DESCRIPTION:

The x-H3x-xx_E3D-2.5kHz-0.1-2T is a high accuracy magnetic flux density-to-analogue-voltage transducer with a high-level and temperature compensated output signal for each of the three components of the measured magnetic flux density.

The temperature measurement feature allows user to take temperature readings while monitoring the magnetic field.

The transducer consists of two modules (as shown in Fig.1):

1. Hall probe Module H, and
2. Electronics Module E.

To build up a complete measurement system the module E needs to be connected with an adequate power supply and three voltmeters.

TYPICAL APPLICATIONS:

- Quality control and monitoring of magnet systems (generators, motors, etc.);
- Quality control of permanent magnets;
- Development of magnet systems;
- Mapping magnetic field;
- Process control;
- Application in laboratories and in production lines, etc.

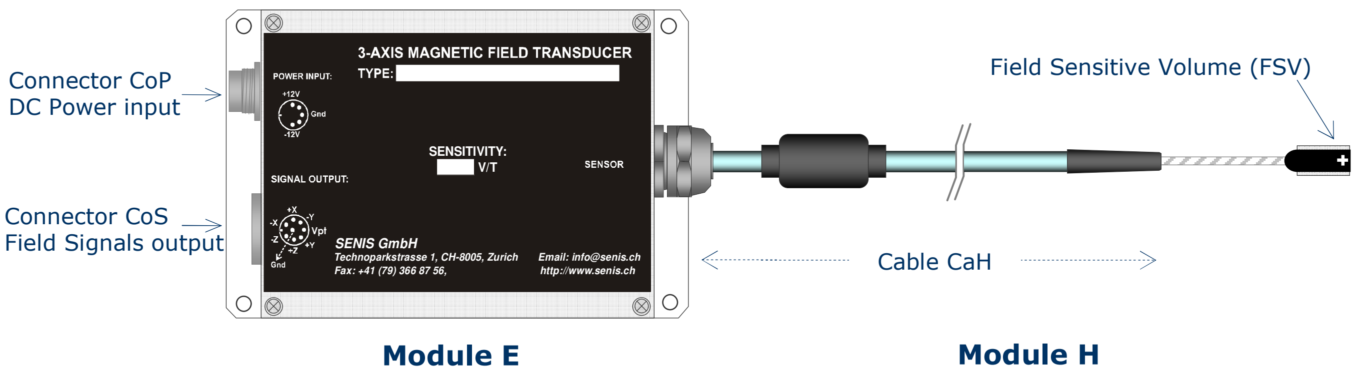

Figure 1. Schema of the SENIS's high-accuracy Hall Magnetic Field Transducer:
- Module H, consisting of the Hall Probe and the CaH Cable;
- Module E, Analog electronics for signal conditioning.

Note: Fixed (non-detachable) CaH cable connection to the transducer's electronic module.

SPECIFICATIONS:

Unless otherwise noted, the given specifications apply for all three B-measurement channels X, Y and Z at room temperature (23°C) and after a device warm-up time of 3 minutes.

Magnetic & Electrical Device Properties:

Parameter	*Value*	*Remarks*
Maximum (full scale) magnetic flux density ($\pm B_{FS}$)	±3 T (±30 kG)	No saturation of the outputs
Linear range of magnetic flux density ($\pm B_{LR}$)	±2 T (±20 kG)	Calibrated range
Accuracy	< 0.1% of B_{LR}	See note 1
Output voltages (V_{out})	differential	See note 2
Sensitivity to DC magnetic field (S)	5 V/T (0.5 mV/G)	Differential output; see note 3
Tolerance of sensitivity (S_{err}) (@ $B \leq \pm B_{LR}$)	< 0.02% of S	$100 \cdot \lvert S' - S \rvert / S$; see notes 3 and 4
Temperature coefficient of sensitivity	< ± 100 ppm/°C	@ T= 23°C ± 10°C
Non-linearity (NL)	< 0.05 % @ $B \leq \pm B_{LR}$;	See note 4
Planar Hall voltage (V_{planar}) (@ $B \leq \pm B_{LR}$)	< 0.01% of V_{normal}	See note 5
Long-term instability of sensitivity	< 1% over 10 years	
Offset (@ B = 0T) (V_{off} (B_{off}))	< ± 3 mV (± 0.6 mT)	@ Temp. range 23°C ± 3°C
Temperature coefficient of the offset	< ± 0.25 mV/°C (± 0.05 mT/°C)	
Offset fluctuation & drift (Δt = 0.05s, t = 100s)	< 0.5 mV_{p-p} (0.1 mT_{p-p})	Corresponding Standard deviation RMS values are: < 85 μV_{RMS} (17 μT_{RMS}); see note 6
Output noise		
Noise spectral density @ f = 1Hz (NSD_1)	≈ 35 $\mu V/\sqrt{Hz}$ (7$\mu T/\sqrt{Hz}$)	Region of 1/f-noise
Corner frequency (f_C)	≈ 10 Hz	Where 1/f-noise = white noise

Noise spectral density @ f >10 Hz (NSD$_w$)	≈ 10 μV$\sqrt{Hz}$	(2 μT/$\sqrt{Hz}$)	Region of white noise
Broad-band noise (10 Hz to f$_T$) (V$_{nRMS-B}$)	< 0.6 mV	(0.12 mT)	RMS noise; see note 7
Resolution			See notes 6 - 10
Typical frequency response			
0.1% error	> 110 Hz		Test: $B \simeq 150mT \cdot \sin(2\pi ft)$; see "Frequency Response" below
1.0% error	> 350 Hz		
Bandwidth [f$_T$]	> 2.5 kHz		Sensitivity decrease -3dB; see note 11
Output resistance	< 10 Ω, short circuit proof		
Temperature output			
[T(°C)-(23°C ± 0.5°C)] x 500 [mV/°C]			Single-ended
Environmental Parameters:			
Operating Temperature	+5°C to +45°C		
Storage Temperature	-20°C to +85°C		
Electromagnetic	Compliant to standard norms		Documentation available upon request.

Magnetic Flux Density (B) Units:

- 1 T = 10 kG; 1 μT = 10 mG

Recommended Accessories:

- Power supply S12-5 [DC output: ±12 V, +5V]; [AC input: ~110/220V, 50/60 Hz]

(http://www.senis.ch/images/power%20supply%20S12-5%20version%20C_datasheet.pdf)

- Zero Gauss Chamber: ZG12

(http://www.senis.ch/images/Zero%20Gauss%20chamber%20ZG12.pdf)

- Output cable 1.5 meter: CO15-G
- Three-Axis Differential-to-Single ended Adapter 3DSA-05
- Probe support: PSB

(http://www.senis.ch/images/PSB-R04.pdf)

DC Calibration

The calibration table of the transducer can be ordered as an option. The calibration table is an Excel-file, giving the actual values of the transducer output voltages for the test DC magnetic flux densities measured by a reference NMR Tesla-meter. The standard calibration table covers the linear range of magnetic flux density ± 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

Another option is the calibration table of the frequency response. This is an Excel file, giving 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’s 3-axes integrated Hall probe works well in the B-frequency range from DC to 2.5KHz (-3dB point) (B denotes here the density of the measured magnetic flux). In addition to the Hall voltage, at high B–frequencies appear also inductive signals 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 a "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 3 axes (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:

Max. Relative Error: $M.R.E. = S_{err} + NL + 100 \cdot Res / B_{LR}$ [unit: % of B_{LR}] 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) Sensitivity is given as the nominal slope of an ideal linear function $V_{out} = f(B)$, i.e.

$$V_{out} = S \cdot B$$ Eq. [2]

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

4) 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:

$$NL = 100 \cdot \left[\frac{V_{out} - V_{off}}{S'} - B \right]_{MAX} / B_{LR} \qquad (\text{for } -B_{LR} < B < B_{LR})$$ 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

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:

$$\left.\frac{V_{planar}}{V_{normal}}\right|_{@\ B=2T\ (DC)} = 4 \cdot \left.\frac{V_{planar}}{V_{normal}}\right|_{@B=1T\ (DC)} \qquad \text{Eq. [4]}$$

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:

$$V_{nRMS\text{-}B} \approx \left[NSD_{1f}^2 \cdot 1Hz \cdot \ln\left(\frac{f_H}{f_L}\right) + 1.57 \cdot NSD_W^2 \cdot f_H \right]^{1/2} \qquad \text{Eq. [5]}$$

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. (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, 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 9). The number of samples can be reduced by averaging every N subsequent samples, $N \leq f_{samP} / f_{samS}$.

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 bandwidth from DC to f_T. The calibration table of the frequency response is available as an option.