Low ohmic measurements
(comparison Euromet.EM-S22)

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NMi VSL and NPL

Outline

- Background
- VSL measurement set-up
  - Schematic
  - Uncertainty
- NPL set-up
  - Schematic
  - Uncertainty
- Comparison
  - Aim & Protocol
  - Results
  - Preliminary conclusion
- Outlook / discussion

Low ohmic measurements

Applications:

- Shunts – large currents / energy
- Reference for cable manufacturers

Traditional setup:

GL9920 with range extender

$\rightarrow$ time consuming (drifts, power effects)

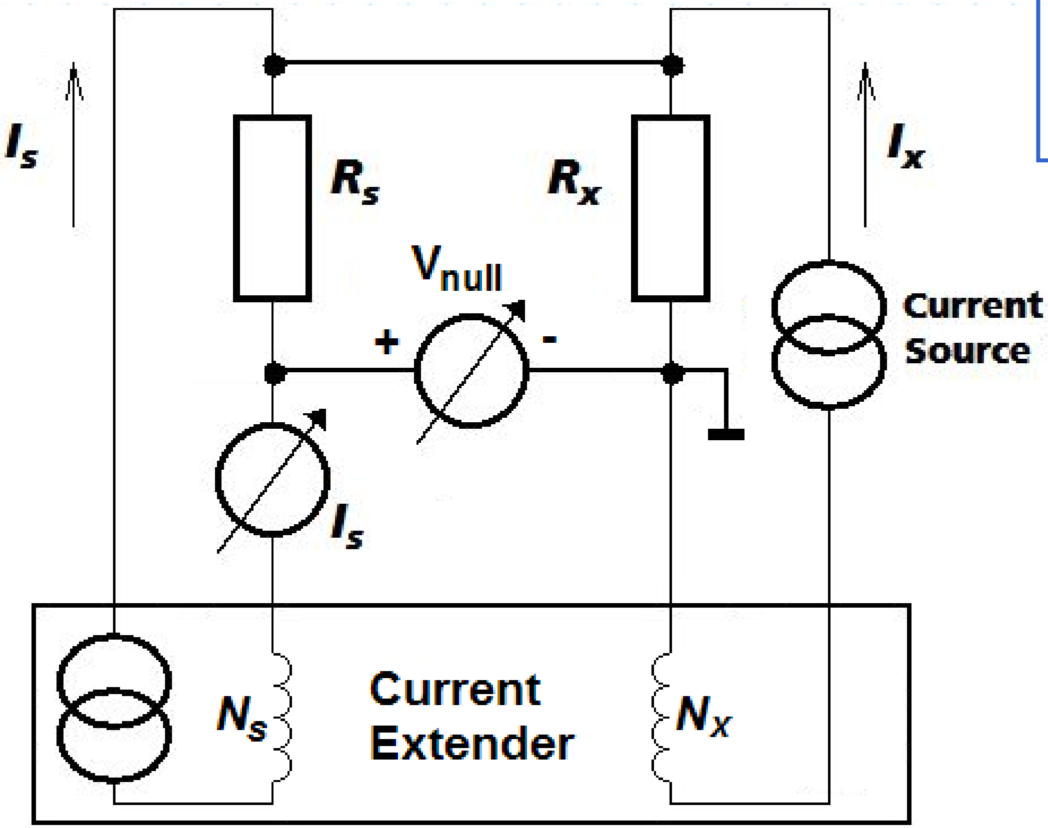
$\rightarrow$ ‘reliable’ accuracy?

$\rightarrow$ limited insight in the process

Comparisons of the past 20 years?

VSL set-up

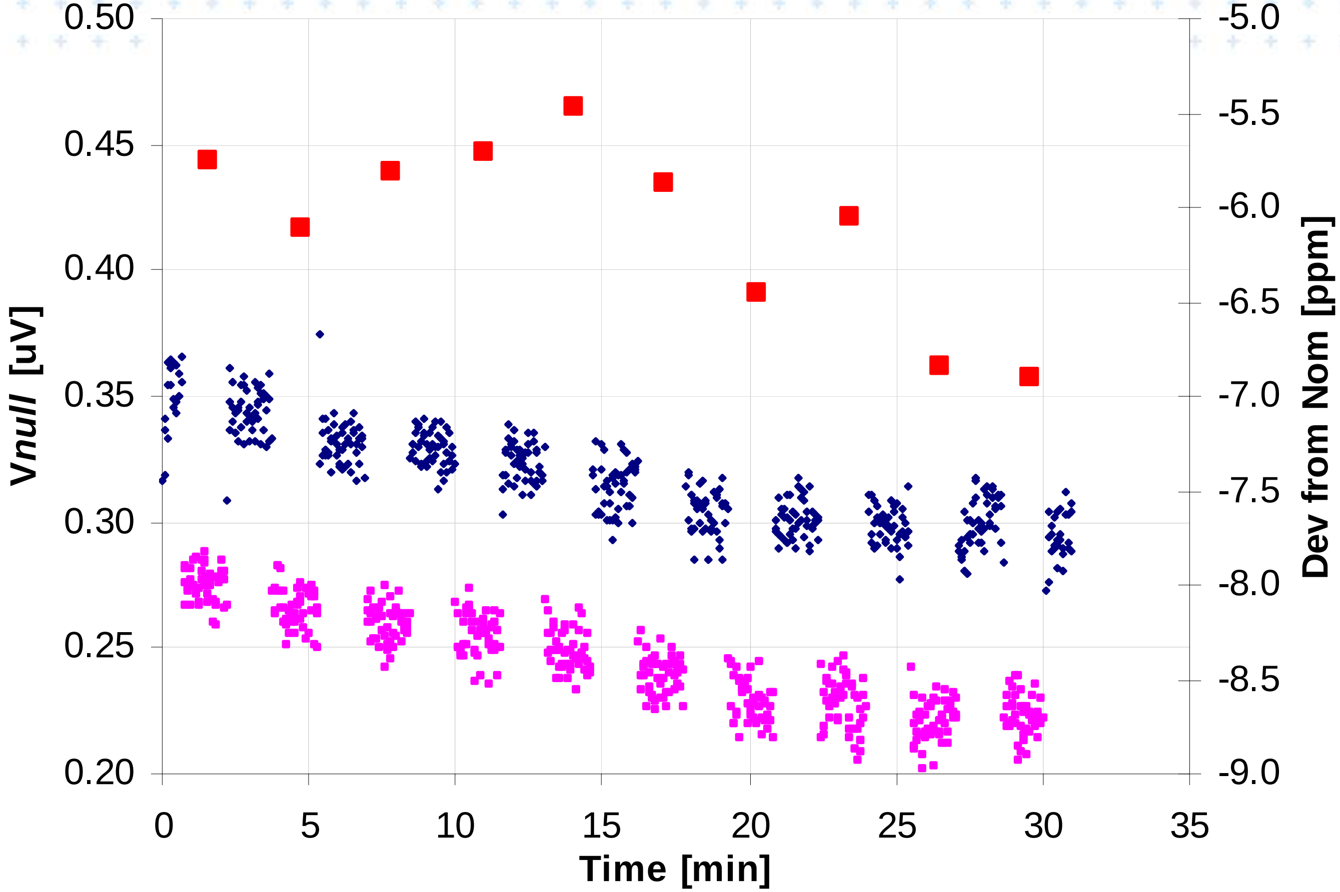
Based on MIL6000A extender + HP34420 nV-meter



$$R_x = \frac{R_s}{r} + \frac{V_{null}}{I_x}$$

VSL set-up

Advantages: Automated, Insight in process, Lower uncertainty



Uncertainty budget

$$R_x = \frac{R_s}{r} + \frac{V_{null}}{I_x}$$

$$R_x = \frac{R_s}{r} + \frac{V_{null} + \delta V_{cal} + \delta V_{th}}{(I_s + \delta I_{cal} + \delta I_0)\cdot r}$$

Quantity	Value	Standard Uncertainty	Distr.	Sens. Coef.	Uncertainty Contribution
R_s	0.1 Ω				
r	1000	$58\cdot10^{-6}$	rect	$-0.10\cdot10^{-6}$ Ω	$-5.8\cdot10^{-12}$ Ω
V_{null}	139 nV	1.00 nV	normal	0.033 A^{-1}	$33\cdot10^{-12}$ Ω
δV_{cal}	0.0 V	1.15 nV	rect	0.033 A^{-1}	$38\cdot10^{-12}$ Ω
δV_{th}	0.0 V	0.58 nV	normal	0.033 A^{-1}	$19\cdot10^{-12}$ Ω
I_s	-0.03 A	1.30 μA	normal	$150\cdot10^{-9}$ VA^{-2}	$0.2\cdot10^{-12}$ Ω
δI_{cal}	0.0 A	0.5 μA	normal	$150\cdot10^{-9}$ VA^{-2}	$0.08\cdot10^{-12}$ Ω
δI_o	0.0 A	38.1 μA	normal	$150\cdot10^{-9}$ VA^{-2}	$5.9\cdot10^{-12}$ Ω
R_x	100.00463 μΩ	Exp. Unc. $1.1\cdot10^{-6}$ (relative k=2)			

Uncertainty CMC: 0.2 μΩ/Ω – 1.5 μΩ/Ω for 0.1 Ω - 0.1 mΩ

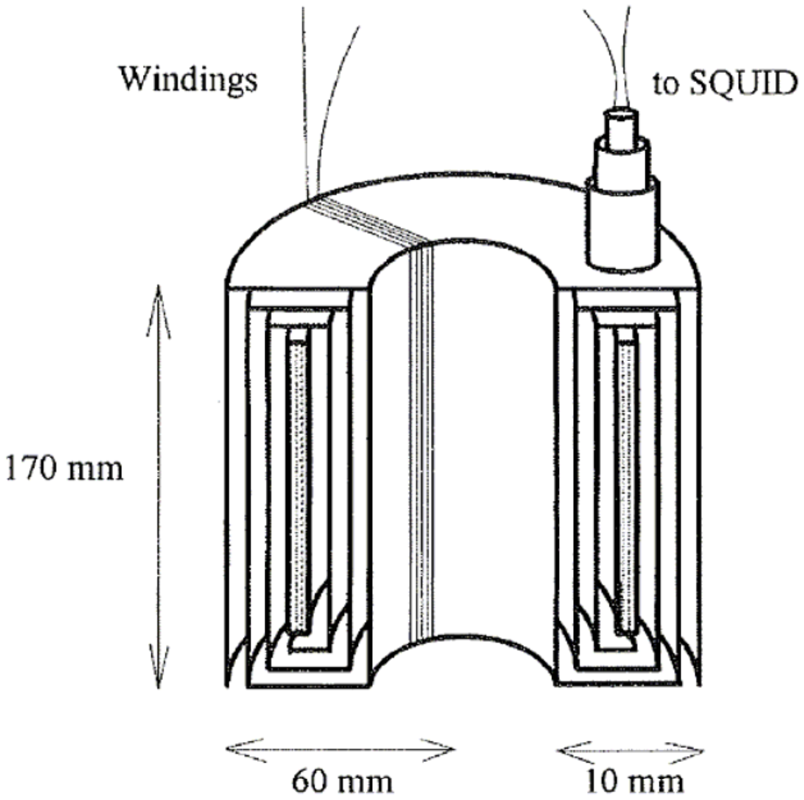
Cross-checks: closure 1–0.01–0.1–1: (0.03 ± 0.08) μΩ/Ω

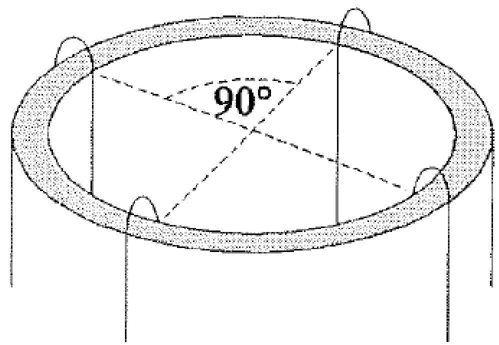
NPL set-up: CCC

CCC type II

- windings 1 – 1000, binary built-up
- 12 mA t / Φ_o – 2 μA/√Hz

Rope	Windings (no. turns)
100 A, 2 × 1T	1, 1
15 strands, 1T	1, 2, 4, 8
15 strands, 8T	8, 16, 32, 64
15 strands, 125T	125, 250, 500, 1000





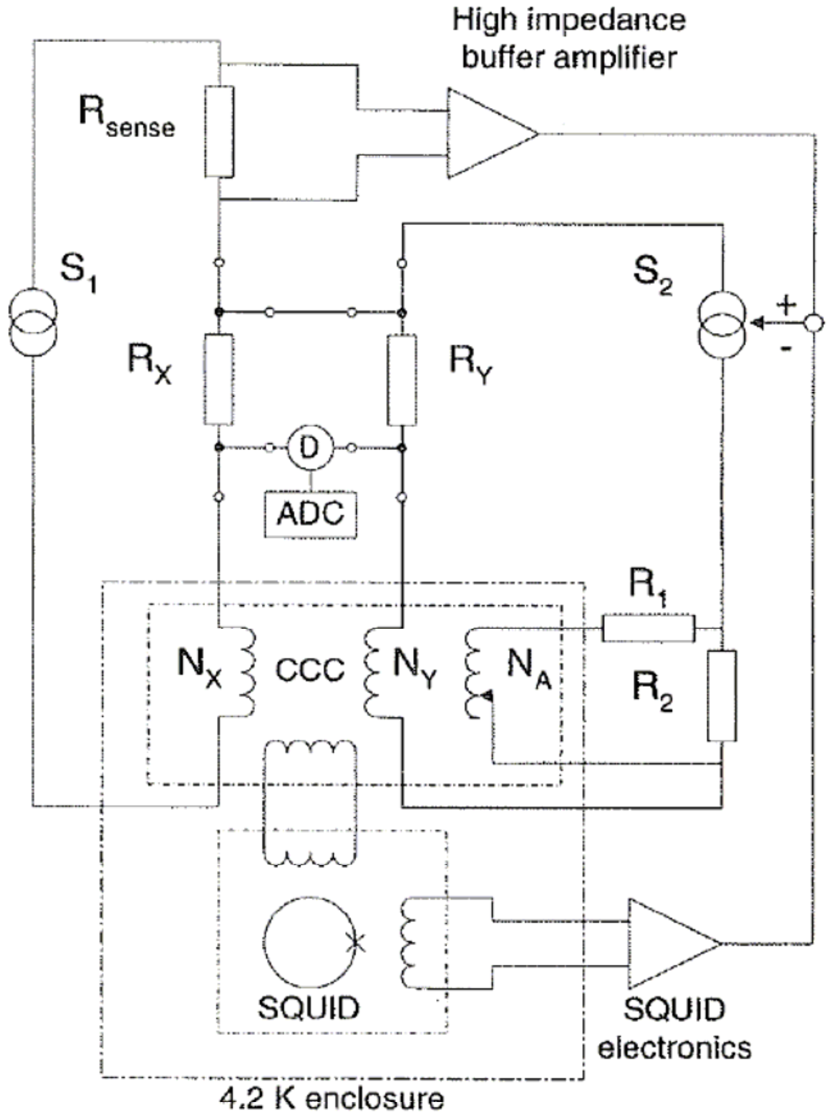
TEST OF CCC SHIELD ACCURACY

Error in 0° plane	E_1	6.3×10^{-9}
Error in 90° plane	E_2	2.2×10^{-9}
Total maximum error	$(E_1^2 + E_2^2)^{½}$.	6.7×10^{-9}

NPL set-up: bridge

'Standard' CCC bridge

- Null detector:
  EM model P13
  (130 pV/√Hz)
- Uncertainty:
  0.85 µΩ/Ω at 1 mΩ



NPL set-up: power test

LOW POWER RESISTANCE MEASUREMENTS

$R_Y : R_X$	$N_Y : N_X$	I_X (A)	P_X (mW)	σ (μΩ/Ω)
1 Ω : 100mΩ	1000 : 100	0.1	1	0.03
1 Ω : 1 mΩ	1000 : 1	3.0	9	0.10
100 mΩ : 100 μΩ	1000 : 1	10.0	10	0.21

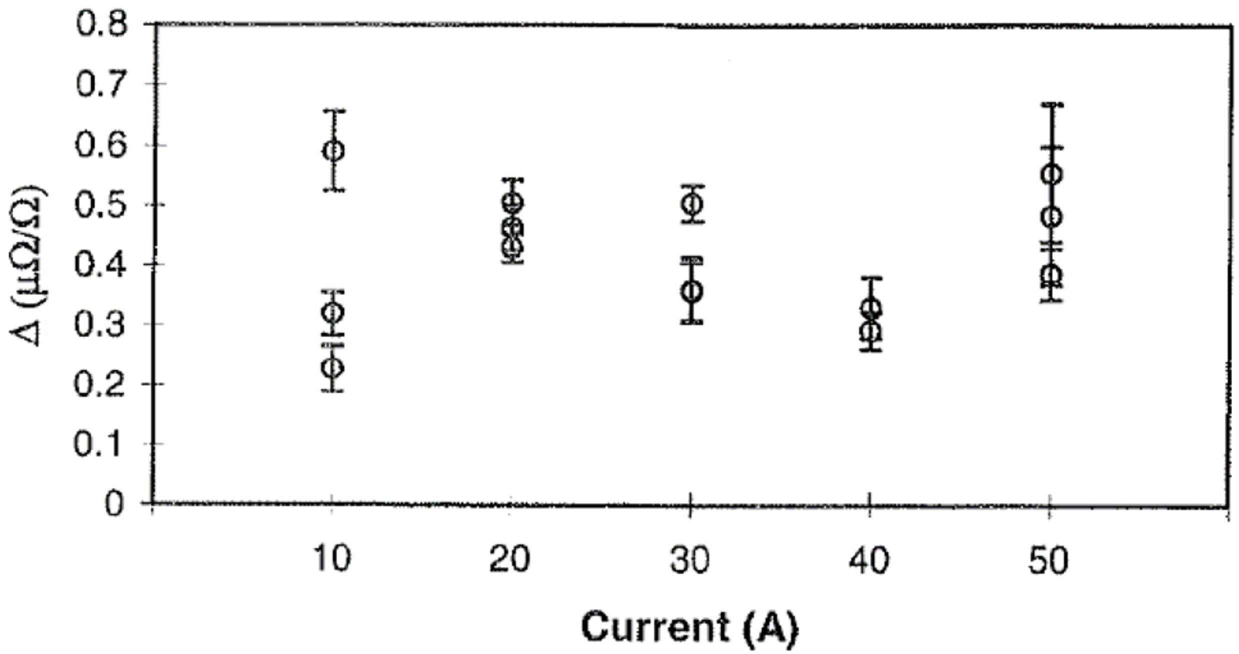


Fig. 6. 10 mΩ resistor as a function of current, $R = 10[1-(92\times10^{-6}+\Delta)]$ mΩ.

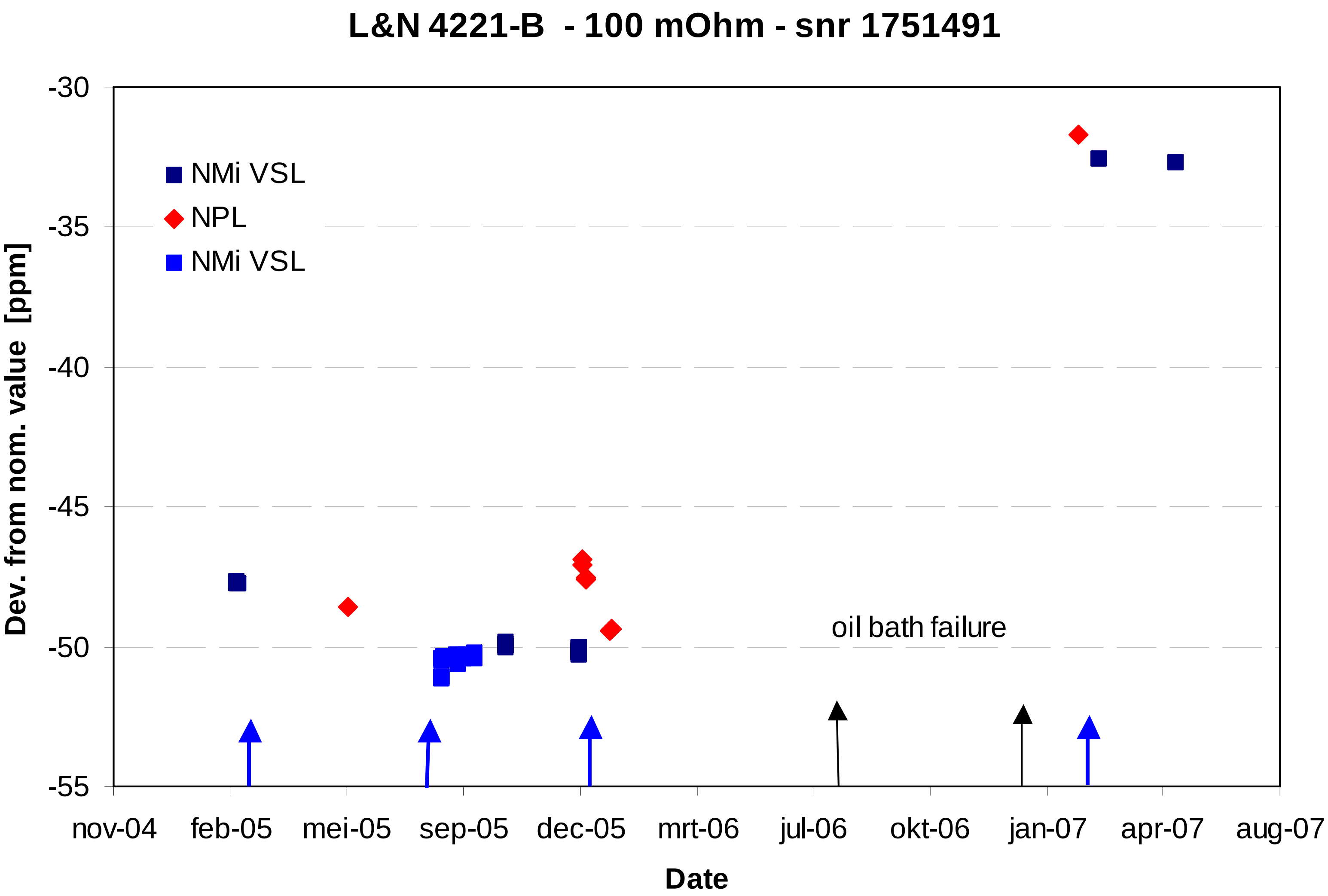
Low ohmic comparison

Aim: provide independent evidence for CMC entries in resistance < 1 Ω

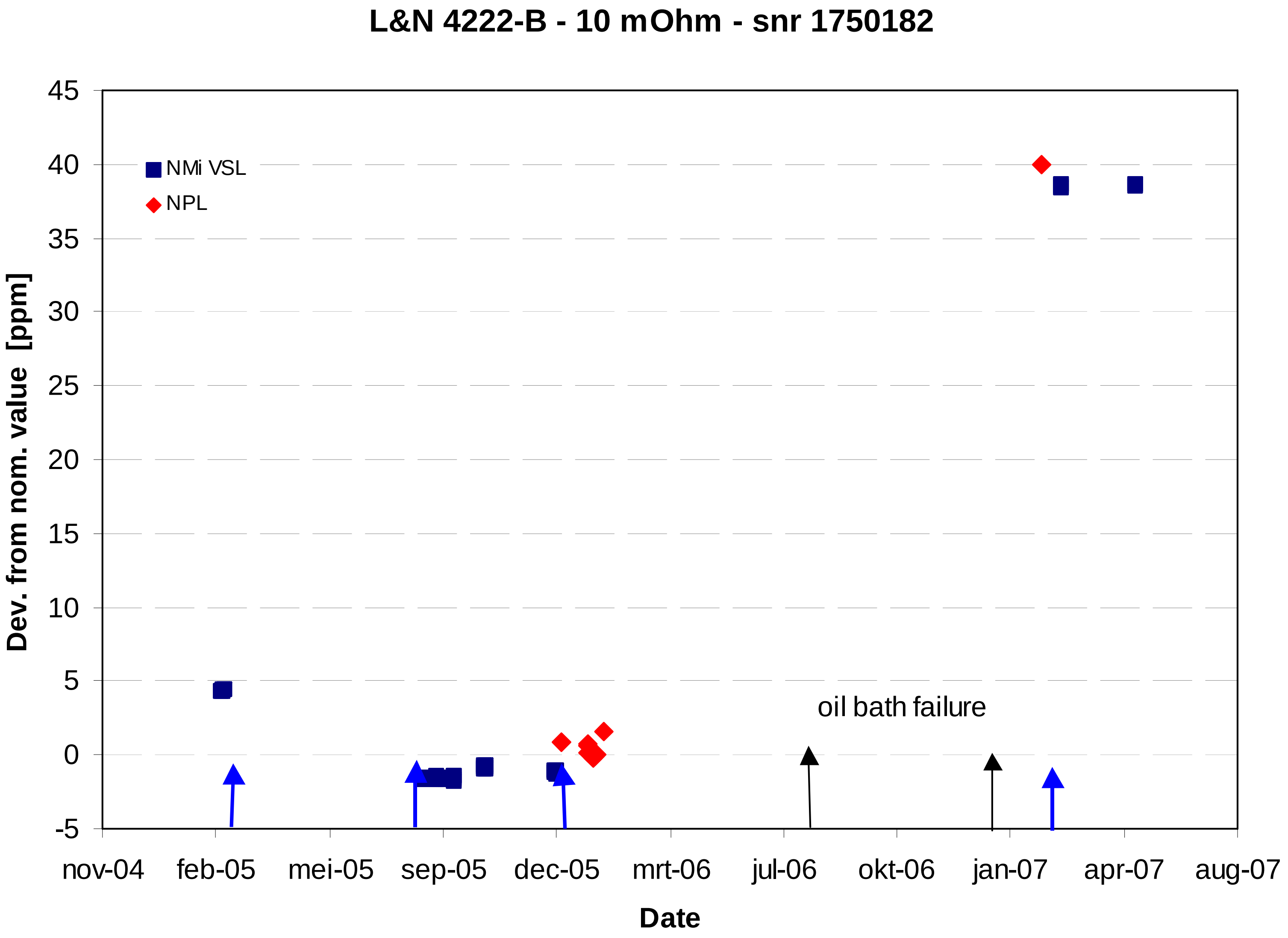
- Compare bridge based on RT comparator (NMi VSL) with 100 ampere CCC (NPL)
- Travelling behaviour of low-ohmic resistors

- Four L&N 422X-B resistors
  (100 mΩ, 10 mΩ, 1 mΩ, 100 μΩ)
- Measurement in oil, 23 °C
- Measurements at different power levels

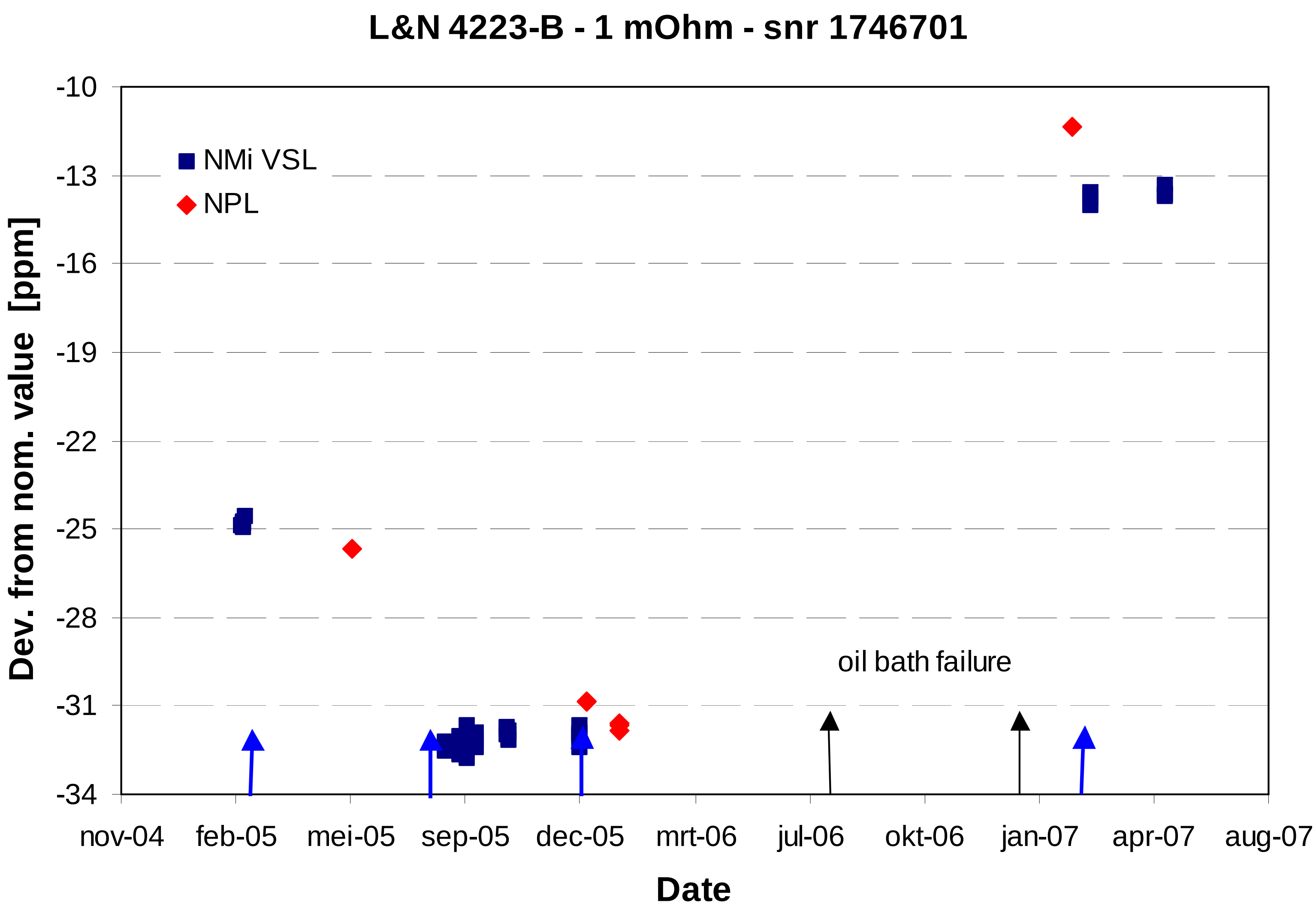
100 mΩ resistor



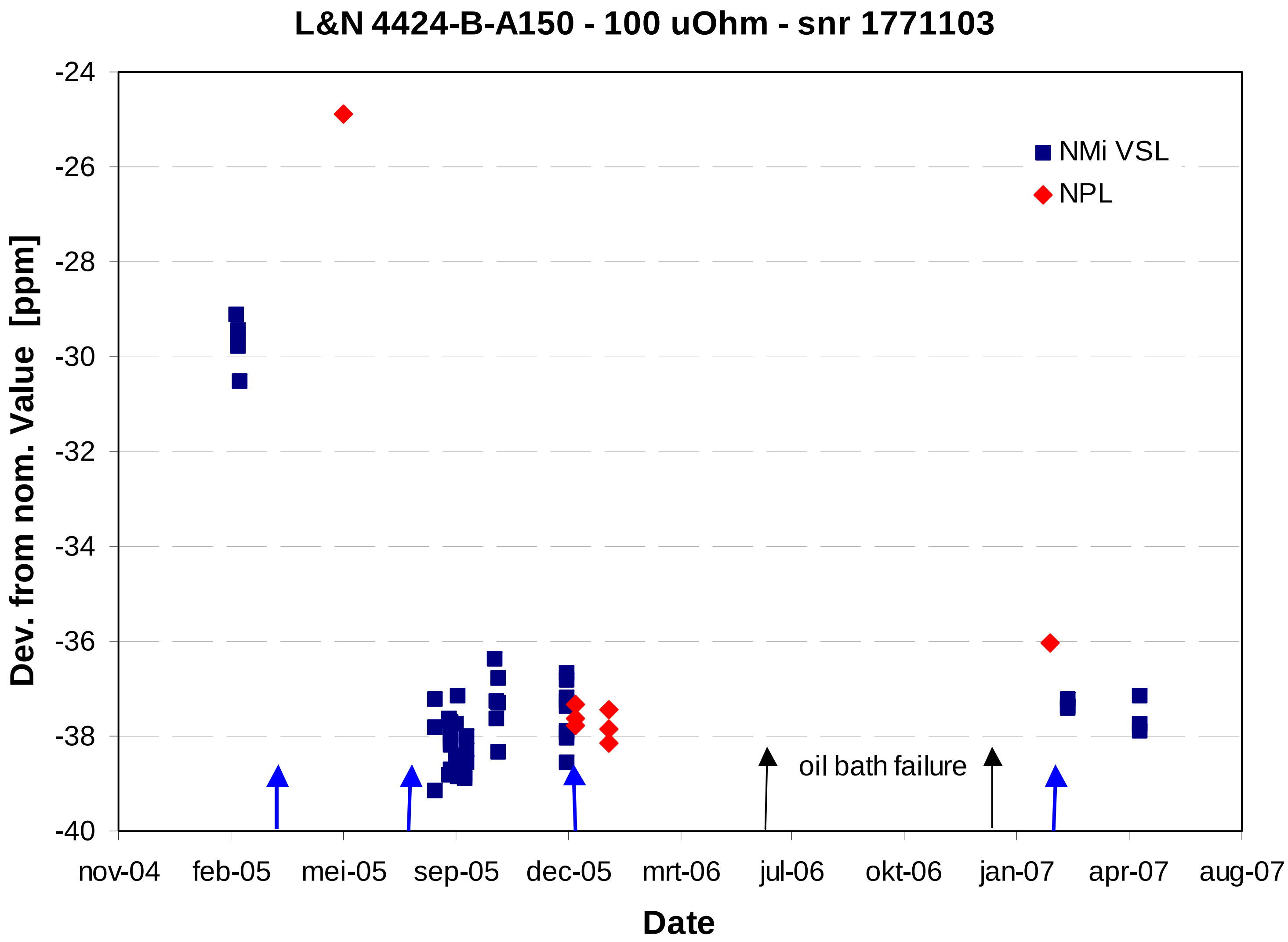
10 mΩ resistor



1 mΩ resistor



100 μΩ resistor



Preliminary conclusions

- NL – UK travelling behaviour is reasonable but not ideal (few ppm)
- Large temperature excursions have huge effects on the resistance value
  $\rightarrow$ shifts up to 40 ppm

The travelling resistors seem to be the limiting factor in the comparison

Compare 1 – 3 ppm $\leftrightarrow$ 0.1 – 1.5 ppm CMCs

Outlook & discussion

- How independent are measurement methods? (RTCCs + range extenders)
- Uncertainty sources?
- Required cross-checks?

- How should comparison proceed?
  $\rightarrow$ better resistors needed!

NMi VSL setup: IEEE I&M 2007, **56**, pp. 406 - 409

NPL setup: IEEE I&M 1999, **48**, pp. 375 - 378