Datasheet: K3A CRYOGENIC MAGNETIC FIELD TRANSDUCERS

Ultra-Low-Noise Magnetic Field Transducers with 3-axis Cryogenic Hall Probe

DESCRIPTION:

The SENIS K3A cryogenic low-noise magnetic field transducer accurately measures the amplitude and direction of magnetic fields at cryogenic temperatures down to about 1 K.

With a size of 4.5 x 4.5 x 9 mm, its sensor head is very compact. It features the world's smallest field sensitive volume of less than 0.6 mm^3.

The high precision electronics has very low drift, ultra-high resolution and low noise. The instrument provides an analog voltage for each magnetic field direction. Accurate calibrations (0.25 %) and high field calibrations (up to ±9 T) at the cryogenic temperatures (4 K) are available as an option.

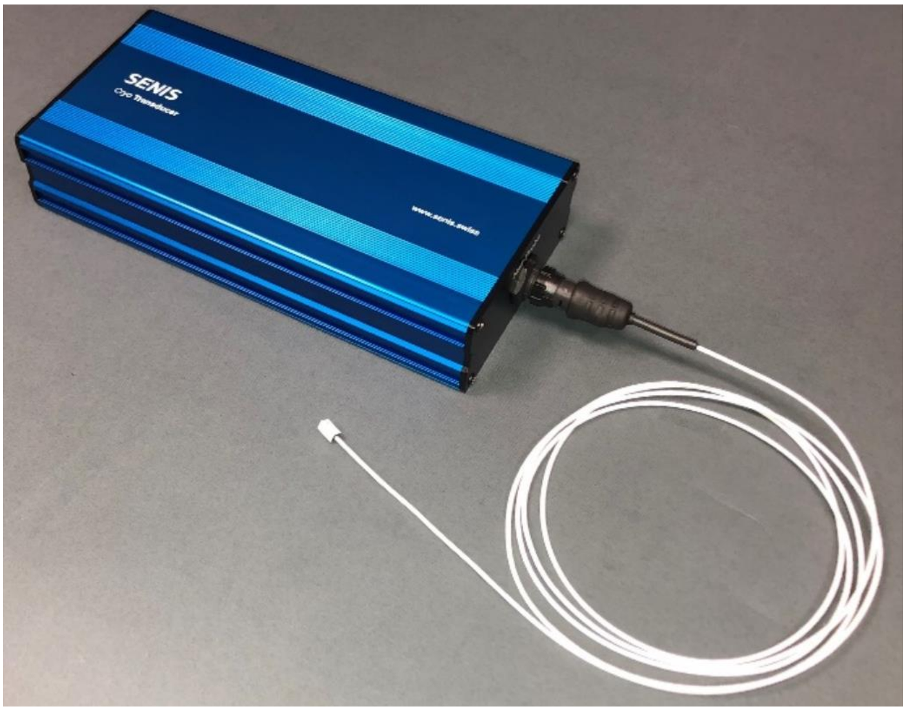


Figure 1: K3A Cryogenic Low Noise Transducer with compact probe head

The cryogenic Hall probe integrates three high-resolution discrete (hybrid) Hall sensors with good angular accuracy (orthogonality error < 2°) of the three measurement axes of the probe.

The Hall probe is connected with an electronic box (module E in Fig. 2). The Module E provides power to the Hall probe by using the spinning-current technique, which reduces the offsets, 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 and limitation of the frequency bandwidth.

The outputs of the K3A cryogenic magnetic field transducer are three differential voltages (Vx, Vy, Vz) proportional to all three measured components (Bx, By, Bz, respectively) of the magnetic flux density, and these are available at the connector CoS of the Module E.

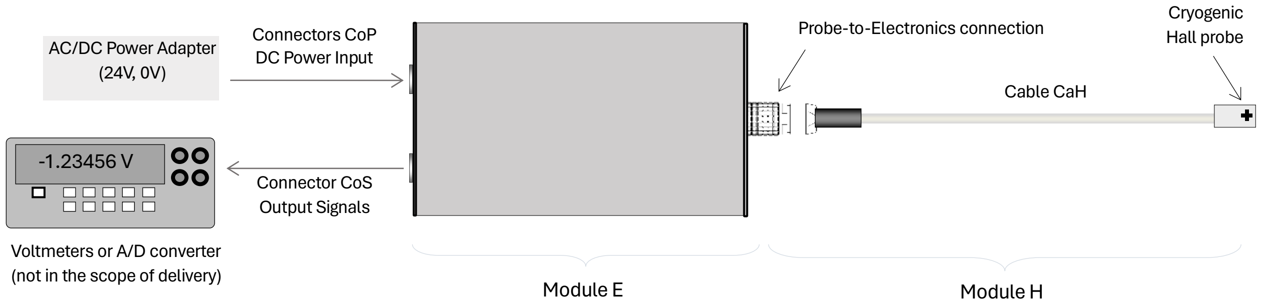


Figure 2: Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with cryogenic 3-axis Hall probe (Module H) and Electronic (Module E)

KEY FEATURES:

- Measures 3D (Bx, By, Bz) magnetic fields at cryogenic temperatures down to ~ 1 K
- Highly compact sensor head: 4.5 x 4.5 x 9 mm
- World's smallest field sensitive volume of less than 0.6 mm^3
- Stable, low noise, ultra-high resolution and low drift electronics
- Accurate calibration of 0.25 % at fixed temperature down to 4 K available as an option
- High field calibration up to ±9 T available as an option

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
Measurement range (Full scale, ±B_{FS}) *	Standard: ±2 T	Options: ±5 T ±7 T ±10 T	No saturation of the outputs. Other full scales are available.
In-factory calibrated measurement range (±B_{LR})	±2 T		Calibrated at the room temperature (296 ±1) K
Calibration DC accuracy	Standard: Optional:	< 1 % full scale < 0.25 % full scale	Percentage defined with respect to full scale field. Optional: <±0.25 %, including the corresponding DC Calibration Table. See note 1
Output voltages	Differential (±10 V @ ±B_{FS})		Differential output @ ±full scale See note 2
Nominal Magnetic Sensitivity (S)	5 V/T	10V · $(B_{FS})^{-1}$ (B_{FS} is full scale expressed in T-tesla)	Measured at the room temperature (296 ±1) K. Differential outputs. See note 3
Tolerance of sensitivity (S_{err}) @ B < ±B_{LR}	Depends on the measurement range. Determined by the utilization of the corresponding DC Calibration Table.		See notes 3 and 4
Nonlinearity (NL) @ B < ±B_{LR}			See note 4
Planar Hall voltage (V_{planar}) @ B < ±B_{LR}	< 0.01 % of V_{normal}		See note 5
Temperature Coefficient of Sensitivity	< ±25 ppm/K (±0.0025 %/K)		@ room temperature (296 ± 1) K
Long-term instability of Sensitivity	< 1 % over 10 years		
Offset (@ B = 0 T)	< ±0.5 mT		
Temperature Coefficient of the Offset	< ±0.5 µT/K		
Offset fluctuation & drift (@ 0.01-10 Hz, eg., Δt=0.05 s, t=100 s)	< 2 -3 μT_{PP}		Peak-to-peak values. See note 6
Output Noise:			
Noise Spectral Density @ f = 1 Hz	< 0.2 $\mu T/Hz^{1/2}$	< 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	< 0.05 $\mu T/Hz^{1/2}$	< 0.15 $\mu T/Hz^{1/2}$	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)	Standard: 0.5 kHz Maximum: 5 kHz		Sensitivity attenuation is -3 dB. See note 11
Output resistance	< 1 kΩ, short circuit proof		
Magnetic Flux Density (B) units: tesla (T) – gauss (G):			
1 T = 10^4 G = kG 1 mT = 10 G 1 µT = 10 mG			

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

HALL PROBE and CABLE – MECHANICAL SPECIFICATIONS:

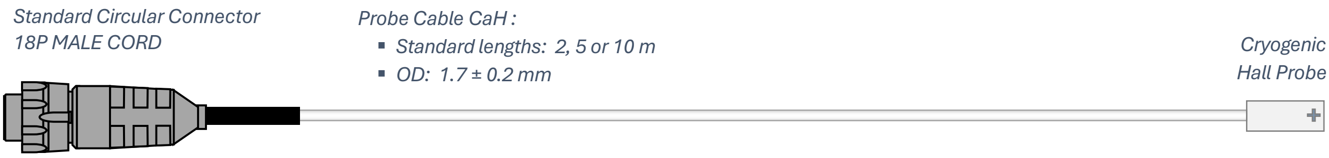


Figure 3: Dimensions of the Hall probe-to-transducer Cable CaH

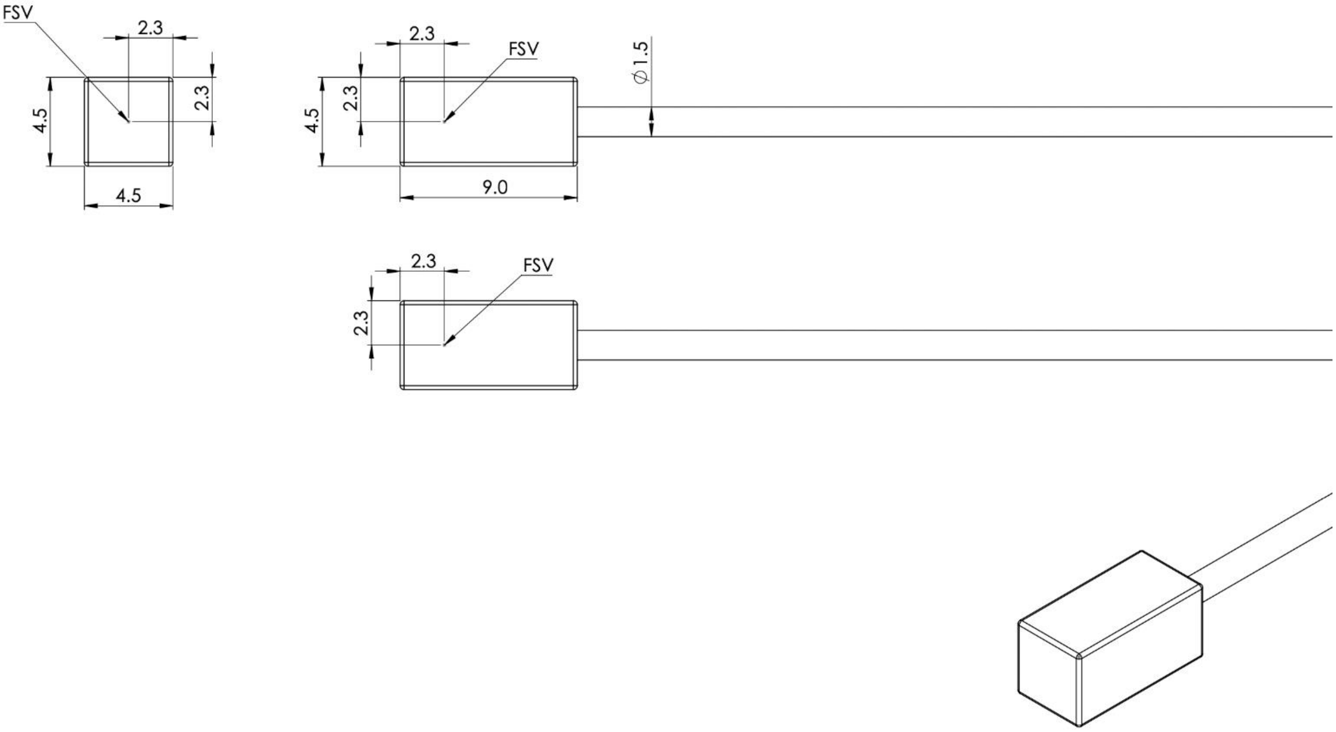


Figure 4: Cryogenic Probe size. All dimensions are in millimeters (mm)

Cryogenic Hall probe:	
External dimensions (L x W x H):	9 x 4.5 x 4.5 mm
3D Magnetic Field Sensitive Volume:	1.5 x 1.3 x 0.3 mm

OUTLINE DIMENSIONS:

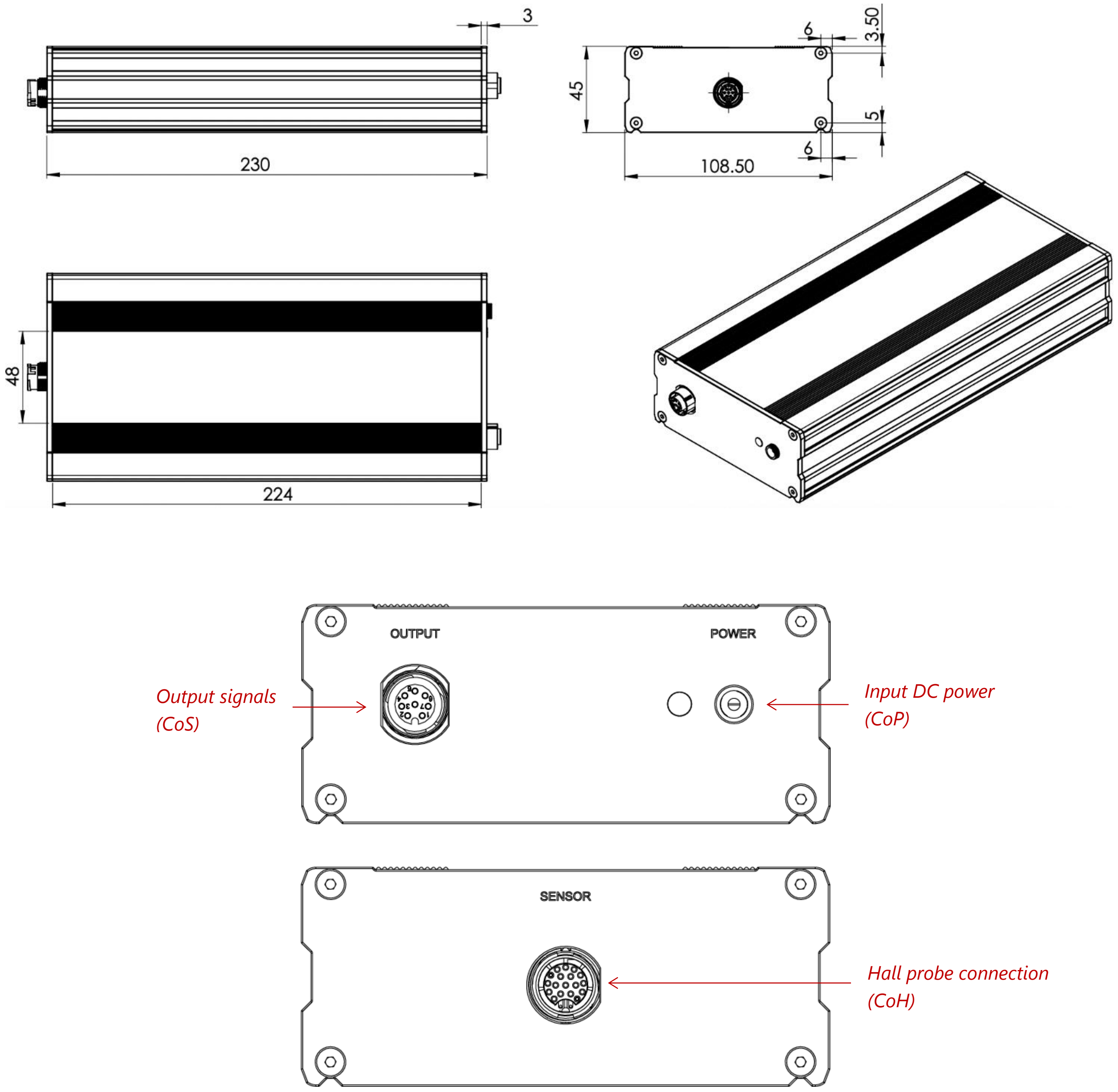
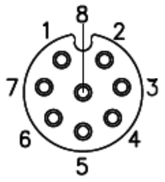


Figure 5: Dimensions of the transducer box. All dimensions are in millimeters (mm).

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

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:

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

Here, *Serr* is the tolerance of the sensitivity (relative error in % of S), *NL* is the maximum 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: 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:

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

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 (also: **sensitivity error**) can be calculated as follows:

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

5) **Planar Hall voltage** (PHV) is the voltage at the output of a Hall transducer produced by a magnetic flux density vector co-planar with the Hall plate. PHV 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!

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}	1/f noise voltage spectral density (RMS) @ f = 1 Hz;
- NSD_w	RMS white noise voltage spectral density;
- f_L and f_H	low and high frequency limit of the frequency bandwidth of interest, respectively;
- *1.22*	numerical factor 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:

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

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.