CMN1000: a fast, accurate and easy to use thermometer for the range 10 mK - 2 K

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Introduction

The CMN1000 is a dedicated version of the 'classic' powdered cerium magnesium nitrate (CMN) susceptibiliy thermometer [1]. The new thermometer was developed to support thermometry alongside the SRD1000 [2], a device that provides calibrated reference points between 15 mK and 1.2 K. Physical dimension, electrical signal parameters, temperature range and resolution were designed to match and support the performance of the SRD1000 device and the related MIDS-20x type of detection electronics.

CMN1000 design

The thermometer constructional parts:
(1) protective cylinder with Nb shield
(2) sealed capsule (ø 3 x 3 mm) with powdered CMN sample and silver-foil thermal link
(3) detection transformer
(4) compensation transformer
(5) base for mechanical and thermal connection
(6) shielded twisted pair leads (primary and secondary coil connections) with rf-filtered terminals

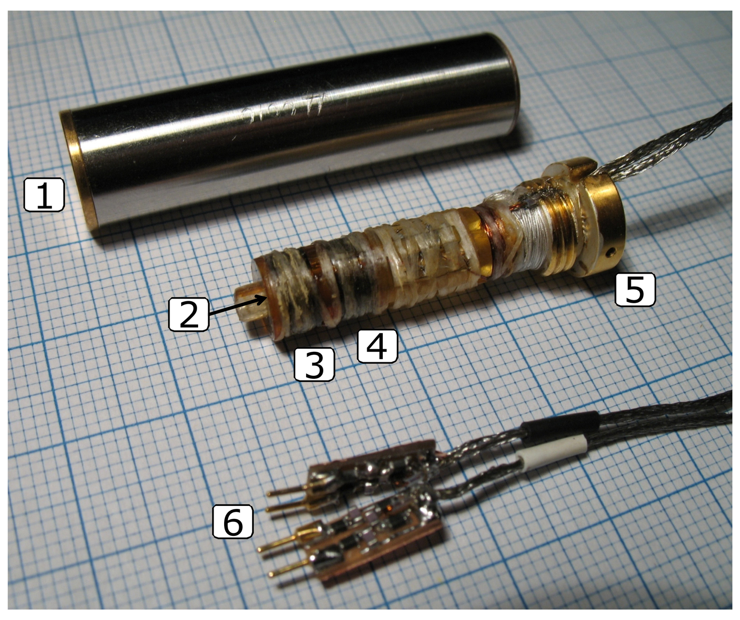

Figure 1. CMN1000 constructional parts

Design highlights:
- relative easy to fabricate;
- set of detection coils small enough to be integrated in the SRD1000 device;
- balanced transformers minimise signals other than those of the CMN sample;
- silver-foil thermal link with CMN powder to achieve low thermal relaxation times;
- sealed capsule to prevent dehydration of the CMN powder;
- special transformer wire and geometric design to achieve low spurious temperature dependent flux changes or phase shifts.

CMN1000 signal and detection

The CMN1000 signal is measured with the MIDS-20x type of mutual inductance detection electronics ([2] and Figure 2), which is also used for the SRD1000 device.

Figure 2. MIDS-201 (1-channel) detection electronics; the MIDS-202 is a version for independent and simultaneous 2-channel measurements.

Signal characteristics:

- the susceptibility X of CMN follows the Curie-Weiss law below approximately 3 K: $X_{CMN} \sim C / (T - \Delta)$, with C the Curie-constant and T the temperature; Δ is related to the magnetic ordering temperature of CMN;
- the MIDS-20x output voltage V is proportional to the susceptibility X of the thermometer, so a first order approximation of $V(T)$ is :
  $V(T) = A + B / (T - d)$; (1);
- the constants A, B and d are related to the instrumentation and need to be calibrated for each thermometer.

Test set-up

Several CMN1000 thermometers were characterised in the cryo-free dilution refrigerator of the *Interface Physics Group* at LION.

The items of the test set-up:
(1) CMN1000 thermometer;
(2) thermal plate - with heaters and resistance thermometers for temperature control - attached to the mixing chamber;
(3) SRD1000 reference devices to establish an accurate local temperature scale. The devices contain reference points for thermometry based on the superconductive transitions of various metals[1]. The points were calibrated according to PLTS-2000 / ITS-90 temperatures by PTB Berlin [3].

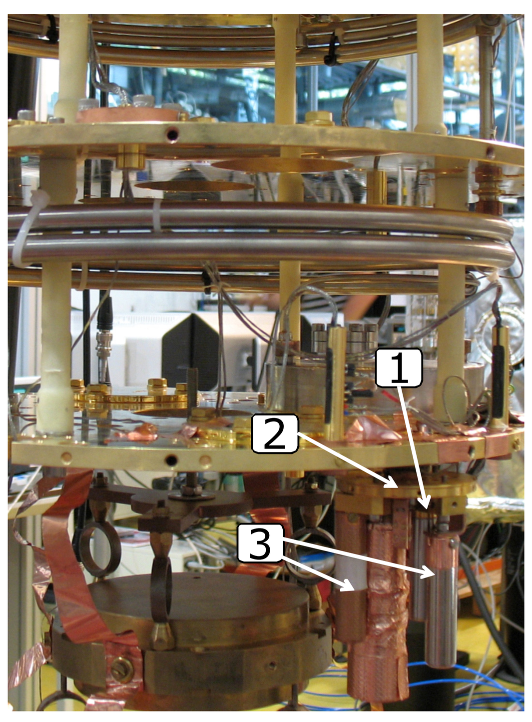

Figure 3. Test set-up

[1] list of the SRD1000 reference points:

15 mK (W), 21 mK (Be), 30 mK ($Ir_{80}Rh_{20}$), 65 mK ($Ir_{92}Rh_{08}$), 100 mK (Ir), 145 mK ($AuAl_2$), 208 mK ($AuIn_2$), 520 mK (Cd), 850 mK (Zn) and 1.2 K (Al).

Measurement results

Figure 4 shows a typical $V(T)$ curve of a CMN1000 measured with the MIDS-20x. The thermometer signal matches the dynamic range of the electronics between 10 mK and 2 K without having to change any ranges or settings.

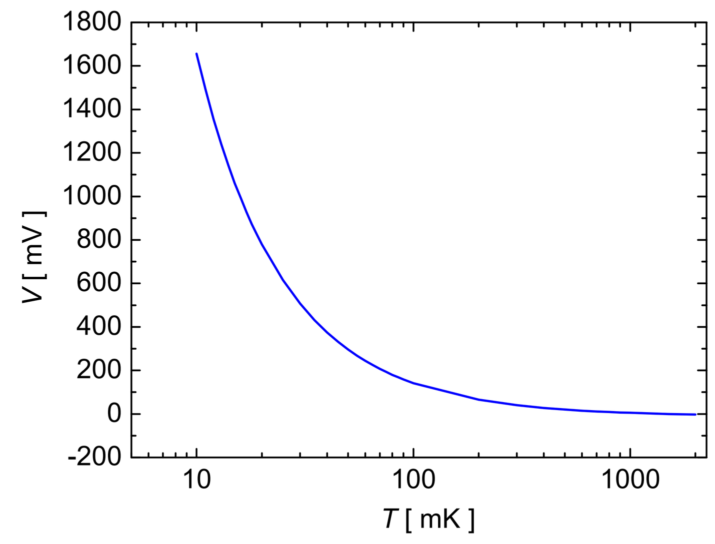

Figure 4. System output voltage V versus T

The resolution ΔT_{RES} of the temperature reading is limited by the noise voltage level N_{PP} of the output signal V:
$\Delta T_{RES} = 0.5\, N_{PP}\, |\, dT / dV \,|$ with $N_{PP} \approx 30\ \mu V_{PP}$.
Figure 5 shows that ΔT_{RES} varies between 10^{-4} mK at 10 mK, 0.2 mK at 500 mK and 4 mK at 2 K.

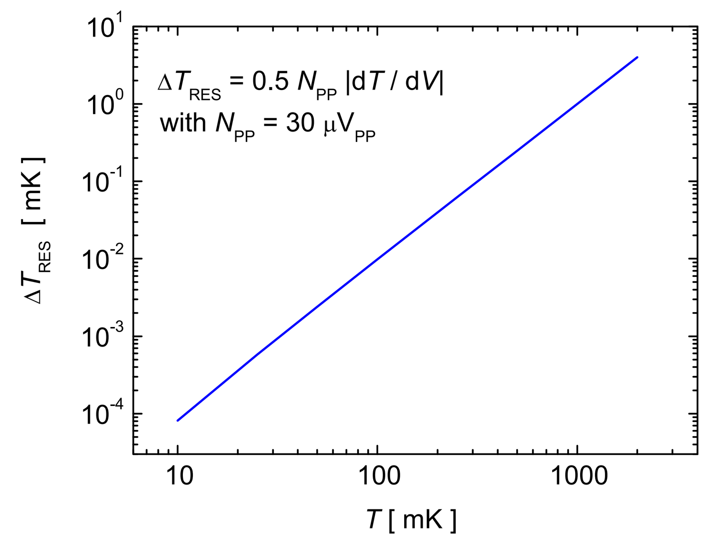

Figure 5. Temperature resolution versus T

Figure 6 gives the relative resolution $100\ \Delta T_{RES}\ /\ T$. The resolution is better than 0.2 % of the temperature below 2 K.

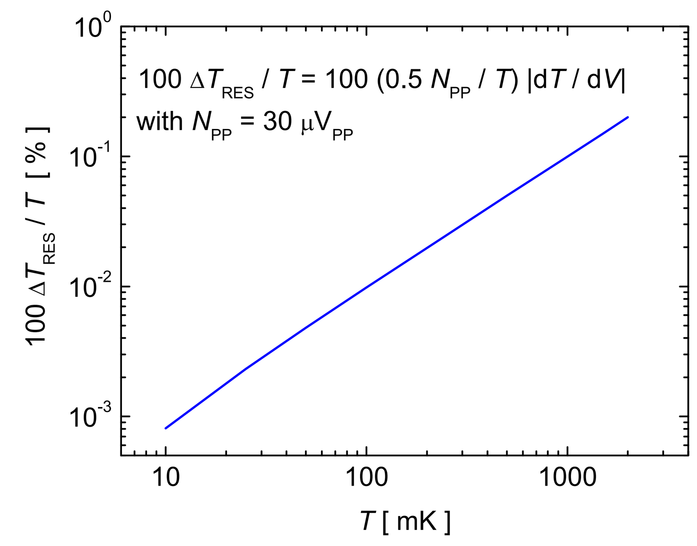

Figure 6. Relative resolution versus T

The V values measured at the reference temperatures were fitted according to equation (1). Typical values found for the equation constants are: $A = -10$ mV, $B = 1.5\ 10^{4}$ mV.mK and $d = 1$ mK.
Figure 7 shows that the error of such a fit is less than about 0.2 % below 200 mK.
For the entire range 10 mK - 2 K the error is less than 1 % . The error becomes << 1% if for example a more complicated polynomial expansion of ln(V) versus ln(T) is used.

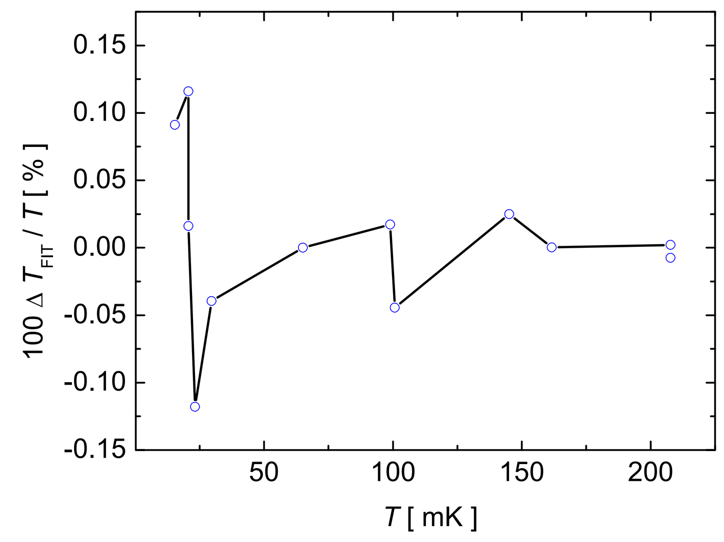

Figure 7. Fitting error versus T

Other results found:
- (self-)heating effects resulting from the excitation of the thermometer are negligible down to the lowest temperatures;
- the thermal response time is faster than that of the thermal plate of the test set-up; the estimated time constant is < 5 s at 10 mK and is smaller at higher temperatures;
- the reproducibility during test runs with frequent warming - cooling cycles is within the noise level. After a cycle to room temperature the deviation is less than 1 % .

Conclusion

Our measurements show that the CMN1000 is easy to calibrate, fast responding and has sufficient resolution to support accurate thermometry between 10 mK and 2 K alongside the SRD1000 superconductive reference device and MIDS-20x electronics.

References

[1] for example: D.S. Greywall and P.A. Busch, Rev. Sci. Instrum. **51**, 471 (1989).
[2] see the SRD1000 website: *www.xs4all.nl /~hdleiden/srd1000*
[3] PTB is the German metrology institute, website: *www.ptb.de*

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Further information

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