

New perspectives on the measurement and generation of very small electric currents

Abstract

- Accurate measurement or generation of small electrical currents is essential, e.g., in the fields of ionizing radiation, aerosol & photometry
- The **Ultrastable Low-noise Current Amplifier (ULCA)**, developed by PTB, enables highly accurate measurements in the pA to nA range
→ ULCA is widely used by NMIs and calibration labs
- Recently a simplified variant has been developed, the **Advanced Low-Current Amplifier (ALCA)**
→ improved performance for ultra-low currents below about 1 pA
→ increased output voltage range ± 10 V
- ULCA and ALCA together cover a range from 1 fA to 10 μ A with unprecedented accuracy
→ 0.1 μ A/A at 100 pA for ULCA
→ 100 μ A/A at 100 fA for ALCA
- ULCA is commercially available, ALCA will be available soon

Two-stage ULCA/ALCA concept

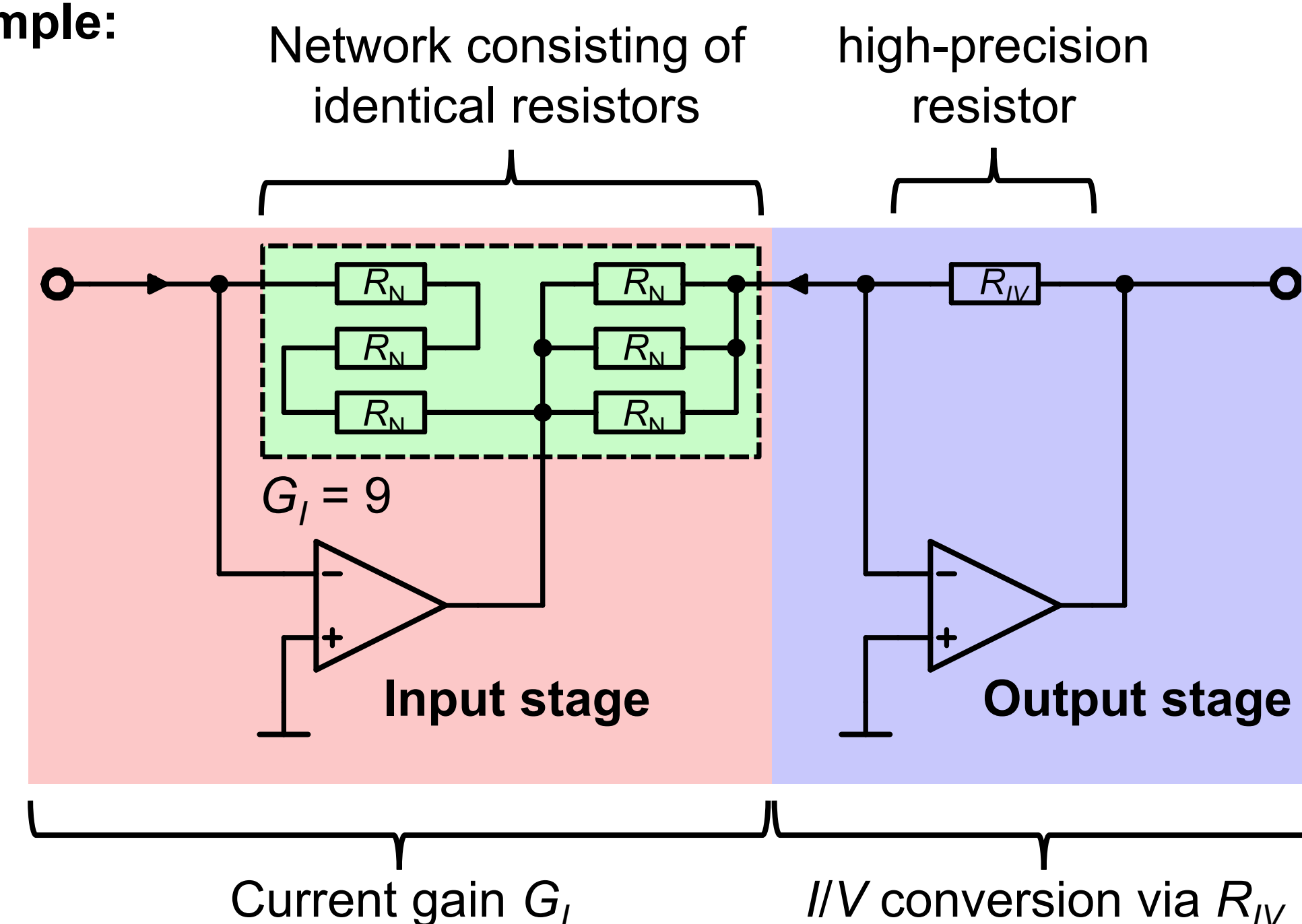
Input stage: current gain G_I

- resistor network with many identical resistors R_N
- parallel & series connection of R_N creates accurate current gain G_I

Output stage: current/voltage conversion via R_{IV}

- high-precision R_{IV} possible due to high current gain G_I
- high overall transresistance $A_{TR} = G_I R_{IV}$

Example:

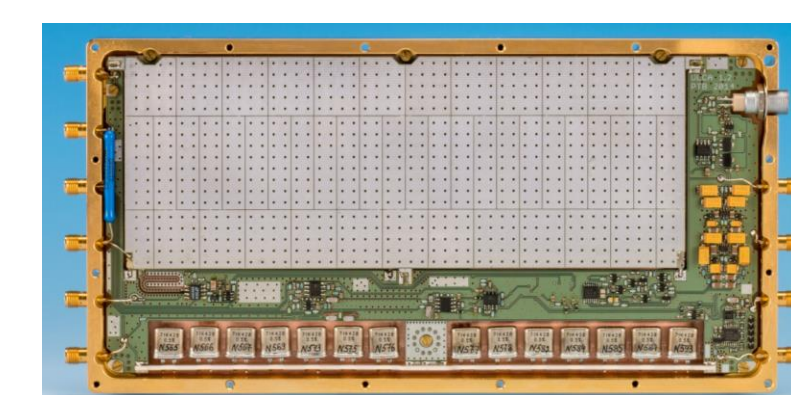


Traceability of G_I , R_{IV} and A_{TR}

Cryogenic current comparator (CCC)

Calibration of G_I and R_{IV}

ULCA



Calibration of A_{TR} and R_{IV}

Calibration via CCC or ULCA dependent on required accuracy

Calibration of G_I and R_{IV}



ALCA

ULCA/ALCA variants

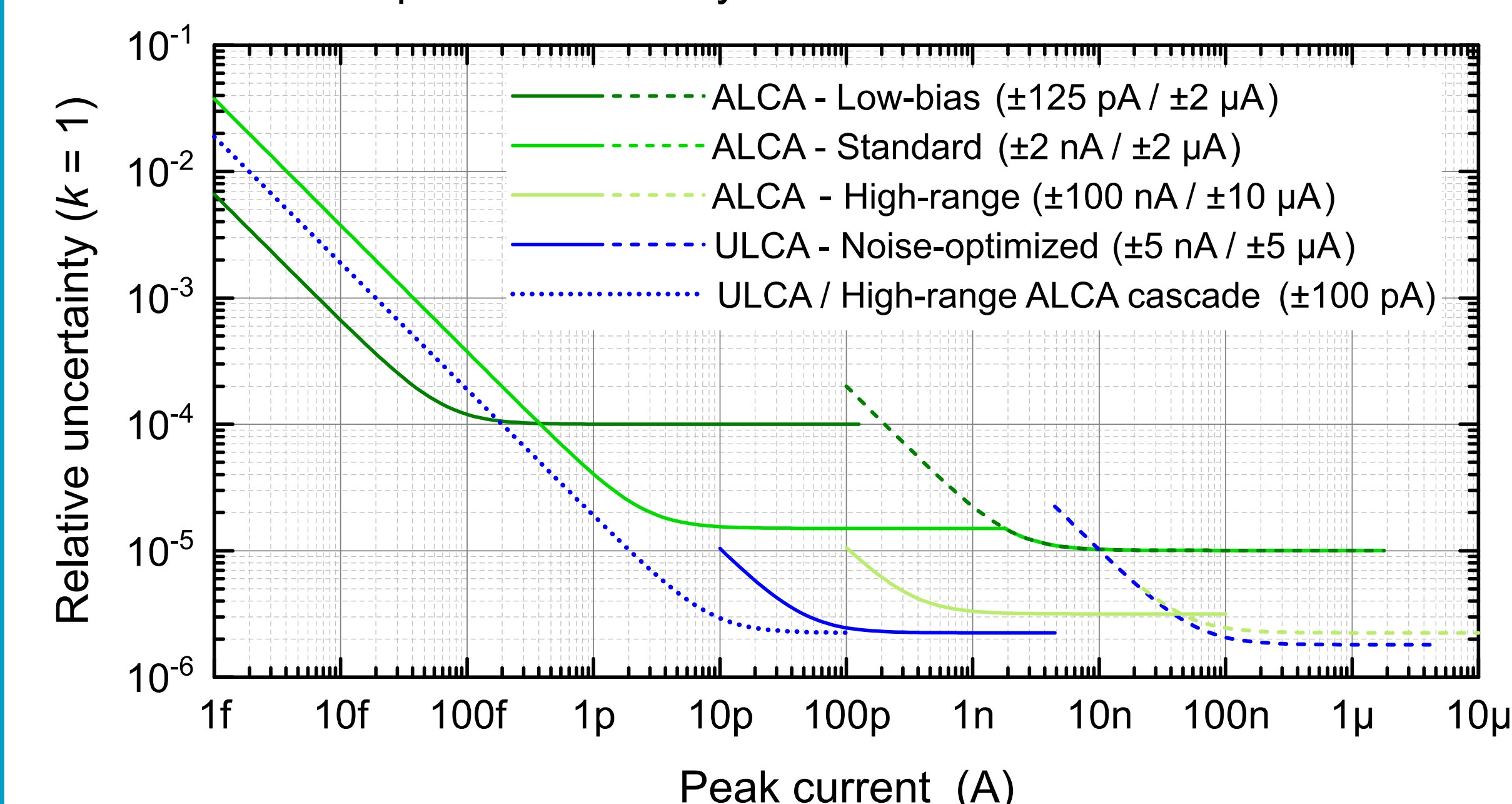
Variant	Noise-optimized ULCA	Low-bias ALCA	Standard ALCA	High-accuracy ALCA	High-range ALCA
Range (nA) ^a	± 5	± 0.125	± 2	± 10	± 100
Gain G_I	1000	16000	1000	1000	100
R_{IV} (M Ω)	1	5	5	1	1
$A_{TR} = G_I R_{IV}$ (G Ω)	1	80	5	1	0.1
Noise (fA/ $\sqrt{\text{Hz}}$)	1.6	0.55	2.7	4.5	13.3
Input bias (fA)	± 15	± 0.2	± 5	± 10	± 100
1-year stability of A_{TR} ($\mu\Omega/\Omega$) ^b	4	200	30	6	6

^a Extended mode (output stage only) increases range by factor of G_I .

^b Temperature within ± 5 K of calibration.

Application example

- Ammeter or current source calibration with ULCA/ALCA
- Expected uncertainty for the following assumptions:
→ 1 hour measurement time
→ Current reversal with $\pm$ peak current
→ 1 μ V/V relative and 0.1 μ V absolute voltmeter uncertainty
→ Quarterly calibration of ULCA/ALCA
→ ± 1 K temperature stability



Conclusion

- The ULCA is a well-established instrument for accurate small current measurement and generation
- The recently developed ALCA expands its application range
- Together, they cover currents from 1 fA to 10 μ A, spanning 10 orders of magnitude
- Calibration of ultra-high value resistors also possible
- Commercialization makes this technology widely accessible

References

ULCA: <https://doi.org/10.1063/1.4907358>
<https://doi.org/10.1063/1.5078572>
<https://doi.org/10.1109/TIM.2016.2611298>

ALCA: Advanced low-current amplifier: A versatile instrument for small dc applications (in preparation)