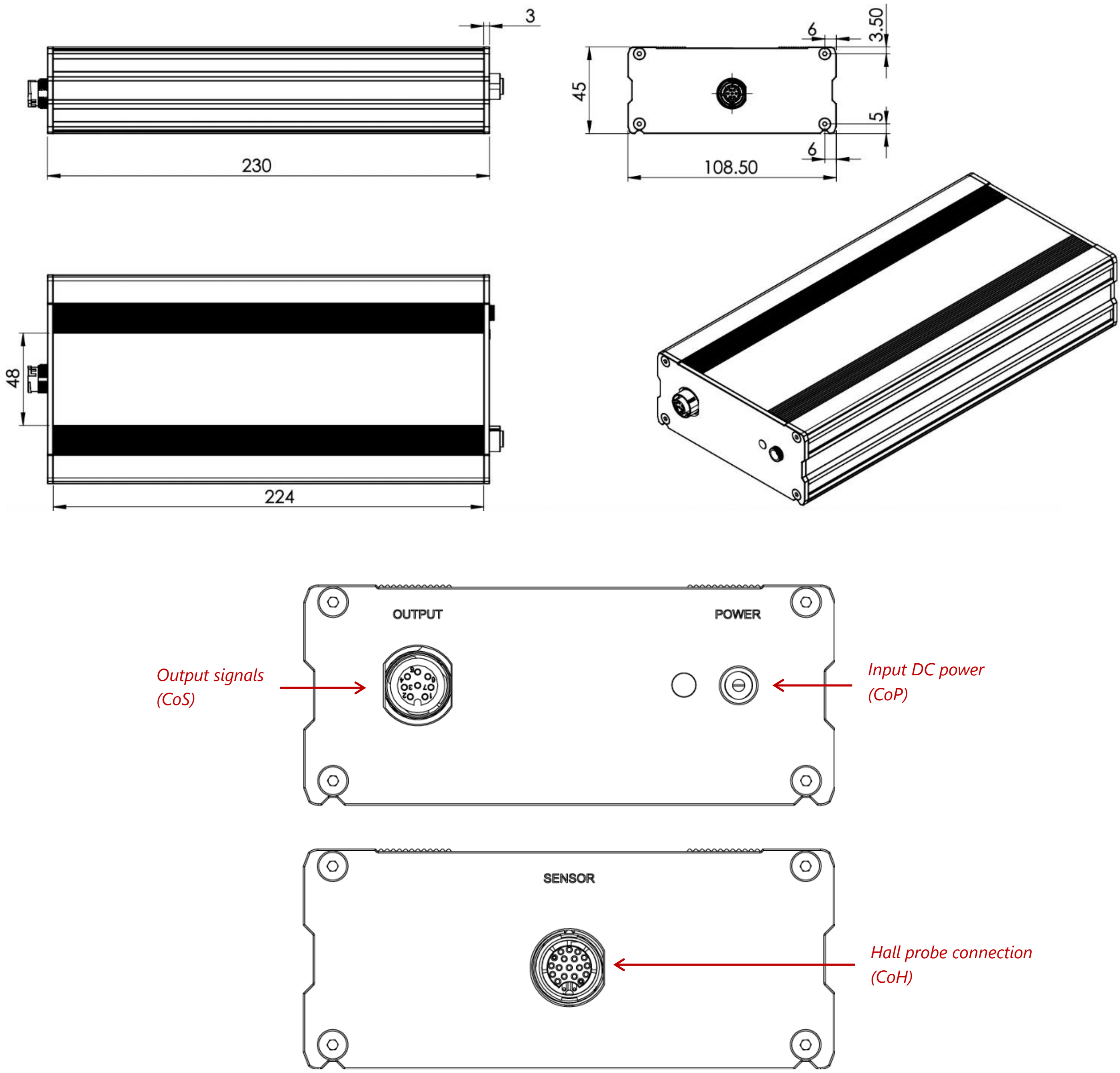
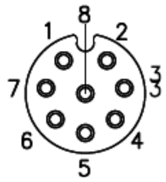



**Figure 4:** Dimensions of the transducer box (all dimensions are in milometers (mm)).

<table>
<tr><td>Module E</td><td colspan="3">High mechanical strength, electrically shielded aluminium case<br>[109 W x 230 L x 45 H mm] with mounting provision (see Fig. 4)</td></tr>
<tr><td>Connector CoS<br>M12-F1-S8, 8-pins PCB connector, female<br>Mating plug:<br>M12-A1-P8, 8-pins, male</td><td>Field signal X-, X+<br>Field signal Y-, Y+<br>Field signal Z-, Z+<br>Probe Temperature (Vpt)<br>Signal common (GND)</td><td>Pins 4, 5<br>Pins 6, 7<br>Pins 1, 2<br>Pin 3<br>Pin 8</td><td></td></tr>
<tr><td>Connector CoP<br>PJ-066B<br>Mating plug:<br>EP501B - Power Barrel Connector Plug, ID 2.5 mm, OD 5.5 mm)</td><td colspan="3">Power, +24 V<br>Power common (0 V)</td></tr>
<tr><td>Hall Probe Connector CoH</td><td colspan="3">Standard Circular Connector 18P MALE CORD<br>(Manufacturer Part Number: EN3C18M26X)<br>Mating connector: Standard Circular Connector FEML 18 PIN RA PCB WIDE IP68 (Manufacturer Part Number: EN3P18FRAPCBW)</td></tr>
<tr><td>DC power</td><td>Voltage:<br>Max. Ripple:<br>Current:</td><td colspan="2">24 V nominal, ±2 %<br>100 mVpp<br>≈ 0.3 A</td></tr>
<tr><td>Environmental</td><td colspan="3">Operating Temperature: +5 °C to +45 °C<br>Storage Temperature: -20 °C to +85 °C</td></tr>
<tr><td>Accessories</td><td colspan="3">• AC/DC Adapter SDI12-24-UD (CUI Inc.) :<br>AC Input : 90-264 V / 47-63 Hz ; DC Output : 24 V/0.5 A ;<br>• Output Signals Cable CO20-X-V2 (standard length 2 m);<br>• Zero Gauss Chamber ZG12-LN.</td></tr>
</table>

## I3D TRANSDUCER MODEL NUMBER CHART:

| I3 | x | - | H1 | H2 | H3 | H4 | H5 | H6 | - | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type ID (3 characters) | | | Module H (6 or 7 characters) | | | | | | | Module E (8 characters) | | | | | | | |

- **I3** Magnetic Field Transducer (MFT) identifier;
- **x** product release version, currently D;
- For Module H (6 or 7 characters) and Module E (8 characters) see the document MFT Model Numbering Chart.pdf.

## NOTES:

**1)** **Accuracy** of the transducer is defined as the maximum difference between the actual measured magnetic flux density and that given by the transducer. In other words, the term accuracy expresses the maximum measurement error. After zeroing the offset at the nominal temperature, the worst-case relative measurement error of the transducer is given by the following expression:

Max. Relative Error: $$M.R.E. = S_{err} + NL + 100 \times Res / B_{LR} \quad \text{[unit: \% of } B_{FS}] \qquad \text{Eq. [1]}$$

Here, *Serr* is the tolerance of the sensitivity (relative error in % of S), *NL* is the maximum relative nonlinearity error (see note 4), Res is the absolute resolution (Notes 6-10) and $B_{LR}$ is the linear range of magnetic flux density.

**2)** The output of the measurement channel has two terminals and the output signal is the (differential) voltage between these two terminals. However, each output terminal can be used also as a single-ended output relative to common signal. In this case the sensitivity is approx. 1/2 of that of the differential output.

***Remark: The single-ended outputs are not calibrated.***

**3)** **Sensitivity** (also: **magnetic sensitivity**) is given as the nominal slope of an ideal linear function *Vout* = *f(B)*, i.e.,

$$V_{out} = S \times B \qquad \text{Eq. [2]}$$

where *Vout*, *S* and *B* represent transducer output voltage, sensitivity and the measured magnetic flux density, respectively.

**4)** **Nonlinearity** is the deviation of the function $B_{meas} = f(B_{act})$ from the best linear fit of this function. Usually, the maximum of this deviation is expressed in terms of % of the full-scale input. Accordingly, the nonlinearity error is calculated as follows:

$$NL = 100 \times \left[ \frac{V_{out} - V_{off}}{S'} - B \right]_{max} / B_{LR} \quad (\text{for } -B_{LR} < B < B_{LR}) \qquad \text{Eq. [3]}$$

Notation:

| | |
|---|---|
| *B* | Actual testing DC magnetic flux density given by a reference high-precision NMR PT2025 teslameter or a high-accuracy 3MH6 digital teslameter |
| $V_{out}(B) - V_{off}$ | Corresponding measured transducer output voltage after zeroing the Offset |
| *S'* | Slope of the best linear fit of the function $f(B) = V_{out}(B) - V_{off}$ (i.e., the actual magnetic sensitivity) |
| $B_{LR}$ | Linear range of magnetic flux density |

**Tolerance of sensitivity** can be calculated as follows:

$$Serr = 100 \text{ x } |S' - S| / S \qquad \text{Eq. [4]}$$

**5)** **Planar Hall voltage** is the voltage at the output of a Hall transducer produced by a magnetic flux density vector co-planar with the Hall plate. This voltage is approximately proportional to the square of the measured magnetic flux density. Therefore, for example:

$$\left.\frac{V_{planar}}{V_{normal}}\right|_{@ B=B_0} = 4 \text{ x } \left.\frac{V_{planar}}{V_{normal}}\right|_{@ B=B_0/2} \qquad \text{Eq. [5]}$$

where $V_{normal}$ denotes the normal Hall voltage, i.e., the transducer output voltage when the magnetic field is perpendicular to the Hall plate.

**6)** This is the "6-sigma" peak-to-peak span of offset fluctuations with sampling time Δt = 0.05 s and total measurement time t = 100 s. The measurement conditions correspond to the frequency bandwidth from 0.01 Hz to 10 Hz. The "6-sigma" means that in average 0.27 % of the measurement time offset will exceed the given peak-to-peak span. The corresponding root mean square (RMS) noise equals 1/6 of "Offset fluctuation & drift".

**7)** Total output RMS noise voltage (of all frequencies) of the transducer. The corresponding peak-to-peak noise is about 6 times the RMS noise. See also Notes 7 and 8.

**8)** Maximal signal bandwidth of the transducer, determined by a built-in low-pass filter with a cut-off frequency *Bw*. In order to reduce the output noise or avoid aliasing, the frequency bandwidth may be limited by passing the transducer output signal trough an external filter (see Notes 8 and 9).

**9)** **Resolution** of the transducer is the smallest detectable change of the magnetic flux density that can be revealed by the output signal. The resolution is limited by the noise of the transducer and depends on the frequency band of interest.

**DC resolution** is given by the specification "Offset fluctuation & drift" (see also Note 6).

The worst-case (**AC resolution**) is given by the specification "Broad-band noise" (see also Note 7). The resolution of a measurement can be increased by limiting the frequency bandwidth of the transducer. This can be done by passing the transducer output signal trough a hardware filter or by averaging the measured values.

***Caution: Filtering produces a phase shift, and averaging causes a time delay!***

The RMS noise voltage (i.e., resolution) of the transducer in a frequency band from $f_L$ to $f_H$ can be estimated as follows:

$$V_{nRMS\text{-}B} \approx \sqrt{NSD_{1f}^2 \times 1Hz \times \ln\left(\frac{f_H}{f_L}\right) + 1.22 \times NSD_W^2 \times f_H} \qquad \text{Eq. [6]}$$

where:

- $NSD_{1f}$ is the 1/f noise voltage spectral density (RMS) @ f = 1 Hz;
- $NSD_w$ is the RMS white noise voltage spectral density;
- $f_L$ is the low, and $f_H$ is the high-frequency limit of the frequency bandwidth of interest;
- the numerical factor 1.22 comes under the assumption of using a second-order low-pass filter.

For a DC measurement:

$$f_L = 1/\text{measurement time}.$$

The high-frequency limit cannot be higher than the cut-off frequency of the built-in filter Bw:

$$f_H \leq Bw.$$

If the low-frequency limit fL is higher than the corner frequency fC, then the first term in Eq. (5) can be neglected. Otherwise, if the high-frequency limit $f_H$ is lower than the corner frequency $f_C$, than the second term in Eq. (5) can be neglected.

The corresponding peak-to-peak noise voltage can be calculated according to the "6-sigma" rule:

$$V_{nP\text{-}P\text{-}B} \approx 6 \times V_{nRMS\text{-}B}.$$

**10)** Let us denote this signal sampling frequency by $f_{samS}$.

According to the sampling theorem, the sampling frequency must be at least two times higher than the highest frequency of the measured magnetic signal. However, in order to obtain the best signal-to-noise ratio, it is useful to allow for over-sampling (this way we avoid aliasing of high-frequency noise).

Accordingly, for best resolution, the recommended physical sampling frequency of the transducer output voltage is:

$$f_{samP} > 5 \times Bw,$$

or:

$$f_{samP} > 5 \times f_H$$ (if an additional low-pass filter is used, see Note 8).

The number of samples can be reduced by averaging each N subsequent samples, where is:

$$N \leq f_{samP} / f_{samS}.$$

**11)** When measuring fast-changing magnetic fields, one should take into account the transport delay of the Hall signals, small inductive signals generated at the connections Hall probe–thin cable, and the filter effect of the electronics in the E-Module. Approximately, the transducer transfer function is similar to that of a first-order low-pass filter, with the frequency bandwidth $f_{(-3\ dB)} = Bw$.

The attenuation of the applied filter is -40 dB/dec (-12 dB/oct).

The AC Calibration Table (AMP & PHASE vs. FREQ) of the frequency response is available as an option.

**12)** The switching "noise" is a periodic signal at $f_{sw}$ = 16.67 kHz and the related harmonics. It is due to the switching transients produced by the so-called spinning current process in the Hall elements.

When performing A/D conversion of the transducer output signal, the sampling rate should be well above $2 \times f_{sw}$ in order to avoid aliasing of the switching noise.

The switching noise can be efficiently suppressed by averaging the transducer signal over a time period of $N \times 1/f_{sw}$, where N being an integer number.

**13)** The equation:

$$V_{TH}[mV] = T_{HALL}[°C] \times K_{TH}[mV/°C] + V_{TH}(0)$$

is valid for the standard temperature range between +5 °C and +45 °C.

The temperature-proportional voltage output of the transducer ($V_{TH}$) is taken from a calibrated temperature sensor in the Hall probe itself. It therefore measures the local temperature of the Hall elements ($T_{HALL}$), but NOT the ambience (room) temperature.

Due to power loss in the sensor the sensor temperature is always higher than the environmental temperature.

The difference between the temperature of the sensor and the environment is more pronounced if the sensor tip is free hanging in the air. In this case the silicon Hall sensor may be between 5 °C and 12 °C hotter than the environment.

If the sensor is well attached or clamped down on a heat conducting surface, such as a metal, the sensor is typically between 1 °C and 5 °C hotter than the environment.