Datasheet: # I1A MAGNETIC FIELD TRANSDUCERS

Very Low-Noise & Low-Offset Magnetic Field Transducers with Integrated 1-Axis (By) Hall Probe

DESCRIPTION:

The **I1A** denotes a range of SENIS analog magnetic field-to-voltage transducers with integrated 1-axis Hall Probe that measures magnetic fields perpendicular to the probe plane (By).

The Hall probe contains a CMOS integrated circuit, which incorporates a Hall element and a temperature sensor.

The integrated Hall element occupies very small area (22 µm x 22 µm), which provides very high spatial resolution of the probe, see Figure 1:

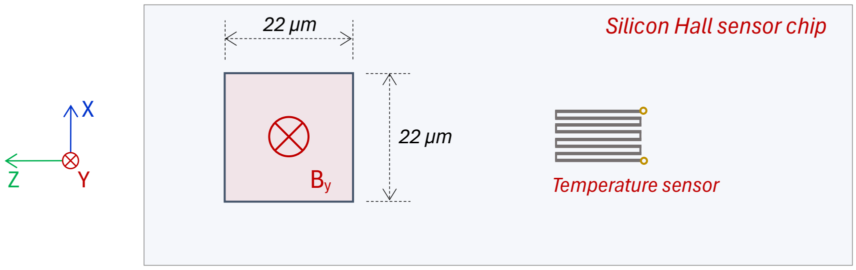


Figure 1: Magnetic field sensitive volume (FSV) of the applied integrated CMOS 1-axis Hall sensor

The Hall probe is connected with an electronic box (Module E in Fig. 2).

The Module E provides biasing for the Hall probe. The additional conditioning of the Hall probe signals in the electronic box includes Hall signal amplification, non-linearity correction, compensation of the offset and sensitivity temperature variations, limitation of the frequency bandwidth and fine tuning of sensitivity.

The outputs of the I1A magnetic field transducer are available at the connector CoS on the Module E:

- high-level differential voltage (Vy) proportional with the measured transverse (By) component of a magnetic flux density, and
- ground-referred voltage (Vpt) proportional with the actual local temperature of the Hall sensor.

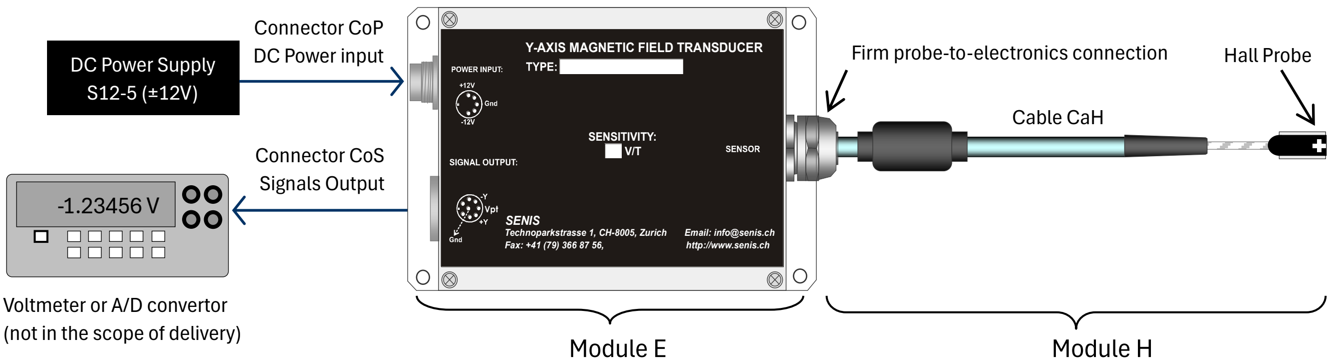


Figure 2: Standard measurement setup with a SENIS magnetic-field-to-voltage transducer with integrated 1-axis Hall Probe (Module H) and Electronic (Module E)

KEY FEATURES:

- Integrated CMOS 1-axis Hall probe that measures magnetic field component perpendicular to the probe plane (By).
- Very high spatial resolution: 0.022 x 0.005 x 0.022 mm^3.
- Very low-noise and low-offset fluctuations.
- Very high linearity.
- Very low planar Hall voltage.
- Integrated temperature sensor in the probe for temperature compensation.
- Negligible inductive loops on the probe, etc.

TYPICAL APPLICATIONS:

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

Figure 3: Photo of a 1-axis magnetic field transducers I1A with integrated 1-axis (By) Hall Probe

MAGNETIC and ELECTRICAL PERFORMANCES:

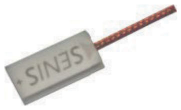
NOTE: Unless otherwise noted, please allow for 15 minutes warm up time to achieve optimal performances.
The listed specifications apply for all three measurement channels at room temperature (+23 ± 1) °C.

Parameter	Value				Remarks
Standard measurement range (±B_{FS}) *	±0.1 T	±0.2 T ±0.5 T	±1 T ±2 T ±3 T	±5 T ±10 T ±20 T	*No saturation of the outputs. Other measurement ranges are available on a request.*
Linear range of magnetic flux density (±B_{LR})	±0.1 T	±0.2 T ±0.5 T	±1 T ±2 T ±2 T	±2 T	*Optimal, fully in-factory calibrated measurement range*
Measurement DC accuracy @ B < ±B_{LR}	< ±0.1%	< ±0.1%	< ±0.1%	< ±1%	*Measured at DC fields as % of full scale. See note 1*
Output voltages	Differential (±10 V @ ±B_{FS})				*See note 2*
Magnetic sensitivity (S)	100 V/T	50 V/T 20 V/T	10 V/T 5 V/T 3.3 V/T	2 V/T 1 V/T 0.5 V/T	*Measured at DC fields. Differential outputs. See note 3*
Tolerance of sensitivity (S_{err}) @ B < ±B_{LR}	< 0.03%	< 0.03%	< 0.03%	< 0.5%	*See notes 3 and 4*
Nonlinearity (NL) @ B < ±B_{LR}	< 0.03%	< 0.05%	< 0.05%	< 0.25%	*See note 4*
Planar Hall voltage (V_{planar}) @ B < ±B_{LR}	< 0.01% of V_{normal}				*See note 5*
Temperature Coefficient of Sensitivity	< ±100 ppm/°C (0.01 %/°C)				*@ Temperature range (25 ± 10) °C*
Long-term instability of Sensitivity	< 1% over 10 years				
Offset (@ B = 0 T)	< ±6 µT	< ±20 µT	< ±0.2 mT	< ±1 mT	*@ Temperature range (25 ± 5) °C*
Temperature Coefficient of the Offset	< ±1 µT/°C	< ±4 µT/°C	< ±20 µT/°C	< ±100 µT/°C	
DC Resolution / Offset fluctuation & drift (@ 0.01-10 Hz, eg., Δt_s=0.05 s, t=100 s)	< 5 µT	< 7 µT	< 10 µT	< 50 µT	*Peak-to-peak values. See note 6*
Output Noise:					
Noise Spectral Density @ 1 Hz	< 0.1 $\mu T/Hz^{1/2}$	< 0.2 $\mu T/Hz^{1/2}$	< 0.3 $\mu T/Hz^{1/2}$	< 1.5 $\mu T/Hz^{1/2}$	*Region of 1/f noise*
Corner frequency (f_C)	~ 10 Hz				*Where 1/f noise = white noise*
Noise Spectral Density @ f > f_C	< 0.04 $\mu T/Hz^{1/2}$	< 0.09 $\mu T/Hz^{1/2}$	< 0.12 $\mu T/Hz^{1/2}$	< 0.6 $\mu T/Hz^{1/2}$	*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*
AC Resolution					*See notes 6 - 10*
Typical Frequency response:					
Frequency Bandwidth (Bw)	500 Hz 1 kHz maximum: 2.5 kHz				*Sensitivity attenuation is -3 dB. See note 11*
Output resistance	< 1 kΩ, short circuit proof				
Probe temperature output:					
Voltage-to-ground (Vtp)	V_{PT}[mV] = (T_{Hall}[°C] - 25 °C ± 1 °C) · 50 mV/°C				*T_{Hall} being the actual local temperature of the Hall sensor. See note 12*
Magnetic Flux Density (B) units: tesla (T) - gauss (G):					
1 T = 10 kG 1 mT = 10 G 1 µT = 10 mG					

* The device provides only one measurement range - a subject of selection prior to ordering.

HALL PROBE and CABLE - MECHANICAL SPECIFICATIONS:

The I1A magnetic field transducers apply a number of different geometries/dimensions of Hall probes available that fulfil a wide range of application requirements:

Hall Probe Type:	**External Dimensions:** **L x W x H (mm)**	**Magnetic Field Sensitive Volume** **(FSV, μm³)**
Type A 1) 	**A:** 16.5 x 5.0 x 2.3	22 x 5 x 22
Type C 2) 	**C:** 8.0 x 4.0 x 0.9	
Type H 3) 	**HL:** 71.0 x 2.0 x 0.75 **HM:** 47.0 x 2.0 x 0.75 **HS:** 8.0 x 2.0 x 0.75	

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

REMARKS:

1) Very robust probe package.
2) Standard, robust and compact ceramics package.
3) Narrow and thin probe package with mechanically protected chip.
   It is available in 3 (three) different lengths: long (L), medium (M) and short (S).

For Hall probe selection please see the list of the available probes at:
https://www.senis.swiss/magnetometers/#hall-probes .

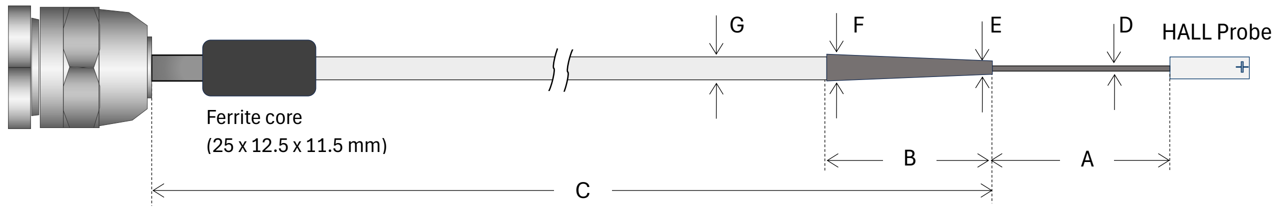


Figure 4: Standard configuration of the H-module (Hall probe and cable)

Dimension	Measure	Remark
A	50 ± 1 mm	Standard for all probes. Optional: maximum up to 200 mm
B	35 ± 2 mm	Applied to all probes.
C	2 m 5 m 10 m	Different lengths are available upon a request.
D	Ø 1.7 ± 0.2 mm	Standard for all probes
E	Ø 3.3 ± 0.5 mm	
F	Ø 6.0 ± 0.5 mm	
G	Ø 4.8 ± 0.2 mm	

I1A MAGNETIC FIELD TRANSDUCERS - MODEL NUMBER CHART:

I1	x	-	H1	H2	H3	H4	H5	H6	-	E1	E2	E3	E4	E5	E6	E7	E8
Type ID (3 characters)			Module H (6 or 7 characters)							Module E (8 characters)							

- **I1** Magnetic Field Transducer (MFT) identifier;
- **x** product release version, currently **A**;
- For Module H (6 or 7 characters) and Module E (8 characters) see the document *MFT Model Numbering Chart.pdf*.

OUTLINE DIMENSIONS:

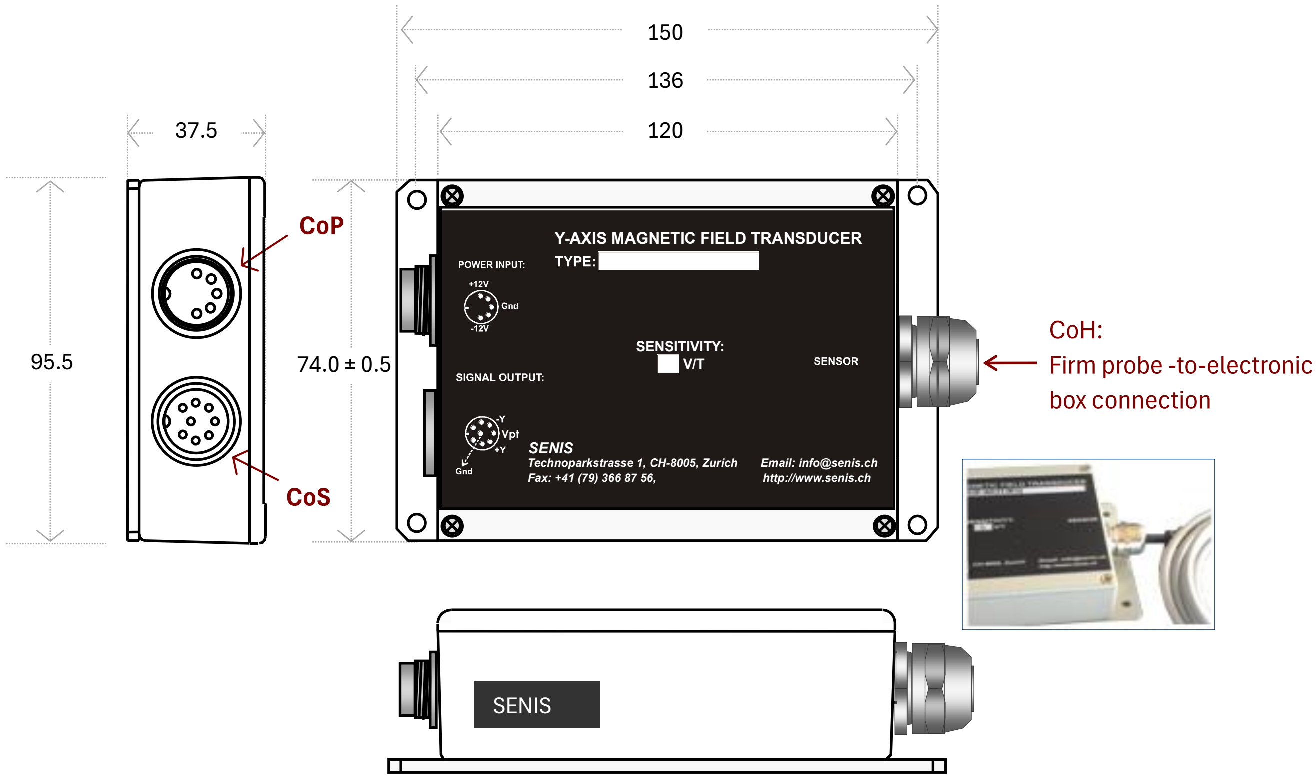
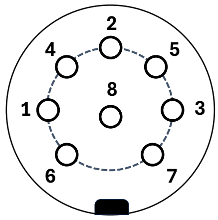
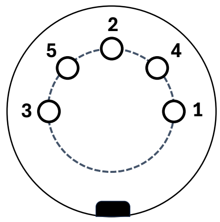


Figure 5: Structure and dimensions of the single-channel analog processing module of the I1A magnetic field transducers

Module E	High mechanical strength, electrically shielded aluminium case [dim. 95 **W** x 120 **L** x 37 **H** mm] with mounting provision (see Figure 5)		
Connector CoS DIN KFV81, 8 poles (Mating plug: DIN SV81)	Field signal (Y+, Y-) Probe Temperature (Vpt) Signal common (GND)	<u>Outside view:</u> Pins 5 and 4, resp. Pin 2 Pin 8	
Connector CoP DIN SFV50, 5 poles (Mating plug: DIN KV50)	Power, +12 V Power, -12 V Power common (GND)	<u>Outside view:</u> Pin 3 Pin 1 Pin 2	
Hall Probe connection:	Fixed connection:	Cable gland MS PG11	
Input DC Power:	DC Voltage: Max. Ripple: DC Current:	±12 V nominal, ±2% 100 mV_{PP} ~ 40 mA	
Environmental Parameters:			
Operating Temperature	(+5, +45) °C		
Storage Temperature	(-20, +85) °C		

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:

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

where is:

- S_{err} tolerance of the sensitivity (relative error in % of S - see below note 3),
- *NL* maximal relative nonlinearity error (see below note 4),
- *Res* absolute resolution (see below Notes 6 - 10), and
- B_{FS} measurement range (full scale) of the subject magnetometer.

2) Each 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 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.

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

Here 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, nonlinearity error is calculated as follows:

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

Notation:

- *B* actual testing DC magnetic flux density measured by a reference NMR Teslameter PT2025 or a high-accuracy digital Teslameter/gaussmeter 3MH6 traceable to the NMR standard,
- $V_{out}(B) - V_{off}$ 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_{FS} full scale of magnetic flux density.

Tolerance of sensitivity (also: sensitivity error) can be calculated as follows:

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

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

V_{planar} approximately proportional to the square of the measured magnetic flux density.

Therefore, for example:

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

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_s = 0.05 s (sampling rate 20 samples/s), and total measurement time *t* = 100 s. The measurement conditions correspond to the frequency bandwidth within (0.01 - 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:

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

Notation:

- *NSD_{1f}* 1/f noise voltage spectral density (RMS) @ f = 1 Hz,
- *NSD_w* RMS value of the white-noise voltage spectral density,
- *f_L and f_H* Low and High-frequency limit of the bandwidth of interest, respectively, and
- *1.57* numerical factor that comes under the assumption of using the first-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, eg.

$$V_{nP\text{-}P\text{-}B} \approx 6 \times V_{nRMS\text{-}B}.$$

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:

$$f_{samP} > 5 \times f_H$$ (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:

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

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

The attenuation of the applied filter is -20 dB/dec (-6 dB/oct).

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

12) The equation:

$$V_{PT}[mV] = (T_{HALL}[°C] - 25°C \pm 1°C) \cdot 50\ [mV/°C]$$

is valid in the temperature range (+5, +45) °C.

The probe temperature-proportional voltage output of the transducer (V_{PT}) is taken from a calibrated temperature sensor integrated in the CMOS Hall sensor. It therefore measures the local temperature of the Hall elements. Due to power loss in the sensor, its temperature is always higher than the environmental temperature.

The difference between the temperature of the sensor (T_{HALL}) and the environment is more pronounced if the sensor tip is free hanging in the air. In this case the sensor may be (5 - 15) °C hotter than the environment, depending on the probe geometry and applied materials for the probe housing.

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 5°C hotter than the environment.