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Advances in electrical current metrology for ionisation chamber readout

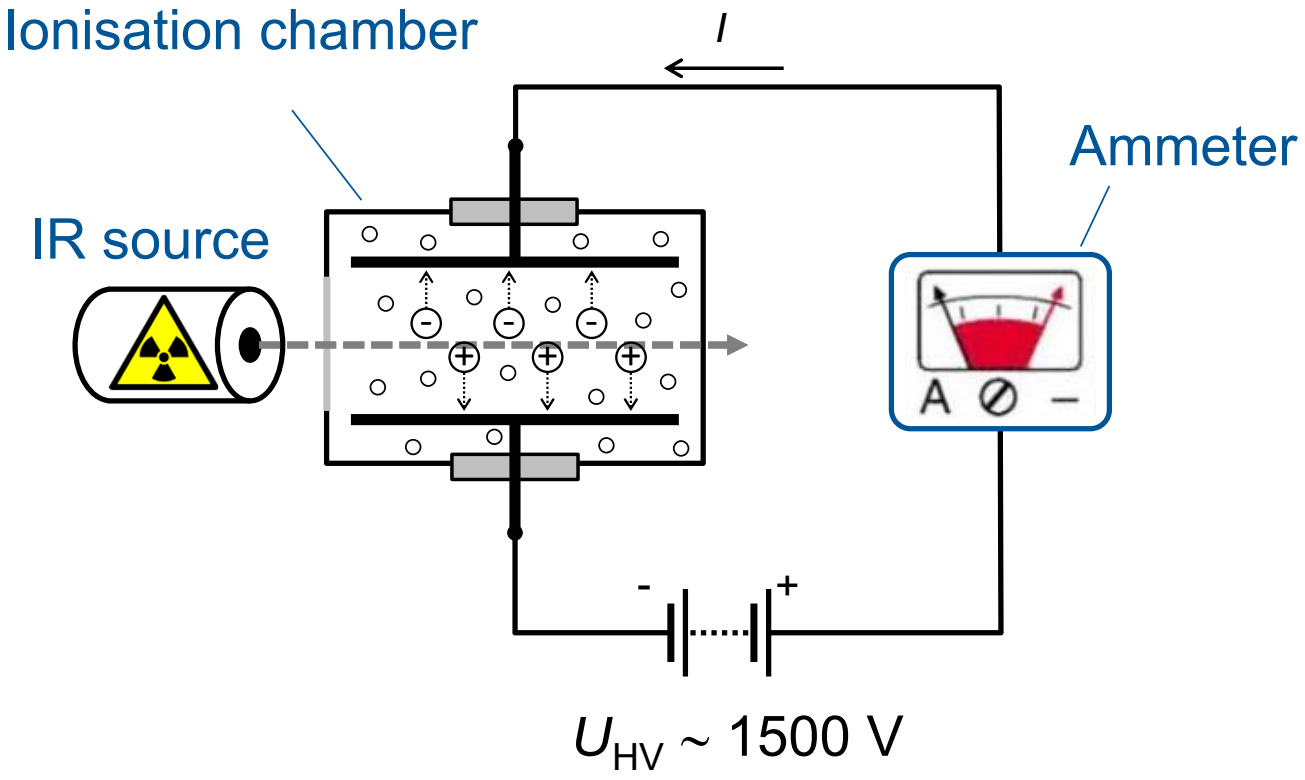
Stephen Giblin – chairperson, joint CCEM-CCRI task group on small current measurement for radionuclide metrology

V-CARM conference, 25th November 2020

Slides 3-5 also shown at CCEM meeting, 15th April 2021

- The intersection between electrical and ionising radiation metrology
- Recent advances in electrical metrology
- The CCEM-CCRI working group and what it is doing

Ionisation chambers



Thanks to Hansjörg Scherer of PTB for providing this graphic

Activity is calculated from the current using primary radionuclide methods and referring to long-half-life “check sources”.

Linearity and stability of ammeter can be verified by calibrating with reference current sources.

There have been important developments in small current metrology in the last 20 years, which could be useful to the radionuclide community. **This talk is about these developments.**

Small current metrology, research and applications

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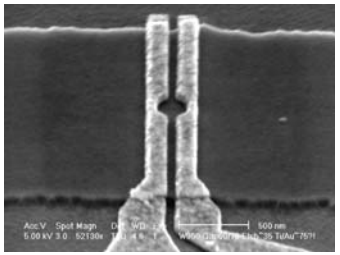
Electron pumps generate a current by moving electrons one at a time. They are research devices generating approx. **100 pA** with **0.1 ppm accuracy.**
An important driver for improving small current capability in NMIs!



Scanning electron microscope image of an electron pump

S. P. Giblin et al, Metrologia 56, 044004 (2019)

The Ultrastable low-noise current amplifier (ULCA) was developed as a research project at PTB, and is now commercially available. It can source or measure currents up to 5 nA with 1-2 ppm accuracy up to a year after calibration.

For more information on the ULCA:
www.magnicon.de

Several metrology areas require sub-nA current calibration at 1% - 0.001% levels:

- Environmental monitoring: calibration of particle-counting electrometers
- Measurement of high leakage resistances for semiconductor fabrication
- Calibration of focussed ion beam currents for nano-fabrication
- Optics metrology – current amplifier calibration
- Ionisation chamber readout for radionuclide metrology

Joint CCEM-CCRI task group on current measurement for radionuclide metrology

- Set up in late 2019

  "…to guide the introduction of new technologies for the measurement of low electrical current for ionization chambers used in the measurement of radionuclide standards."

- The group combines 18 experts in electrical measurement and radionuclide metrology.
- 2 on-line meetings so far this year.
- Formal output of the group will be a published "best practice" guide.

Content of best practice guide

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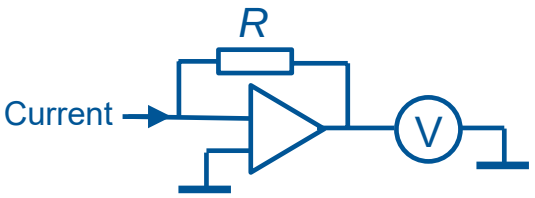
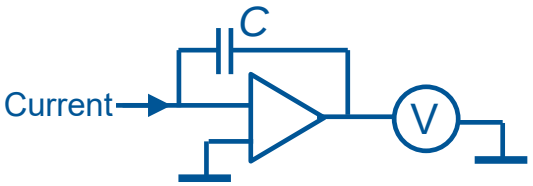
- Electrical measurement best practice (grounding etc)
- Choice of high voltage power supplies to minimise noise
- Evaluation of uncertainty and optimisation of measurement time
- Choice of measurement systems (tradeoff between uncertainty and cost)
- Example case studies of measurement systems, traceability routes and uncertainty budgets

Types of current readout

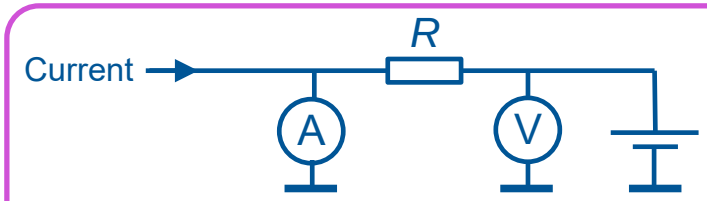


Direct-reading ammeter
(transimpedance amplifier)
$I = V/R$

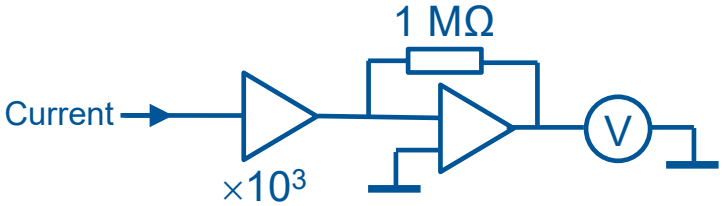


Capacitor ramp electrometer
$I = C\mathrm{d}V/\mathrm{d}t$

In widespread use in radionuclide laboratories



Standard resistor and
precision voltmeter
$I = V/R + I_A$



ULCA
$I = V/G_I$ (G_I = current gain)

Some trials underway

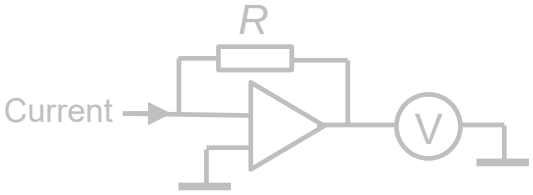
1000 ppm

100 ppm

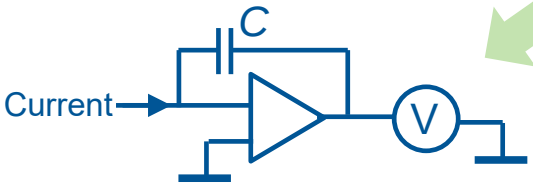
10 ppm

1 ppm

Recent work I: accuracy of capacitor ramp systems



How accurate are these?



Capacitor ramp electrometer
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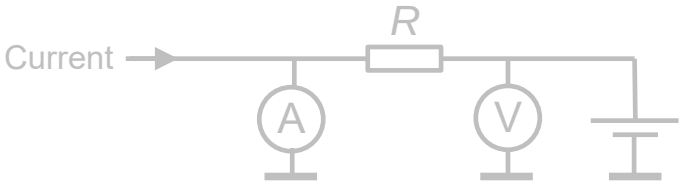

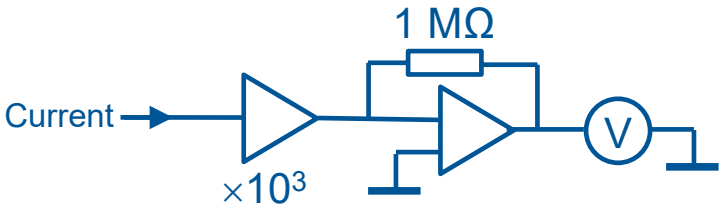

ULCA
$I = V/G_I$ (G_I = current gain)

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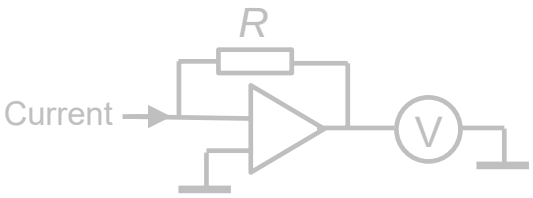
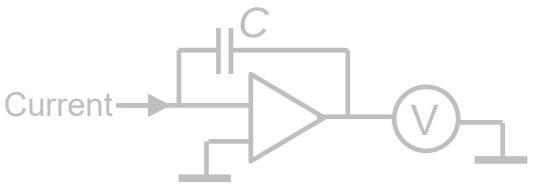
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

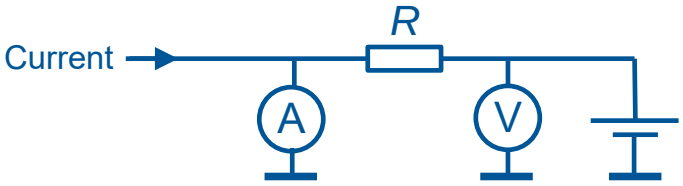
L. Callegaro et al, “Comparison between two dc low current traceability chains” *Conference on precision electromagnetic measurements* (2020)

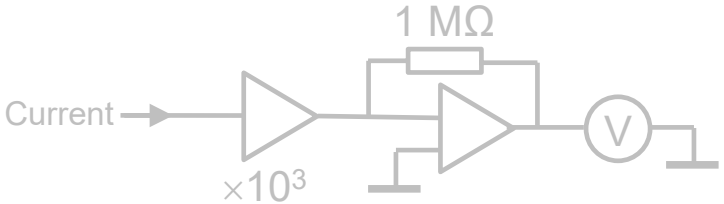
Compared capacitor ramp method with ULCA **(agreement at 10s of ppm level)**, and discussed possible causes of error in capacitor ramp method.

Recent work II: Precision reference current source in radionuclide lab









Standard resistor and precision voltmeter

$I = V/R + I_A$

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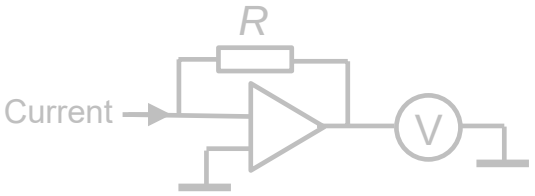
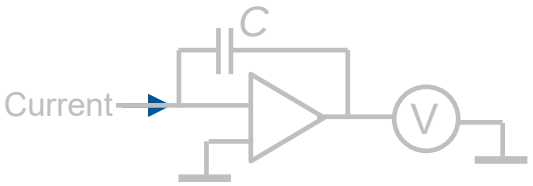
D. Jarrett et al, "Ohms law low-current calibration system for ionization chambers" *Conference on precision electromagnetic measurements* (2020)

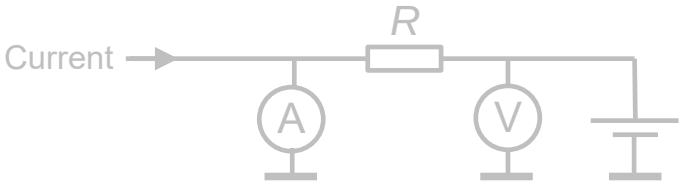
Evaluation of precision reference current sources based on standard resistors in ion chamber laboratory

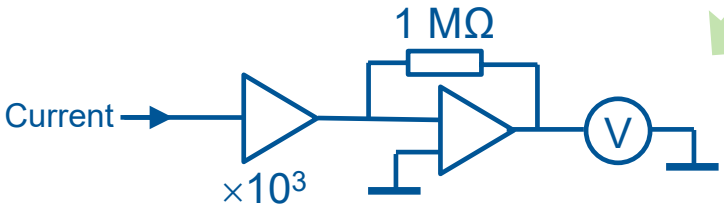
NIST National Institute of Standards and Technology U.S. Department of Commerce

Recent work III: introduction of ULCA into ion chamber labs









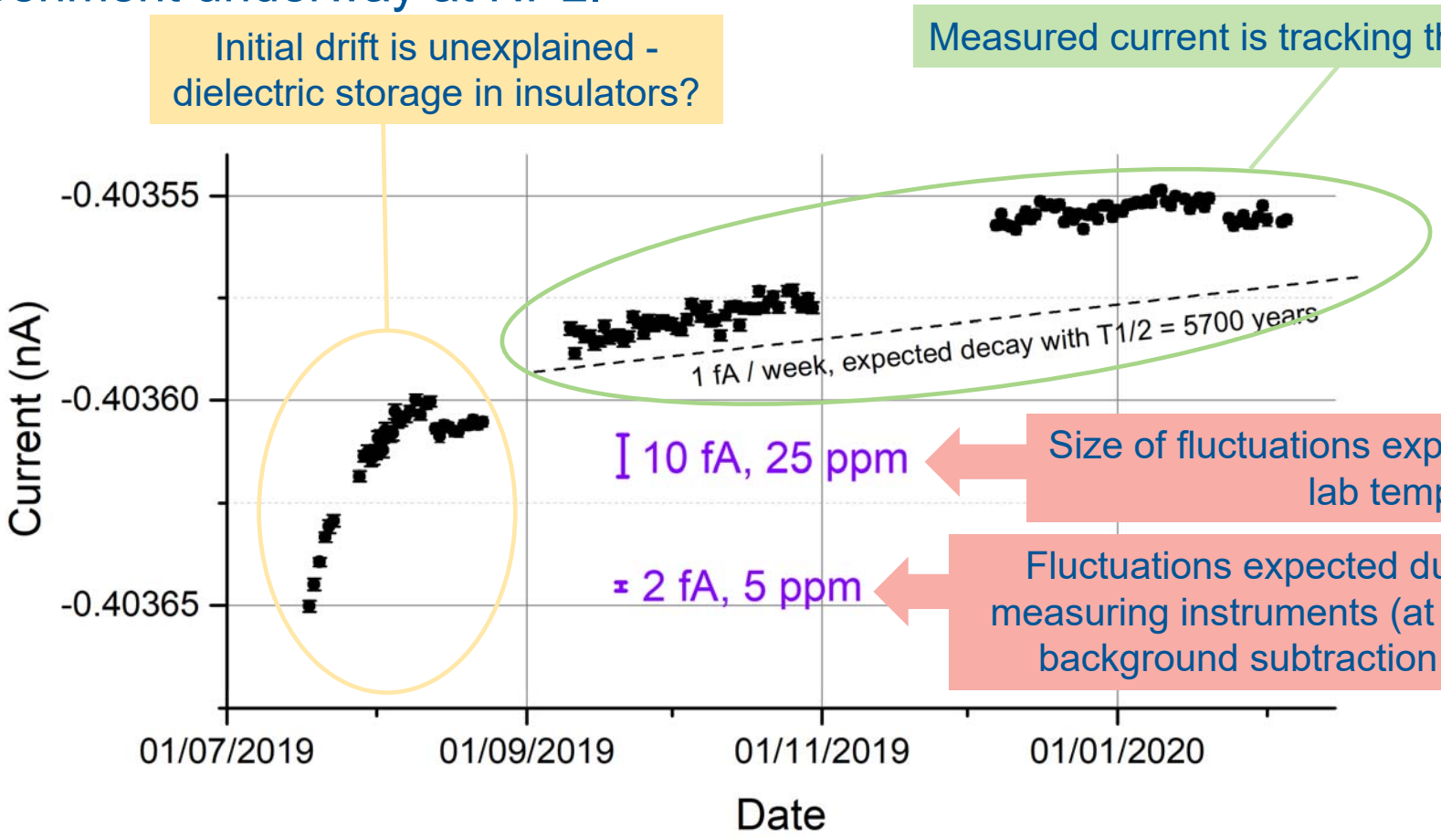
ULCA
$I = V/G_I$ (G_I = current gain)

The ppm-level linearity and accuracy of ULCA: Useful as a primary laboratory current reference, or for half-life measurements?

Ongoing projects at 2 laboratories to use ULCAs as reference current sources and measurement systems in radionuclide laboratories

Is it possible to do radionuclide metrology with ppm accuracy?

Can we directly measure the half-life of carbon – 14? Proof-of-concept experiment underway at NPL.



Size of fluctuations expected due to stability of lab temperature

Fluctuations expected due to stability of current measuring instruments (at present, calibrations and background subtraction are not very frequent)

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