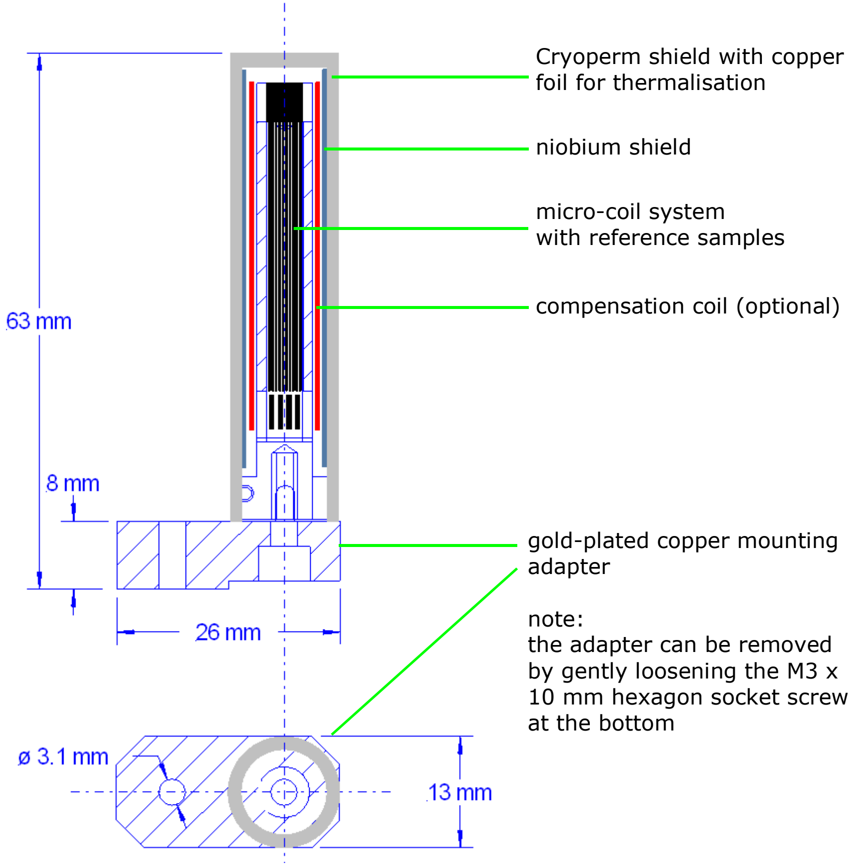


Figure 2. The SRD1000 sensor components and dimensions.

2.2. Mechanical and thermal connections

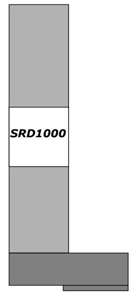
The sensor is installed in a dilution refrigerator by fixing the mounting adapter to a thermal plate in the experimental region using a M3 bolt and washer. Prior to mounting remove any oxidation on the thermal plate when necessary and clean both contacting surfaces thoroughly with for example acetone / alcohol to reduce the thermal resistance of the press-contact joint.

In most cases the shielded signal leads are to be mechanically (and electrically) fixed at the same thermal plate as to which the sensor is being attached. The shielding of the leads is made of phosphor-bronze mesh. Each lead contains 2 superconductive conductors (Ø 0.1 mm NbTi in a Cu-matrix). The leads are thermally anchored to the sensor body inside the shield.

HDL HIGHTECH DEVELOPMENT LEIDEN

SRD1000 superconductive reference device

user guide, version SRD1000-20100401



HDL

contact dr. ir. W.A. Bosch

tel +31(0)5210672
fax +31(0)5236916

address P.O. Box 691
2300 AR Leiden

e-mail HDLinfo@xs4all.nl
website www.xs4all.nl/~hdleiden/srd1000

Contents

1. Introduction

The SRD1000 sensor contains an array of mutual inductance detectors, consisting of integrated planar Nb micro-coils. Samples of various superconductive reference materials are attached to the detector array. The assembly is thermally connected to a gold-plated mounting adapter at the bottom of the sensor (see Figure 1, part [1]). To reduce ambient magnetic fields near the samples the sensor is equipped with a cylindrical (annealed Cryoperm / niobium) shield [2]. An optional 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 [3] and equipped with filters [4, 5, 6] to suppress electro-magnetic interferences. Figure 2 shows the sensor components and dimensions.

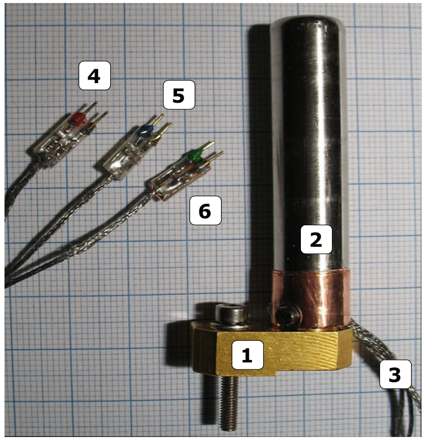


Figure 1.
SRD1000 cryogenic sensor

2. Mechanical properties

2.1. Handling the sensor

Generally handle the sensor with great care. Avoid mechanical stress to the annealed Cryoperm 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 are not sensitive to electrostatic discharge. The resistance of the circuitry may be measured using a standard digital multi-meter at ranges equal and below 20 MΩ.

5. Procedure HDL calibration

The SRD1000 sensor is measured in the HDL calibration set-up with a MIDS-20x type of detection electronics by observing the DC output voltage V of the electronics versus sensor temperature T. To determine the parameters of each reference point the temperature is increased from $T<T_{SC}$ to $T>T_{NC}$ by small steps. After each step sufficient time is taken to obtain thermal equilibrium between all thermometers of the set-up. The number of steps is such that the 80% region of the transition is resolved in at least 5 data points.

The local temperature scale used in the set-up is based on the reference points of SRD1000 device no. 008 and SRM768 device nr. 48, both calibrated by PTB in Berlin (web site: www.ptb.de) against the PLTS-2000 and ITS-90. During each run of the set-up two resistance thermometers and a CMN thermometer are calibrated using the devices as mentioned. Next the data points of the values of the thermometers observed at the reference points are fitted to polynomial equations to derive a local scale between about 10 mK and 2 K.

6. Using the calibrated reference points for thermometry

Some hints and tips for the practical realisation of the reference points in a cryogenic set-up:
- demagnetise the Cryoperm shielding of the SRD1000 at room temperature prior to each cool-down using the DCS-10.
- mount the sensor onto a clean, polished surface of the thermal plate of the set-up to ensure a low thermal resistance of the press-contact joint and thus ensuring a low thermal relaxation time of the sensor.
- connect the primary and secondary coil connectors and verify (at room temperature) that they are not interchanged by measuring their resistance value with the test box and a multimeter.
- at least one (resistance) thermometer with related electronics is required in the set-up for the measurement and control of the temperature.
- during the cool-down of the fridge, record the output voltage V of the MIDS-20x detection electronics versus temperature T (or time). Select the filter setting 'fast' for fast tracking of signal changes. An example of a $V(T)$ curve is shown in Figure 5. The voltage level and sequence of the steps eases linking the steps and their corresponding reference points.
- next derive the V_{NC} and V_{SC} level of each transition and calculate its midpoint level $V_C = 0.5\ (V_{NC} + V_{SC})$.
- to reach the reference temperature T_C of a specific point, slowly increase the temperature of the thermal plate until $V \approx V_C$ to reach $T = T_C$. Set the MIDS-20x filter to 'slow' to optimise the signal-to-noise ratio.
- note that V is a steep function of T around T_C, with
  $dV/dT \approx (V_{90} - V_{10}) / W_C = 0.8\ (V_{NC} - V_{SC}) / W_C$.
  For accurate measurements the temperature instabilities should be smaller than 0.1 W_C to limit fluctuations in V to less than about 0.08 $(V_{NC} - V_{SC})$.
- allow sufficient time for all elements of the set-up to reach a thermal equilibrium before the final data at the reference point are taken.

3. Electrical properties

3.1 Signal connections

The sensor contains a set of mutual inductors to detect the transitions of the reference samples, as shown by the red and blue coils in Figure 3. An (optional) compensation coil, depicted in green, allows reduction of residual magnetic fields near the samples.

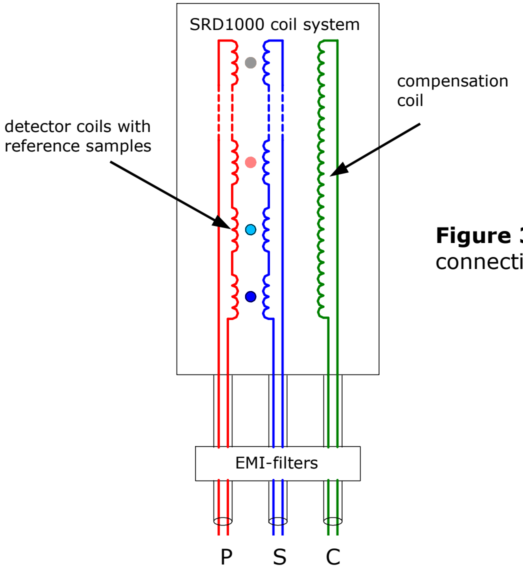


Figure 3. The sensor circuitry and connections.

The coils are connected through shielded superconductive signal leads.

Each lead contains a twisted pair of inner signal conductors and is terminated with a 2-way connector with integrated EMI filter ([4,5,6] in Figure 1). The pin spacing is 2.56 mm / 0.1" which fits into a standard type IC socket (e.g. a SIL-socket connector).

The letters and colours at the connectors indicate the type and polarity of the connection: P = primary coil (red = P+), S = secondary coil (blue = S+), C = compensation coil (green = C+).

Table 1 overviews the connections and typical values of the electrical resistance of the coils at 300 K, 77 K and at T < 9 K.

The values for a specific sensor are listed on the label that can be found on its storage box.

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.

Table 1. Overview sensor connections with typical values for the electrical resistance.

Connection	Terminals	Colour code +	R @ 300 K	R @ 77 K	R < 9 K
P (primary coil)	P+ , P-	red	70 - 180 kΩ	35 - 90 kΩ	<10 Ω
S (secondary coil)	S+ , S-	blue	250 - 700 kΩ	125 - 350 kΩ	<10 Ω
C (compensation coil)	C+ , C-	green	38 Ω	19 Ω	0 Ω

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.

4. Parameters to characterise the reference points

The SRD1000 sensor contains samples of various superconductive reference materials. Each sample shows a characteristic temperature range T_{SC} to T_{NC} in which its electrical conductivity transfers from a superconducting to a normal conducting state. When measured with the MIDS-20x type of detection electronics, the sensor produces a DC output voltage V at the electronics which changes from V_{SC} to V_{NC} during the superconductive transition, as shown in Figure 4.

The reference or 'transition' temperature T_C of the sample is defined as the temperature at which 50% of the transition is completed. At this temperature V equals V_C with
$V_C = V_{SC} + 0.5\ (V_{NC} - V_{SC})$.

The width of the transition W_C equals the temperature interval T_{10} to T_{90} in which 80% of the transition is completed. In this interval V changes from V_{10} to V_{90} with
$V_{10} = V_{SC} + 0.1\ (V_{NC} - V_{SC})$
$V_{90} = V_{SC} + 0.9\ (V_{NC} - V_{SC})$.

W_C is one of the main parameters that determine the uncertainty U_C of the realisation of a calibrated reference temperature:
$U_C \approx 0.2\ W_C$.

Finally the parameter U_{CT} is an estimate of the total uncertainty in a calibrated reference temperature based on U_C and the uncertainty U_{CS} of the realisation of the local temperature scale. Finally the relative uncertainty $U_{CT}\%$ equals 100 U_{CT} / T_C.

Table 2 summarises the parameters characterising a transition.

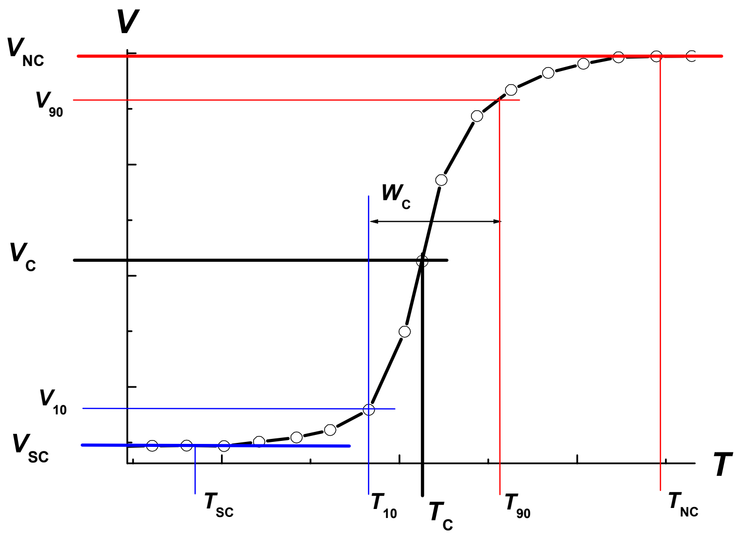


Figure 4. Output voltage V of the detection electronics versus sensor temperature T for a superconductive transition.

Table 2. Parameters to characterise a superconductive transition.

Parameter	Definition
T_{SC}	Temperature at which the sample is (sufficiently) in the superconducting state
T_{NC}	Temperature at which the sample is (sufficiently) in the normal conducting state
V	DC output voltage of the MIDS-20x detection electronics
V_{SC}	V at $T \approx T_{SC}$
V_{NC}	V at $T \approx T_{NC}$
V_{10}	V after completing 10% of the transition: $V_{10} = V_{SC} + 0.1\ (V_{NC} - V_{SC})$
V_{90}	V after completing 90% of the transition: $V_{90} = V_{SC} + 0.9\ (V_{NC} - V_{SC})$
V_C	V after completing 50% of the transition: $V_C = V_{SC} + 0.5\ (V_{NC} - V_{SC})$
T_{10}	T at which 10% of the transition is completed
T_{90}	T at which 90% of the transition is completed
T_C	Reference or 'transition' temperature (50% of the transition is completed)
W_C	Width of the transition: $W_C = T_{90} - T_{10}$
U_{CT}	Estimate of the total uncertainty of the determination of T_C
$U_{CT}\%$	relative uncertainty 100 U_{CT} / T_C

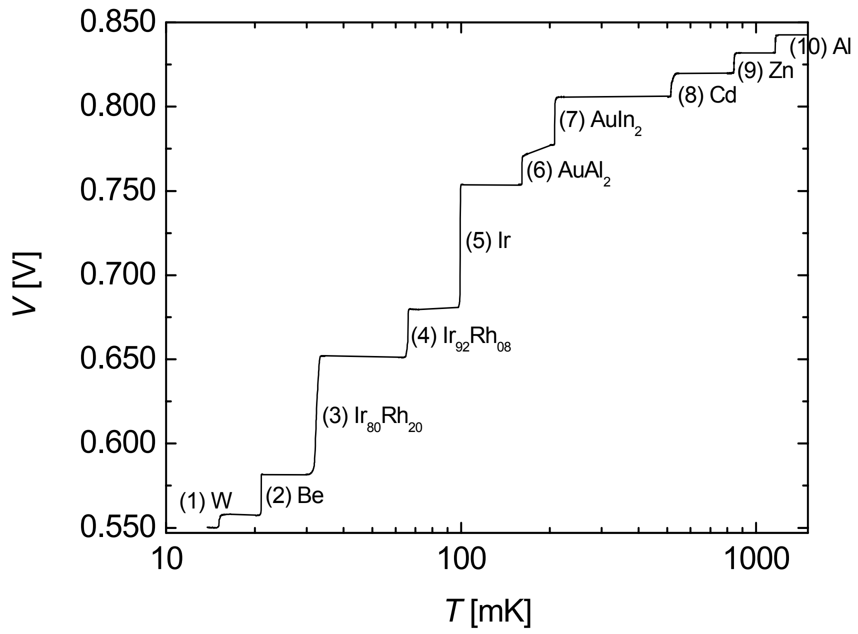


Figure 5. MIDS-201 output voltage *V* versus sensor temperature *T* showing 10 voltage steps at the reference temperatures.