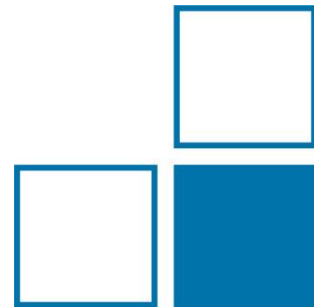


Recent developments in ultra-low current measurement technology

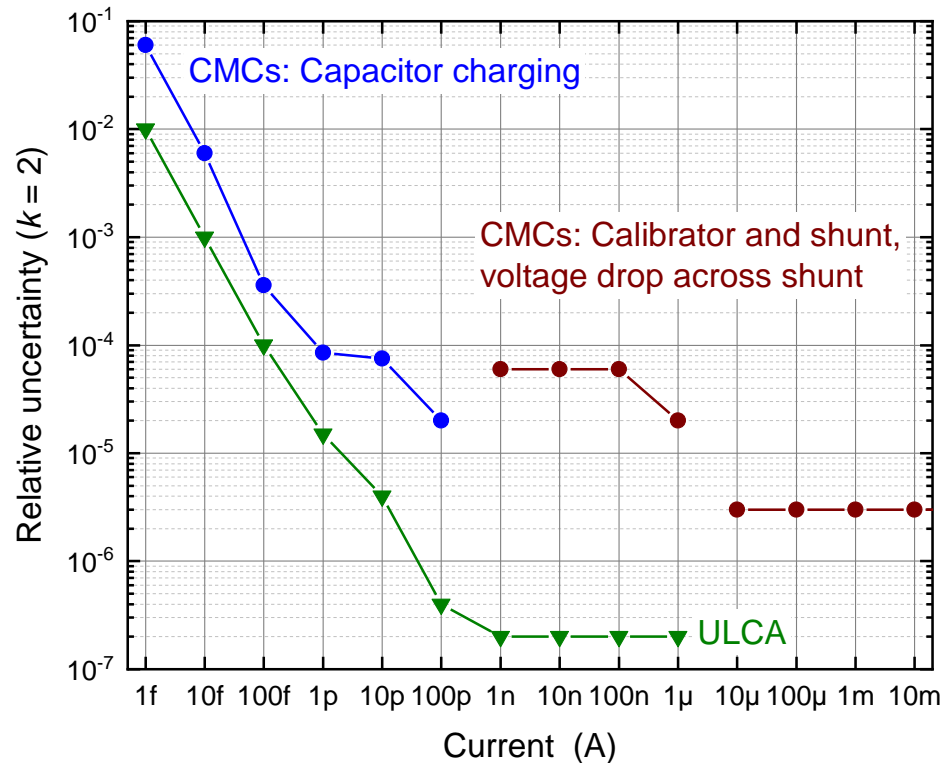
Aktuelle Entwicklungen in der Kleinststromstärkemesstechnik

Christian Krause, 7.6



Small current:

- Range from μA down to fA
- Significant improvement in CMCs achieved thanks to ULCA

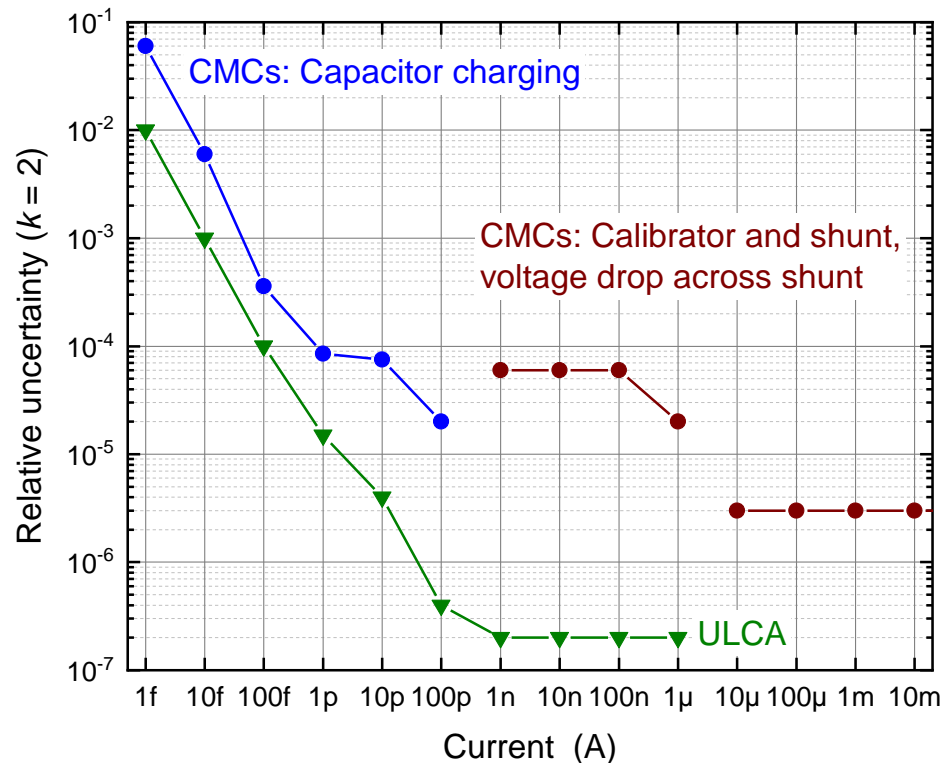


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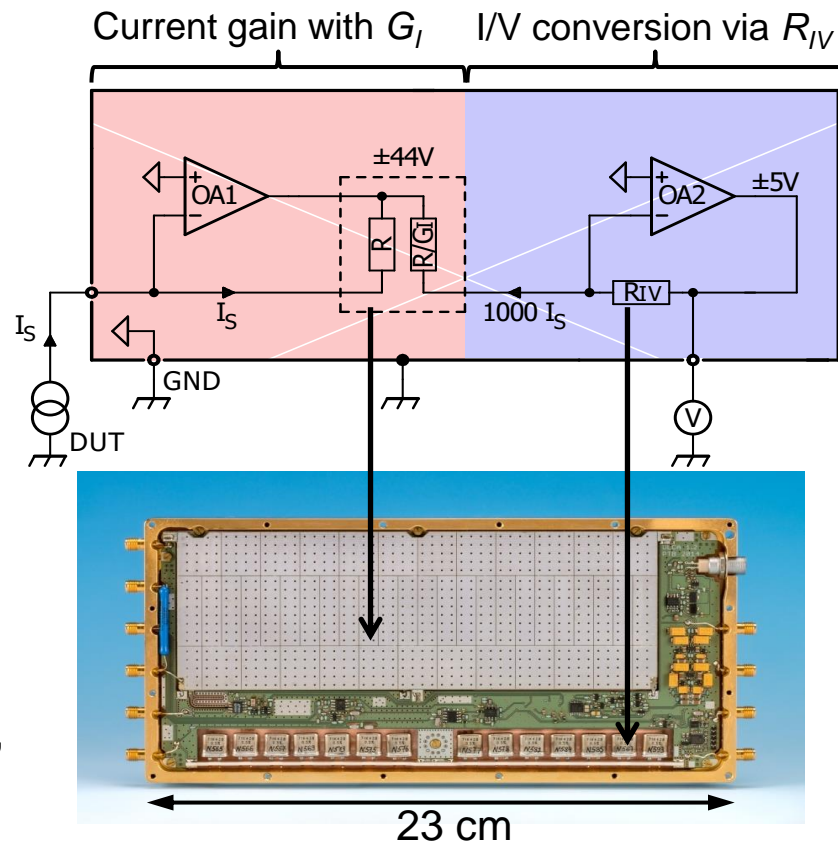


ULCA?

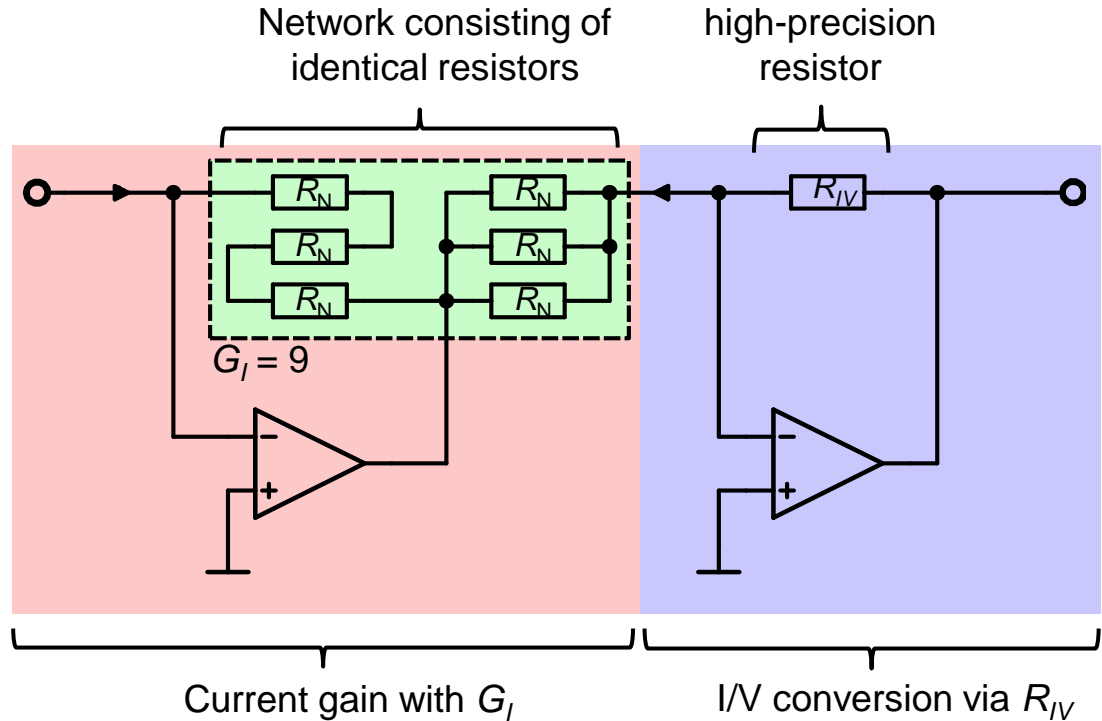


PTB What is the ULCA?

- **U**ltrastable **L**ow-noise **C**urrent **A**mplifier
- Two-stage current/voltage converter
- 1st stage: 1000-fold current amplification via resistor network
- 2nd stage: Current-voltage conversion with high-precision resistor
- Different operating modes
→ Both **measurement and generation** of small currents possible
- Field of application: Measurement/generation of small direct currents with ultimate accuracy (e.g., ionizing radiation, photometry, radiometry)



- Realization of current amplification
 - using resistor network with thousands of identical surface mounted R_N
 - parallel and series connection of R_N creates ratio and current gain, e.g., here $G_I = 9$
- Realization of I/V conversion
 - due to current amplification lower-ohmic R_{IV} is possible
 - high-precision resistor, e.g., metal foil, for conversion



- ULCA improved state-of-the-art in small current measurement/generation by **two orders of magnitude**
- Instrument is commercially available
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- Setup is not always straight forward

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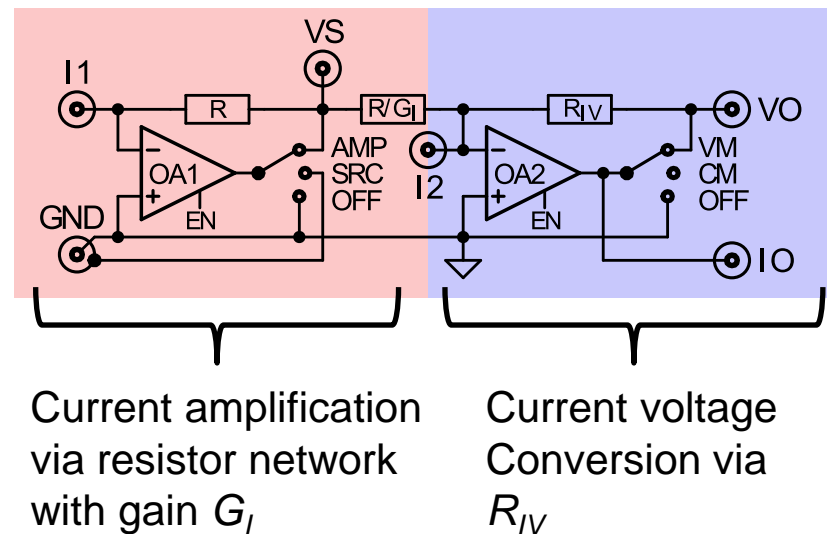
New development

New development:

- Advanced Laboratory Current Amplifier
- “Little brother of ULCA”

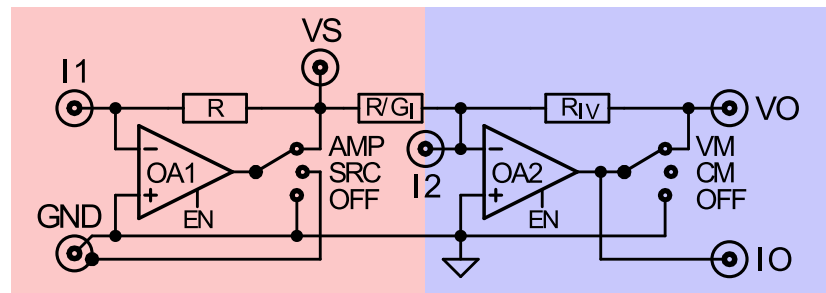
Features:

- Table-top device
- Easy to use
- Uninterruptable operation via two NiMH batteries (easily replaceable)
- Operates as amplifier or source
- Different operating modes selectable via mechanical switches
- ± 10 V output voltage adapted to 3458A
→ best overall performance
- Several variants planned
→ easily adapted to application

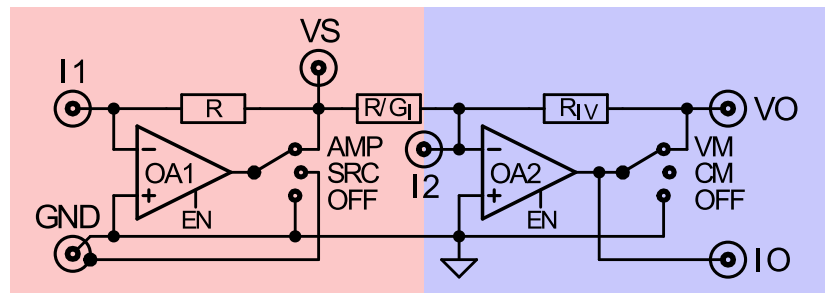


PTB ALCA: variants

- Various variants are currently under development
- Two main variants are currently being prepared for commercialization



Variant	10 M Ω ALCA	100 M Ω ALCA	1 G Ω ALCA	5 G Ω ALCA	66 G Ω ALCA
Current range	$\pm 1 \mu\text{A}$	$\pm 100 \text{ nA}$	$\pm 10 \text{ nA}$	$\pm 2 \text{ nA}$	$\pm 125 \text{ pA}$
Input gain G_I	100	100	1000	1000	16000
Output R_{IV}	100 k Ω	1 M Ω	1 M Ω	5 M Ω	5 M Ω
Total $A_{TR} = G_I R_{IV}$	10 M Ω	100 M Ω	1 G Ω	5 G Ω	80 G Ω
Noise @ 0.1 Hz	41 fA/ $\sqrt{\text{Hz}}$	13 fA/ $\sqrt{\text{Hz}}$	4.1 fA/ $\sqrt{\text{Hz}}$	1.9 fA/ $\sqrt{\text{Hz}}$	0.6 fA/ $\sqrt{\text{Hz}}$
1-year stability of A_{TR}	$< 10 \mu\Omega/\Omega$	$< 10 \mu\Omega/\Omega$	$< 10 \mu\Omega/\Omega$	$< 300 \mu\Omega/\Omega$	$< 300 \mu\Omega/\Omega$



Amplifier mode	Source mode	Normal mode	Extended mode
Current measurement	Current generation*	Both stages used: current amplification and //V conversion	Only output stage used for //V conversion → range extension

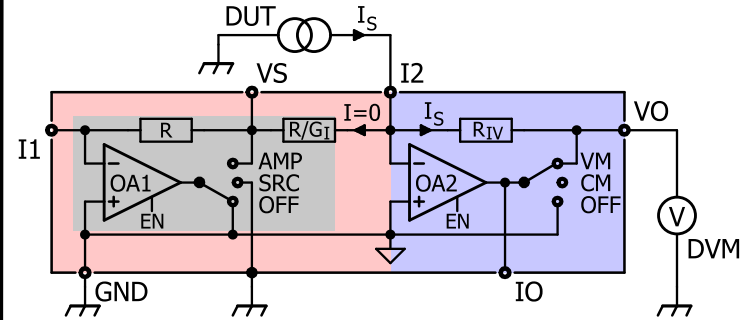
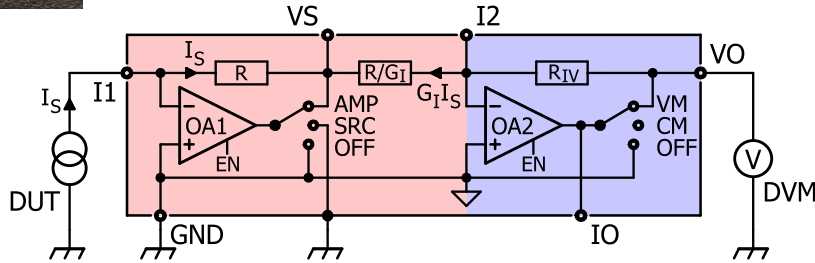
*Current is generated with moderate accuracy but known with ultimate accuracy



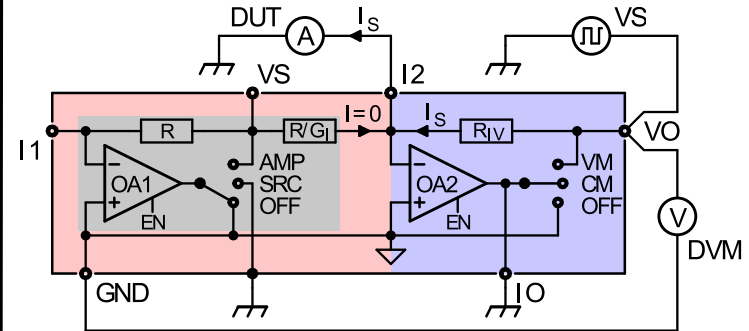
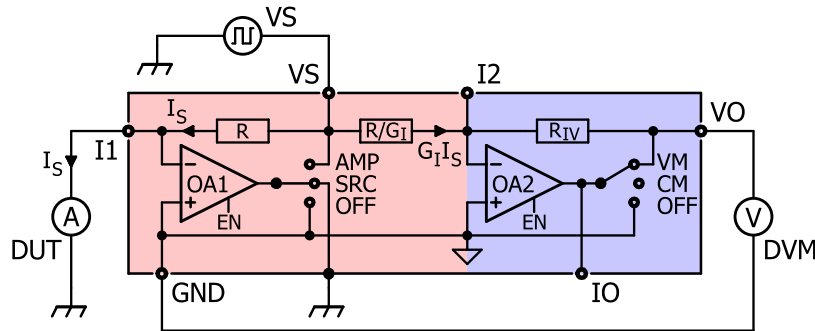
Normal mode

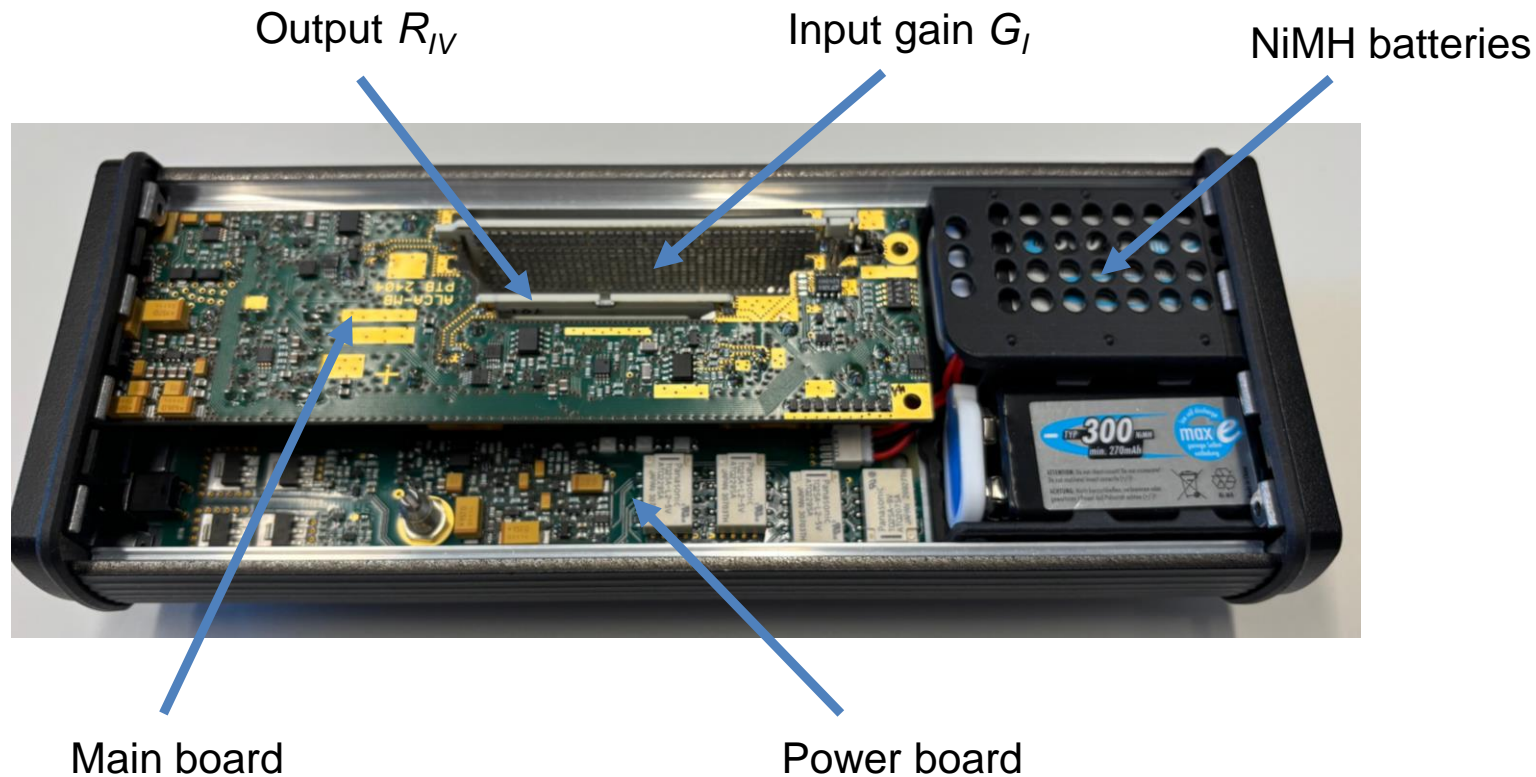
Extended mode

Amplifier
mode

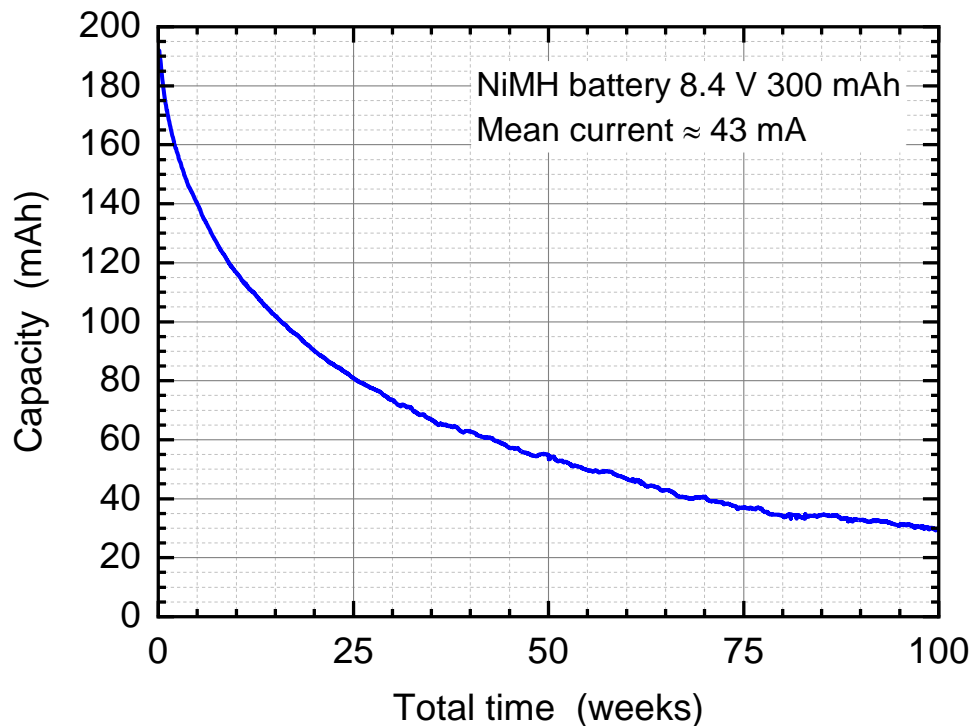


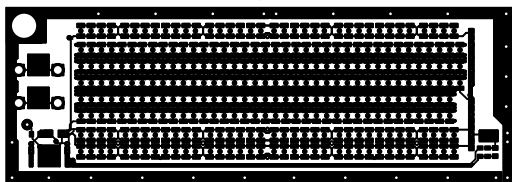
Source
mode



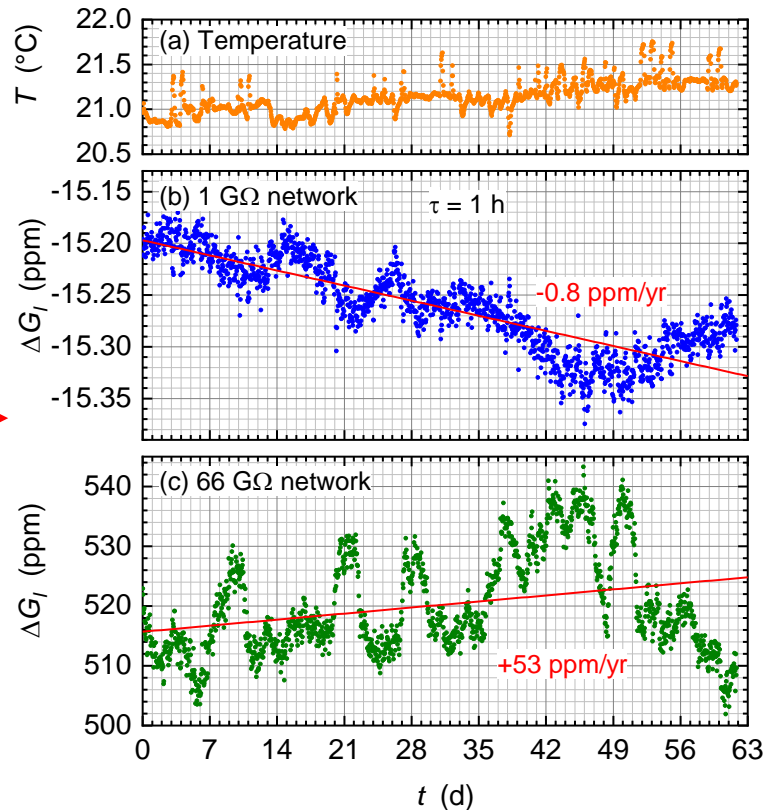


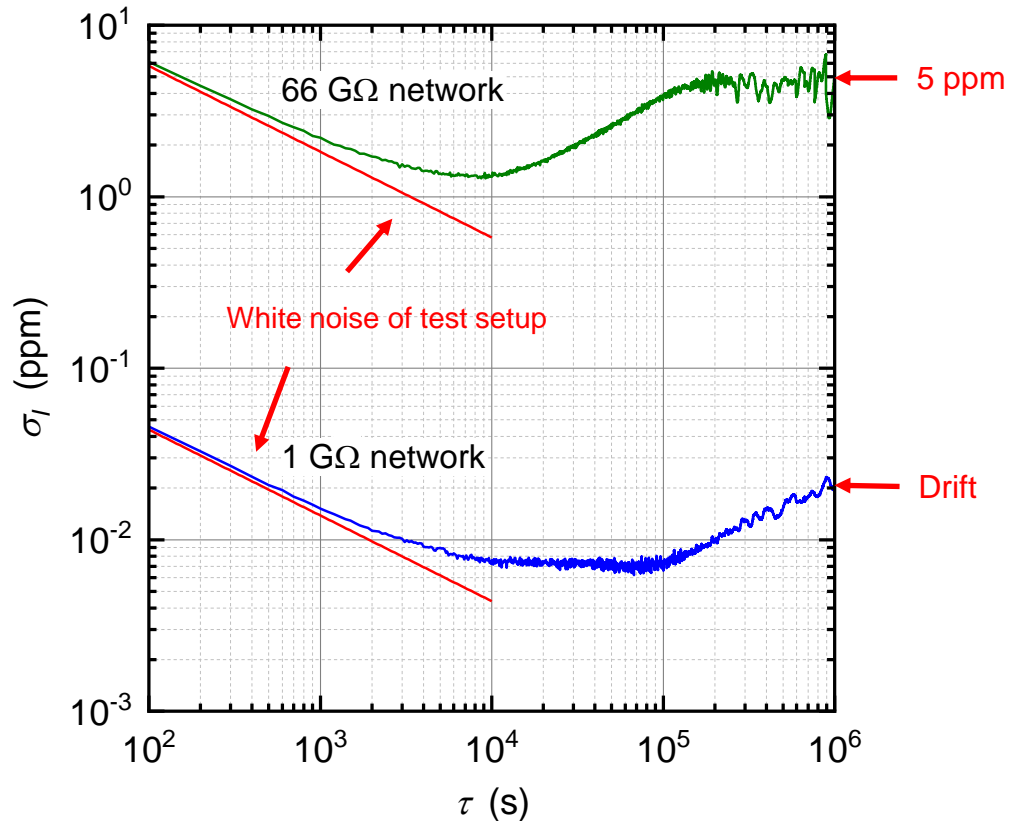
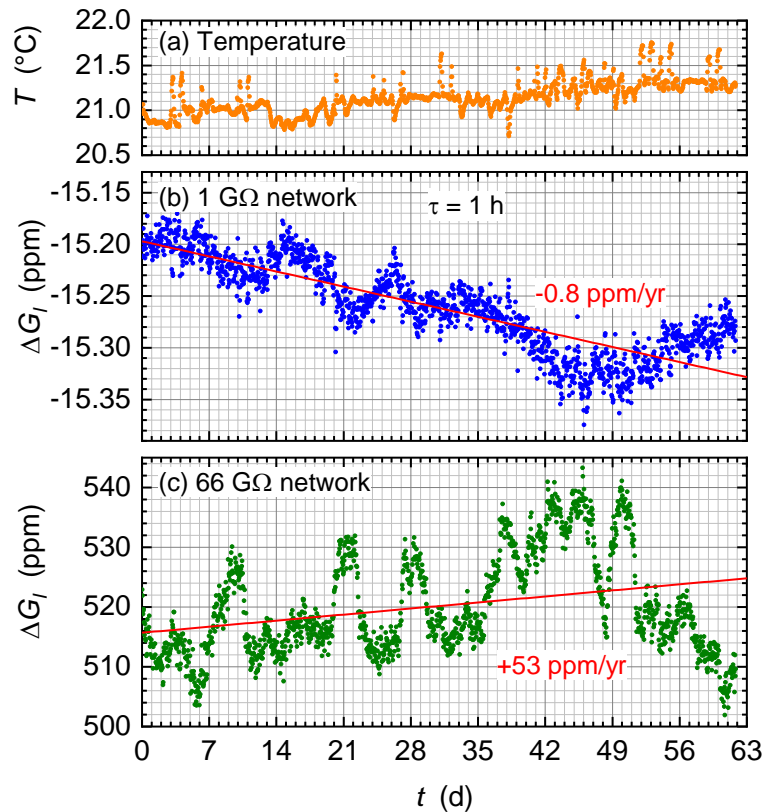
- Long-term measurement of battery packs in use
- ALCA current consumption approx. 10 mA
→ 10 years continuous operation
- Easily replaceable batteries





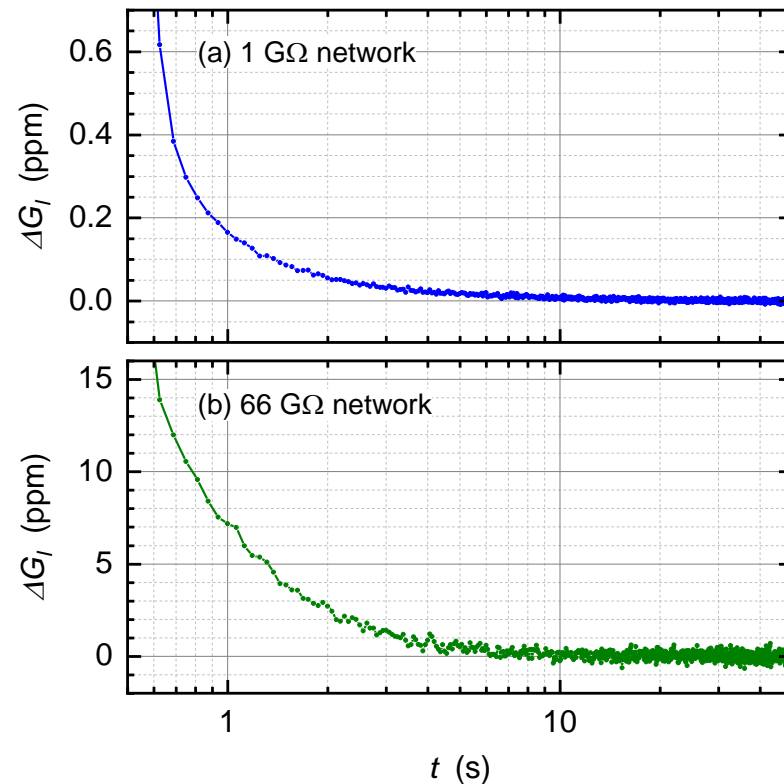
- 1 GΩ network about 1 ppm per year
- 66 GΩ network probably in the range of 100 ppm per year





After current reversal:

- 1 G Ω network reaches < 0.1 ppm after ~2 seconds
- 66 G Ω network reaches < 3 ppm after ~2 seconds

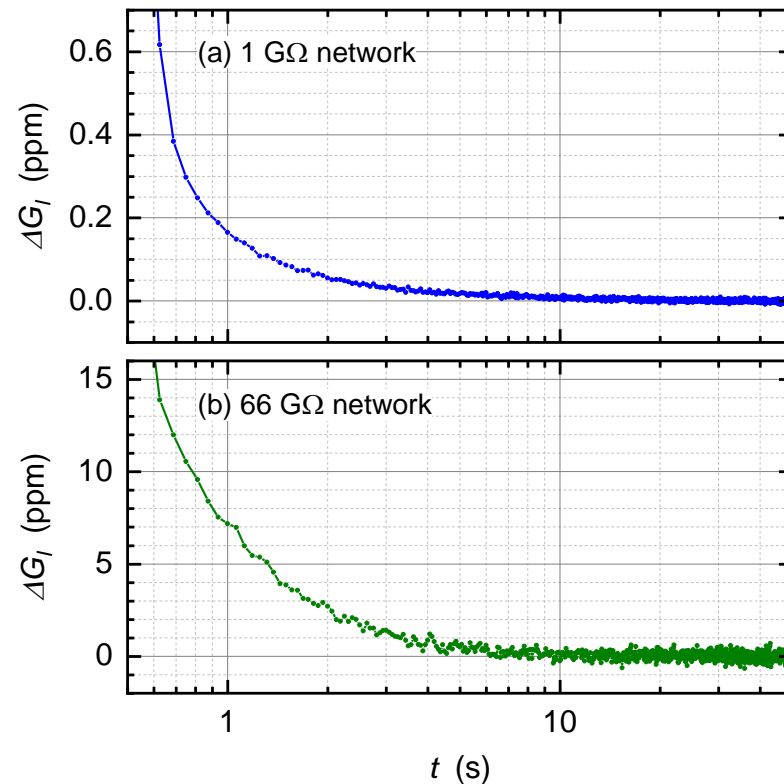


After current reversal:

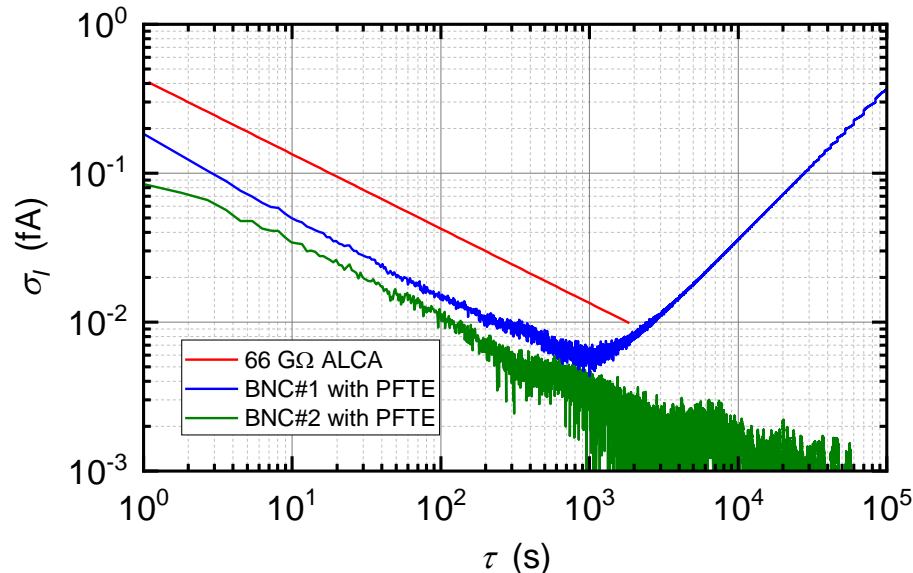
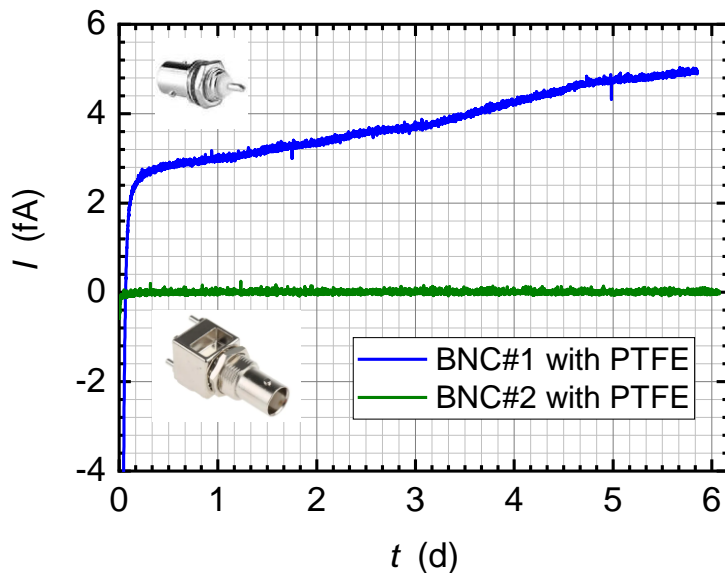
- 1 G Ω network reaches < 0.1 ppm after ~2 seconds
- 66 G Ω network reaches < 3 ppm after ~2 seconds



Settling is sufficiently fast



- fA range: input connection is crucial
- Investigation of different connectors is running
- Connector may substantially degrade performance
- Effects depends on material and construction



Different possibilities for calibration

- Calibration with ULCA and voltmeter
- Ultimate accuracy: directly with cryogenic current comparator (CCC)
- Optionally: calibration with standard resistor and voltmeter



- New direct current amplifier ALCA
 - Can measure and generate current
- Simplified realization of the ULCA concept
 - More affordable
- Different variants to cover a wide current range from fA up to μA
- Two main variants are currently being prepared for commercialization
 - 1 G Ω ALCA, ± 10 nA input current range, 4.1 fA/ $\sqrt{\text{Hz}}$ noise
 - 66 G Ω ALCA, ± 125 pA input current range, 0.6 fA/ $\sqrt{\text{Hz}}$ noise
- Networks successfully checked for stability, settling and achievable uncertainty
- Uninterruptable operation for **~ 10 years** with one battery pack
- Next step: Calibration and traceability
 - Calibration with ULCA as intended standard method
 - Calibration using CCC for highest accuracy
- Commercialization via Magnicon GmbH is planned

Thanks for your attention



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