DESCRIPTION:

The F3B-03V02F-A.5T25KJ very accurately measures the magnetic flux density in a single spot. Within the range of ±0.5 T (±5 kG) it provides a temperature compensated linear output voltage for each of the three components of the measured magnetic flux density (Bx, By, Bz) and the temperature of the sensor.

As a very unique feature, the special package of the sensor head allows to sample magnetic surfaces to within less than 0.2 mm perpendicular to the sensor surface with a depth resolution of less than 10 µm. Parallel to the sensor surface magnets can be approached to within less than 0.3 mm and a depth resolution of less than 80 µm is achieved.

The F3B-03V02F-A.5T25KJ magnetic field transducer comprises the basic 2 modules: H-module (Hall probe and Cable) F3B-03V02F, with the Hall probe mounted in a probe holder, and the E-Module A.5T25KJ.

The Hall probe is connected with an electronic box (Module E in Fig. 1). The Module E provides biasing for the Hall probe and additional conditioning of the Hall probe output signals: amplification, linearization, cancelling offset, compensation of the temperature variations, and limitation of the frequency bandwidth.

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

- the three high-level differential voltages (Vx, Vy, Vz) proportional with each of the three measured components of a magnetic flux density (Bx, By, Bz, respectively), and
- a ground-referred voltage (Vpt) proportional with the local temperature of the Hall sensor.

KEY FEATURES:

- Fully integrated CMOS 3-axis (Bx, By, Bz) Hall Probe, of which one, two, or three channels are used
- Very high spatial resolution: 0.15 x 0.01 x 0.15 mm^3
- Sensitive volume less than 0.15 mm below the probe surface and less than 0.25 mm from the front
- High depth resolution of less than 10µm
- High angular accuracy (orthogonality error < 1°)
- Virtually no planar Hall effect
- High frequency bandwidth (DC up to 25 kHz)
- High disturbance immunity
- Negligible inductive loops on the Probe
- Integrated temperature sensor on the probe for temperature compensation

TYPICAL APPLICATIONS:

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

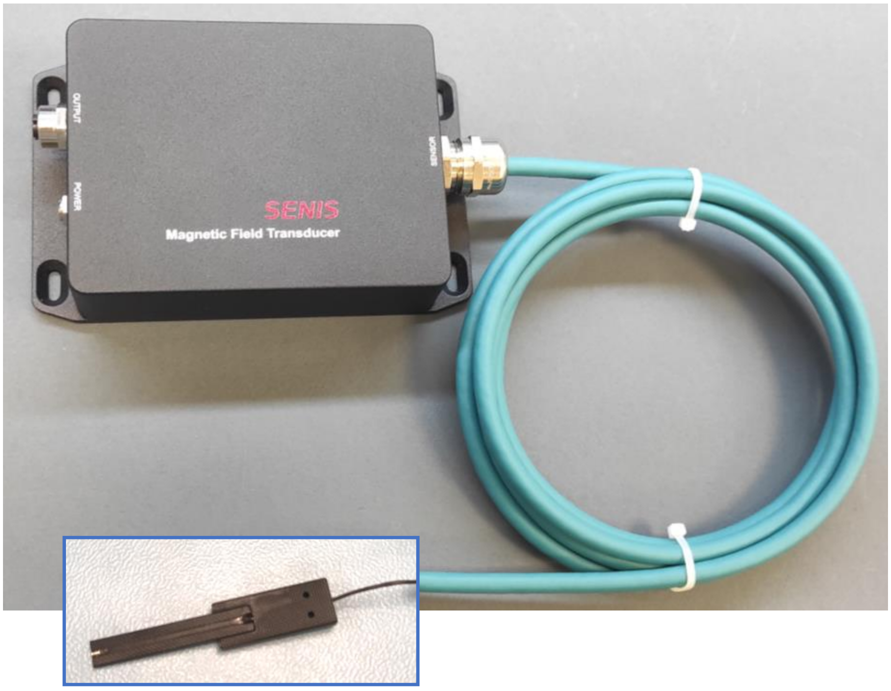

Figure 1. 3-axis analog magnetic field transducer type F3B-03V02F-A.5T25KJ

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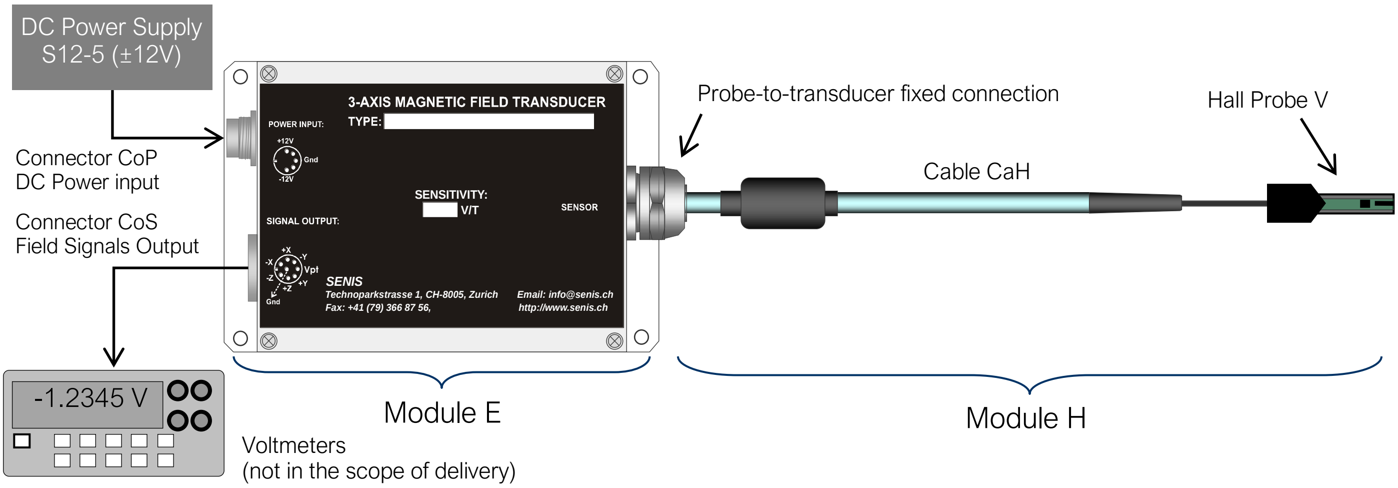


Figure 2. Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with fully integrated 3-axis Hall Probe (Module H) and Electronic (Module E)

SPECIFICATIONS (Module H):

Hall Probe type V for the SENIS F3B magnetic field transducers and 3MH3 digital Teslameters with the naked Si chip is a very thin (0.5 mm) and long (47 mm) single-chip fully integrated 3-axis Hall-Probe.

The probe is additionally glued into the black fiberglass holder that provides both mechanical protection and a precise positioning of sensitive probe tip.

The Hall probe V contains a CMOS integrated circuit, which incorporates three groups of mutually orthogonal Hall elements, biasing circuits, amplifiers, and a temperature sensor.

The integrated Hall elements occupy very small area (150 µm x 150 µm), which provides very high spatial resolution of the probe. The CMOS IC technology enables very high precision in the fabrication of the vertical and horizontal Hall elements, which gives high angular accuracy (orthogonality error < 1°) of the three measurement axes of the probe.

The on-chip application of the spinning-current technique in the biasing of the Hall elements suppresses the planar Hall effect.

The on-chip signal pre-processing enables a very high frequency bandwidth (DC to 25 kHz) of the probe, and on-chip signal amplification provides high output signals of the Hall probe.

Key features of the applied Hall probe 03V:

- Hall probe type 03V with the naked Si chip is very thin (0.5 mm) and long (47 mm) Hall probe permanently assembled into the black fiberglass probe holder that provides both mechanical protection and a precise positioning of sensitive probe tip
- Sensitive volume less than 0.15 mm below the probe surface and less than 0.25 mm from the front
- Fully integrated CMOS 3-axis (Bx, By, Bz) Hall Probe, of which one, two, or three channels are used
- Very high spatial resolution: By: 0.030 x 0.005 x 0.030 mm^3; Bx & Bz: 0.150 x 0.010 x 0.150 mm^3
- High angular accuracy: orthogonality error between the three measurement axes of the probe is < 1°
- Virtually no planar Hall Effect
- High frequency bandwidth: DC - 25 kHz (-3 dB sensitivity attenuation)
- High disturbance immunity
- Negligible inductive loops on the Probe
- Integrated temperature sensor on the probe for temperature compensation

Hall Probe and Cable – Mechanical specifications:

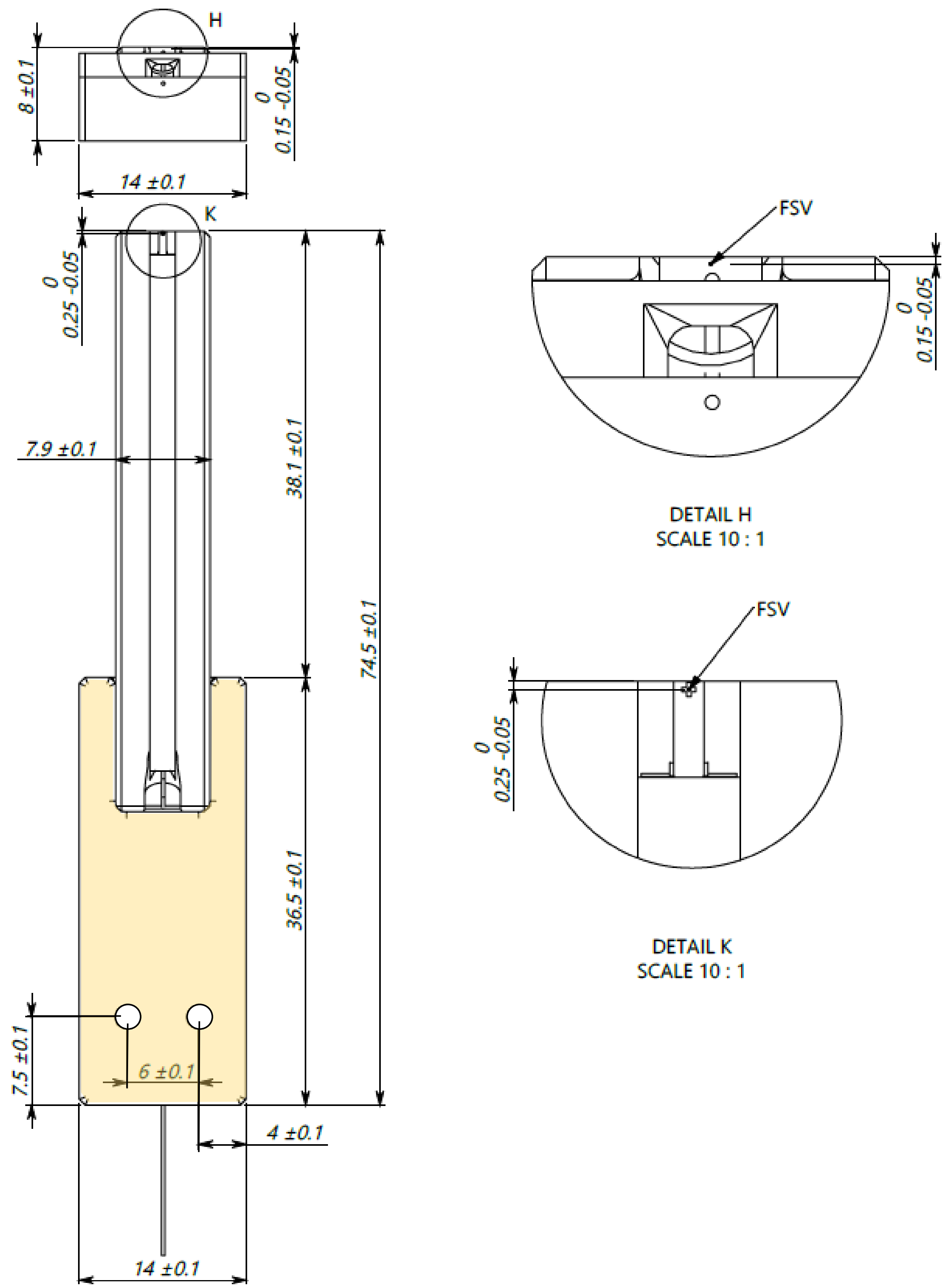


Figure 3. Dimensions of the assembling Hall probe type V + Probe holder

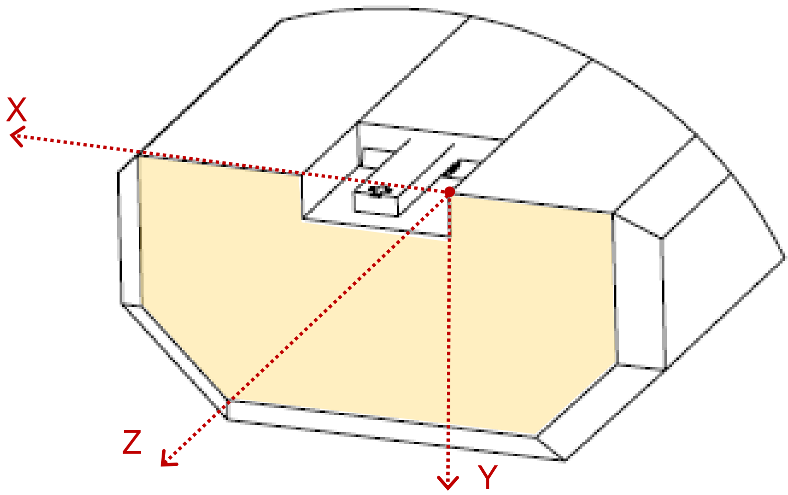


Figure 4: Reference Cartesian coordinate system (X, Y, Z) of the SENIS 3-axis Hall probe type V fitted in the Probe Holder

Dimension	X [mm]	Y [mm]	Z [mm]
Magnetic field sensitive volume (MFSV)	0.15	0.01	0.15
Position of the centre of MFSV (corresponding to the reference Cartesian coordinate system defined by Fig. 3 and 4)	1.00 ± 0.05	0.15 -0.05/+0.00	-0.25 -0.00/+0.05
Hall Probe external dimensions (including the holder)	7.9 ± 0.1 (holder tip)	8.0 ± 0.1	38.1 ± 0.1 (holder tip)
Orthogonality of the measurement axes	< ±1° with respect to the reference surface (marked in YELLOW in Fig. 3 and 4)		
Parallelism of the holder surfaces	< ±1° (NOTE: this angular error adds the max inaccuracy of the magnetic field measurement < ±0.015 %)		
Roughness of the probe holder surfaces	Roughness class N7 (ISO 1302)		
Hall probe Cable (CaH)	Shielded, with a flexible thin part near the probe, and a ferrite sleeve close to the Electronics module		
Total length of the probe Cable (CaH):	▪ Standard: 2 m (Probe notation: F3A-03V02F) ▪ Optional: X m (Probe notation: F3A-03V0XF) Note: Different lengths of the probe cable are available on a demand.		

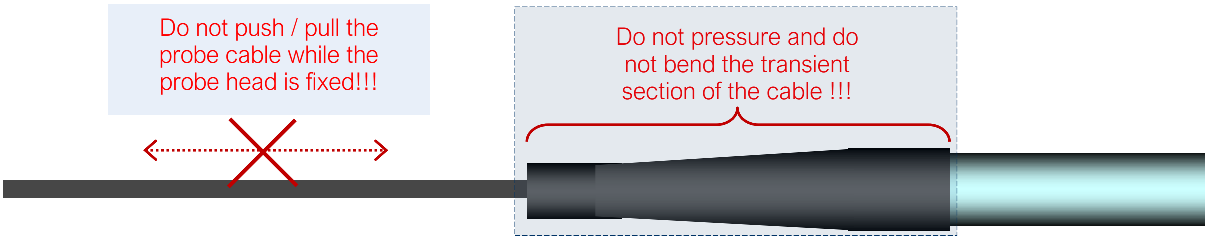
INSTALLATION MANUAL FOR THE 03V HALL PROBE

NOTE: The Probe tip is fragile! Please handle it with a special care.

The probe package is made of the Al_2O_3 ceramic substrate, which is additionally permanently fixed into a black fiberglass holder.
The Hall IC is naked and could be easily broken. Therefore, avoid any mechanical contact of the silicon Hall sensor with other objects! Moreover, avoid the immersion of the probe of any liquid, and its exposure to moisture and aggressive gasses.

The following precautions shall help ensure that the transducer accurate calibration remains preserved:

- The mounting of the probe should be carried out by application of very low pressure to its back-end and thin wires.
- If the probe head is clamped, the user should make sure that the substrate surface in contact with the reference plane of the probe is flat and covers as much of the probe reference surface as possible.
- Do not apply more force than required to hold the probe in its place. Any damage of the applied silicon Hall sensor will destroy the Probe automatically. We strongly suggest storing the probe in a protective case when not in use.
- In order to prevent rupture of the thin wires from the probe head, the user should fix and secure the probe cable in the proximity of the probe. The thin wires of the flexible section of the cable may be folded with care. Repeated strong bending should be avoided.
- Avoid any high pressure and bending of the transient section between the thin and the thick cables:



- Applied Hall sensor is sensitive to electrostatic discharge (ESD), so that it is strongly recommended to follow the proper ESD protection procedures when handling the device.

MAGNETIC and ELECTRICAL SPECIFICATIONS:

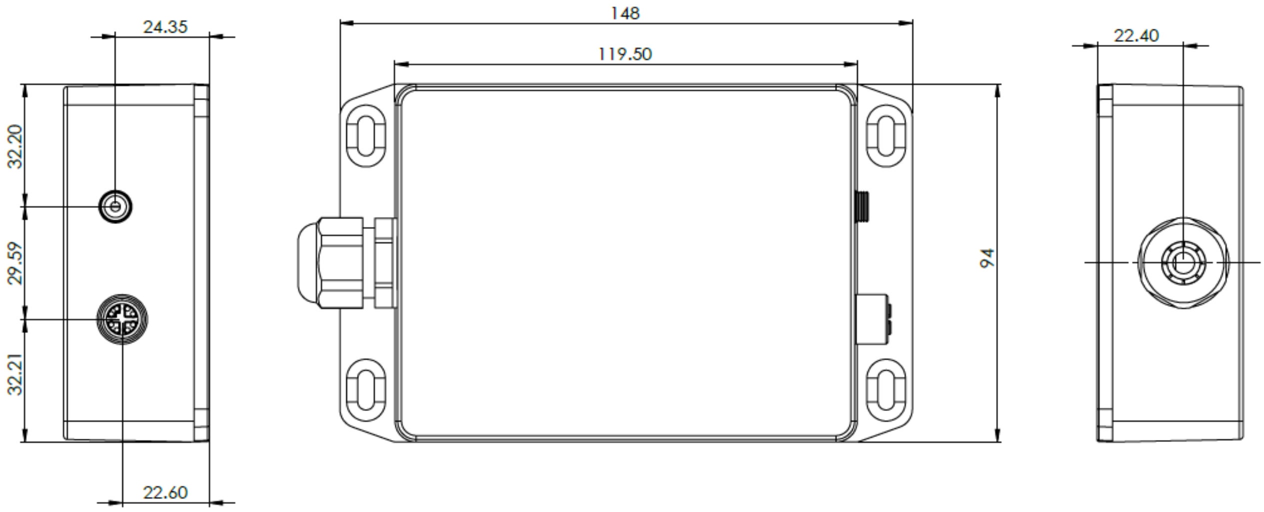
NOTE: Unless otherwise noted, please allow for 15 minutes warm up time to achieve optimal performances.
The listed specifications apply for all three measurement channels at room temperature (23 °C ± 1 °C).

Parameter	Value	Remarks
Full scale magnetic flux density ($\pm B_{FS}$)	±0.5 T (±5 kG)	No saturation of the Probe outputs
Linear range of magnetic flux density ($\pm B_{LR}$)	±0.5 T (±5 kG)	Fully calibrated measurement range
Measurement DC accuracy @ $B \leq \pm B_{FS}$	< ±0.1 % of B_{FS}	See note 1
Output voltages (V_{out})	differential	See note 2
Sensitivity to DC magnetic field (S)	20 V/T (2 mV/G)	Differential output; See note 3
Tolerance of sensitivity (S_{err}) @ $B \leq \pm B_{FS}$	< 0.03 % of S	$100 \times \lvert S' - S \rvert / S$; See notes 3 and 4
Nonlinearity (NL) @ $B \leq \pm B_{FS}$	< 0.05 %	See note 4
Planar Hall voltage (V_{planar}) @ $B \leq \pm B_{FS}$	< 0.01 % of V_{normal}	See note 5
Temperature Coefficient of Sensitivity	< ±100 ppm/°C (±0.01 %/°C)	@ Temp. range +15 °C to +35 °C
Long-term instability of Sensitivity	< 1 % over 10 years	
Offset (@ B = 0 T)	< ±3 mV (±0.15 mT)	@ Temp. range +20 °C to +30 °C
Temperature Coefficient of the Offset	< ±0.2 mV/°C (±0.01 mT/°C)	
Offset fluctuation & drift (@ 0.01 - 10 Hz, eg. Δt = 0.05 s, t = 100 s)	< 0.8 mV_{P-P} (40 μT_{P-P})	Standard Deviation (RMS) value is < 0.13 mV_{RMS} (6.5 μT_{RMS}); See note 6
Output noise		
Noise Spectral Density @ f = 1 Hz (NSD_1)	≈ 40 $\mu V/Hz^{1/2}$ (2 $\mu T/Hz^{1/2}$)	Region of 1/f-noise
Corner frequency (f_C)	≈ 10 Hz	Where 1/f = white noise
Noise Spectral Density @ f > 10 Hz (NSD_W)	≈ 15 $\mu V/Hz^{1/2}$ (0.75 $\mu T/Hz^{1/2}$)	Region of white noise
Broad-band Noise (V_{nRMS-B}) @ $f_C < f < Bw$	≈ 2.5 mV_{RMS} (0.5 mT_{RMS})	RMS noise; see note 7
Resolution		See notes 6 - 10
Typical frequency response		
Sensitivity attenuation < 0.1 %	< 200 Hz	Test-signal: $B = 10mT \times \sin(2\pi ft)$
Sensitivity attenuation < 1 %	< 500 Hz	See page 9: AC Calibration Table - Frequency Response characterization
Frequency Bandwidth (Bw)	≈ 25 kHz	Sensitivity attenuation ≈ -3 dB; Note 11
Output resistance	< 10 Ω, short circuit proof	
Temperature output		
Ground-referred voltage:	$V_{PT}[mV] = (T_{HALL}[°C] - 25\ °C \pm 3\ °C) \times 100\ [mV/°C]$ (where T_{HALL} denotes a local Hall sensor temperature ; See Note 12)	

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

1 T = 10 kG   1 mT = 10 G   1 μT = 10 mG

E-MODULE - MECHANICAL and ELECTRONICS SPECIFICATIONS:



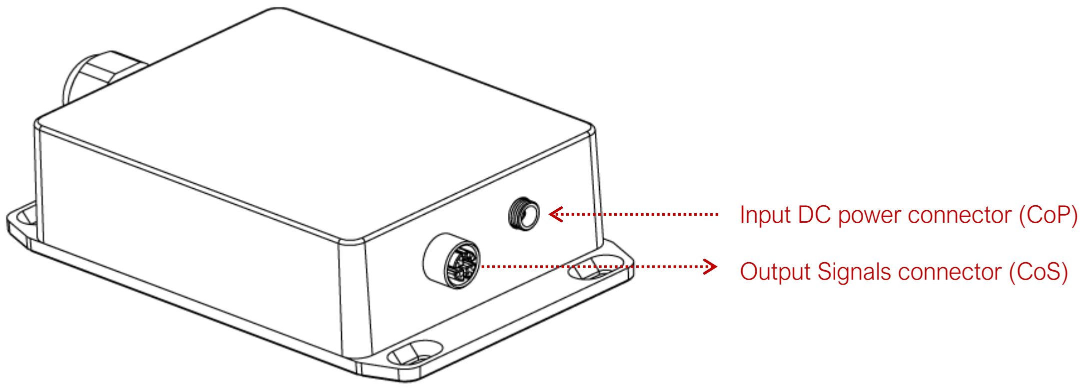
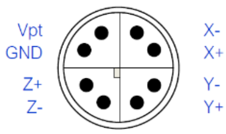


Figure 6. Structure and dimensions of the new 3-channel analog E-module A.5T25KJ

Module E	High mechanical strength, electrically shielded aluminium case [94 **W** x 120 **L** x 38 **H** mm] with mounting provision (see Fig. 6)		
Connector CoS M12-8L-S-X, 8-pins PCB connector, female (Mating plug: M12-8L-S-X, 8-pins, male)	Field signal X-, X+ Field signal Y-, Y+ Field signal Z-, Z+ Probe Temperature (Vpt) Signal common (GND)	Pins 6 and 5 Pins 4 and 3 Pins 2 and 1 Pin 7 Pin 8	
Connector CoP PJ-066B (Mating plug: EP501B - Power Barrel Connector Plug, ID 2.50 mm, OD 5.50 mm)	Power, +24 V Power common (0 V)		
Hall Probe connection	Fixed connection:	Cable gland MS PG11	
DC Power	Voltage: Max. Ripple: Current:	±12 V nominal, ±2 % 100 mVpp ≈ 0.12 A	
Environmental Parameters:			
Operating Temperature	+5 °C to +45 °C		
Storage Temperature	-20 °C to +85 °C		

The ADDITIONAL CALIBRATION OPTIONS:

1. DC Calibration Table (V_{OUT} vs. B_{REF})

DC Calibration Table (Vout vs. Bref), where Vout represents any of the three analog outputs Vx, Vy and Vz of the transducer, can be ordered as an option. The DC 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 high-precision NMR teslameter PT2025 or a high-accuracy digital teslameter/gaussmeter 3MH6 with an integrated 3D Hall probe.

The standard DC 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 utilization of the calibration table, the accuracy of DC and low-frequency magnetic measurement can be improved up to the limit given by the DC resolution of the transducer (see Notes 1 and 6 - 10).

2. AC Calibration Table - Frequency Response characterization

Another option is the AC Calibration Table (Amplitude and Phase vs. Frequency) 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 B_W, measured in the steps of $B_W/10$. Different AC calibration tables are also available upon request.

By the application of the Frequency Response Calibration Table the overall measurement accuracy of the AC magnetic fields measurements can be improved almost up to the limit given by the AC resolution of the device (see Notes 1 and 6 - 11).

The SENIS 3-axis analog magnetic field transducer F3B-03V02F-A.5T25KJ is applicable in the B-frequency range from DC to 25 kHz (-3 dB point of sensitivity attenuation, where 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:

$$S = S_H + jS_I ,$$

where:

- 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).

The AC Calibration data can be ordered for S_H and S_I for all three measurement axes (Bx, By, Bz) 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's output voltages V_{out}.

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: $M.R.E. = S_{err} + NL + 100 \times Res / B_{LR}$ [unit: % of B_{LR}] Eq. [1]

Here, S_{err} is the tolerance of the sensitivity (relative error in % 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.

NOTE: The single-ended outputs are not calibrated.

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

$$V_{out} = S \times B$$ 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:

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

Notation:

B = Actual testing DC magnetic flux density given by a reference NMR PT2025 or 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 sensitivity)

B_{LR} = Linear range of magnetic flux density.

Tolerance of sensitivity can be calculated as follows:

$$S_{err} = 100 \times |S' - S| / S$$ 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. The planar Hall voltage is approximately proportional to the square of the measured magnetic flux density. Therefore, for example:

$$\left.\frac{V_{planar}}{V_{normal}}\right|_{@B=B_0} = 4 \times \left.\frac{V_{planar}}{V_{normal}}\right|_{@B=B_0/2}$$ 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 = 0.05 s and total measurement time t = 100 s. The measurement conditions correspond to the frequency bandwidth within

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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 8 and 9.

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 to 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.

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:

$$V_{nRMS\text{-}B} \approx \sqrt{NSD_{1f}^2 \times 1\text{Hz} \times \ln\left(\frac{f_H}{f_L}\right) + 1.16 \times NSD_W^2 \times f_H} \quad \text{Eq. [6]}$$

Notation:

- 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 bandwidth of interest;
- the numerical factor *1.16* comes under the assumption of using a third-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):

$$f_H \le Bw.$$

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:

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

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

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 third-order Butterworth low-pass filter, with the cut-off frequency $f_{(-3dB)} = Bw$.

The attenuation of the applied filters is -60 dB/dec (-18 dB/oct).

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

12) The equation:

$$V_{PT}[mV] = (T_{HALL}[°C] -25 °C \pm 3 °C) \times 100 [mV/°C]$$

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

The temperature-proportional voltage output of the transducer (V_{PT})is taken from a calibrated temperature sensor in the Hall probe itself. It therefore measures the local temperature of the Hall elements (T_{HALL}).

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 sensor is between 5 °C and 15 °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 4 °C hotter than the environment.