HIGHTECH
DEVELOPMENT
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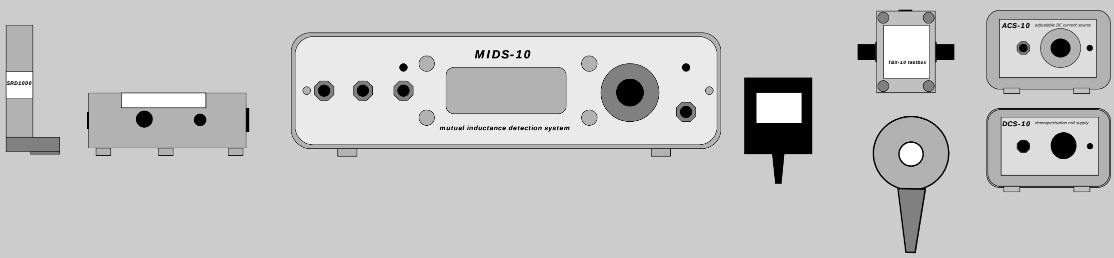
User's Manual

SRD1000 System



supports precision thermometry on the PLTS-2000

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Contents

1. Introduction to the SRD1000 system

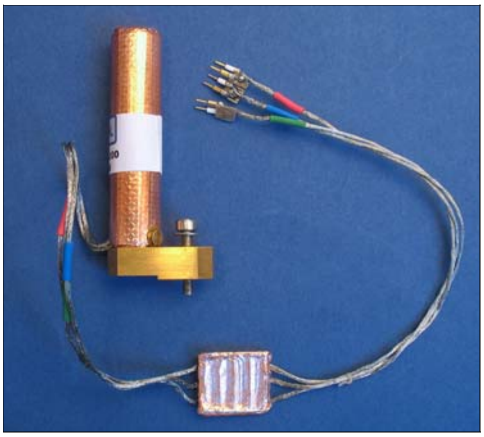
The SRD1000 system comprises a cryogenic sensor and related measurement equipment to establish a series of reference points for thermometry between approximately 15 mK and 1.2 K.

The points are realised by observing superconductive transitions of a set of samples of reference materials using a mutual inductance detection technique.

An overview of the main system components:

(1) SRD1000 cryogenic sensor

The sensor contains a mutual inductance detector array of integrated planar micro-coils to which samples of various superconductive reference materials are attached. The detector array and the samples are thermally connected to a gold-plated mounting plate at the bottom of the sensor.



The temperatures of the superconductive transition of the materials depend on the presence of a magnetic field. To reduce ambient magnetic fields, the sensor is equipped with a cylindrical (Cryoperm / niobium) shield.

A compensation coil inside the shield surrounding the detector assembly allows for additional testing and suppression of magnetic fields in the sensor.

The signal leads of the sensor are shielded and equipped with a filter to suppress RF-interference.

The user has to attach the sensor to a thermal plate inside the low temperature area of a cryogenic set-up and connect it to the room temperature MIDS-10 electronics via 3 pairs of (shielded) twisted conductors.

Annex A. provides information on the dimensions and the electrical connections of the sensor.

(2) MIDS-10 mutual inductance measurement system

The measurement system drives the cryogenic sensor and provides an output voltage proportional to the sensor signal to detect the superconductive transitions.

The system comprises the following components:

- a control unit;

- a preamplifier unit to drive current to the primary coil input of the sensor and amplify the voltage of the secondary coil output;

- a mains adapter for powering the MIDS-10;

- a test plug to verify the functioning of the pre-amplifier / control unit;

- a cable (grey, 5 m, 8-way Lemo 1B connectors) to connect the preamplifier with the control unit ;

- a cable (black, 0.75 m, 5-way Lemo 0B connector) to connect the preamplifier with the cryostat connector;

- a test unit (TBX-10) which converts 'Lemo' to 'BNC' and thus allows easy testing of the sensor connections.

Annex B gives additional information on the MIDS-010 system, explaining the controls and terminals on the front and rear panels and the pin layout of the cable connections.

(3) Calibration certificate

A calibrated cryogenic sensor and MIDS-10 system is supplied with a PTB certificate stating the temperatures of the reference points.

Annex E lists the symbols and definitions that are used to present the characteristics of the transitions.


Physikalisch-Technische Bundesanstalt PTB

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(4) DCS-10 degauss tools

The DCS-10 supply unit with degauss coil enables the demagnetisation of the Cryoperm magnetic shielding of the cryogenic sensor at room temperature prior to a low temperature run.

Annex C presents additional information on the DCS-10, describing the items on the front and rear panels.

(5) ACS-10 current source

The ACS-10 adjustable current source is used to test for residual magnetic fields in the sensor at cryogenic temperatures.

The ACS-10 is supplied with:

- a cable (black, 0.75 m, 5-way Lemo 0B connector) to connect the unit to the compensation coil in the sensor to reduce the Z-component of a residual magnetic field;

- a cable (black, 0.75 m, 5-way Lemo 0B connectors) to connect the unit to the preamplifier to reduce the X,Y-components of a residual magnetic field;

- 9 V PP3 alkaline battery to power the current source.

Annex D gives additional information on the ACS-10, describing the items on the front and rear panels.

This chapter provides an overview of the installation of the system components. Please refer to Section 2.5 for a system map. The Annexes A to D provide details on the features of the various components.

Please e-mail HDL if you experience any problems during the installation of the SRD1000 system.

2.1. Handling the cryogenic sensor

Figure 2.1 shows the SRD1000 cryogenic sensor. The outer shield [1] of the cryogenic sensor is made of annealed Cryoperm covered with a layer of copper foil for thermal conduction. Avoid mechanical stress to this shield, as this may reduce its shielding performance. Do not try to open the sensor by removing the shield as you may damage the internal circuitry. Do not immerse the sensor directly and quickly from room temperature and atmospheric conditions into liquid N_2. Always cool and warm it gradually and in a protected atmosphere, like in the IVC of a dilution refrigerator. This will avoid severe internal stress to the reference samples and the detection circuitry.

The electrical connections [5] are not sensitive to electrostatic discharge. The resistance of the circuitry may be measured using a digital multimeter at ranges equal and below 20 MΩ.

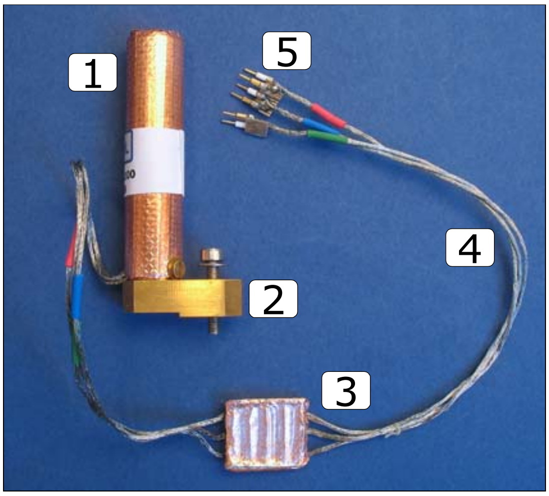


Figure 2.1. The SRD1000 cryogenic sensor.

2.2. Mechanical and thermal connections

The mounting adapter [2], made of gold-plated OFHC copper, is attached to a thermal plate in the experimental region of a dilution refrigerator using a (stainless steel) M3 bolt and washer. Prior to mounting, remove any oxidation on the thermal plate when its surface is not gold plated, and clean the contacting surfaces thoroughly with acetone and alcohol to reduce the thermal resistance of the joint.

In most cases the filter [3] and the three shielded leads [4] are mechanically (and electrically) fixed at the same thermal plate as to which the sensor is being attached. The thermal conduction of the leads is low at cryogenic temperatures, as the shield of the leads is made of phosphor-bronze mesh and the internal conductors are of NbTi. The leads are already thermally anchored inside the sensor body.

2.3. Electrical connections

2.3.1. Signal connections

The sensor contains a set of mutual inductors, the red and blue coils in Figure 2.2, to detect the transitions of the reference materials. A compensation coil (the green coil) allows reduction of residual magnetic fields in the sensor shield.

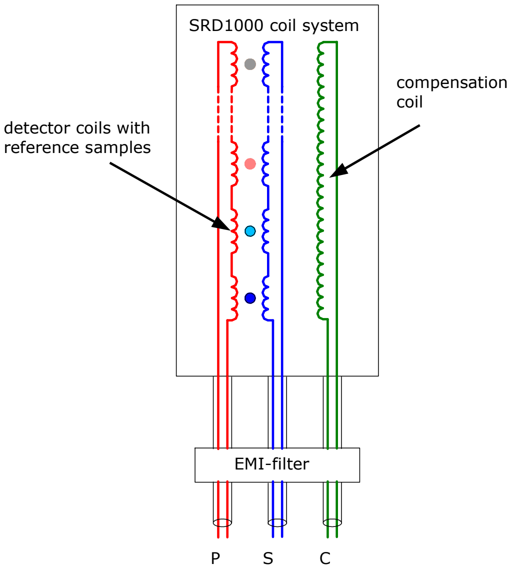


Figure 2.2. The sensor circuitry and connections.

The coils are connected through 3 shielded superconductive leads. These are about 20 cm long and each one contains a twisted pair of insulated conductors.

A filter reduces spurious (EMI) signals entering the sensor through the leads.

Each lead is terminated with a 2-way connector (pin spacing 2.56 mm / 0.1"), see Figure 2.3, which fits into a standard type IC socket (e.g. a SIL-socket connector). The colour of the tubing indicates the type of connection (P, primary coil = red; S, secondary coil = blue; C, compensation coil = green).

Figure 2.3. The P, S and C connectors.

Table A.1 in Annex A summarizes the connections and lists general values for the electrical resistance of the coils at 300 K, 77 K and at T < 9 K. The label on the transport box of the sensor gives the specific values.

At room temperature, the resistance between the primary and secondary circuitry should be higher than a few MΩ. This also applies for the resistance between the circuitries and the sensor housing.

2.3.2. Signal parameters

The signal parameters of the sensor are:

(1) primary current: 50 μA @ 976.5 Hz, producing a field of less than 0.4 μT near the reference samples;
(2) secondary voltage: 2 nV – 2 μV, depending on the temperature of the sensor;
(3) compensation coil current: 0 - ± 2 mA, producing a field of about 0 – ±5 μT near the samples.

2.3.3. Requirements for electro-magnetic shielding and filtering in the cryostat

The amplitude of the AC field produced by the sensor detection circuitry is negligible outside the sensor shielding («100 nT). The SRD1000 measurement electronics was designed for use in ultra-low temperature set-ups and have proved not to cause RF-heating or other interference in cryogenic experiments.

The sensor is equipped with a filter to reduce RF-energy penetrating the sensor housing. Additional filtering of sensor signal leads in the cryostat may lead to phase shifts and distortions while measuring the transitions of the device. However, the effects of small capacitors (< 0.2 nF) and ferrite chokes are negligible.

For specific cases, please contact HDL.

2.3.4. Connections from the sensor to the top part of the cryostat

For optimal results use 3 separate cables in the cryostat to connect the primary, secondary and compensation coils of the sensor. Preferably, one should use a shielded twisted pair cable for each connection. In the section of the cryostat at temperatures below 9 K this should preferably be superconductive cable. Ensure proper thermal anchoring at various suitable points in the set-up.

Small diameter (about ∅ 1 mm) superconductive or normal conductive shielded twisted pair cable made by Habia is obtainable through HDL (Figure 2.4). Similar types are available from other companies, like Lake Shore.

The DC resistance of each lead of a connection to the sensor should be less than about 50 Ω when the cryostat is at cryogenic temperatures.

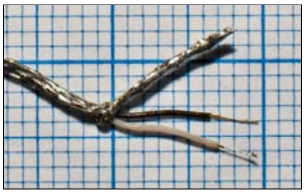


Figure 2.4. Cryogenic shielded twisted pair cable.

2.3.5. Connections between the cryostat and the electronics

The electronics are supplied with 2 (black) shielded cables (Figure 2.5) for the room temperature connections to the cryostat:

(1) mutual inductance cable for connecting the MIDS-10 preamplifier;
(2) compensation coil cable for connecting the ACS-10 current source.

Each cable is about 0.75 m long and contains 3 shielded twisted pair conductors.

One side is terminated with a 5-way Lemo 0B free plug, the connector at the other side of the cable has to be selected by the user to fit the connector at the top part of the cryostat.

Figure 2.6 gives the pin layout for the Lemo connector and Table 2.2 shows the connection scheme of the cables. The shields of the cables are to be connected to the ground/chassis of the cryostat.

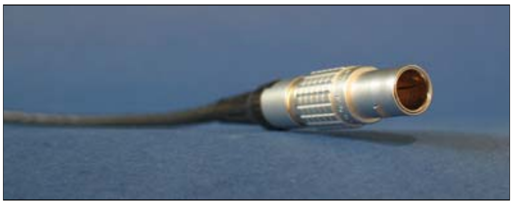


Figure 2.5. Black cable with 5-way Lemo 0B connector.

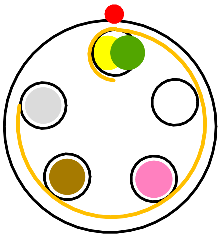


Figure 2.6. Pin layout of the 5-way Lemo 0B connector (front view of the male free plug or rear (solder) contact view of the female chassis socket). The yellow line indicates the direction of the pin number count.

Table 2.2.

Lemo 0B pin #	lead colour	mutual inductace connection (1)	compensation coil connection (2)
(1)	yellow / green	ground / shield	ground / shield
(2)	white	secondary coil V +	-
(3)	violet	primary coil I +	current C+
(4)	brown	secondary coil V -	-
(5)	grey	primary coil I -	current C-

2.3.6. Testing the connections

After the installation of the sensor and the signal leads it is important to verify that all connections are made correctly before the sensor circuitry becomes superconducting.

If, for example the connection to the primary coil is accidentally interchanged with the one to the secondary coil, the sensor may seem to operate correctly at low temperatures. However, in this case the primary current is running in the secondary coil, producing a magnetic field near the reference samples that is a factor 10 higher than during normal operation. Consequently the superconductive transitions are shifted to lower temperatures.

The connections can be verified by checking the resistance values of the coils at the Lemo 0B's connectors outside the cryostat.

The TBX-10 test box (Figure 2.7) facilitates these checks by converting the Lemo 0B connections to BNC terminals clearly marked with 'primary coil' [P] and 'secondary coil' [S].

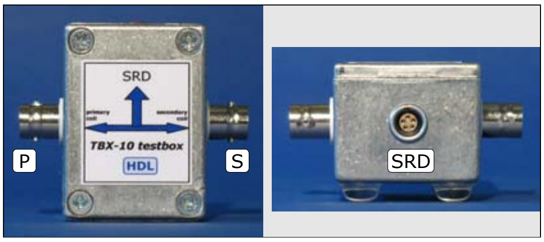


Figure 2.7. TBX-10 test box.

Figure 2.8. MIDS-10 preamplifier unit.

2.4. Measuring the signals

2.4.1. Connecting the electronics

The MIDS-10 system is designed for use at room temperature in a laboratory environment. Refer to Annex B for more information regarding the system components.

Position the MIDS-10 preamplifier unit (Figure 2.8) near the top of the cryostat and connect the cryogenic sensor to the preamplifier unit using the black interconnecting cable (see section 2.3). Ensure that the preamplifier is not too close to a source of electro-magnetic interference, such as a mains transformer of another instrument.

Position the MIDS-10 control unit (Figure 2.9) at a convenient position to monitor the SRD1000 signal.

Connect the preamplifier (terminal [2]) to the control unit (terminal [12]) using the 5 m grey cable (Figure 2.10). Ensure that the 8-way Lemo 1B connectors at both ends of the grey cable are firmly plugged in all the way (a clicking sound is heard when the connector snaps into its mechanical restraint).

Connect the mains adapter (Figure 2.11) to the mains supply and to the control unit (terminal [6]).

Figure 2.9a. MIDS-10 control unit, front panel.

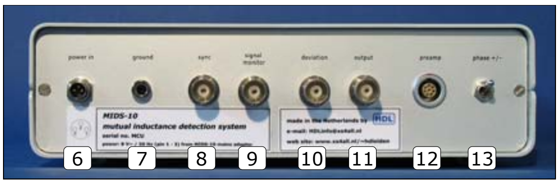


Figure 2.9b. MIDS-10 control unit, rear panel.

Figure 2.10. Grey cable with 8-way Lemo 1B connector.

Figure 2.11. MIDS-10 mains adapter.

Switch on the power switch [5] of the control unit (the blue power LED's at both the control and preamplifier unit are on). Set the primary current switch [1] to 'off', the filter switch [2] to 'fast', and display switch [3] to 'output' (blue display LED is on*)*. The front panel meter should settle down at about *000.*

When the cryogenic sensor is at temperatures below 9.5 K, its circuitry is superconducting and one can switch the primary current switch [1] to 'on'. The front panel meter should settle at a value between *500* and *1000*, which equals the system output voltage in mV. If the display shows a negative sign, reverse the phase +/- switch [13] at the rear of the MIDS-10 unit.

Set the filter switch [2] to 'slow' for normal operation at a low noise level (the time constant of the system output voltage is about 62.5 s).

2.4.2. Output signal versus sensor temperature

The output signal of the system is a DC voltage at the output terminal [11] located at the rear panel of the control unit.

The voltage level depends on the temperature of the cryogenic sensor, see Figure 2.12 for a typical example. It varies from about 550 mV at a temperature T < 15 mK to about 850 mV at T > 1.2 K.

The ten steps of the staircase pattern are at the ten superconductive transitions of the reference samples. The height of a transition step varies between about 5 mV to 100 mV depending on the sample.

The noise present in the signal is about 0.4 mV peak-to-peak, when the filter of the control unit is set to 'slow'.

To record the signal with a computer, use for example a DVM with a resolution of at least 0.1 mV at a full range of 2 V, equipped with a computer interface.

Please be aware of the influence (like heating effects) that such digital meters and interfaces may produce on low temperature set-ups due to the generation of RF-energy.

Whenever possible, apply an optical interface between the computer and the measuring equipment to reduce such interference problems.

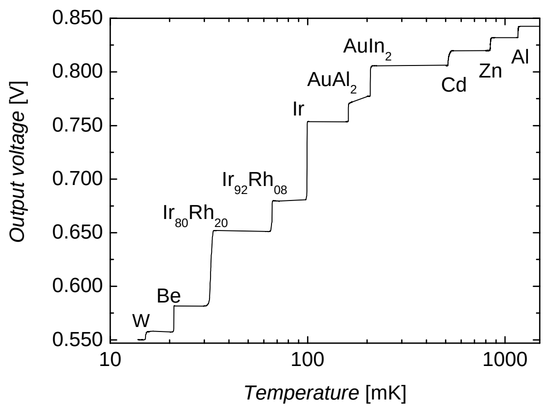


Figure 2.12. Output voltage control unit as a function of the temperature of the cryogenic sensor.

2.4.3. Testing the MIDS-10 system

In order to test the basic transfer function of MIDS-10 electronics, one can connect the test plug to the preamplifier instead of the cryogenic sensor (Figure 2.13).

At the control unit, set the primary current switch [1] to 'on', the filter switch [2] to 'slow' and display switch [3] to 'output'. This should produce a voltage value at the output terminal [11] as is indicated on the test plug. The value displayed on the front panel meter may deviate ± 1 LSB from this value.

To test the performance of the front panel meter, set the primary current switch [1] to 'off' and turn the offset control knob [4] fully clockwise.

When the display switch [3] is set to:

- 'output', the meter should read *000*,

- 'offset', it should read *1000*,

- 'deviation', it should read *–1000*

(all indications are ± 1 LSB).

An oscilloscope connected to the signal monitor terminal [9] enables the observation of the amplified AC signal of the sensor or test plug.

The signal should be sinusoidal with a frequency of about 977 Hz and its amplitude varies somewhat due to noise of the preamplifier (see Figure 2.14). The sync output terminal [8] provides a square wave signal to trigger the oscilloscope.

Figure 2.15 shows a set-up for testing the effective value of the AC primary current.

Connect the SRD terminal [1] of the preamplifier to the test box using the black Lemo 0B cable supplied with the ACS-10 unit.

One can measure the current at the primary coil terminal [P] of the test box with a true-RMS type current meter. The meter preferably should be powered by a battery and not by the mains supply. The effective value of the current should be 50 µA ±1% (@ 977 Hz).

Figure 2.13. The test plug connected to the preamplifier; the control unit displays the value as indicated on the plug.

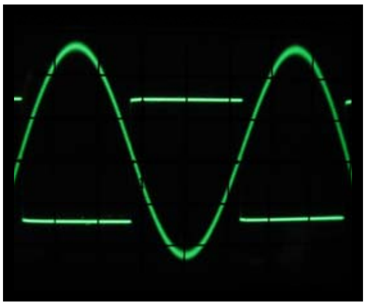


Figure 2.14. Sensor and sync signal displayed on an oscilloscope.

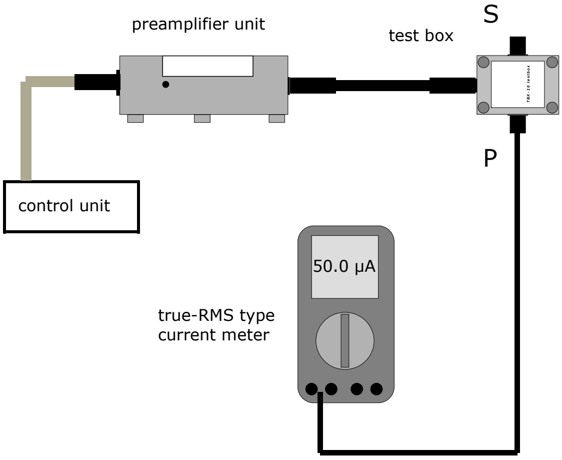
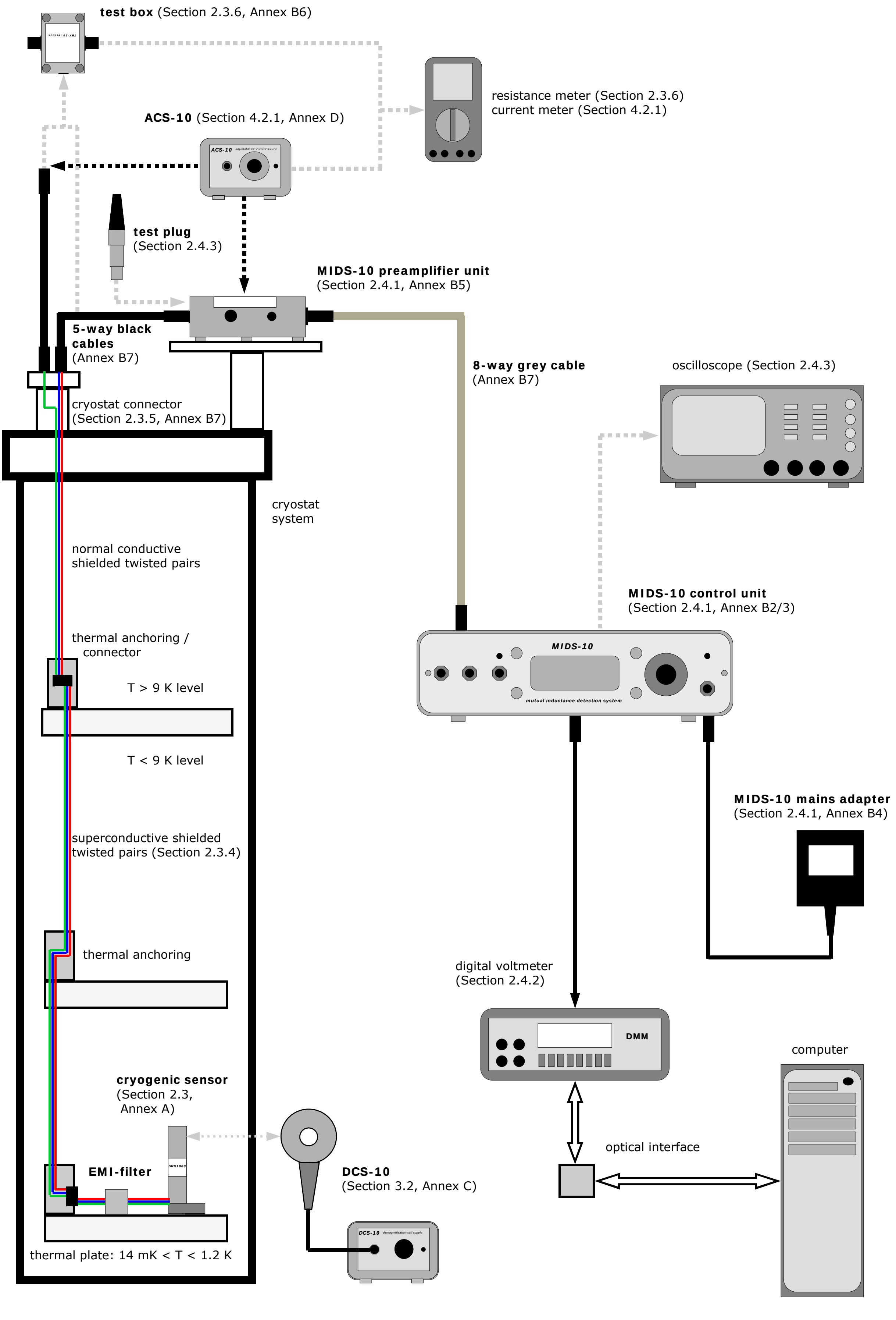


Figure 2.15. Testing the primary current.

2.5. System map



3.1. Experimental set-up

Figure 3.1 shows a set-up typical for the realisation of the reference points of the SRD1000 cryogenic sensor.

The sensor is attached to a thermal plate together with some thermometers. The plate is connected to the mixing chamber of a dilution refrigerator with a heat link. A heater is attached to the link for temperature regulation. In order to reduce thermal gradients within the plate, the heater is not positioned at the plate itself. One of the thermometers is used to provide a PID-feedback loop to control the heater power. A thermal shield surrounding the set-up reduces gradients produced, for example, by thermal radiation or residual exchange gas.

Make sure that the thermal resistance of the pressed contact between the mounting adapter of the sensor and the thermal plate is as low as possible. Especially at temperatures below 50 mK the heat flow from / to the Cryoperm shield of the sensor may otherwise lead to significant (time-dependent) temperature differences between the sensor and the thermal plate and thus to errors in the realisation of the reference points. Always clean the contacting surfaces with acetone and alcohol before the joint is made. If the thermal plate is not gold-plated, first remove any oxide layer by gently polishing the contact area.

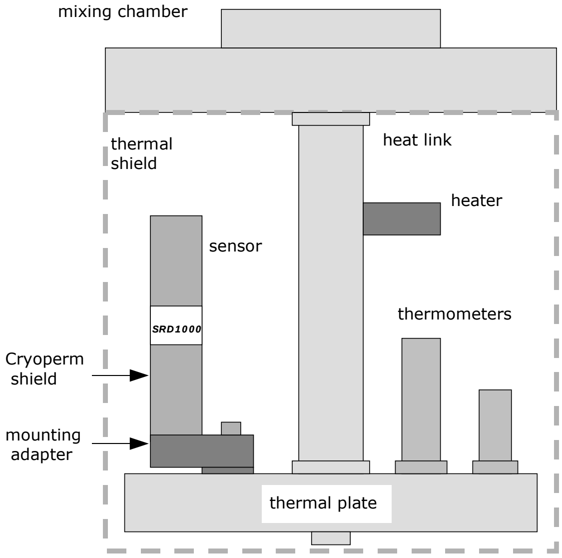


Figure 3.1. Set-up for thermometry with the SRD1000 cryogenic sensor.

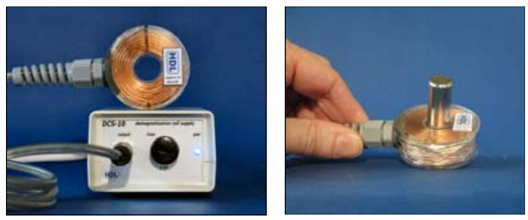


Figure 3.2. DCS-10 and the degauss coil.

3.2. Degaussing the Cryoperm magnetic shield

The strength of ambient magnetic fields at the mounting position of the sensor should be in the order of 100 μT or less (the earth magnetic field). In order to obtain an optimal shielding performance at low temperatures, the Cryoperm shield should be degaussed at room temperature using the DCS-10 unit and the degauss coil (Figure 3.2.) prior to each low temperature run.

Proceed by connecting the degauss coil to the DCS-10 supply unit (terminal [1], Figure 3.3). Next, connect the DCS-10 to the mains supply (cable [5]) and switch on the unit (switch [4], the blue LED [3] is on).

Move the degauss coil slowly starting from about 5 cm above the Cryoperm shield downwards and then upwards again (see Figure 3.4. a, b, c, d, e). The total sequence should take about 20 s. Repeat the sequence at least one more time.

Do not forget to switch off the DCS-10 after the procedure. The supply unit and coil may become warm after prolonged use. This is a normal situation. Do not cover the supply unit to prevent overheating.

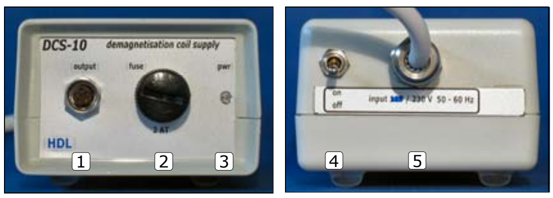


Figure 3.3. Front and rear view of the DCS-10.

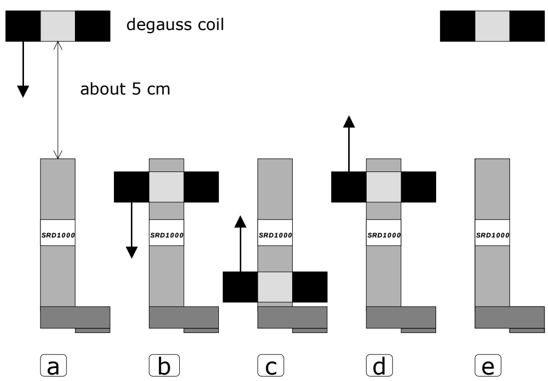


Figure 3.4. Degauss sequence Cryoperm shield.

3.3. Temperature and width of a reference point

A reference point is observed by monitoring the output voltage *V(T)* of the MIDS-10 electronics as a function of the temperature *T* of the cryogenic sensor.

Figure 3.5 shows an example of the superconductive transition of an $Ir_{92}Rh_{08}$ sample.

When the temperature is increased, the state of the reference sample in the sensor gradually changes from the superconducting state, corresponding to a system output voltage $V = V_{SC}$, to a state of normal conducting, with $V = V_{NC}$.

In this manual reduced output voltages V^* relative to voltages in the superconducting state are used to present the data of the transitions, with $V^* = V - V_{SC}$.

The reference point T_C is defined as the temperature when 50% of the transition is completed, which is at $V(T_C) = 0.5\ (V_{NC} + V_{SC})$. Relative to the superconducting state this it at:
$V_C^* = V^*(T_C) = V(T_C) - V_{SC} = 0.5\ (V_{NC} - V_{SC})$.

For many transitions the most temperature-sensitive part occurs when the signal level is between approximately 10% and 90% of the interval $V_{NC} - V_{SC}$. The corresponding temperature interval is defined as the width W_C of the transition: $W_C = T\ (V_{90}^*) - T\ (V_{10}^*)$, with $V_{90}^* = 0.9\ V_{NC}^*$ and $V_{10}^* = 0.1\ V_{NC}^*$.

The transition of Figure 3.5 shows a width W_C of 0.24 mK and provides a reference point at T_C = 65.34 mK with V_C^* = 21.3 mV.

Annex E gives an overview of the symbols and definitions to present the characteristics of a transition.

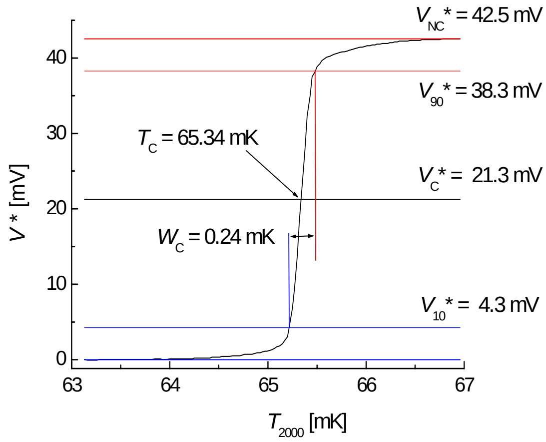


Figure 3.5. Superconductive transition of an $Ir_{92}Rh_{08}$ sample.

3.4. Staircase patterned temperature sweep

In order to observe a transition, preferably a *staircase pattern* is used to increase the temperature of the thermal plate, see Figure 3.6.

This means that each time temperature T is increased with a step ΔT, next, during a stabilisation time Δt, the temperature is stabilised at T+ΔT before a next ΔT step is made.

The interval Δt has to be sufficiently long to establish thermal equilibrium between all relevant elements at the thermal plate before the data point at T+ΔT is collected.

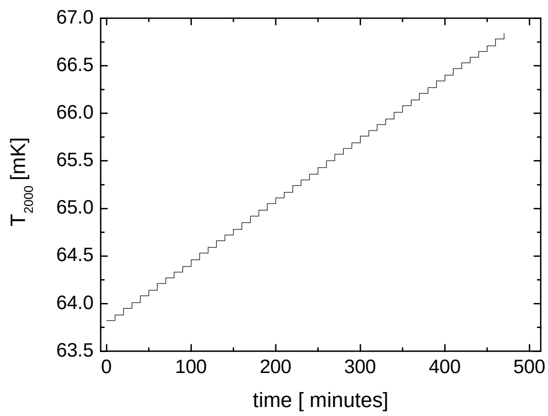


Figure 3.6. Temperature sweep following a staircase pattern.

In order to reproduce a transition with sufficient resolution at least 5 data points are to be measured along the most temperature-sensitive part of the transition.

This means that step ΔT should be smaller than W_C / 5. It also means that the stability of the temperature regulation during the sweep should be (significantly) better than W_C / 5.

Remark. *Figure 3.6 shows the staircase pattern of the temperature sweep between about 64 mK and 67 mK that was used during a calibration run to record the transition of Figure 3.5. The size of each ΔT step of the staircase is about 60 μK and the period Δt after a step is about 10 minutes. Depending on the thermal characteristics of a set-up and the desired accuracy level of the reproduction of T_C different settings for ΔT and Δt might be used.*

4.1. T_C shifts due to magnetic fields

The T_C value of a reference sample is reduced by the presence of a magnetic field. Tabel 4.1 presents estimated values for the shift dT_C / dB of each type of sample material.

Experimental work has shown that the magnetic shielding of the sensor sufficiently reduces common ambient magnetic fields in a cryostat once the shield is properly degaussed at room temperature before the start of a low temperature experiment (see Section 3).

However, in order to reproduce the reference points with the highest accuracy, one should verify that residual fields in the sensor are sufficiently low.

Table 4.1. Shift dT_C / dB of the reference materials.

#	Material	T_C [mK]	dT_C /dB [mK/μT]	Ref.
1	W	15	-0.09	[1]
2	Be	21	-0.14	[1]
3	$Ir_{80}Rh_{20}$	30	-0.03	[2]
4	$Ir_{92}Rh_{08}$	65	-0.03	[3]
5	Ir	98	-0.09	[3]
6	$AuAl_2$	145	-0.10	[3]
7	$AuIn_2$	208	-0.16	[3]
8	Cd	520	-0.14	[3]
9	Zn	850	-0.06	[3]
10	Al	1180	-0.06	[1]

[1] J.R. Schooley et al., *Temperature, Its Control and Measurement in Science and Industry*, **5**, p. 251-260, 1982;
[2] Estimated value based on measurements on $Ir_{92}Rh_{08}$ samples [3];
[3] W.A. Bosch et al., Measurements on the SRD1000 reference materials, Kamerlingh Onnes Laboratorium, Leiden, 2005.

4.2. Test procedure for residual magnetic fields

Figure 4.1 shows the shield and coil configurations of the cryogenic sensor.

An electrical current running in the detector coils (green squares) will generate a magnetic field in the X,Y-plane (horizontal component). A current in the compensation coil (red cylinder) will result in a magnetic field in the Z-direction (vertical component).

The ACS-10 current source is a tool which allows an adjustable DC current to run *either* in the detector coils, superimposed on the AC primary current to analyse the horizontal (X,Y) component, *or* in the compensation coil to analyse the vertical (Z) component. Please note that the ACS-10 does not provide for testing a combination of the horizontal and vertical components at the same time.

Experimental work proved that in most cases, due to the geometry of the shielding, the X,Y-components are significantly smaller than the Z-component. Thus analysing only the Z-component will generally suffice for the residual field test.

By varying the strength and the sign of the current while operating the cryogenics sensor and observing a transition, one can find a value for the current at which a residual magnetic field near the samples is reduced or compensated.

Please note that connecting the ACS-10 current source to the sensor circuitry should only be done for an occasional field test. For standard operation to reproduce the reference points it is advised to disconnect the ACS-10.

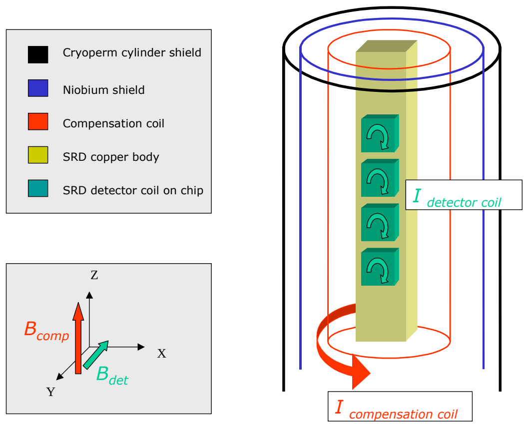


Figure 4.1. Shield and field configurations of the cryogenic sensor.

4.2.1. Preparing the ACS-10

Before using the ACS-10 (see Figure 4.2) insert a 9V PP3 battery in the bottom compartment. When the on/off switch [4] is operated, the blue power LED [3] should go on and off, if not the battery voltage is too low.

Connect a DC current meter (e.g. a digital multi-meter) at the BNC output [6]. In order to activate this output, set the monitor output switch [7] in the 'on' position.

- To test for the Z-component of the residual field, connect the compensation coil input [C] of the cryogenic sensor to the current output [5] at the rear of the ACS-10, see Figure 4.3. (a);
- To test for X,Y-components, connect the input marked 'ACS-10' at the preamplifier unit to the current output [5] at the rear of the ACS-10 using the black cable supplied with the ACS-10, see Figure 4.3. (b).

Remark. *One can check the performance of the ACS-10 by inserting the test plug (see Section 2.5) in output [5]. Next switch the unit on and turn knob [2] fully clockwise. The current meter should read +2 mA or −2 mA depending on the position of switch [1]. Note that the indication of the ten-turn dial has to be multiplied by a factor 2 to find the setting of the output current, so for example '500' gives an output of 1 mA.*

4.2.2. T_C versus I_{DC} measurements

To determine the residual field component one has to measure the shift of T_C as a function of the ACS-10 current I_{DC} in the sensor.

The $AuAl_2$ transition is well suited for these measurements. The transition at about 145 mK is located in a temperature region where most dilution refrigerators work well and where temperature control is often easy. The transition is also smooth and narrow, and the midpoint is easily determined.

Two methods are possible, each requiring different skills from the operator:

(1) stabilise the temperature to reach the mid-point of the transition, apply a current I_{DC} and adjust the temperature of the thermal plate so that the midpoint is indicated again, then go for the next current setting, adjust the temperature, etc.

(2) make various temperature sweeps (staircase patterned, like in Figure 3.6) through the mid-point, each time for a different current setting I_{DC}. Figure 4.4 shows an example: for each I_{DC} setting a T_C value is found at $V = V_C$.

Figure 4.2a. ACS-10, front view.

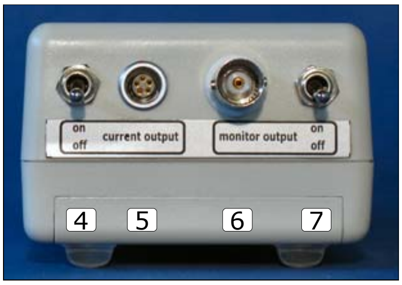


Figure 4.2b. ACS-10, rear view.

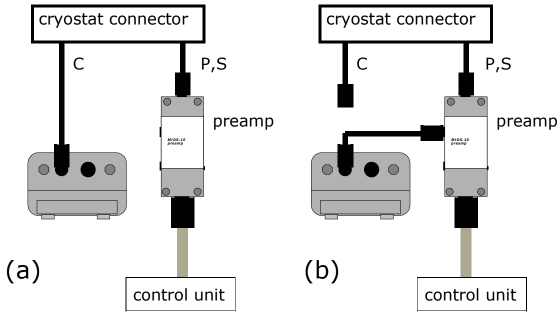


Figure 4.3. Connecting the ACS-10, see the text.

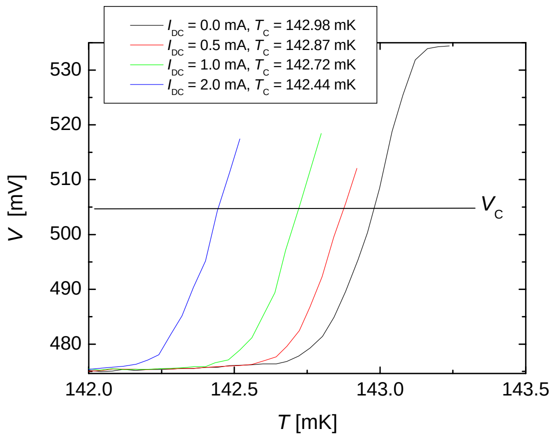


Figure 4.4. Example of an $AuAl_2$ transition observed for various currents settings.

Method 2 is more time-consuming, but often easier to perform as the demands for the temperature stabilisation are easier to meet.

The goal for each method is to acquire transition data to determine the various T_C values for several settings of I_{DC}.

For example, start by setting I_{DC} at 0 μA and find T_C (0 μA) = T_0, next set I_{DC} at 100 μA to find T_{100}, switch to -100 μA for T_{-100} , next to -200 μA, + 200 μA, etc.

Analyse the collected data by making a graph of the observed T_C and I_{DC} values, like in Figure 4.5. Find the intersection point of the blue and red lines, corresponding to the maximum T_C value T_{MAX} and the current value I_{RES}.

One can derive the residual magnetic field B_{RES} near the tested sample by multiplying the value I_{RES} by the material-dependent coil constant that can be found in Table 4.2.

The coil constants were derived both by calculations and experiments. Experimental work on the value of the coil constants is still in progress and future results shall be reported to the user.

Example. *Figure 4.6 shows an example of a measurement of the shift ΔT_C of an $AuAl_2$ sample versus the current I_{DC} in the compensation coil, with: $\Delta T_C = T_C(I_{DC})$ - maximum T_C value. The position of the measured data points (marked '+') deviates from the blue and red straight lines for $|I_{DC}| < 300$ μA. The intersection point of the lines is assumed to indicate the T_C value of the sample in zero magnetic field. The shift δT of 39 μK between this value and the top of the set of date points is supposed to be caused by the AC detection field near the sample, which has an amplitude of about 0.3 μT. The I_{DC} value at the intersection point of the lines is close to zero, which indicates that the residual DC magnetic field near the sample is negligible.*

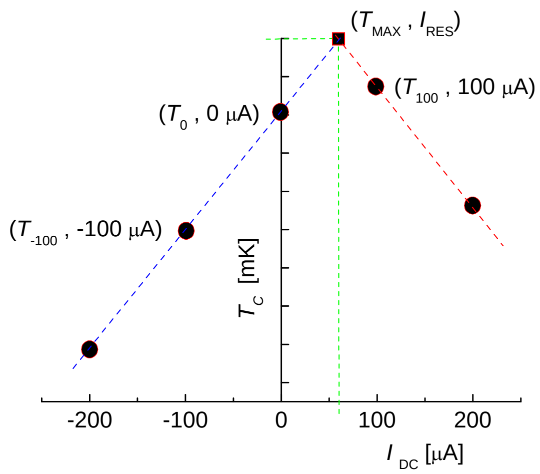


Figure 4.5. Example of T_C values as a function of applied current I_{DC} .

Table 4.2. Coil constants cryogenic sensor.

#	Material	Coil constant XY-field [μT / μA]	Coil constant Z-field [μT / μA]
1	W	$6 \cdot 10^{-3}$	$2.5 \cdot 10^{-3}$
2	Be	$6 \cdot 10^{-3}$	$2.5 \cdot 10^{-3}$
3	$Ir_{80}Rh_{20}$	$6 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$
4	$Ir_{92}Rh_{08}$	$6 \cdot 10^{-3}$	$2.8 \cdot 10^{-3}$
5	Ir	$6 \cdot 10^{-3}$	$2.6 \cdot 10^{-3}$
6	$AuAl_2$	$6 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$
7	$AuIn_2$	$6 \cdot 10^{-3}$	$2.8 \cdot 10^{-3}$
8	Cd	$6 \cdot 10^{-3}$	$2.9 \cdot 10^{-3}$
9	Zn	$6 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$
10	Al	$6 \cdot 10^{-3}$	$2.5 \cdot 10^{-3}$

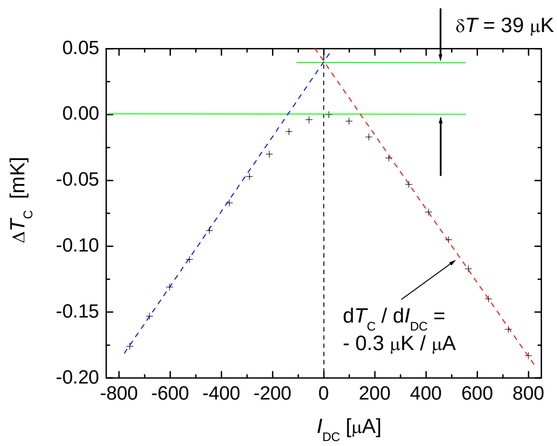


Figure 4.6. Shift ΔT_C of an $AuAl_2$ sample versus I_{DC} in the compensation coil (measurements by the PTB institute).

A1. Dimensions and connections of the SRD1000 cryogenic sensor

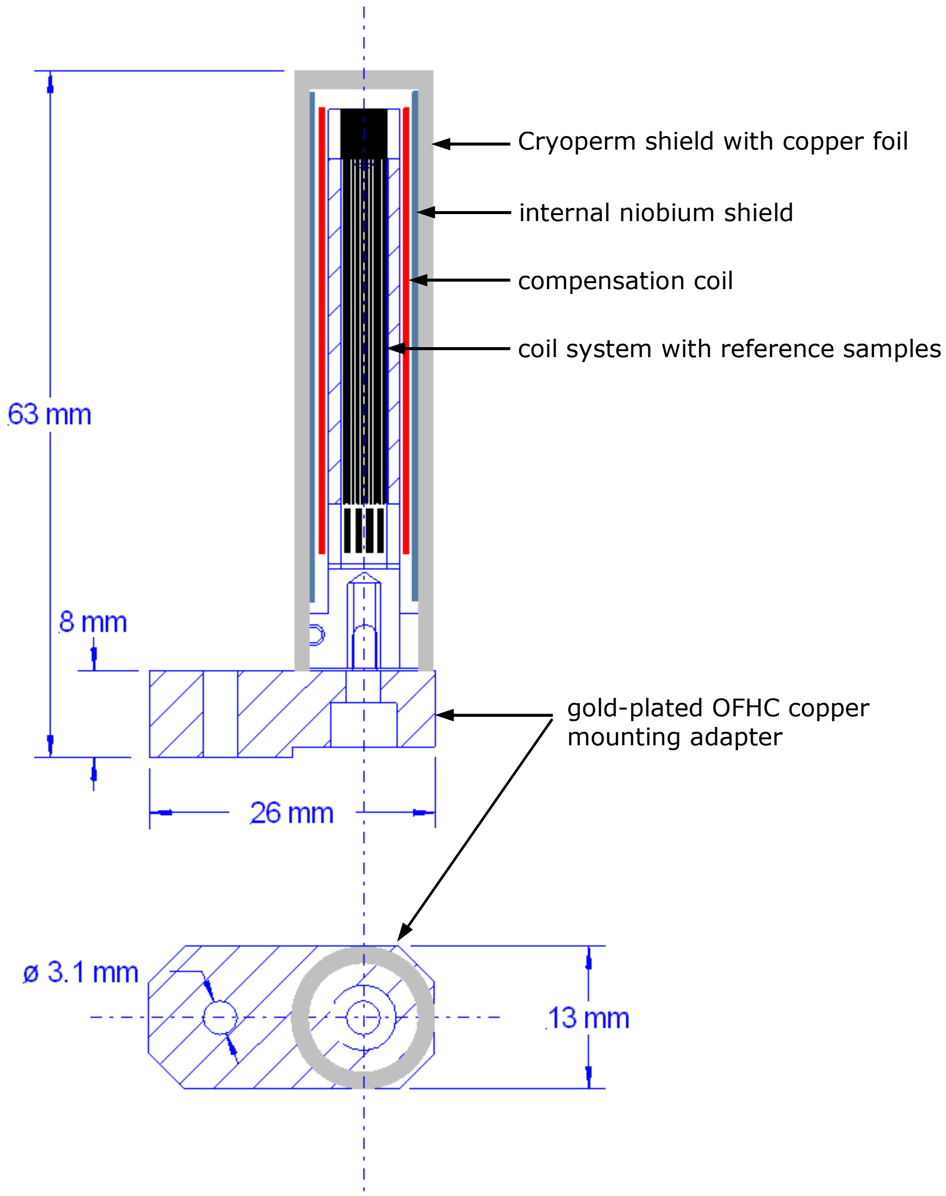


Figure A1. The sensor and its outer dimensions.

Table A1. Sensor signal connections with general values for the electrical resistance.

#	Connection type	Function	Colour code	R (300 K)	R (77 K)	R (< 9 K)
1	P (primary coil)	I+ , I-	**red** (+ = white)	180.000 Ω	90.000 Ω	0 Ω
2	S (secondary coil)	V+ , V-	**blue** (+ = white)	700.000 Ω	350.000 Ω	0 Ω
3	C (compensation coil)	C+ , C-	**green**	38 Ω	19 Ω	0 Ω

B1. Features

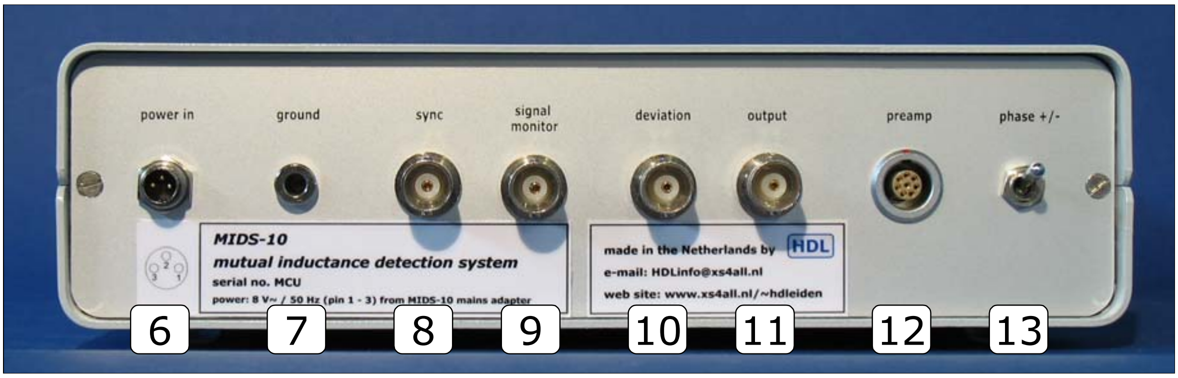
- detection electronics to establish the temperature reference points of the cryogenic sensor;
- 'plug and play'; no adjustments are required for the entire temperature range of the sensor;
- primary current: 50 μA @ 976.5 Hz;
- system voltage output : 0 - 1000 mV_{DC} proportional to the sensor signal;
- temperature coefficient of the parameters of the electronics: < 50 ppm/°C;
- design ensures minimal RF-heating in ultra-low temperature experiments.

B2. Control unit, front panel

Item	Description	Position	Function
[1]	primary current switch	on*) / off	primary current (50 μA @ 976.5 Hz) is switched on or off; the 'off' position may be used to diagnose heating effects of the sensor, or to monitor possible interference at the system output
[2]	filter switch	slow*) / fast	filter time constant of the system output [11] (rear panel) is set to 'slow' (τ = 62.5 s) or 'fast' (τ = 10 s); the normal operation mode is 'slow'. The noise level of the signal at the system output at 'slow' is about 0.4 mVpp, at 'fast' this is about 0.9 mVpp
[3]	display switch	output*)	front panel meter shows the voltage V_{OUT} [mV] at the system output [11] (blue output LED is on)
		offset	front panel meter shows the set-point of the offset voltage V_{OFF} [mV] (blue output LED is off)
		deviation	front panel meter shows the voltage $V_{DEF} = V_{OUT} - V_{OFF}$ [mV] at the deviation output [10] (blue output LED is off)
[4]	offset control	10-turn	changes the level of the offset voltage V_{OFF} (0 - 1000 mV)
[5]	power switch	on*) / off	power of the MIDS-10 main unit and preamplifier unit is switched on or off, as is indicated by the blue power LED's

*) *default setting for normal operation*

B3. Control unit, rear panel

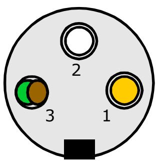


Item	Description	Function
[6]	power-in terminal (3-way male socket, Binder type 711)	power input 8 V~, 50 mA max, 50 / 60 Hz (pin 1-3 or pin 1-2 depending on the regional voltage of the mains supply); only use the mains adapter that is supplied for powering the MIDS-10 system to avoid any damage to the electronics
[7]	ground (4 mm) socket	terminal to ground the main unit (grounding is not required in most cases)
[8]	sync output (BNC)	AC square wave signal (1 V_{PP}, f = 976.5 Hz) to synchronise an oscilloscope while monitoring the sensor signal [9]
[9]	signal monitor output (BNC)	AC amplified secondary voltage of the sensor (f = 976.5 Hz) to be monitored on a oscilloscope for diagnoses purposes
[10]	deviation output (BNC)	DC deviation voltage $V_{DEV} = V_{OUT} - V_{OFF}$ to monitor small changes in the system output voltage [11] relative to the set-point of the offset voltage [4]
[11]	system output (BNC)	DC output V_{OUT} (0 - 1000 mV) proportional to the secondary voltage of the sensor
[12]	preamp terminal (8-way Lemo 1B female socket)	to connect the 5m grey cable leading to the preamplifier unit
[13]	phase +/- switch	to change the phase of the sensor signal by 180º when the front panel meter shows a negative sign; for normal operation select a setting that will result in a positive sign on the meter; note that as V_{OFF} is a positive voltage, only a positive V_{OUT} can be fully compensated by V_{OFF} at the deviation output

B4. Mains adapter

The mains adapter.

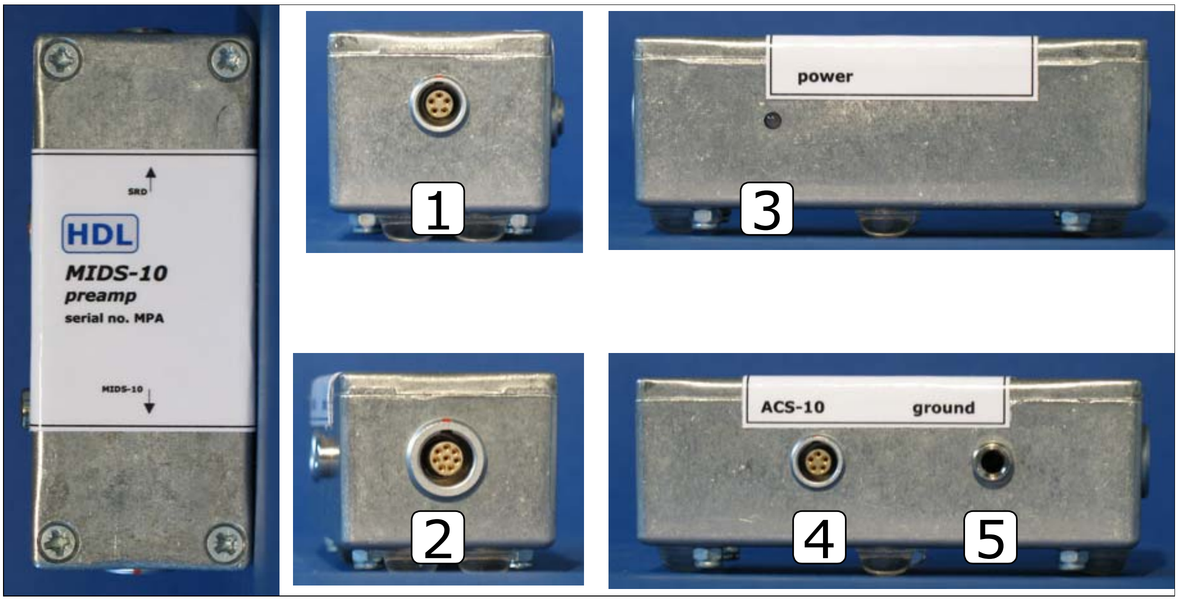
Power supply connection:
3-way female socket, Binder type 712 (nr. 99-0406-00-03).



Pin lay-out:
front view of the male panel socket or solder contact view of the female cable socket; the lead colour codes of the supply cable are indicated.

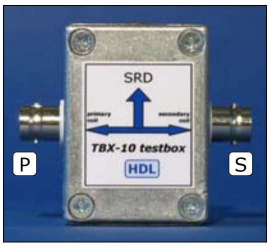
Pin 1-3: 7.3 V~ @ input 230 V~ / 50 Hz / 7 VA;
Pin 2-3: 8.3 V~ @ input 230 V~ / 50 Hz / 2 VA;
Pin 1-2: 7.8 V~ @ input 115 V~ / 60 Hz / 7 VA.

B5. Preamplifier unit



Item	Description	Function
[1]	sensor terminal (5-way Lemo 0B female socket)	to connect the black cable from the cryostat connection to the sensor
[2]	control unit terminal (8-way Lemo 1B female socket)	to connect the 5 m grey cable leading to the control unit
[3]	power LED	indicates the power status of the preamplifier; when connected to the main unit, the preamplifier unit is switched on / off by switch [5] at the control unit
[4]	ACS-10 input terminal (5-way Lemo 0B female socket)	refer to Section 4.2; this input is used to connect the black cable leading to the ACS-10 current source for analysing X,Y magnetic field components in the sensor
[5]	4 mm ground socket	terminal to ground the preamplifier unit (grounding is not required in most cases)

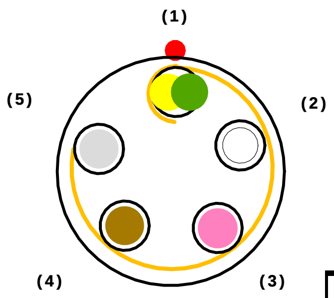
B6. Test box

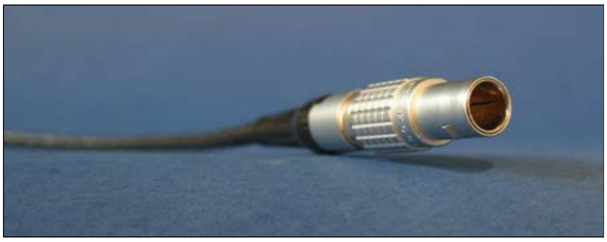


Item	Description / function
[SRD]	input terminal (5-way Lemo 0B) for the black sensor cable from the cryostat in order to test the electrical connections to the sensor
[P]	BNC connection to the primary coil section of the SRD connector: BNC shield -> Lemo pin 5 (I-), BNC centre pin -> Lemo pin 3 (I+); connecting a resistance meter allows the checking of the primary coil connections of the sensor
[S]	BNC connection to the secondary coil section of the SRD connector: BNC shield -> Lemo pin 4 (V-), BNC centre pin -> Lemo pin 2 (V+); connecting a resistance meter allows the checking of the secondary coil connections of the sensor

B7. Connections and cable arrangements

Pin layout of the 5-way Lemo 0B connector and the composition of the black connecting cables.

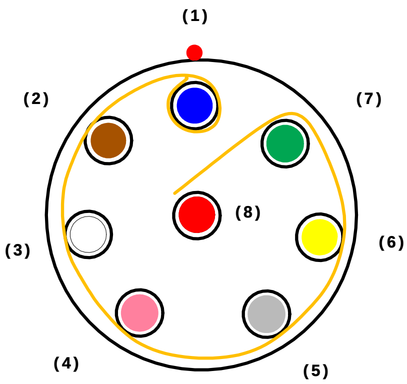




Front view of the male free plug or rear / solder contact view of the female chassis socket; the yellow line indicates the direction of the pin number count.

Contact	Lead colour	Mutual inductance connection	Compensation coil connection
(1)	yellow / green	ground / shield	ground / shield
(2)	white	secondary coil V +	-
(3)	violet	primary coil I +	current C+
(4)	brown	secondary coil V -	-
(5)	grey	primary coil I -	current C-

Pin layout of the 8-way Lemo 1B connector and the composition of the grey cable between preamplifier and control unit.



Front view of the female chassis socket or solder contact view of the male free plug; the yellow line indicates the direction of the pin number count.

Contact	Lead colour	Connection
(1)	blue	ground
(2)	brown	sensor current reference +
(3)	white	sensor current reference -
(4)	violet	- 5 V supply
(5)	grey	ground / spare
(6)	yellow	amplified sensor voltage +
(7)	green	amplified sensor voltage -
(8)	red	+ 5 V supply

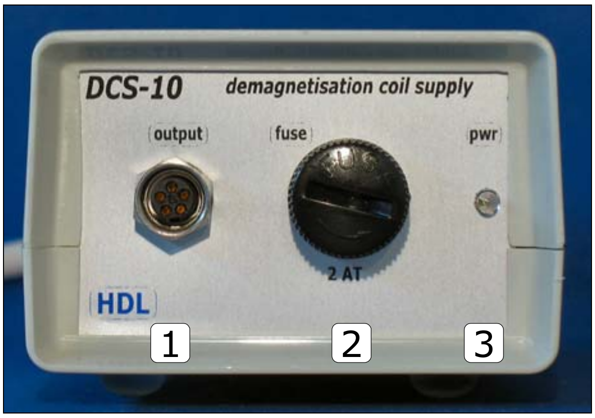
C1. Features

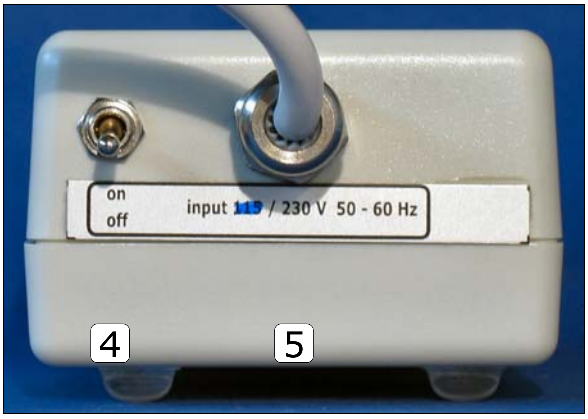
- tool for degaussing the Cryoperm shielding of the sensor to optimise its magnetic properties;

- supply provides 1.7 A, 50 - 60 Hz to drive the degauss coil;

- input 230 - 240 V / 50 Hz, (model a) or 115 V, 50 - 60 Hz, (model b), max. 10 W.

C2. Front / rear view





Item	Function
[1]	AC current output to connect the degauss coil (5-way female socket, Binder type 711)
[2]	fuse holder (contains 2 AT glass fuse, 20 x 5 mm) to limit the output current
[3]	blue power LED is on indicates that the output circuitry is on. When the degauss coil is not connected, the LED shines bright, it dims when the coil is connected
[4]	power on / off switch
[5]	mains input 115 or 240 V / 50 - 60 Hz (depending on the model), 10 W max

D1. Features

- battery-powered precision current source for compensating residual fields in the cryogenic sensor;

- DC output current adjustable between 0 μA and 2000 μA with a polarity selection for the sign of the output current;

- the compliance voltage is about 3 V;

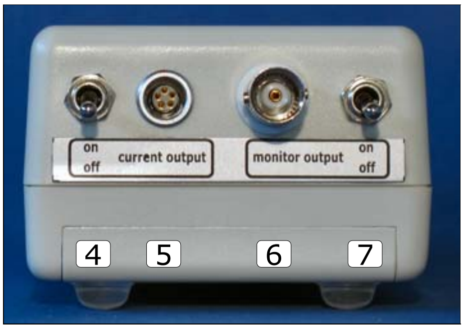
- temperature coefficient electrical parameters: smaller than 50 ppm/°C;

- the low load capacitance allows direct superimposing of the DC output current on the AC primary current of sensor;

- output to monitor the current;

- powered by one 9V PP3 battery; indication of low battery voltage.

D2. Front / rear / bottom view



Item	Description / function
[1]	polarity switch + / - to change the sign of the output current
[2]	ten-turn control to set the level of the DC output current between 0 - 2000 μA; note that the setting of the dial needs to be multiplied by a factor 2 to find the value of the output current, so for example '500' equals a current output of 1000 μA
[3]	power LED is on, indicates that the power is switched on and that the battery voltage is OK. Replace the internal battery in the bottom compartment [8] if the LED is off when the power switch [7] is on. Operating the ACS-10 with low battery voltages may result in unstable currents. Use 9 V PP3 alkaline type batteries only
[4]	switch on/off for power and output current
[5]	current output terminal (5-way Lemo 0B) to drive the sensor compensation coil or detector coils (refer to Section 4.2)
[6]	monitor output (BNC) to connect an external current meter to monitor the output current (0 - 2000 μA); the meter is connected in series with the current flow: when the meter is not connected, switch [7] should be set to the 'off' position
[7]	monitor output on/of switch to shunt the monitor output [6] and to disconnect the BNC terminal from the current circuitry
[8]	battery compartment at the bottom of the unit for one 9 V PP3 alkaline type battery

Table E1 provides an overview of the symbols and definitions that are used in this manual to present the characteristics of a superconductive transition.

Table E1. Symbols and definitions to characterise a superconductive transition.

Symbol	**Definition**
T_{2000} , T_{90}	Temperature along the PLTS-2000 and ITS-90 scales, respectively
T_C	Reference (or 'transition') temperature, $T_C = T(V_C*)$
$U(T_C)$	Expanded uncertainty of the determination of the transition temperature [1])
$U(T_{2000\,/\,90})$	Expanded uncertainty of the corresponding temperature scale realisation [1])
V	Output voltage MIDS-10 measurement electronics
V_{SC}	Output voltage when sample is (sufficiently) in the superconducting state
$V*$	Output voltage relative to superconducting state: $V* = V - V_{SC}$
$V_{10}*$	Relative voltage after completing 10% of the total variation $V_{NC} - V_{SC}$
V_C*	Relative voltage after completing 50% of the total variation $V_{NC} - V_{SC}$
$V_{90}*$	Relative voltage after completing 90% of the total variation $V_{NC} - V_{SC}$
V_{NC}	Output voltage when sample is (sufficiently) in a normal conducting state
$V_{NC}*$	Relative voltage $V_{NC} - V_{SC}$, which equals the step height of the transition
W_C	Width of the transition = $T(V_{90}*) - T(V_{10}*)$

[1]) please refer to a PTB calibration certificate for more information.