DESCRIPTION:

The model F3A-03KS02C-A.1T25KJ is a high accuracy magnetic flux density-to-analog 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 specially customized mounting of the Hall probe in the ceramic friction pad and in the special prismatic-like package forms the sliding probe allowing in-contact magnetic field measurements (magnetic field sensitive volume, further MFSV, of the Hall sensor is 0.5 mm from the magnet surface).

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: 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

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.

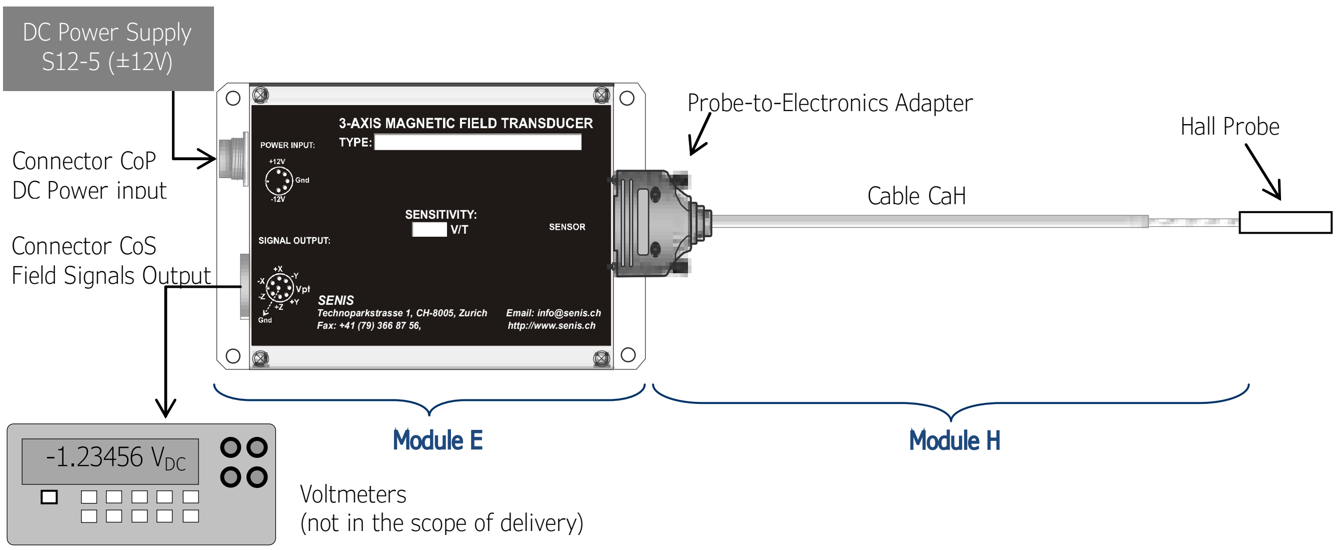


Figure 1. **Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with fully integrated Hall Probe (Module H) and Electronic (Module E)**

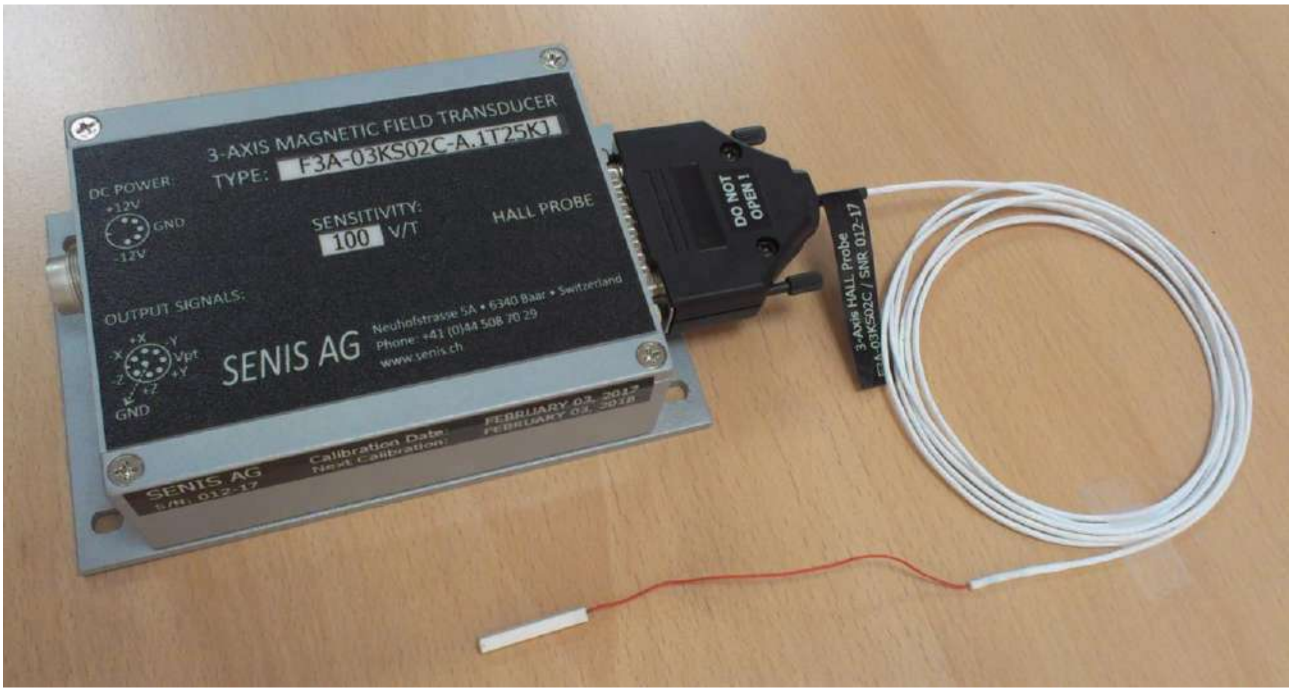


Figure 2. **3-axis magnetic field transducer type F3A-03KS02C-A.1T25KJ**

SPECIFICATIONS (Module H):

The new developed 3-Axis Sliding Hall Probe system (further SHP) is a module particularly designed to allow in-contact magnetic field measurements. It can be efficiently applied for low magnetic fields measurement on the magnet surface (linear encoders, code-plates, magnetic bar codes, microfluidic flow cells, magnet arrays, multi-pole magnets, etc.).

It allows for very small distance (0.5 mm) between the magnet surface and the MFSV of the Hall probe. The SHP system is optimized to provide an easy integration in SENIS F3A Analog Magnetic Transducers, 3MH3A Digital Teslameters and MMS-1A-RS Mapping Systems.

The SHP system integrates the three basic parts:

1. a fully integrated SENIS 3-Axis Hall probe type 03KS (ext. dimensions 8.0 x 2.0 x 0.5 mm);
2. a special prismatic-like probe package made of alumina-ceramic (Al_2O_3), ext. dimensions: 25 x 3 x 3 mm;
3. a ceramic friction pad (on the front side) made of ZrO_3, which allows in-contact magnetic field measurements.

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

The integrated horizontal and vertical Hall elements occupy very small MFSV (150 x 10 x 150 μm^3), 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 very good angular accuracy (orthogonality error < 0.1° after calibration) 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 signal pre-processing on the chip 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 Sliding Hall Probe (SHP) system

→ The new SENIS 3-axis Sliding Hall Probe (SHP) allows in-contact magnetic field measurements (magnetic field sensitive volume of the applied fully integrated 3D Hall sensor is 0.5 mm from the SHP tip)
→ The probe package is fully made of Al_2O_3 ceramic, with the chip and cable connecting pads directly printed on the ceramic substrate
→ Fully integrated CMOS 3-axis (Bx, By, Bz) Hall Probe, of which one, two, or three channels are used
→ Very high spatial resolution (By: 0.03 x 0.005 x 0.03mm^3; Bx and Bz: 0.15 x 0.01 x 0.15 mm^3)
→ High angular accuracy (orthogonality error less than 0.1° after calibration)
→ High frequency bandwidth (DC up to 25kHz)
→ Virtually no planar Hall effect
→ Negligible inductive loops on the Probe
→ Integrated temperature sensor on the probe for temperature compensation

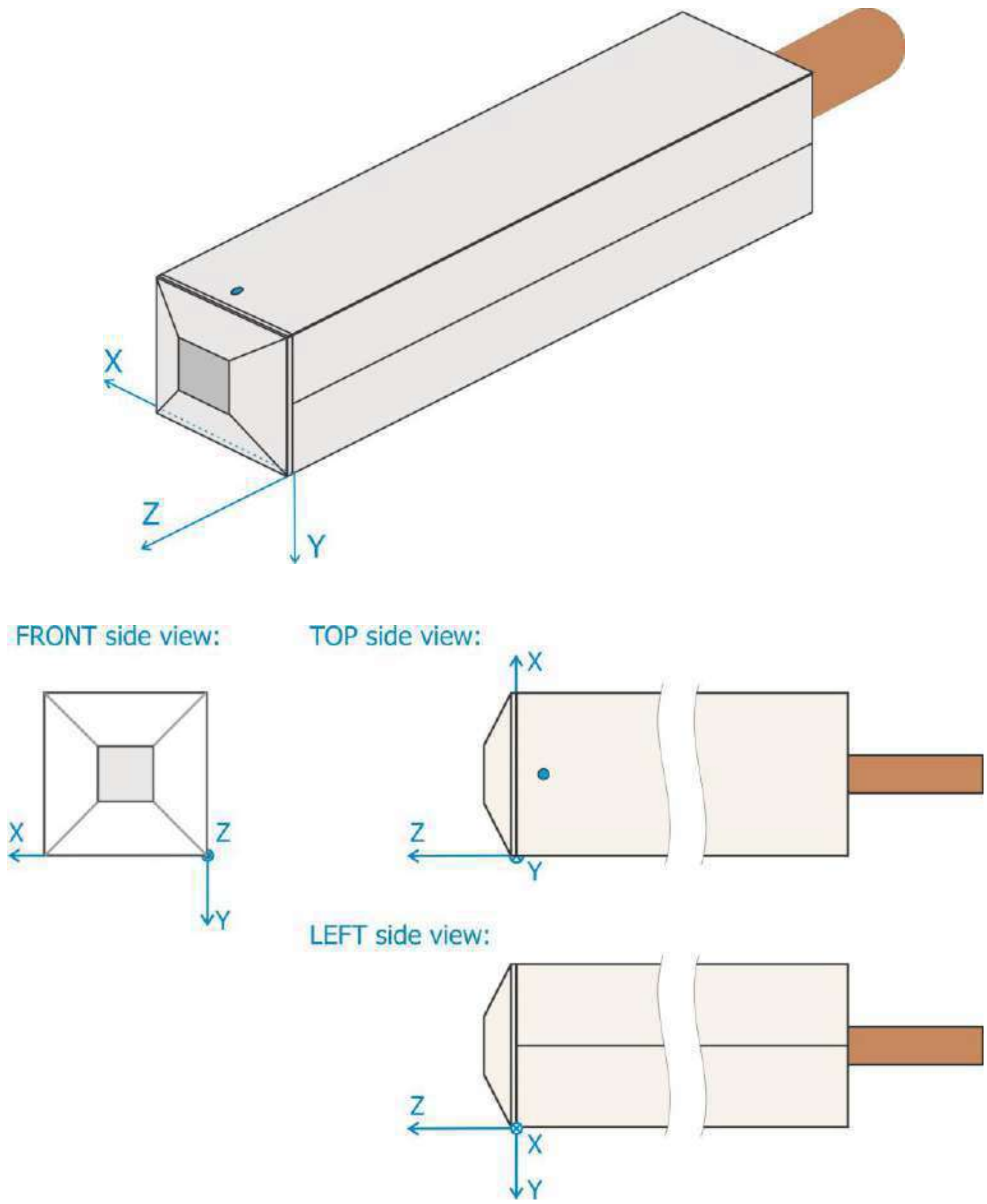
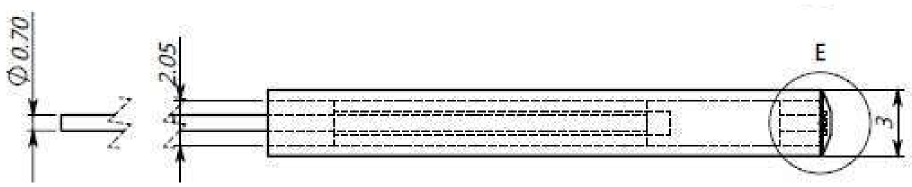


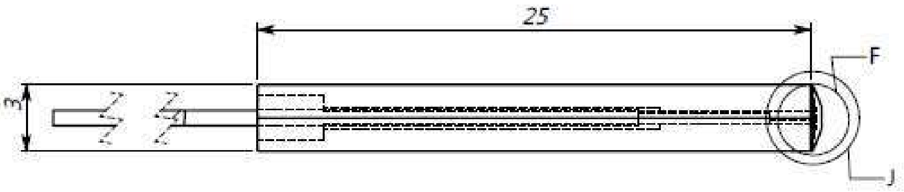
Figure 3: **Reference Cartesian coordinate system of the Sliding Hall Probe (SHP). BLUE point denotes the TOP surface of the probe.**

PROBE AND CABLE - DIMENSIONS AND CHARACTERISTICS

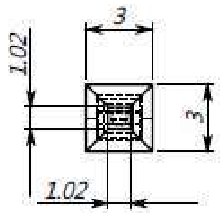
TOP view:



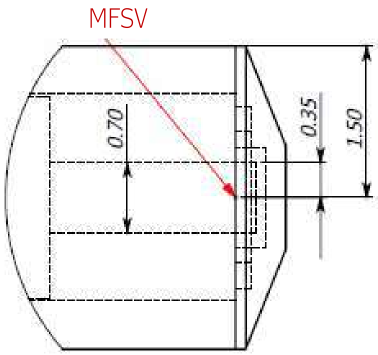
RIGHT side view:



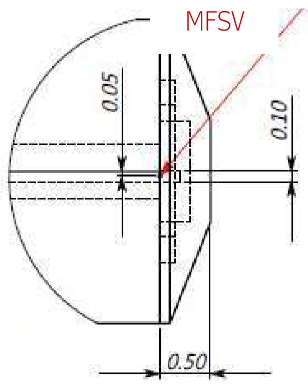
FRONT side view:



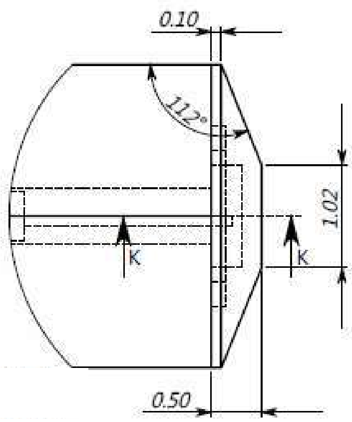
Detail E (TOP view):



Detail F (RIGHT side view):



Detail J (RIGHT side view):



Section K-K:

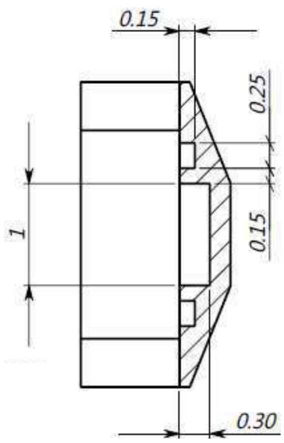


Figure 4. **Dimensions of the Sliding Hall Probe (SHP). All measures are in millimetres (mm). The maximum tolerances:**
X.X: ±0.1 mm
X.XX: ±0.03 mm

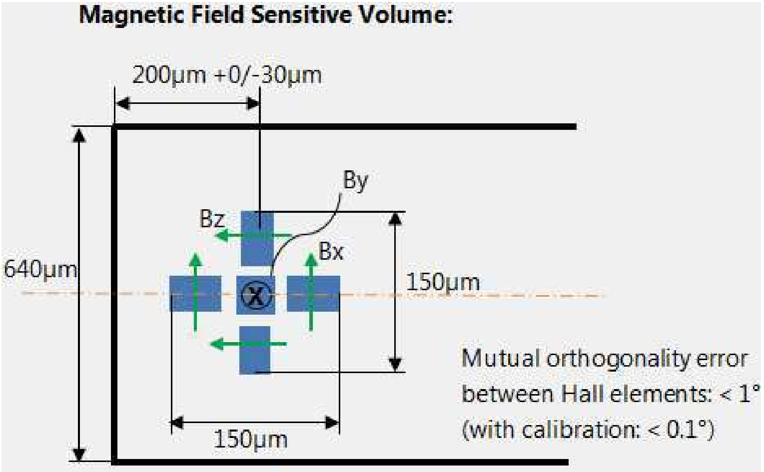


Figure 5. **Overall magnetic field sensitive volume (MFSV) of the applied fully integrated 3D Hall sensor**

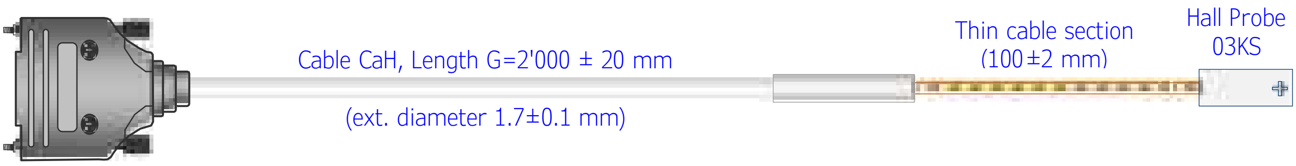


Figure 6. **Dimensions of the cable CaH**

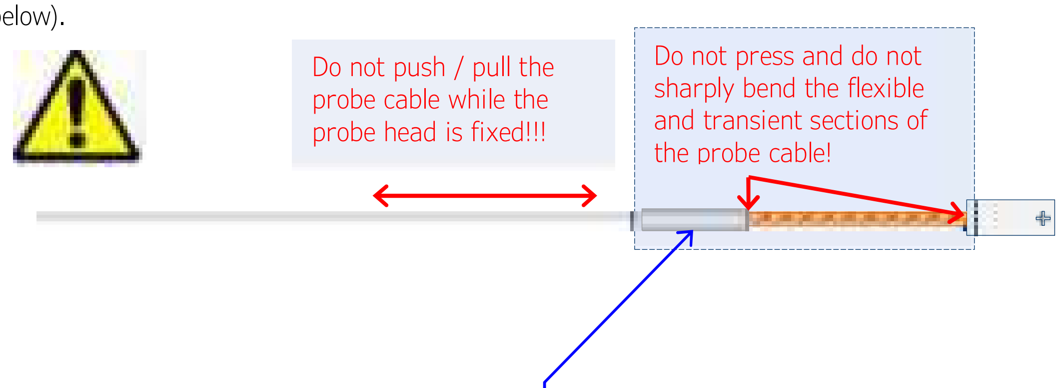
Probe dimensions & characteristics			
Dimension	X [mm]	Y [mm]	Z [mm]
Magnetic field sensitive volume (MFSV) (Fig. 5)	0.15	0.01	0.15
Position of the centre of MFSV (Fig. 3 and 4)	1.5 ± 0.1	-1.5 ± 0.1	0.00 ± 0.05
External dimensions of the Probe	3.0 +0.1/-0.0	3.0 +0.1/-0.0	25.0 ± 0.2
Angular accuracy of the measurement axes	- within ±1° with respect to the reference surface - corrected (after calibration): better than ±0.1°		
CaH Cable	Shielded, with a flexible thin part near the probe		
	Conductor: Silver plated soft copper core, 7 x 44 AWG Insulation: PFA (Perfluoro Alkoxy), diameter 0.30 mm Twisting: 15 x Diameter Shield: Silver plated soft copper braid Jacket: PFA (Perfluoro Alkoxy) Service temperature: -196 / +200 °C Linear resistance: 1.4 Ω/m Rated voltage: 150 Vac		

INSTALLATION MANUAL FOR THE SLIDING HALL PROBE

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

The probe package is made of alumina (Al_2O_3) and zirconium-trioxide ($Zr0_3$) ceramic parts, so it is very robust respective to its small size. However, the following precautions shall help ensure that the transducer accurate calibration remains preserved:

- Always disconnect powering of the Electronic module before plugging/unplugging the Hall probe!
- 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 needs to 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 (see image below).



- Before the probe head is mounted, the white cable should be fixed nearby so it cannot be torn away from the probe head if accidentally pulled. The thin flexible cable section adjacent to the probe head can be carefully folded to allow the cable to come away in any direction, but avoiding any strong repeating of this section:

- In order to prevent rupture of the flexible PCB wires from the probe head, the user should fix and secure the probe cable in the proximity of the head. The thin wires of the flexible section of the probe need to be folded with a special care.
- Avoid any high pressure and bending of the **transient section** between the flexible PCB and the Probe cable.
- Avoid the immersion of the probe of any liquid, and its exposure to moisture and aggressive gasses.
- Do not apply more force than required to hold the probe in its place. Damage of the silicon Hall sensor or ceramic package will destroy the Probe. We strongly suggest storing the probe in its protective case when not in use.
- Keep the cable out of the way of foot traffic. Do not pinch the cable, or drop sharp or heavy objects on it. A severed cable cannot be re-joined without altering the probe performance, and requires factory repair and a full re-calibration of the device.
- The first ensure that the Electronic module is turned off. If so, carefully plug the Probe connector (female SUB-D/25-pins connector) to the corresponding male SUB-D/25-pins connector on the electronic box. Ensuring that its pins engage correctly, tighten the metal screws of the probe connector. Do not leave these loose since they are the component part of the shielding system of the transducer.
- Since the Hall sensor is sensitive to electrostatic discharge (ESD), an operator must take care that the proper ESD-protection procedures are observed while handling the sensor.

MAGNETIC and ELECTRICAL SPECIFICATIONS:

NOTE: Unless otherwise noted, the given specifications apply for all three measurement axes (X, Y, and Z) at room temperature (25°C) and after a device warm-up time of at least 15 minutes.

Parameter	Value	Remarks
Maximum (full scale) magnetic flux density ($\pm B_{FS}$)	±100 mT (±1 kG)	No saturation of the Probe outputs
Linear range of magnetic flux density ($\pm B_{LR}$)	±100 mT (±1 kG)	Fully calibrated measurement range
Total measuring Accuracy @ $B \leq \pm B_{LR}$	better than ±0.1%	See note 1
Output voltages (V_{out})	differential	See note 2
Sensitivity to DC magnetic field (S)	100 V/T (10 mV/G)	Differential output; See note 3
Tolerance of sensitivity (S_{err}) @ $B \leq \pm B_{LR}$	< 0.03 % of S	100 x |S' - S| / S ; See notes 3 and 4
Nonlinearity (NL) @ $B \leq \pm B_{LR}$	< 0.05 %	See note 4
Planar Hall voltage (V_{planar}) @ $B \leq \pm B_{LR}$	< 0.01% of V_{normal}	See note 5
Temperature Coefficient of Sensitivity	< ±100 ppm/°C (±0.01 %/°C)	@ Temp. range 25°C ± 10°C
Long-term instability of Sensitivity	< 1% over 10 years	
Offset (@ B = 0T)	< ±5 mV (±50 μT)	@ Temp. range 25°C ± 5°C
Temperature Coefficient of the Offset	< ±1 mV/°C (±10 μT/°C)	
Offset fluctuation & drift (within 0.01-10Hz, eg. Δt = 0.05s, t = 100s)	< 3.5 mV_{P-P} (35 μT_{P-P}) X and Z < 2.0 mV_{P-P} (20 μT_{P-P}) Y axis	Standard Deviation (RMS) values: < 0.60 mV_{RMS} (6 μT_{RMS}) **X & Z axes** < 0.35 mV_{RMS} (3.5 μT_{RMS}) **Y axis** See note 6
Output noise		
Noise Spectral Density @ f = 1 Hz (NSD_1)	≈ 200 $\mu V/Hz^{1/2}$ (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)	≈ 70 $\mu V/Hz^{1/2}$ (0.7 $\mu T/Hz^{1/2}$)	Region of white noise
Broad-band Noise (10 Hz to f_T) (V_{nRMS-B})	< 12 mV_{RMS} (0.12 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%	< 1 kHz	Page 9: AC Calibration-Frequency Response characterisation
Frequency Bandwidth [f_T]	≈ 25 kHz	Sensitivity decrease -3dB; Note 11
Output resistance	< 10 Ω, short circuit proof	
Temperature output		
Ground-referred voltage :	V_T [mV] = (T [°C] – 25°C ± 2°C) x 500 [mV/°C]	

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

1 T = 10 kG 1 mT = 10 G 1 μT = 10 mG

MECHANICAL and ELECTRONICS SPECIFICATIONS (Module E):

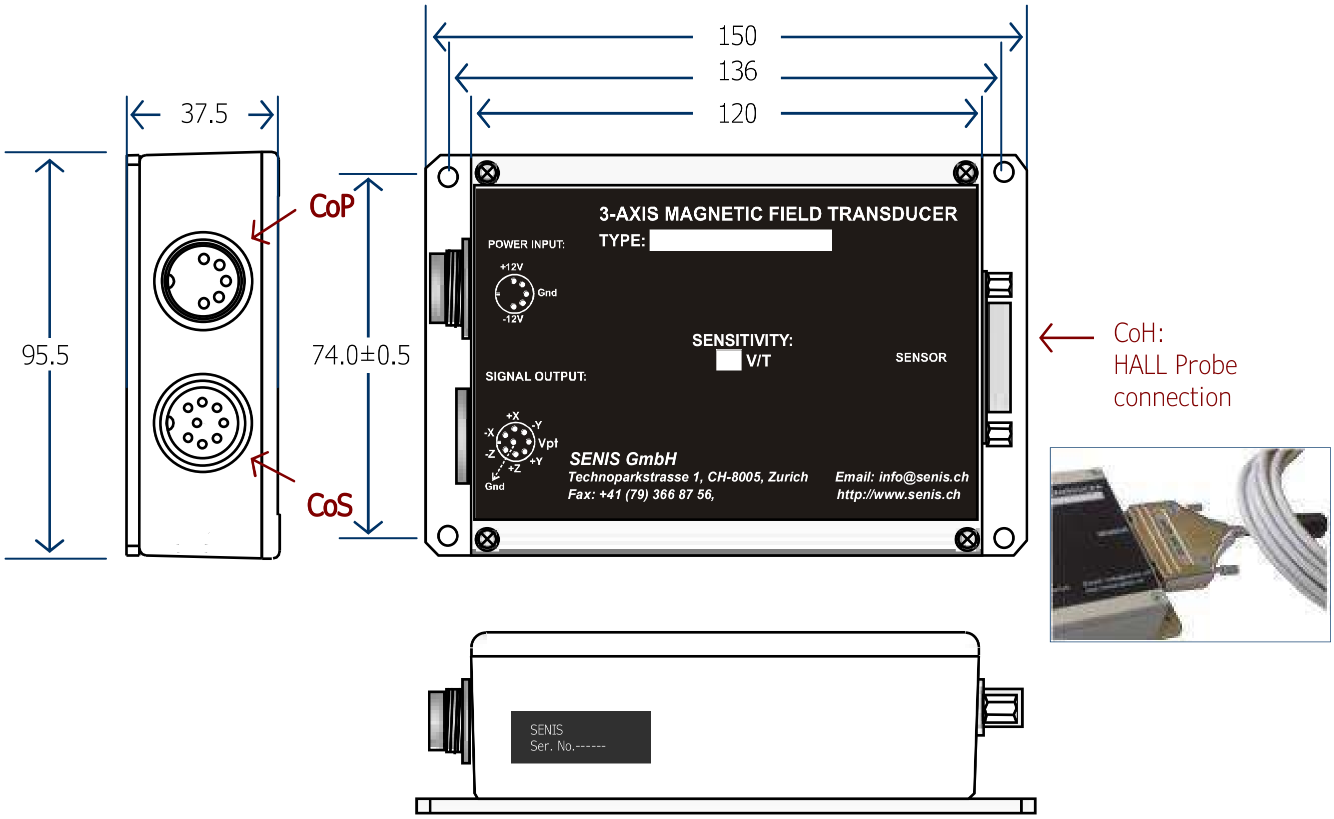


Figure 7. **Dimensions and tolerances of the 3-channel analog processing module type A.1T25KJ**

Module E	High mechanical strength, electrically shielded aluminium case [95 **W** x 120 **L** x 37 **H** mm] with mounting provision (see Fig. 7)	
Connector CoS DIN KFV81, 8 poles (Mating plug SV81)	Field signal X+, X- Field signal Y+, Y- Field signal Z+, Z- Temperature signal Signal common (GND)	Pins 1 and 6, respectively Pins 5 and 4, respectively Pins 3 and 7, respectively Pin 2 Pin 8
Connector CoP DIN SFV50, 5 poles (Mating plug KV50)	Power, +12V Power, -12V Power common (GND)	Pin 3 Pin 1 Pin 2
Connector CoH	Detachable connection:	Standard: D-SUB25, socket, 25-pins
DC Power	Voltage: Max. Ripple: Current:	±12 V nominal, ±2% 100 mV_{pp} ca. ±50 mA
Environmental Parameters:		
Operating Temperature	+5°C to +45°C	

Storage Temperature	-20°C to +85°C

OPTIONS:

DC Calibration Table (Vout vs. Bref)

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 or a high-accuracy digital teslameter/gaussmeter. 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 characterization

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 3-Axis analog magnetic field transducer F3A-03KS02C-A.1T25KJ is applicable in the B-frequency range from DC to 25 kHz (-3dB point), 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:

$$S = S_H + jS_I$$

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 measurement axes (Bx, By, and Bz) as an option. This allows a user 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) 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: $M.R.E. = S_{err} + NL + 100 \times Res / B_{LR}$ [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) The sensitivity is given as the nominal slope of an ideal linear function $V_{out} = f(B)$, i.e.

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

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:

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

Notation:

B = Actual testing DC magnetic flux density measured by a reference NMR or a high-accuracy 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

The tolerance of sensitivity can be calculated as follows:

$$S_{err} = 100 \times |S' - S| / S \qquad \text{Eq. [4]}$$

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:

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

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) The 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:

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

Notation:

- 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 *1.16* comes under the assumption of using a third-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: $f_H \le f_T$. 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, $N \le f_{samP} / f_{samS}$.

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 bandwidth from DC to f_T.
The filter attenuation is -60 dB/dec (-18 dB/oct).
The calibration table of the frequency response is available as an option.