

## DESCRIPTION:

The Multi-Probe Magnetic Field Transducer (hereinafter MPMFT) of type **MPA** chassis with **6 x F1A-0YK02D-M02T25KM** is a high accuracy magnetic flux density-to-analogue voltage measurement station that integrates 6 (six) SENIS F1A Single-Axis Hall probes 0YK02D and the corresponding signal processing Electronic modules (magnetic field transducers) M02T25KM.

This measurement device can be used as a compact multi-point monitoring system of complex electromagnetic machines or processes, providing a high-level and temperature compensated output signal for the transverse (Y) component of the measured magnetic flux density of the applied Hall Probes.

## 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.

## KEY FEATURES:

- Measures DC and AC magnetic fields over  $\pm 3\text{T}$  range;
- Frequency Bandwidth: DC to 25kHz;
- Accuracy better than 1% up to  $\pm 2\text{T}$ ; DC accuracy is verified against precision Nuclear Magnetic Resonance (NMR) Teslameter as the measuring standard;
- Probe operational temperature: up to  $+80^\circ\text{C}$ ;
- Uses miniature fully integrated 1-axis Hall probe with pre-amplifier (magnetic field sensitive volume is only  $0.40 \times 0.01 \times 0.04 \text{ mm}^3$ );
- Temperature compensated output signals, etc.



Figure 1. **Multi-Probe magnetic field transducer MPA with 6 x F1A-0YK02D-M02T25KM. Thin long Hall probes 0YK are protected into transparent plastic boxes**

## SYSTEM STRUCTURE:

The multi-probe magnetic transducer system integrates the following parts:

### 1. Module E (Electronics):

- (a) 6 Signal processing electronics modules (magnetic field transducers) type M02T25KM, with
- (b) Power Supply Unit (PSU-24), and
- (c) MPA chassis.

### 2. Module H (Hall probes and Cables):

6 detachable Single-axis Hall probes 0YK02D and Cables CaH (for different Hall Probes selections please see Hall Probes Sections at [www.senis.ch](http://www.senis.ch)).

The Items (a) and (b) are assembled into the aluminum Card Frames and they are integrated into a common 84HP rack enclosure (c).

### 1. E-MODULE (ELECTRONICS):



Figure 2. FRONT PANEL of the MPA chassis

### The Signal Processing Electronic modules type M02T25KM:

1. On the lower part of each of six Electronics AI-boxes there is a panel mounted DIN SFV81 8-pins MALE connector (to match the corresponding Hall Probe). Also, there are 4 non-used and separated positions enabling a simply mounting of up to 4 additional SENIS magnetic field transducers.
2. On the upper side there is a panel mounted DIN KFV81 8-pins FEMALE connector (for the corrected analogue output signals Y+ and Y-, as well as for the probe temperature signal). The default range of the real-time corrected differential voltage outputs is  $\pm 10V$ , which equals to linear  $\pm 2T$  measurement range.

### The Power Supply unit PSU-24:

3. Power switch controls power to the system (ON/OFF).
4. LED indicator highlights when the system is ON, and otherwise.



Figure 3. The REAR PANEL of the MPA chassis

5. The LINE POWER INPUT (88-264 VAC, 47-63Hz), and fuse assembly is the primary entry and control point for AC power to the unit.
6. Fan (ventilator).

## 2. H-MODULE (HALL PROBES and CABLES):



Figure 4. Single-axis Hall probes 0YK02D connected to the multi-probe system

The MPMFT type **MPA** with **6 x F1A-0YK02D-M02T25KM** includes six (6) standard SENIS F1A Single-axis Hall probes type 0YK, with 2m flexible shielded cable, detachable to the corresponding Electronic modules at DIN KV81 8-pins connectors. Detailed specifications of the applied Hall probes are listed below in **APPENDIX 1: FULLY INTEGRATED SINGLE-AXIS HALL PROBE 0YK FOR F1A MAGNETIC FIELD TRANSDUCERS**.

Each Probe is adjusted relative to the corresponding Electronic processing unit; therefore the Hall Probes are not interchangeable!

On request, the different SENIS Hall probe types are available (please find available Hall probe geometries on SENIS web-page [www.senis.ch](http://www.senis.ch)).

## THE OVERALL MAGNETIC AND ELECTRICAL SPECIFICATIONS:

If not noted otherwise, specifications apply for the transverse (Y) measurement channel Y of each probe at room temperature (23°C) and after a warm-up time of 15 minutes.

Parameter	Value	Remarks
Maximum (full scale) magnetic flux density ( $\pm B_{FS}$ )	$\pm 3T$ ( $\pm 30$ kG)	No saturation of the Probe outputs
Linear range of magnetic flux density ( $\pm B_{LR}$ )	$\pm 2T$ ( $\pm 20$ kG)	Optimal, fully calibrated meas. range
Total measuring Accuracy	better than 1% @ $B \leq \pm 2T$	See Appendix 3: Note 1
Output voltages ( $V_{out}$ )	differential	See Appendix 3: Note 2
Sensitivity to DC magnetic field (S)	5 V/T (0.5 mV/G)	Differential output; See Appendix 3: Note 3
Tolerance of sensitivity ( $S_{err}$ ) (@ $B \leq \pm B_{LR}$ )	< 0.5% of S	$100 \times  S' - S  / S$ ; See Appendix 3: Notes 3 and 4
Nonlinearity (NL)	< 0.5 % @ $B \leq \pm 2T$ ;	See Appendix 3: Note 4
Planar Hall voltage ( $V_{planar}$ ) (@ $B \leq \pm B_{LR}$ )	< 0.01 % of $V_{normal}$	See Appendix 3: Note 5
Temperature coefficient of sensitivity	< $\pm 100$ ppm/°C ( $\pm 0.01$ %/°C)	@ Temp. range 23 °C $\pm 10$ °C
Long-term instability of sensitivity	< 1% over 10 years	
Offset (@ $B = 0T$ ) ( $V_{off}$ ( $B_{off}$ ))	< $\pm 2$ mV ( $\pm 0.4$ mT)	@ Temp. range 23 °C $\pm 5$ °C
Temperature coefficient of the offset	< $\pm 0.15$ mV/°C ( $\pm 30$ $\mu$ T/°C)	
Offset fluctuation & drift ( $\Delta t = 0.05s$ , $t = 100s$ )	< 0.3 mV <sub>p-p</sub> (60 $\mu$ T <sub>p-p</sub> )	Standard Deviation RMS value: < 50 $\mu$ V <sub>RMS</sub> (10 $\mu$ T <sub>RMS</sub> ); See Appendix 3: Note 6
<b>Output noise</b>		
Noise Spectral Density @ $f > 1$ Hz (NSD <sub>1</sub> )	$\approx 25 \mu$ V/ $\sqrt{Hz}$ (5 $\mu$ T/ $\sqrt{Hz}$ )	Region of <b>1/f</b> – noise
Corner frequency ( $f_C$ )	$\approx 10$ Hz	Where <b>1/f</b> noise = <b>white</b> noise
Noise Spectral Density @ $f > 10$ Hz (NSD <sub>W</sub> )	$\approx 6 \mu$ V/ $\sqrt{Hz}$ (1.2 $\mu$ T/ $\sqrt{Hz}$ )	Region of <b>white</b> noise
Broad-band Noise (10 Hz to $f_T$ )	< 1.2 mV (0.24 mT)	RMS noise; See Appendix 3: Note 7
Resolution		See Appendix 3: Notes 6 - 10
<b>Typical frequency response</b>		
0.1% error	> 1.1 kHz	Test: $B = 10mT \times \sin(2\pi ft)$ ; See below: <b>OPTION: AC Calibration-Frequency Response</b>
1.0% error	> 3.5 kHz	
Frequency Bandwidth [ $f_T$ ]	> 25 kHz	Sensitivity decrease -3dB; See Appendix 3: Note 11
Output resistance	< 10 $\Omega$ , short circuit proof	
<b>Temperature output</b>		
Ground-referred voltage :	$V_T$ [mV] = ( $T$ [°C] - 23°C $\pm 3$ °C) $\times 100$ [mV/°C]	

## MECHANICAL SPECIFICATIONS:

Part	Description and Dimensions						
MPA Chassis	Case, 3U, 84HP Enclosure Material: Aluminum Cabinet Style: Desktop External Dimensions: Height: 132 mm Width: 447 mm Depth: 315 mm						
Signal Processing Electronics Modules	Card frame, 3U, 7HP (detachable from the MPA chassis) Enclosure Material: Aluminum External Dimensions: Height: 129 mm Width: 35 mm Depth: 167 mm						
Power Supply Unit (PSU-24)	Card frame, 3U, 14HP (not detachable from the MPA chassis) Enclosure Material: Aluminium External Dimensions: Height: 129 mm Width: 70 mm Depth: 167 mm						
<b>Connections:</b>							
AC Power Input	<p><b>REAR PANEL:</b>            A 3-conductor power inlet (with a proper line fuse) on the rear panel for the AC powering. The line cord connects to the power line jack. Line voltage is present across the outer two conductors, and the center conductor is a safety ground.            The fuse holder is integrated into the mains. It contains two 5 x 20 mm(T) fuses. The interior fuse is the active one, and the exterior fuse is the spare one. The proper fuse values are:</p> <ul style="list-style-type: none"> <li>▪ 0.25 Amps (T) for 220-240 VAC, 50 Hz, and</li> <li>▪ 0.50 Amps (T) for 100-120 VAC, 60Hz powering system.</li> </ul> <p><b>FRONT PANEL:</b>            The ON/OFF Switch that controls the power to the unit.            The LED indicates the powering ON/OFF of the system.</p>						
The Hall Probe connector	<p><b>FRONT PANEL:</b>            DIN SFV81 8-pins connector (MALE, panel mounted; mating plug DIN KV81)</p>						
The Analogue Output Signals connector	<p><b>FRONT PANEL:</b>            DIN KFV81 8-pins connector (FEMALE, panel mounted; mating plug DIN SV81):</p> <table> <tbody> <tr> <td>Field signals Y+, Y-</td> <td>Pins 5 and 4, respectively</td> </tr> <tr> <td>Temperature signal</td> <td>Pin 2</td> </tr> <tr> <td>Signal common (GND)</td> <td>Pin 8</td> </tr> </tbody> </table>	Field signals Y+, Y-	Pins 5 and 4, respectively	Temperature signal	Pin 2	Signal common (GND)	Pin 8
Field signals Y+, Y-	Pins 5 and 4, respectively						
Temperature signal	Pin 2						
Signal common (GND)	Pin 8						
Power Requirements:	AC input, 220-240V/50Hz or 100-120V/60Hz; 40 VAmax						
Total System Weight:	11 kg (including the Hall Probes)						

**Environmental Parameters:**

Operating Temperature	H-Module: +5°C to +80°C E-Module: -20°C to +50°C	
Storage Temperature	-20°C to +85°C	

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

$$1 \text{ T} = 10 \text{ kG}$$

$$1 \text{ mT} = 10 \text{ G}$$

$$1 \mu\text{T} = 10 \text{ mG}$$

**OPTIONS:**
***DC Calibration***

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  $\div$  10).

***AC Calibration - Frequency Response***

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  $\div$  11).

SENIS Single-axis magnetic field transducer F1A-0YK02D-M02T25KM is applicable in the B-frequency range from DC to 25 kHz (-3dB point) (here 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 the transverse (Y) axis (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  $V_{out}$ .

**APPENDIX 1:**  
**FULLY INTEGRATED SINGLE-AXIS HALL PROBE 0YK FOR F1A MAGNETIC FIELD TRANSDUCERS**

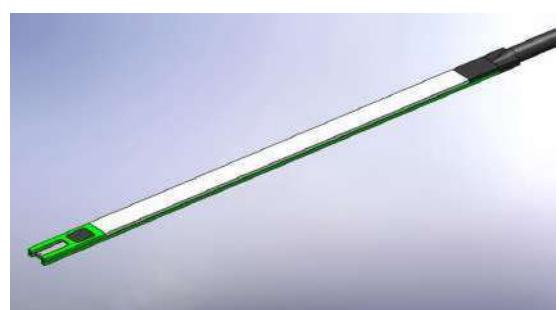
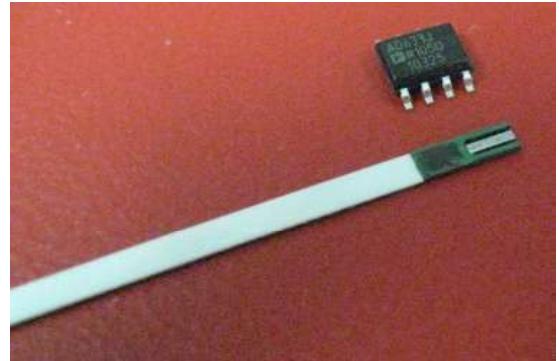
Hall Probe K for F1A Magnetic Transducers with the naked Si chip is a very thin (0.5mm) and long (47mm) single-chip fully integrated 1-axis Hall-Probe. It measures magnetic fields perpendicular to the probe plane (By).

The probe contains a CMOS integrated circuit, which incorporates a group of four Hall elements, biasing circuits, amplifiers, and a temperature sensor. The integrated Hall elements occupy very small area ( $0.4 \times 0.04 \text{ mm}^2$ ), which provides very high spatial resolution 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 max. 75 kHz) of the probe; and on-chip signal amplification provides high output signals of the Hall probe.

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

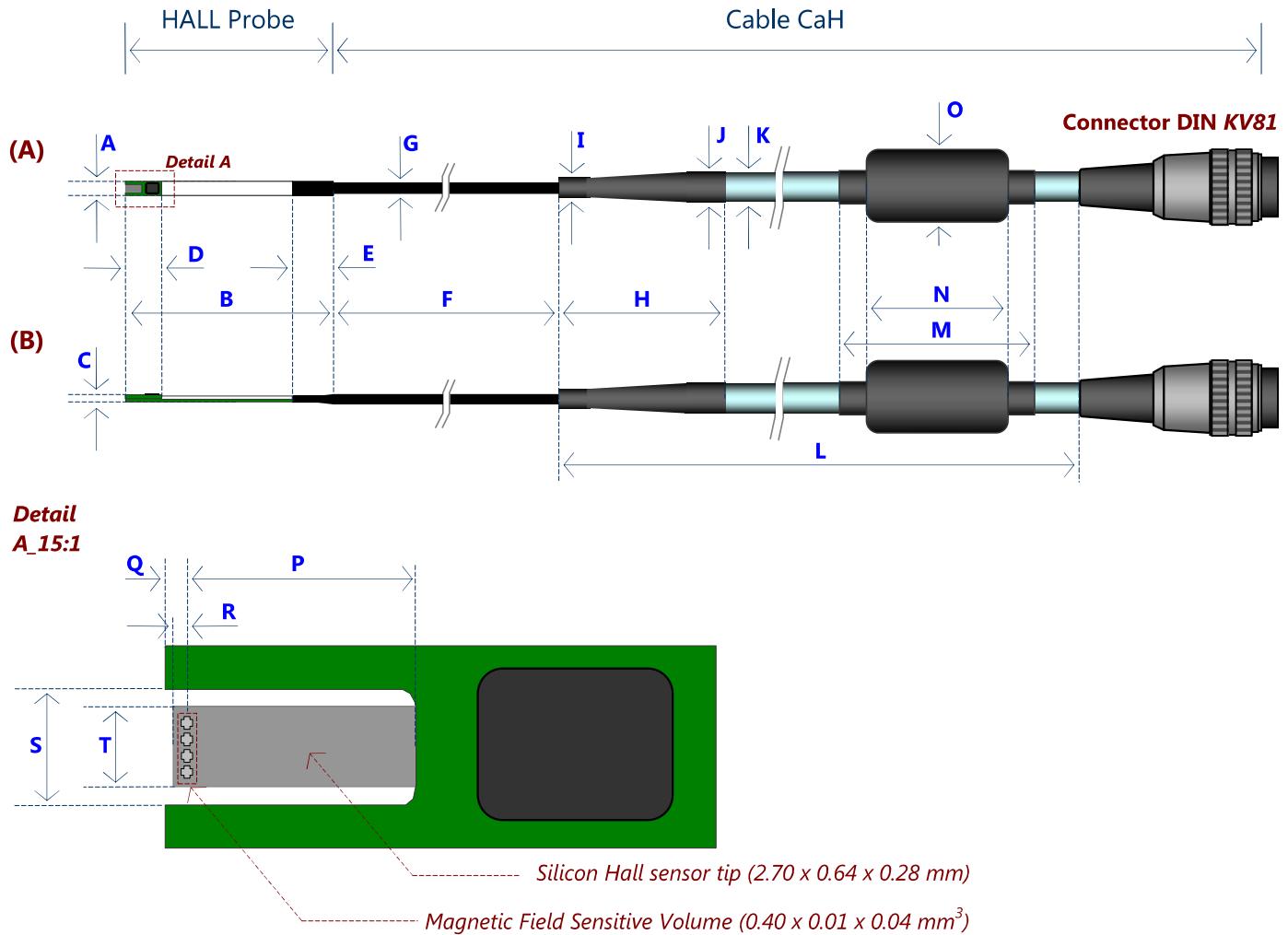
The outputs of the Hall Probe are high-level analog voltages proportional with each of the measured components of a magnetic flux density and a voltage proportional with the probe temperature.



**KEY FEATURES OF THE 0YK HALL PROBE SYSTEM**

- The K Hall probe with the naked Si chip is very thin (0.5mm) and long (47mm)
- Fully integrated CMOS 1-axis (By) Hall Probe
- Very high spatial resolution ( $0.40 \times 0.01 \times 0.04 \text{ mm}^3$ )
- High frequency bandwidth (from DC up to max. 75kHz)
- Virtually no planar Hall effect
- Negligible inductive loops on the Probe
- Integrated temperature sensor on the probe for temperature compensation
- The Hall Probe K for F1A Magnetic Transducers is consisting part (Module H) of the F1A Magnetic Field Transducer, Digital Teslameter and Magnetic Field Mapper
- Suitable as Y-axis (0Y) Hall Probe
- Available as a separate unit for OEM customers

PROBE and CABLE DIMENSIONS and CHARACTERISTICS



Dimension	[mm]	Dimension	[mm]	Dimension	[mm]	Dimension	[mm]
<b>A</b>	$2.0 \pm 0.1$	<b>F</b>	$150 \pm 3$	<b>K</b>	$\varnothing 4.8 \pm 0.2$	<b>P</b>	$2.6 \pm 0.1$
<b>B</b>	$47 \pm 1$	<b>G</b>	$\varnothing 1.1 \pm 0.2$	<b>L</b>	$2'000 \pm 50$	<b>Q</b>	$0.2 \pm 0.1$
<b>C *</b>	$0.5 +0.1/-0.0$	<b>H</b>	$35 \pm 3$	<b>M</b>	$50 \pm 2$	<b>R</b>	$0.15$
<b>D</b>	$6.0 \pm 0.1$	<b>I</b>	$\varnothing 3.4 \pm 0.2$	<b>N</b>	$30 \pm 1$	<b>S</b>	$1.1 \pm 0.1$
<b>E</b>	$5.0 \pm 0.5$	<b>J</b>	$\varnothing 5.7 \pm 0.2$	<b>O</b>	$\varnothing 16 \pm 1$	<b>T</b>	$0.64$

IMPORTANT:

- \* Presented dimension and tolerance of the probe thickness is applied for the 0YK Hall probes manufactured after January, 2012. Those probes are labeled with Serial numbers beginning from **xxx-12**.  
The older 0YK probes with thickness of 0.6 (+0.1/-0.0) mm (labeled with the Serial Numbers up to **xxx-11**) are not longer in production.

Figure 5. Dimensions and tolerances of the 0YK Hall probe and Cable CaH: (A) TOP view; (B) SIDE view.

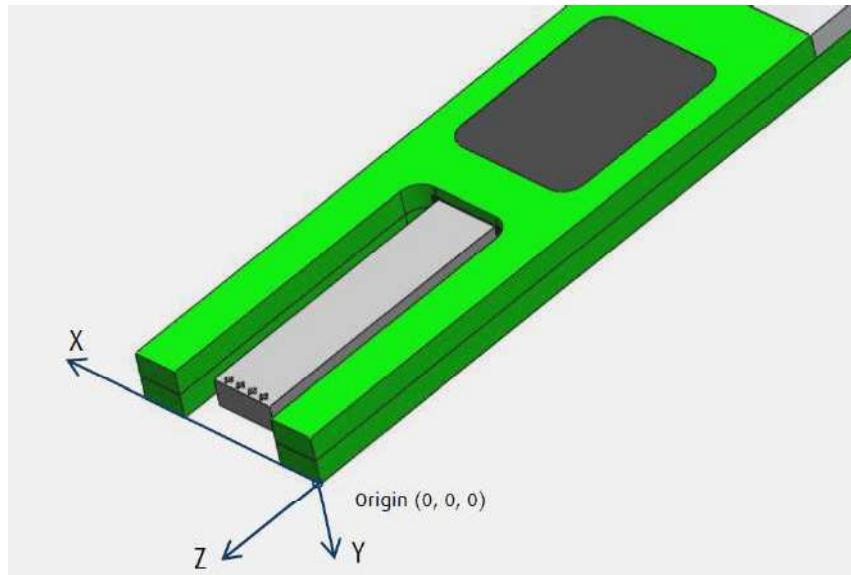


Figure 6. The reference Cartesian coordinate system of the 0YK Hall probe

Dimension	X [mm]	Y [mm]	Z [mm]
Magnetic field sensitive volume (MFSV)	0.40	0.01	0.04
Position of the center of MFSV (corresponding to MFSP, see Fig. 5 and 6)	1.0 ± 0.1	-0.4 ± 0.05	-0.35 ± 0.1
Total Probe external dimensions	2.0 ± 0.1	0.5 +0.1/-0.0	47 ± 1
Angular accuracy of the axes	± 1° with respect to the reference surface		
CaH Cable	Shielded, with a flexible thin part near the probe and ferrite sleeve on the thicker part (see Fig. 5)		
Total length of the CaH cable:	<ul style="list-style-type: none"> <li>▪ Standard: 2 m (Probe notation: <b>0YK02</b>)</li> <li>▪ Optional: xx m (Probe notation: <b>0YKxx</b>)</li> </ul> <i>Various cable lengths are available upon request.</i>		

## APPENDIX 2:

## INSTALLING THE MULTI-PROBE MAGNETIC FIELD TRANSDUCER

## 1. CONNECTING THE HALL PROBE

**Before handling the Hall probes, please read the following:**

SENISS Hall probes are built to be as robust as possible for a small, precision device. However, it is most important that certain precautions be taken when handling and installing probes so that they are not damaged or destroyed, and to preserve their accurate calibration.

Your MPMFT may be used only with the SENISS Hall probes. Each Hall probe is in-factory calibrated relative to its Electronic module type M02T25KM; therefore, the probes cannot be exchanged between the different Electronics.

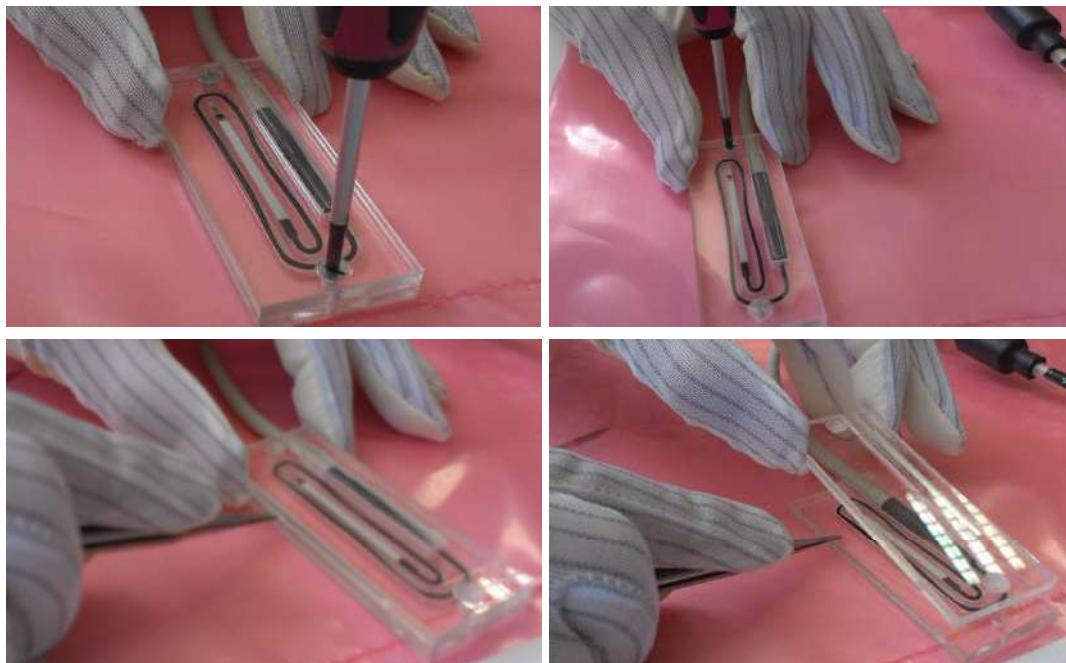
In order to obtain specified performances, make sure that the each Hall probe (labeled with a corresponding Serial Number) is connected properly to its Electronics module (also labeled by the same Serial Number).

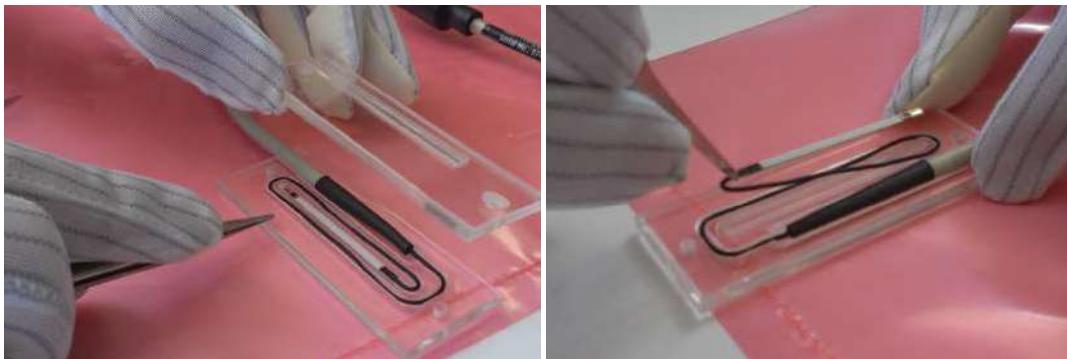
**Warning: the Probe Tip is Fragile!**

In order to achieve the small thickness of the probe, a part of the sensor chip is left non-encapsulated. The sensor chip is a 0.3 mm thick bar of mono-crystalline silicon, and can be easily broken. Therefore, avoid any mechanical contact of the probe chip with other objects! Moreover, avoid the immersion of the probe of any liquid, and its exposure to moisture and aggressive gasses.

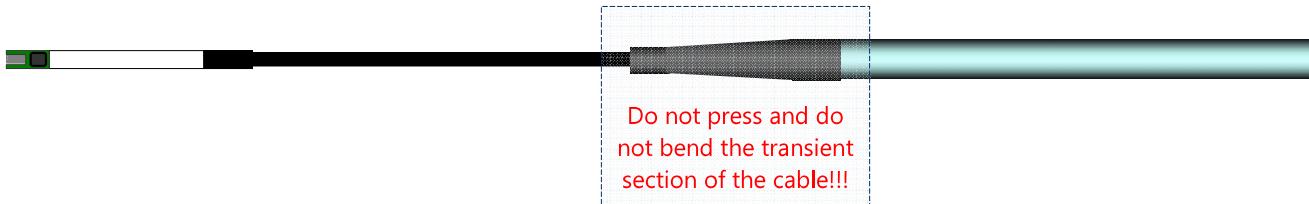
The following precautions shall help ensure that the transducer accurate calibration remains preserved:

- The small probe head is shipped mounted into a transparent protective plastic box. Remove the protection plastic only when there is no danger of a mechanical shock or electrostatic discharge. Carefully open the plastic protection by following the steps illustrated in the figures below:





- 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.
- 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.



- When the probe head is mounted, the cable should be clamped firmly nearby so it cannot be torn away from the probe head if accidentally pulled. The flexible section adjacent to the probe head can be carefully folded to allow the cable to come away in any direction, but avoid repeated flexing of this section.
- 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's performance, and requires factory repair and re-calibration.
- Ensure that the Electronics is not powered. If so, carefully plug the Probe connector (female 8-pins DIN KFV81) to the corresponding male 8-pins DIN SV81 connector on the electronics' front panel. Ensuring that its pins engage correctly, tighten the metal ring of the probe connector. Do not leave these loose as they form part of the shielding system around the transducer.
- **Always disconnect power from the Signal conditioner before connecting or disconnecting the probe!**

## 2. THE AC LINE INPUT CONNECTION

- The MPMFT is equipped with a 3-conductor power line jack (with a proper line fuse) on the rear panel for the AC powering. Line voltage is present across the outer two conductors, and the center one is a safety ground. The safety ground attaches to the instrument chassis and protects the user in case of a component failure.
- The first check if the line voltage is properly selected. Ensure that there is no power. If so, check the outlet and the connection at both ends of the power cord. Next check the fuse. Remove line cord, and then place a small slotted screwdriver in the slot of the small door at the rear of the unit to access the fuse. For 100/120V operation, the fuse rating is 0.5A, and the fuse type is 5 x 20 mmT. For 220/240V operation, the fuse rating is 0.25A, and the fuse type is 5 x 20 mmT. Test the fuse with ohmmeter. Do not rely only on visual inspection of the fuse.
- Always plug the power cord into a properly grounded receptacle to ensure safe operation of the instrument.
- The power switch is a part of the line input assembly on the front panel of the MPMFT and turns line power to the instrument ON and OFF. When the switch is down, power is OFF; otherwise, when the switch is up, power is ON.

## 3. ANALOG OUTPUTS

The corrected analogue voltage signals of each Hall probe are available at the 8-pins DIN connector KFV81, mounted on the upper side on the front panel of the corresponding transducer.

## 4. GROUNDING and SHIELDING

All the parts of the MPMFT's metal chassis MPA are connected together on a manner to form a compact electric shield around the electronics inside. When the probe connector is plugged into the Electronics and the connector's metal ring is properly tightened, the probe connector case and the MPMFT's case are connected together and form an integral shield around the circuitries inside. The cable shield is added to the case shield and extends protection from electrical interference almost up to the probe head. Because there is an internal connection between the electronics common (ground) and the probe connector case, when the probe connector is engaged the inside circuits' common will be connected to the case.

The shielding provided with the above arrangement should be sufficient protection against EMI in most cases.

For electrical safety, the metal case is grounded through the third wire (safety ground) of the AC power input cord.

## APPENDIX 3:

## 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:

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

Here,  $S_{\text{err}}$  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  $B_{\text{LR}}$  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  $V_{\text{out}} = f(B)$ , i.e.

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

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

4) The **nonlinearity** is the deviation of the function  $B_{\text{measured}} = f(B_{\text{actual}})$  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:

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

## Notation:

$B$  = Actual testing DC magnetic flux density given by a reference NMR Teslameter

$V_{\text{out}}(B) - V_{\text{off}}$  = Corresponding measured transducer output voltage after zeroing the Offset

$S'$  = Slope of the best linear fit of the function  $f(B) = V_{\text{out}}(B) - V_{\text{off}}$  (i.e. the actual sensitivity)

$B_{\text{LR}}$  = Linear range of magnetic flux density

**Tolerance of sensitivity** can be calculated as follows:

$$\text{Tolerance of sensitivity} = 100 \times |S' - S| / S \quad \text{Eq. [4]}$$

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:

$$\left. \frac{V_{\text{planar}}}{V_{\text{normal}}} \right|_{@ B=2T} = 4 \cdot \left. \frac{V_{\text{planar}}}{V_{\text{normal}}} \right|_{@ B=1T} \quad \text{Eq. [5]}$$

Here,  $V_{\text{normal}}$  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 through 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 through 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:

$$V_{nRMS-B} \approx \sqrt{NSD_{1f}^2 \times 1Hz \times \ln\left(\frac{f_H}{f_L}\right) + 1.57 \times NSD_w^2 \times f_H}$$

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; 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. (6) can be neglected; otherwise: if the high-frequency limit  $f_H$  is lower than the corner frequency  $f_C$ , then 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.,  $V_{nP-P-B} \approx 6 \times V_{nRMS-B}$ .

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,  $N \leq f_{samp} / f_{sams}$ .

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 Butterworth low-pass filter, with the bandwidth from DC to  $f_T$ . The filter attenuation is -20 db/dec. (-6 db/oct.). The calibration table of the frequency response is available as an option.