DESCRIPTION:

The H3A denotes a range of Low Noise SENIS Magnetic Field-to-Voltage Transducers with hybrid 3-axis Hall Probe.

The Hybrid Hall Probe integrates three high-resolution with good angular accuracy (orthogonality error < 2°) of the three measurement axis of the probe and a temperature sensor.

The Hall probe is connected with an electronic box (Module E in Fig. 1). The Module E provides biasing for the Hall probe and the application of the spinning-current technique, which very effectively cancels 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 the temperature variations, and limitation of the frequency bandwidth.

The outputs of the H3A Magnetic Transducers are available at the connector CoS of the Module E: these are high-level differential voltages proportional with each of the measured components of a magnetic flux density; and a ground-referred voltage proportional with the probe temperature.

KEY FEATURES:

- **Hybrid 1-, 2-, 3-axis (Bx, By, Bz) Hall Probe, of which one, two, or three channels are used**
- **Ultra-low noise & offset fluctuation magnetic transducer, allowing very high resolution measurements (spectral density of noise down to 10 nT/ $\sqrt{\text{Hz}}$)**
- **Very high linearity**
- **Magnetic transducer based on much improved offset and noise reduction technique**
- **Very low planar Hall voltage**
- **A temperature sensor on the probe for temperature compensation**
- **A range of various Hall probe geometries/dimensions available**

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.)

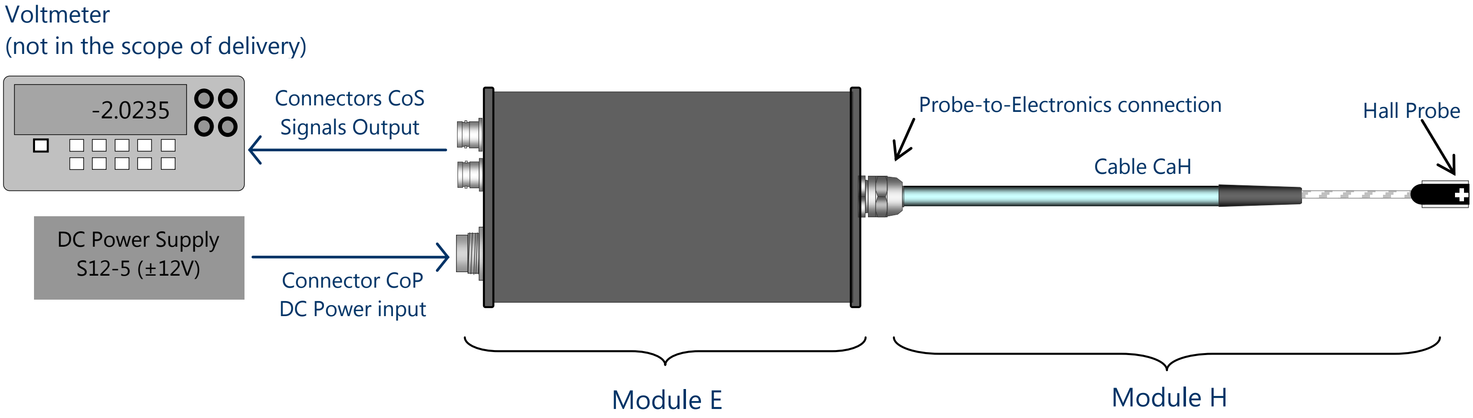


Figure 1. **Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with hybrid 1-and 2-Axis Hall Probe (Module H) and Electronic (Module E, encapsulated in the box type B)**

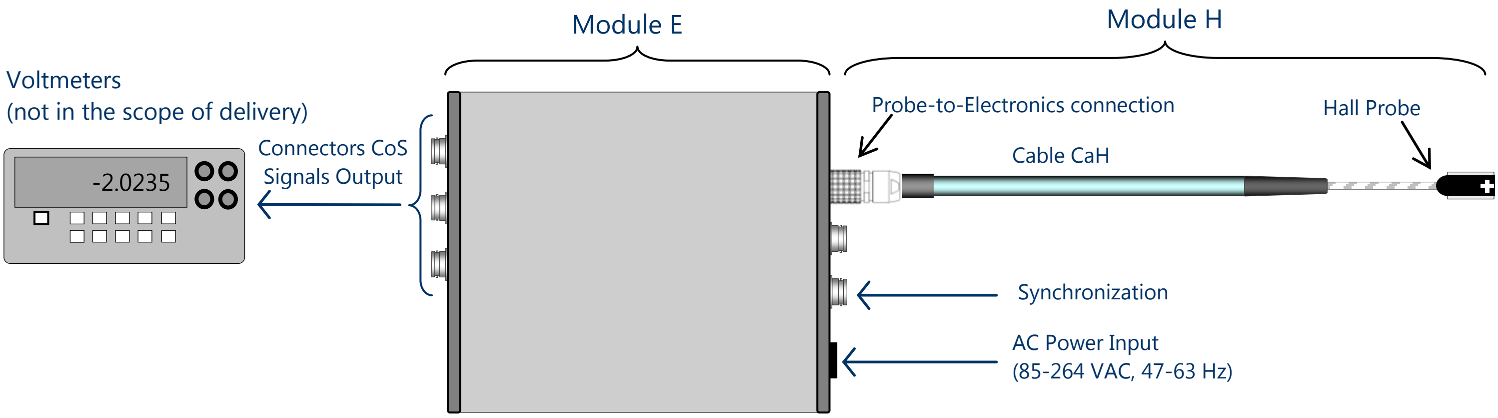
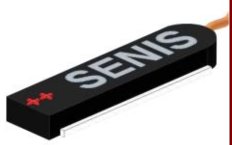
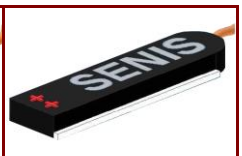


Figure 2. **Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with hybrid 3-Axis Hall Probe (Module H) and Electronic (Module E, encapsulated in the box type G)**

Figure 3. **Photo of a 3-axis (box type G, left) and a of 1- or 2-axis (box type B, right) magnetic field transducer with hybrid Hall Probe**

SPECIFICATIONS (Module H):

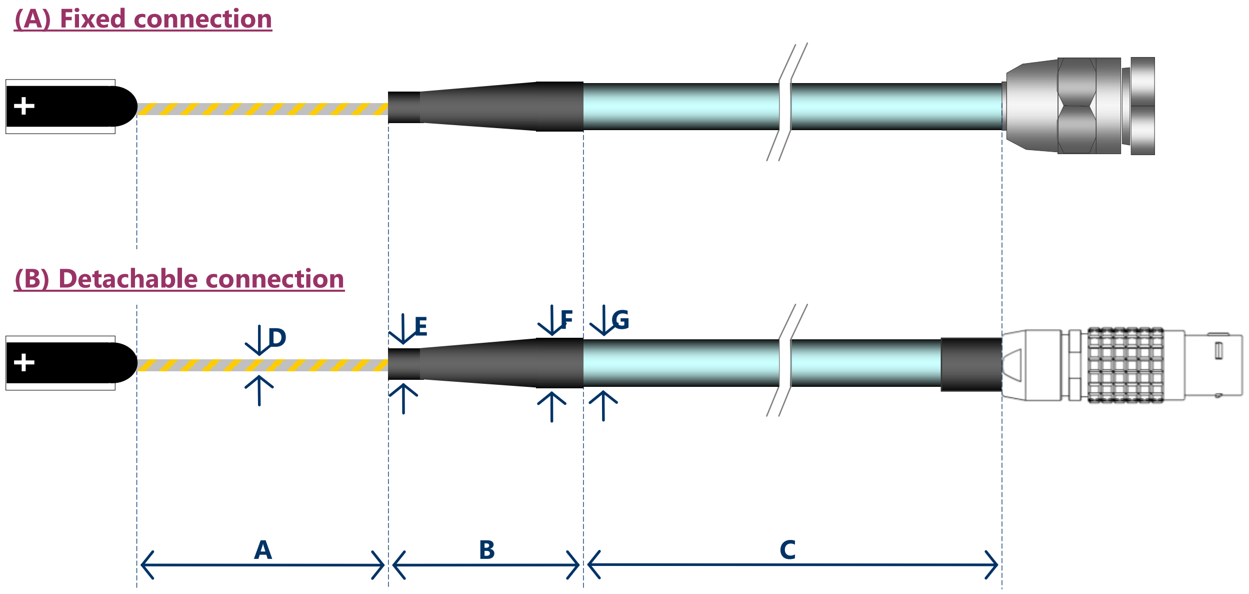
A number of different geometries/dimensions of Hall probes available that fulfills a wide range of application requirements:

FIGURE				
Probe type	**I**	**J**	**N**	**P**
Ext. dimensions L x W x H (mm)	**16.5 x 5.0 x 1.5**	**31.0 x 3.0 x 1.5**	**16.5 x 4.0 x 2.0**	**16.5 x 5.0 x 2.0**

For Probe selection, please see Hall Probes Sections at www.senis.ch

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

CaH Cable - Dimensions and Tolerances:



Dimension	mm	Remark
A	200 ± 5	for 1- and 2-axis probes
	150 ± 3	for 3-axis probes
B	35 ± 3	for 1- and 2-axis probes
		not available for 3-axis probes
C	2m, 5m, 10m ± 1%	Different lengths available upon request
D	Ø 1.0 ± 0.2	for 1- and 2-axis probes
	Ø 0.6 ± 0.2	for 3-axis probes
E	Ø 4.0 ± 0.2	for 1- and 2-axis probes
		not available for 3-axis probes
F	Ø 6 ± 0.2	for 1- and 2-axis probes
		not available for 3-axis probes
G	Ø 5.0 ± 0.2	for 1- and 2-axis probes
	Ø 1.8 ± 0.2	for 3-axis probes

Figure 4. **Standard dimensions and tolerances of CaH cable (fixed and detachable connection options)**

H3x Model Number Chart

H3	x	-	H1	H2	H3	H4	H5	H6	-	E1	E2	E3	E4	E5	E6	E7	E8
Type Id			Module H (6 characters)							Module E (8 characters)							

H3 is Magnetic Transducer Type Identifier

x is a product release version, currently A.

For Module H (6 characters) and Module E (8 characters) see the document MFT Model Numbering Chart.pdf

MAGNETIC and ELECTRICAL SPECIFICATIONS:

Unless otherwise noted, the given specifications apply for all measurement channels at room temperature (23°C) and after a device warm-up time of 30 minutes.

Parameter		Value		Remarks
Standard measurement ranges		**± 0.2T**	**± 2T**	***No saturation of the outputs; Other measurement ranges available***
Linear range of magnetic flux density ($\pm B_{LR}$)		**± 0.2T**	**± 2T**	***Optimal, fully calibrated measurement range***
Total measuring Accuracy (@ $B < \pm B_{LR}$)	**high**	**0.25%**	**0.25%**	***See note 1***
	low	**1.0%**	**1.0%**	
Output voltages (V_{out})		**differential**		***See note 2***
Sensitivity to DC magnetic field (S)		**50 V/T**	**5 V/T**	***Differential output; See note 3***
Tolerance of sensitivity (S_{err}) (@ $B < \pm B_{LR}$)	**high**	**0.02%**	**0.02%**	***See notes 3 and 4***
	low	**0.02%**	**0.02%**	
Nonlinearity (NL) (@ $B < \pm B_{LR}$)	**high**	**0.15%**	**0.15%**	***See note 4***
	low	**0.5%**	**0.5%**	
Planar Hall voltage (V_{planar}) (@ $B < \pm B_{LR}$)		**< 0.05 % of V_{normal}**		***See note 5***
Temperature coefficient of sensitivity		**< ±25 ppm/°C (±0.0025 %/°C)**		***@ Temperature range 23 °C ± 5 °C***
Long-term instability of sensitivity		**< 1% over 10 years**		
Offset (@ B = 0T) (B_{offs})		**< ±0.1 mT**	**< ±0.6 mT**	***@ Temperature range 23 °C ± 5 °C***
Temperature coefficient of the offset		**< ±0.3 µT/°C**	**< ±2 µT/°C**	
Offset fluctuation and drift (0.01 to 0.1 Hz)		**< 1 µT**	**< 4 µT**	***Peak-to-peak values; See note 6***
Output noise				
Noise Spectral Density @ f = 1 Hz (NSD_1)		**0.02 µT/$\sqrt{Hz}$**	**0.2 µT/$\sqrt{Hz}$**	***Region of 1/f – noise***
Corner frequency (f_C)		**10 Hz**		***Where 1/f noise = white noise***
Noise Spectral Density @ f > 10 Hz (NSD_W)		**0.016 µT/$\sqrt{Hz}$**	**0.05 µT/$\sqrt{Hz}$**	***Region of white noise***
Broad-band Noise (10 Hz to f_T)		***depends on the customer's specified frequency bandwidth***		***RMS noise; see note 7***
Resolution				***See notes 6 - 10***
Typical frequency response				
Frequency Bandwidth [f_T]		**0.1 kHz** **0.4 kHz** **max 5 kHz**		***Other frequency bandwidths available; Sensitivity decrease -3dB; See note 11***
Synchronisation signal *(for 3-axis magnetic transducers)*		**500 kHz, TTL**		***External synchronisation: MASTER/SLAVE configuration***
Output resistance		**< 100 Ohms, short circuit proof**		
Temperature output				
Ground-referred voltage		**V_T [mV] = T[°C] x 50 [mV/°C]**		

MODULE E: MECHANICAL AND ELECTRICAL SPECIFICATIONS:

1. E-module type G:

The Module G is a three-channel analogue electronic processing unit. It consists of three separated electronic processing units, one for each of the measurement channels X, Y and Z.

To build up a complete measurement system, the module G needs to be connected with an adequate power supply and three voltmeters and/or a data acquisition system.

Each Module G can be set as “MASTER” or “SLAVE” by setting the slide switch in a proper position. When the device is set as “MASTER” it outputs the control frequency to the SYNC terminal; otherwise, when it’s set as “SLAVE” it can receive the control frequency from the SYNC terminal. This type of operation minimises beating between the devices. One “MASTER” device can drive up to 5 “SLAVE” devices.

Figure 5. **Front and back panel of the 3-channel Electronics module G**

Module E _ type G (for 3-axis magnetic field transducers)	High mechanical strength, EMC shielded aluminium case 240 W x 260 L x 135 H mm (*Fig. 5*); Weight < 3kg
Connectors CoS (Radial BR2 bulkhead receptacle rear mount (mating plug, BR2 straight plug clamp 2 cores cab 4mm))	Field signal X+, X-, ground shielded — front side Field signal Y+, Y-, ground shielded — front side Field signal Z+, Z-, ground shielded — front side Temperature signal (BNC) — back side Synchronisation signal (BNC) — back side
HALL PROBE Connector CaH	Detachable connection: LEMO - EGG.2B.314.CLL - socket, panel, 14 way (back side) (Mating Plug, FGG.2B.314.CLAD92Z)
AC Power Connector CoP	IEC/EN 60950 compliant, 3 poles (L – N – E) (back side)
AC Power	Voltage: 110V/220V Current: ca. 400mA/200mA

2. E-module type B:

Figure 6. **Front panel of the 1- and 2-channel Electronics module B**

Module E _ type B (for 1- and 2-axis magnetic field transducers)	High mechanical strength, electrically shielded aluminium case 110 W x 230 L x 56 H mm (*see Fig. 6*) Weight < 1kg
Connectors CoS (Radial BR2 bulkhead receptacle rear mount (mating plug, BR2 straight plug clamp 2 cores cab 4mm))	Field signal Y+, Y-, ground shielded — front side Field signal Z+, Z-, ground shielded — front side Temperature signal (BNC) — front side
HALL PROBE Connector CaH	Fixed connection: Cable Gland MS PG7
DC Power Connector CoP DIN SFV50, 5 pole (Mating Plug, KV50)	Power, +12V — Pin 3 Power, -12V — Pin 1 Power common (GND) — Pin 2
DC Power	Voltage: ±12V nominal, ±2% Max. ripple: 100mVpp Current: ca. 300mA

Environmental Parameters:		
Operating Temperature	+5°C to +45°C	*Optimal range* +5°C to +45°C
Storage Temperature	-20°C to +85°C	

Magnetic Flux Density (B) units (T-tesla, G-gauss) conversion:

1 T = 10 kG

1 mT = 10 G

1 µT = 10 mG

OPTIONS:

DC Calibration

The calibration table of the transducer can be ordered as an option. The calibration table is an Excel-file, providing the actual values of the transducer output voltage for the test DC magnetic flux densities measured by a reference NMR Teslameter. The standard calibration table covers the linear range of magnetic flux density $\pm B_{LR}$ in the steps of $B_{LR}/10$. Different calibration tables are available upon request. By the utilisation of the calibration table, the accuracy of DC and low-frequency magnetic measurement can be increased up to the limit given by the resolution (see Notes 1 and 6 ÷ 10).

AC Calibration - Frequency Response

Another option is the calibration table of the frequency response. This is an Excel file, providing the actual values of the transducer transfer function (complex sensitivity and Bode plots) for a reference AC magnetic flux density. The standard frequency response calibration table covers the transducer bandwidth, from DC to f_T, in the steps of $f_T/10$. Different calibration tables are also available upon request. Utilisation of the frequency calibration table allows an accuracy increase of the AC magnetic measurements almost up to the limit given by the resolution (see Notes 1 and 6 ÷ 11).

SENIS 1-, 2-, and 3-Axis Ultra-low noise Hall probes works well in the B-frequency range from DC to f_T (-3dB point) (B being the density of the measured magnetic flux). In addition to the Hall voltage, at high B–frequencies also inductive signals are generated at the connection probe-thin cable. Moreover, the probe, the cable and the electronics in the E-module behave as a low-pass filter. As a result, the transducer has the "complex" sensitivity of the form:

$$S = S_H + jS_I$$

Here:

- S_H represents sensitivity for the output signal in phase with the magnetic flux density (that is the real part of the transfer function);
- S_I is the sensitivity with the 90° phase shift with respect to the magnetic flux density (i.e., the imaginary part of the transfer function).

Calibration data can be ordered for S_H and S_I for all three axes X, Y and Z (as an option). This allows the customer to deduce accurate values of the measured magnetic flux density at even high frequencies by an appropriate mathematical treatment of the transducer output voltage V_{out}.

NOTES:

1) The ***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:

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

Here, S_{err} is the tolerance of the sensitivity (relative error in percents of S), NL is the maximal 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 output is not calibrated*).

3) The ***sensitivity*** is given as the nominal slope of an ideal linear function $V_{out} = f(B)$, i.e.

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

where V_{out}, S and B represent transducer output voltage, sensitivity and the measured magnetic flux density, respectively.

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

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

Notation:

B = Actual testing DC magnetic flux density given by a reference NMR 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 sensitivity)

B_{LR} = Linear range of magnetic flux density

Tolerance of sensitivity can be calculated as follows:

$$\text{Tolerance of sensitivity} = 100 \text{ x } |S' - S| / S \qquad \textbf{Eq. [4]}$$

5) The ***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. The planar Hall voltage is approximately proportional to the square of the measured magnetic flux density. Therefore, for example:

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

Here, 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=0.05s and total measurement time t=100s. The measurement conditions correspond to the frequency bandwidth from 0.01Hz to 10Hz. 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 8 and 9.

8) Maximal signal bandwidth of the transducer, determined by a built-in low-pass filter with a cut-off frequency f_T. In order to decrease noise or avoid aliasing, the frequency bandwidth may be limited by passing the transducer output signal trough an external filter (see Notes 9 and 10).

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.

The ***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 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:

$$V_{nRMS\text{-}B} \approx \sqrt{NSD_{1f}^2 \times 1Hz \times \ln\left(\frac{f_H}{f_L}\right) + 1.57 \times NSD_W^2 \times f_H} \qquad \textbf{Eq. [6]}$$

Here NSD_{1f} is the *1/f* noise voltage spectral density (RMS) at f=1Hz; 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 bandwidth of interest; and the numerical factor *1.57* comes under the assumption of using a first-order low-pass filter. For a DC measurement: f_L*=1/measurement time*. The high-frequency limit can not be higher than the cut-off frequency of the built-in filter f_T: $f_H \leq f_T$. If the low-frequency limit f_L is higher than the corner frequency f_C, then the first term in Eq. (6) 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. (6) can be neglected. The corresponding peak-to-peak noise voltage can be calculated according to the *"6-sigma"* rule, i. e., $V_{nP\text{-}P\text{-}B} \approx 6 \times V_{nRMS\text{-}B}$.

10) According to the sampling theorem, the sampling frequency must be at least two times higher than the highest frequency of the measured magnetic signal. Let us denote this signal sampling frequency by f_{samS}. 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 $f_{samP} > 5 \times f_T$ (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 every N subsequent samples, $N \leq f_{samP} / f_{samS}$.

11) Senis low-pass filter and differential-to-single-ended transformer are designed to preserve maximal signal quality when connected to the electronic module E. They don't contribute any additional noise when they are properly connected. The low-pass filter can be used in different frequency ranges depending on the customer specific application resp. expected signal frequency. Approximately, the transducer transfer function is similar to that of a second-order Butterworth low-pass filter, with the bandwidth from DC to f_T. The filter attenuation is -40db/dec. (-12db/oct.).

12) The switching "noise" is a periodic signal at f_{sw} = 15.625 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 x 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 N x $1/f_{sw}$, with N being an integer number.