## DESCRIPTION:

The I3A-03C02F-B02T0K5J denotes a SENIS magnetic field to voltage transducer with integrated 3-axis Hall probe that measures all three components (Bx, By, Bz) of an applied magnetic field.

The Hall Probe contains a CMOS integrated circuit, which incorporates three groups of mutually orthogonal Hall elements and a temperature sensor. The integrated Hall element occupies very small area (100µm x 100µm), which provides very high spatial resolution of the probe.

The Hall probe is connected with an electronic box (module E in Fig. 1). The Module E provides power to the Hall probe by using the spinning-current technique, which reduces 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 temperature variations, and limitation of the frequency bandwidth.

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The outputs of the I3A Magnetic Transducers are available at the connectors CoS of the module E: these are high-level differential voltages proportional to all three measured components (Bx, By, Bz) of the magnetic flux density, and a ground-referred voltage proportional to the probe temperature.

## KEY FEATURES:

- **Integrated CMOS 3-axis Hall Probe (Bx, By, Bz) of which one, two or three channels are used**
- **Low noise & offset fluctuation magnetic transducer, allowing very high resolution measurements**
- **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**
- **Negligible inductive loops on the probe**

## TYPICAL APPLICATIONS:

- Mapping magnetic fields
- Characterization of undulators systems
- Current sensing
- Application in laboratories and in production lines
- Quality control and monitoring of magnet systems (generators, motors, etc.)

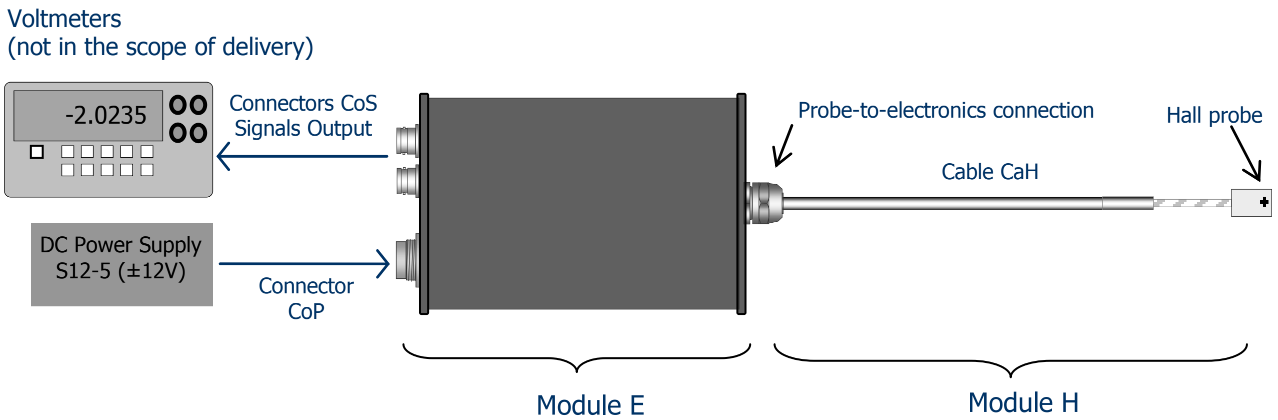



*Figure 1.* Typical measurement setup with a SENIS magnetic-field-to-voltage transducer with integrated 3-axis Hall probe (module H) and electronics (module E, encapsulated in the box type B)


*Figure 2.* 3-axis magnetic field transducer I3A-03C02F-B02T0K5J

## SPECIFICATIONS (Module H):

The SENIS Hall Probe 03C is a very thin 3-axis Hall-probe system that gives an analogue voltage output for all three components of the measured magnetic flux density (Bx, By, Bz) and for the probe temperature. The probe contains a high-resolution Hall element and a temperature sensor.

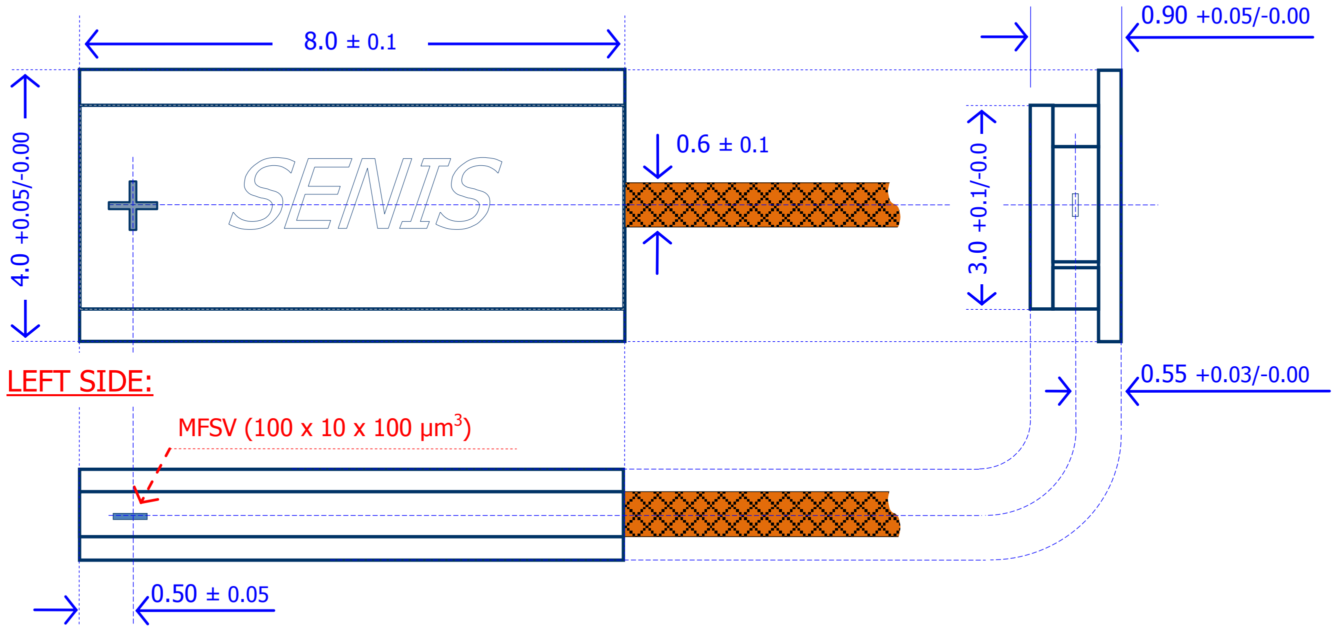
The sensor chip is embedded in the probe package and connected to the CaH cable, which makes this probe both mechanically and electrically very robust. The chip is glued onto a reference ceramic plate suitable for an appropriate fixing of the probe.

The Probe contains a CMOS integrated circuit, which incorporates three groups of Hall elements and a temperature sensor. The integrated Hall elements occupy very small area (100 x 100 µm), which provides very high spatial resolution of the probe.

## Key features of the I3A-03C HALL PROBE SYSTEM:

- Very robust Hall Probe. The chip is glued onto a reference ceramic plate suitable for an appropriate fixing of the probe
- Integrated CMOS 3-axis (Bx, By, Bz) Hall Probe
- Very low noise and offset fluctuations
- Very high spatial resolution (By: 22 x 5 x 22 $\mu m^3$; Bx and Bz: 100 x 10 x 100 $\mu m^3$)
- Very high linearity
- High angular accuracy (orthogonality error less than 0.1°)
- Virtually no planar Hall Effect
- Negligible inductive loops on the Probe
- Integrated temperature sensor on the probe for temperature compensation

## PROBE AND CABLE DIMENSIONS AND CHARACTERISTICS



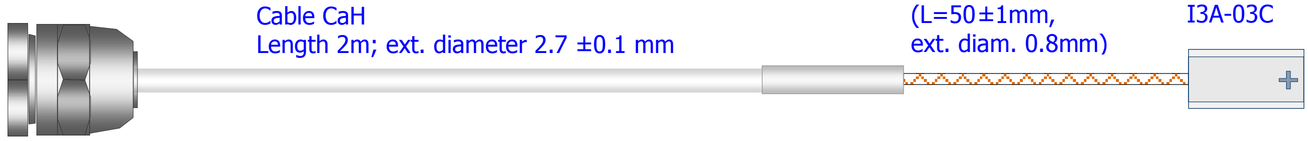




*Figure 3.* Dimensions of the I3C-03C Hall Probe and Cable (Module H).
NOTE: Different Cable lengths are available upon a request.

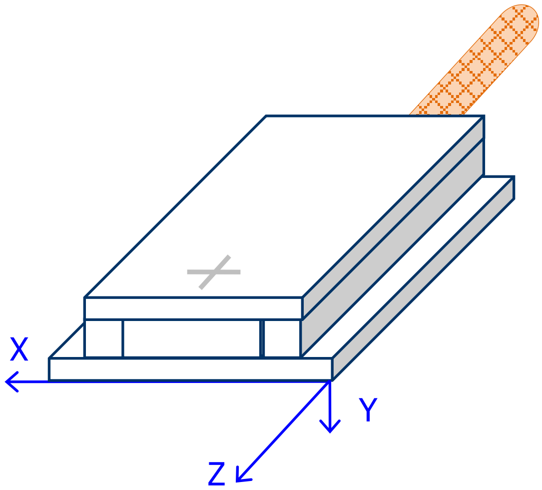



*Figure 4.* Reference Cartesian coordinate system of the SENIS I3A-03C Hall probe.
NOTE: The Probe case of the C-Vacuum probe is open on the front side.

| **Parameter** | | | |
|---|---|---|---|
| Dimensions | X (mm) | Y (mm) | Z (mm) |
| Magnetic Field sensitive volume (MFSV) | 0.10 | 0.01 | 0.10 |
| Position of the centre of FSV | 2.0 ± 0.1 | -0.55 -0.03/+0.00 | -1.0 ± 0.1 |
| External dimensions of the Probe | 4.0 +0.05/-0.00 | 0.90 +0.05/-0.00 | 8.0 ± 0.1 |
| Positioning accuracy | | | |
| Angular accuracy of axes with respect to the reference surface | ±0.5°, Determined during calibration | | |
| Cable properties | | | |
| Conductor: | Silver plated soft copper core, 7 x 44 AWG | | |
| Insulation: | PFA (Perfluoroalkoxy), diameter 0.30 mm | | |
| Twisting: | 15 x Diameter | | |
| Shield: | Silver plated soft copper braid | | |
| Jacket: | PFA (Perfluoroalkoxy) | | |
| Service temperature: | -196 / +200 °C | | |
| Linear resistance: | 1.4 Ω/m | | |
| Rated voltage: | 150 Vac | | |
| RoHS compliance: | Yes | | |

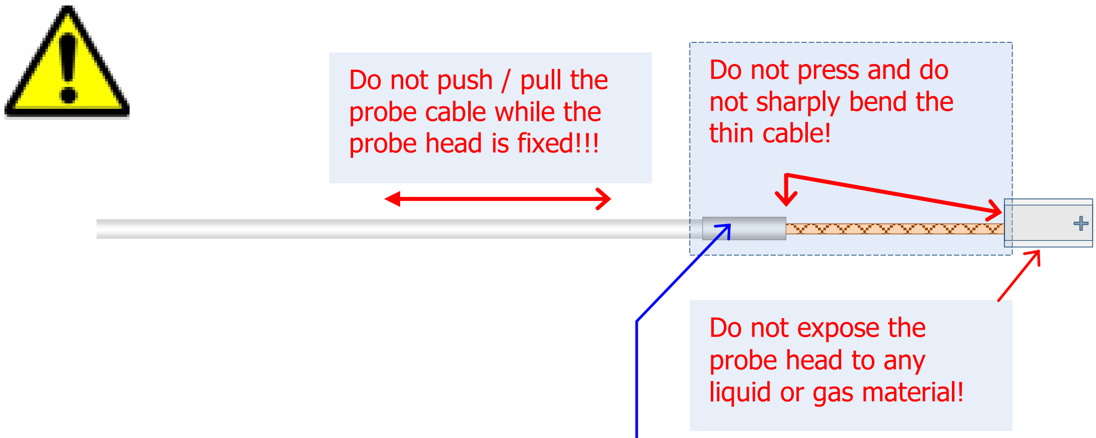
## INSTALLATION MANUAL FOR THE 03C HALL PROBE:

Although the 03C probe is very robust with respect to its size, it should be handled with special care. Considering that we deal with a high-precision device of very small dimensions, following precautions should help to avoid damage to the probe during installation and handling, and ensure that the device's accurate calibration remains preserved:

- The Hall Probe is sensitive to Electrostatic Discharge (ESD). Be sure to ground yourself and follow proper procedure when handling the Hall probe.
- 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 head and particularly on the thin cable.
- Do not apply more force than required to hold the probe in its place. Damage to either the ceramics package of the Hall sensor or thin wiring could destroy the Probe. We strongly suggest storing the probe in its protective case when not in use.

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

- If the probe head is clamped, the user needs to make sure that the environment 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). Do not apply more force than required to hold the probe in its mounting.




- In order to prevent rupture of the thin probe wiring, 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 can be folded only with a special care. Any repetition sharp bending must be strongly avoided.
- Avoid any high pressure and bending of the transient section between the thin and thick Probe cables.
- Avoid the immersion of the probe of any liquid, and its exposure to moisture and aggressive gasses.

## MAGNETIC AND ELECTRICAL SPECIFICATIONS:

NOTE: Unless otherwise noted, the given specifications apply for all measurement channels at room temperature (23°C) and after a device warm-up time of 15 minutes.

| Parameter | Value | Remarks |
|---|---|---|
| Maximum magnetic flux density ($\pm B_{FS}$) | ±2 T (±20 kG) | *No saturation of the outputs* |
| Linear range of magnetic flux density ($\pm B_{LR}$) | ±2 T (±20 kG) | *Fully calibrated measurement range* |
| Total measuring Accuracy (@ $B \leq \pm B_{LR}$) | 0.1% | *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% | *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 | < ±50ppm/°C (±0.005%/°C) | *@ Temperature range 23°C ± 5°C* |
| Long-term instability of sensitivity | < 1% over 10 years | |
| Offset (@ B = 0T) | < ±10 mV (±2 mT) | *@ Temperature range 23°C ± 5°C* |
| Temperature Coefficient of the Offset | < ±20 μV/°C (±4 μT/°C) | |
| Offset fluctuation & drift (within 0.01-10 Hz, i.e. Δt=0.05 s, t=100 s) | < 15 μV (3 μT) | *Peak-to-peak values; See note 6* |
| **Output noise:** | | |
| Noise Spectral Density @ f = 1 Hz ($NSD_1$) | < 0.6 $\mu V/\sqrt{Hz}$ (0.12$\mu T/\sqrt{Hz}$) | *Region of 1/f – noise* |
| Corner frequency ($f_C$) | ~ 10Hz | *Where 1/f noise = white noise* |
| Noise Spectral Density @ f > 10 Hz ($NSD_w$) | < 0.5 $\mu V/\sqrt{Hz}$ (0.1 $\mu T/\sqrt{Hz}$) | *Region of white noise* |
| Broad-band Noise (10Hz to $f_T$) | < 15 μV (3 μT) | *RMS noise; See note 7* |
| Resolution | | *See notes 6 - 10* |
| **Typical frequency response:** | | |
| Frequency Bandwidth [$f_T$] | 500 Hz | *Sensitivity decrease -3dB; Note 11* |
| Output resistance | < 100 Ω, short circuit proof | |
| **Temperature outputs:** | | |
| from the Hall Probe: | $V_{TH}$ [mV] = $V_{TH}$(0°C) + (T[°C] x 20[mV/°C]) | |
| from the Electronic box: | $V_{TE}$ [mV] = $V_{TE}$(0°C) + (T[°C] x 20[mV/°C]) | |
| | $V_{TH}$ and $V_{TE}$ are ground-referred voltages. Values $V_{TH}$(0°C) and $V_{TE}$(0°C) are determined under calibration. | |

## MODULE E: MECHANICAL AND ELECTRICAL SPECIFICATIONS:

### E-module type B:


*Figure 5.* Electronic box (type B) of the I3A magnetic field transducer

| | | |
|---|---|---|
| Module E _ type B | High mechanical strength, electrically shielded aluminium case<br>Dimensions: 103 W x 220 L x 53 H mm (see Fig. 5)<br>Weight: < 1kg | |
| Connectors CoS<br>(Radial BR2 bulkhead receptacle rear mount (mating plug, BR2 straight plug clamp 2 cores cab 4mm)) | Field signal X+, X-, ground shielded<br>Field signal Y+, Y-, ground shielded<br>Field signal Z+, Z-, ground shielded<br>Temperature Probe signal (BNC)<br>Temperature El. box signal (BNC) | front side |
| HALL PROBE Connector CoH | Fixed connection<br>Lapp Kabel, Cable Gland, MSR, M12 | rear side |
| DC Power Connector CoP<br>DIN SFV50, 5 pole (Mating Plug, KV50), front side | Power, +12V<br>Power, -12V<br>Power, +5V<br>Power common (GND) | Pin 3<br>Pin 1<br>Pin 5<br>Pin 2, Pin 4 |
| DC Power | Voltage:<br>Current: | ±12V nominal, ±2%<br>ca. 400mA |

### Environmental Parameters:

| | |
|---|---|
| Operating Temperature | +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 Table

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 characterisation

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).

The SENIS 3-axis magnetic field transducer I3A-03C02F-B02T0K5J is applicable in the B-frequency range from DC to 500 Hz (-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 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 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: $$\mathrm{M.R.E.} = S_{err} + NL + 100 \times Res / B_{LR} \quad \text{[unit: \% of } B_{LR}\text{]} \qquad \textit{Eq. [1]}$$

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.

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

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:

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

*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

The tolerance of sensitivity can be calculated as follows:

$$Serr = 100 \times |S' - S| / S \qquad \textit{Eq. [4]}$$

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:

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

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 $\Delta t$=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:

$$V_{N\_RMS} = \sqrt{NSD_{1f}^2 \times 1Hz \times \ln\left(\frac{f_H}{f_L}\right) + 1.22 \times NSD_W^2 \times f_H} \qquad \text{Eq. [6]}$$

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;
- the numerical factor *1.22* comes under the assumption of using a second-order low-pass filter.

For a DC measurement: $f_L$*=1/measurement time*. The high-frequency limit cannot 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 (SNR), 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) 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 second-order Butterworth low-pass filter, with the bandwidth from DC to $f_T$. The filter attenuation is -40 dB/dec. (-12 dB/oct.). The calibration table of the frequency response is available as an option.

12) The switching "noise" is a periodic signal at $f_{sw}$ = 8.33 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.