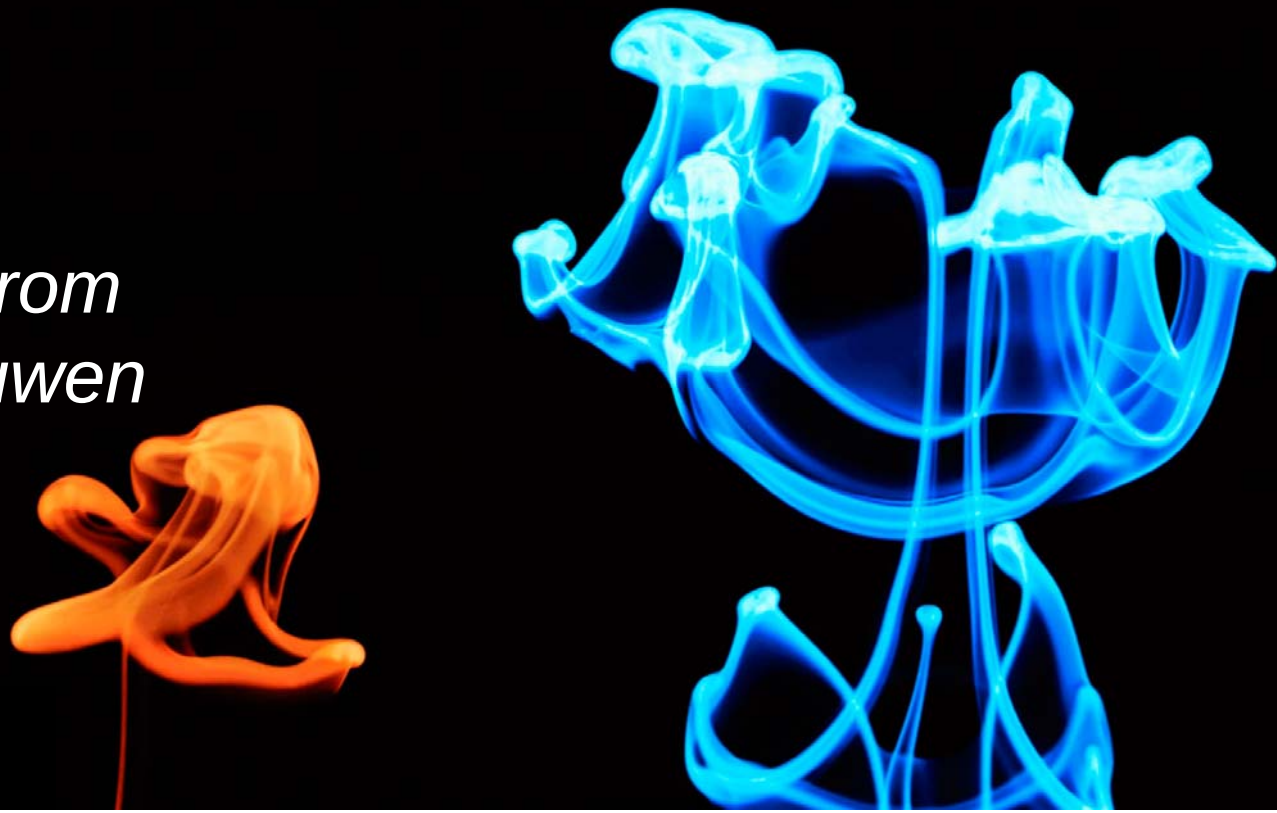
21 February 2019, EMRAILS workshop, Napels, Italy

Characterization of DC current sensors with AC distortion for railway applications

Helko van den Brom
Ronald van Leeuwen



Dutch Metrology Institute

VSL: the Dutch National Metrology Institute

- Maintains and develops the national measurement standards
- Makes measurements directly traceable to international standards
- Supports reliability, quality and innovation both in business and society

- Company with public task
- 100 fte, 50 % MSc/PhD
- Calibrations, reference materials, R&D, consultancy, training
- Independent, reliable, top in measurement, international
- Focus: energy, industry

Dutch Metrology Institute

Beyond all doubt

VSL technologies


Length


Temperature & RH


Electricity


Time and frequency


Chemistry

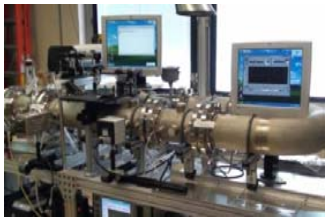

Gas flow


Liquid flow


Optics


Ionising radiation


Mass


Pressure


Viscosity

Dutch Metrology Institute

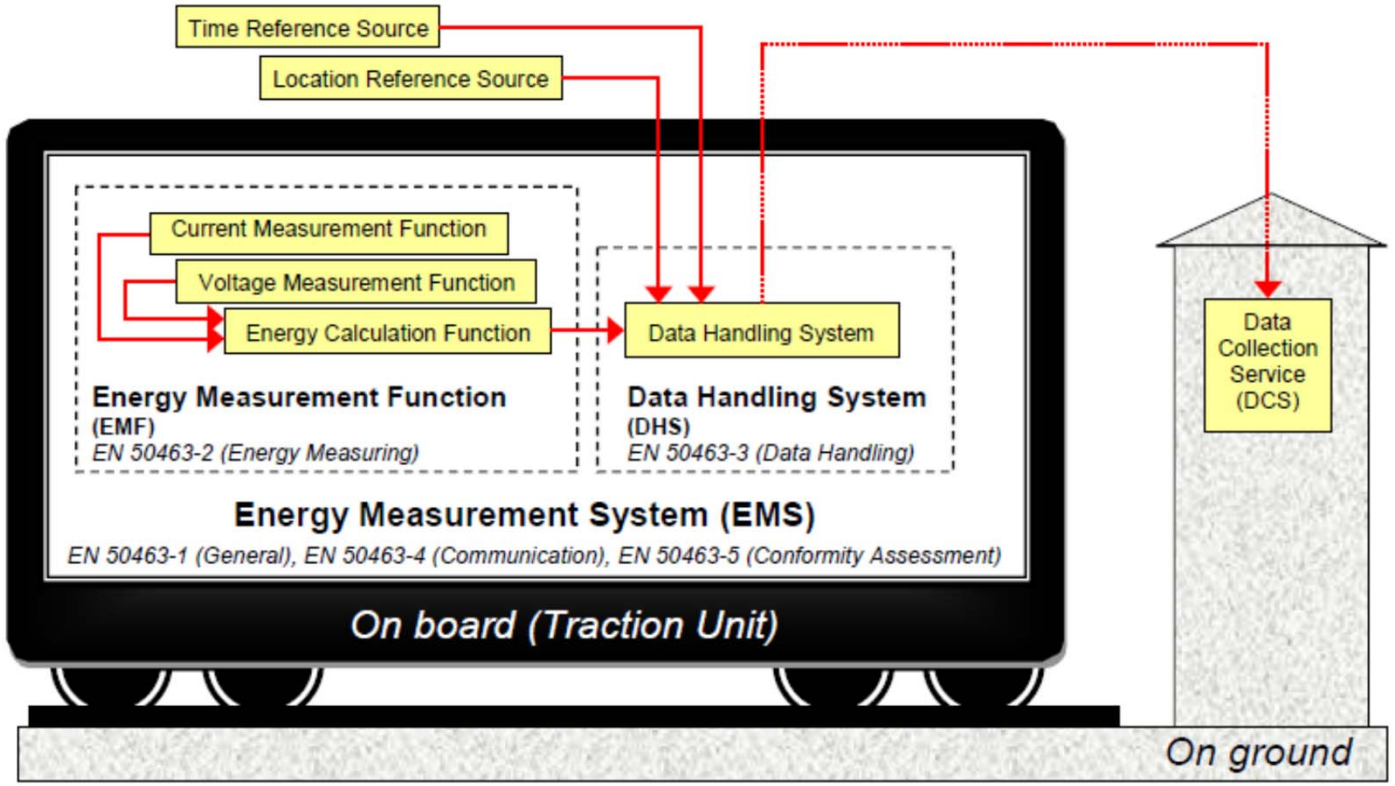
Current measurement on board trains: why?

- Market liberalisation in railway transportation
- EU target of 50 % reduction of CO_2 emission by 2030
- EU regulation: by 2019 energy billing shall be based on measurements on-board trains
- Accurately measure energy of individual trains:
  - energy metering
  - energy-efficient driving
  - smart power management
  - regenerative braking
  - reduction of traction losses
  - renewable energy micro-generation
  - optimization of comfort functions

- Accuracy of the energy measurements defined by EN 50463-2

Dutch Metrology Institute

Energy measurement on board trains



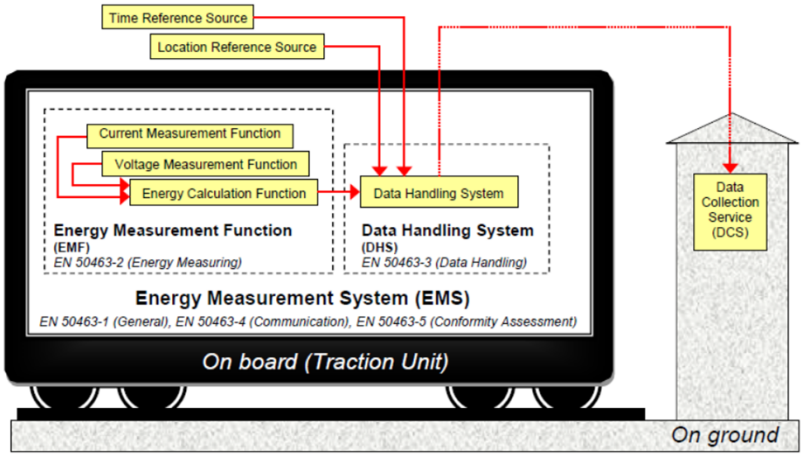
EMF = CMF + VMF + ECF [1]

[1] EN 50463-2

EMPIR project MyRailS

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

- EMPIR - European Metrology Programme for Innovation and Research (EU Horizon 2020)
- MyRailS - Metrology for Smart Energy Management in Electric Railway Systems
  - NMI's: INRIM (I), CMI (CZ), FFII (ES), LNE (F), NPL (GB), VSL (NL), METAS (CH)
  - Metro de Madrid, Trenitalia, R.F.I., Hitachi Rail Italy, Railenium, ASTM
  - Universities: Comillas, Campania, Strathclyde
    - Calibration of EMF for DC and AC systems
    - PQ in railway supply systems
    - Reversible DC substations
    - Ecodriving

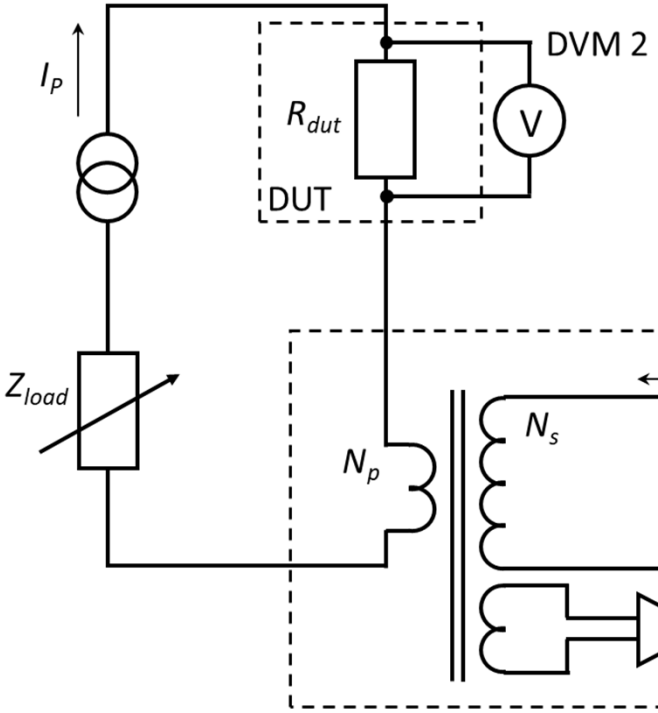


- Aim VSL: traceable calibration of EMF, conformity assessment 50463-2
- Focus of this presentation: CMF for DC traction units

Dutch Metrology Institute

Testing DC current equipment with distortion

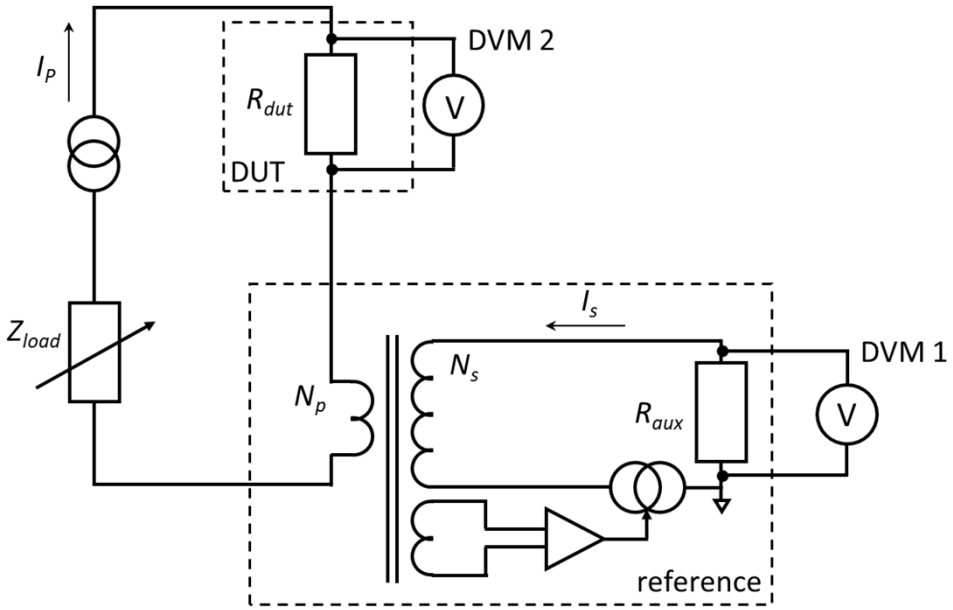
DC+AC programmable electronic load: unipolar, 150 V, 600 A, 20 kHz



Dutch Metrology Institute

Measurand example: transresistance error

- Current-to-voltage transducers:
  transresistance, $R = \frac{V_{out}}{I_{in}}$
- Measurand in this study:
  transresistance error, $\varepsilon = \frac{V_{out}}{R_{nom} \cdot I_{in}} - 1$

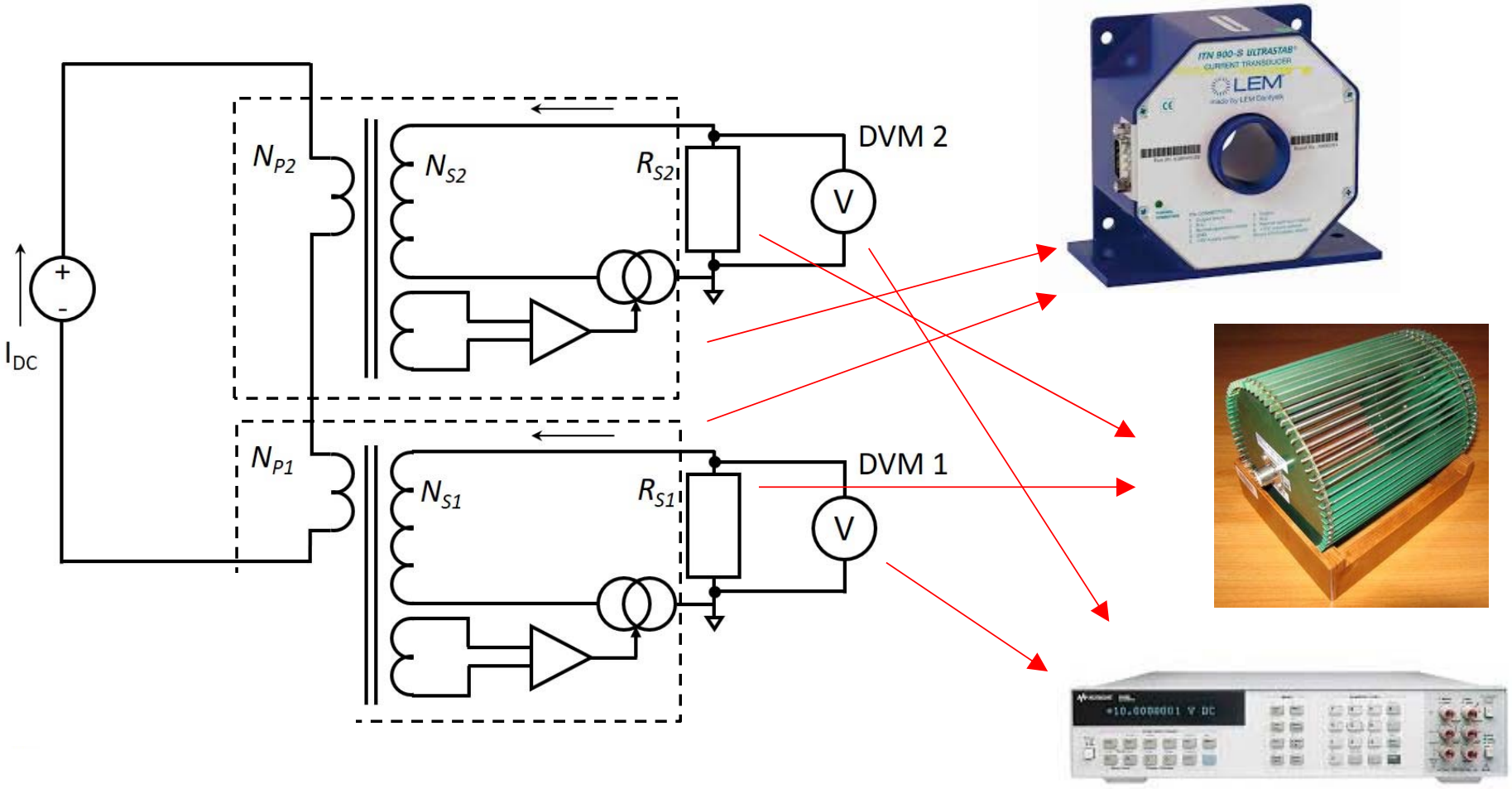


- When comparing two current-to-voltage transducers, to first order:

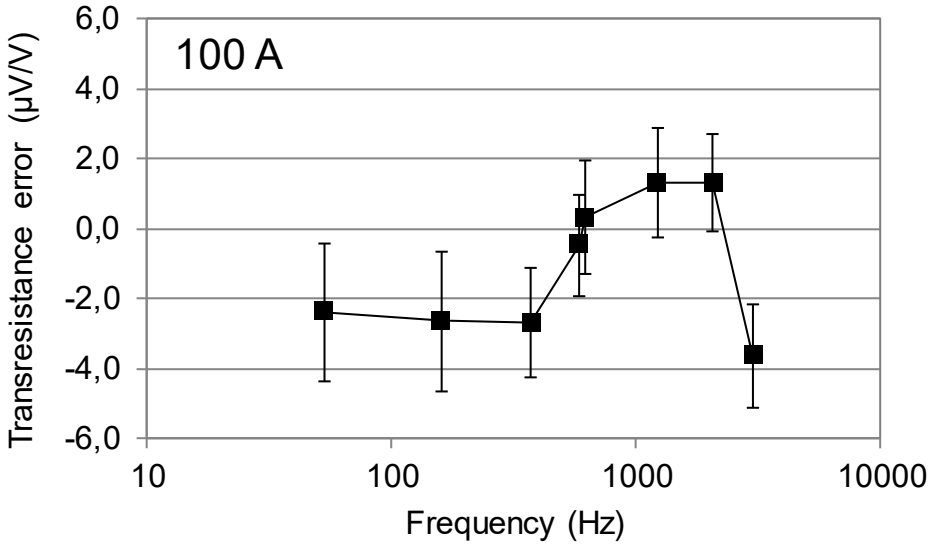
$$\varepsilon_{dut} = 1 - \frac{R_{nom}^{dut}}{R_{nom}^{ref}} \cdot \frac{V_{out}^{ref}}{V_{out}^{dut}} + \varepsilon_{ref}$$

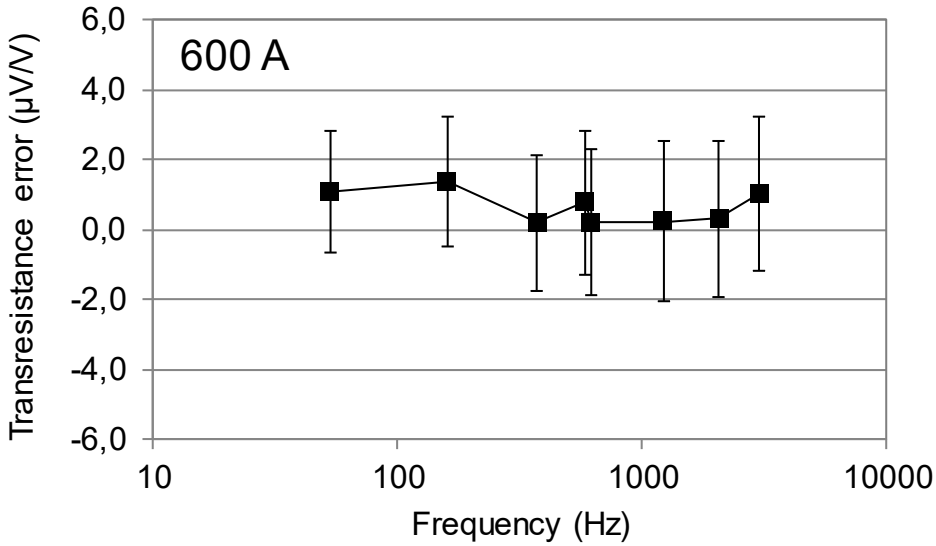
Dutch Metrology Institute

Calibration of reference sensor with AC ripple



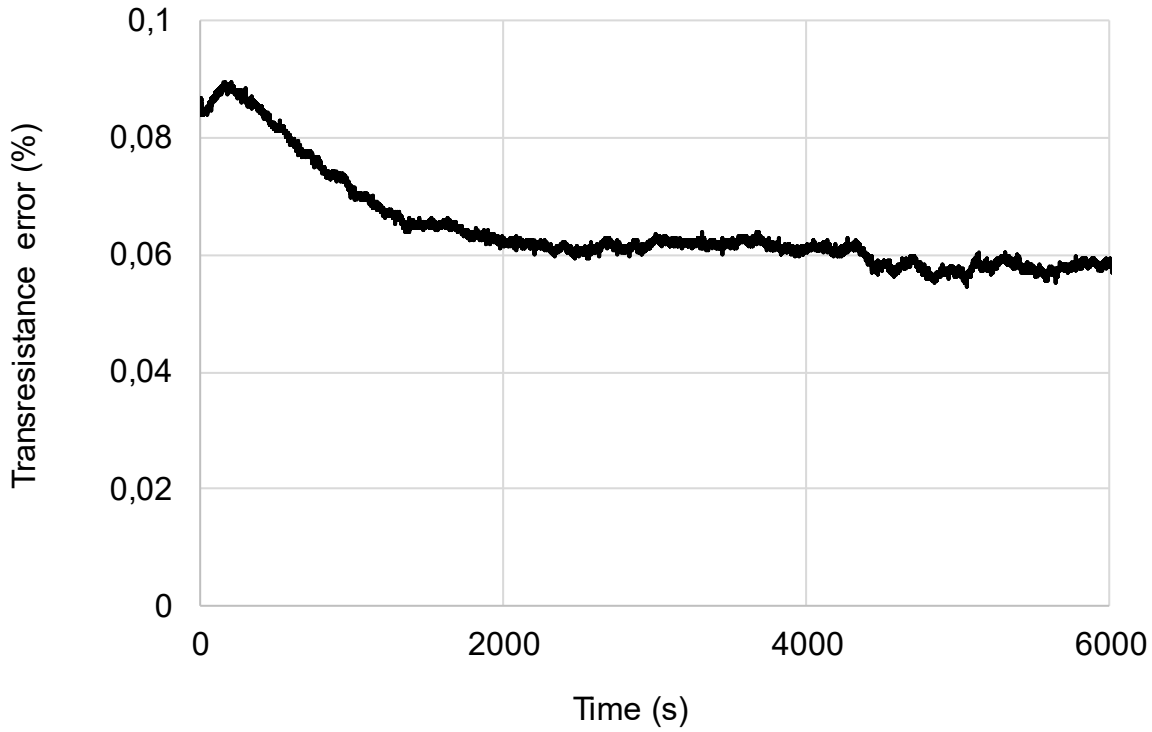
Influence AC distortion on reference sensor

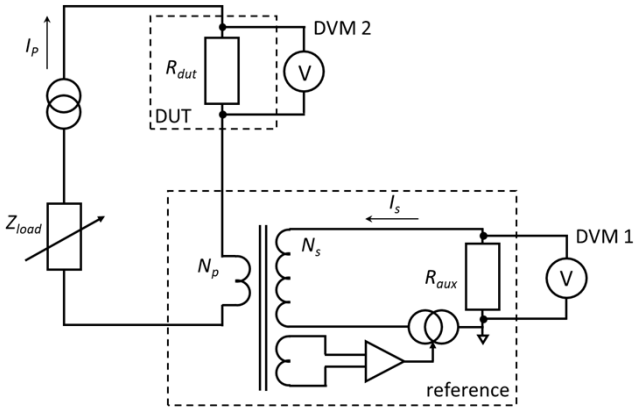




Dutch Metrology Institute

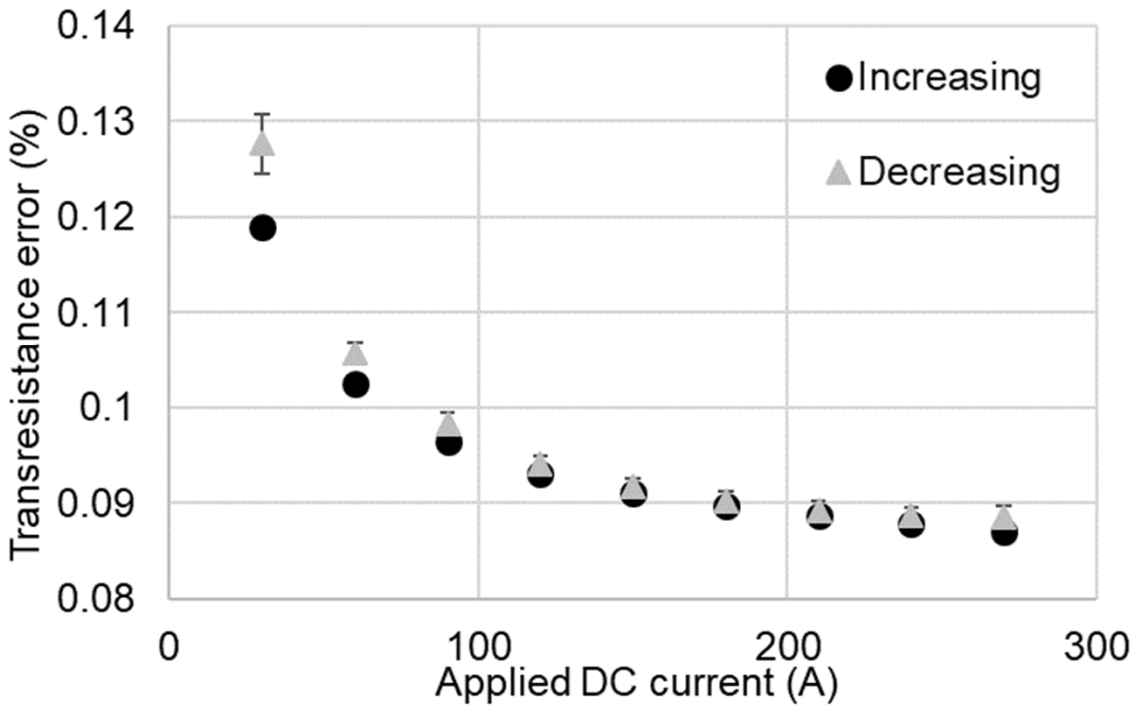
Example: DC calibration of shunt under test

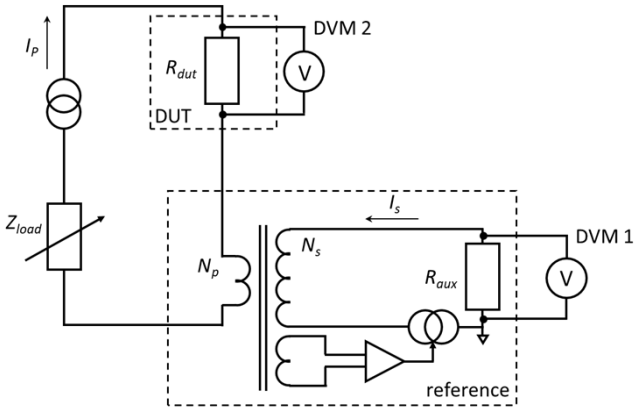




Dutch Metrology Institute

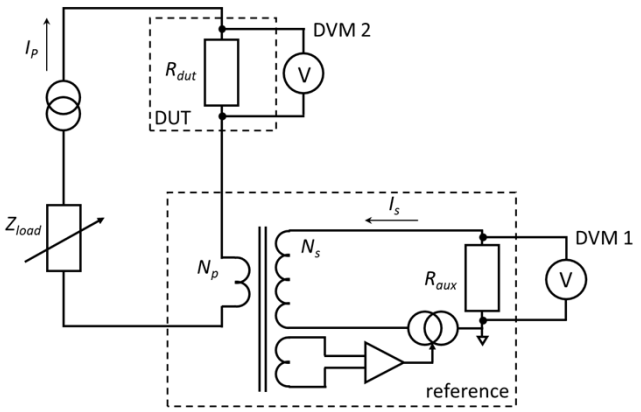
Intrinsic current dependence of shunt



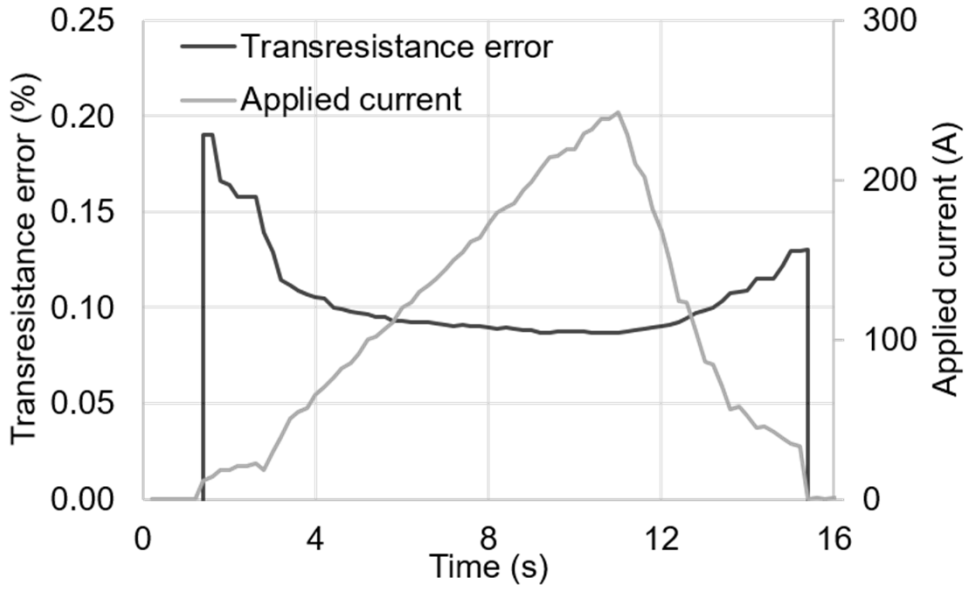


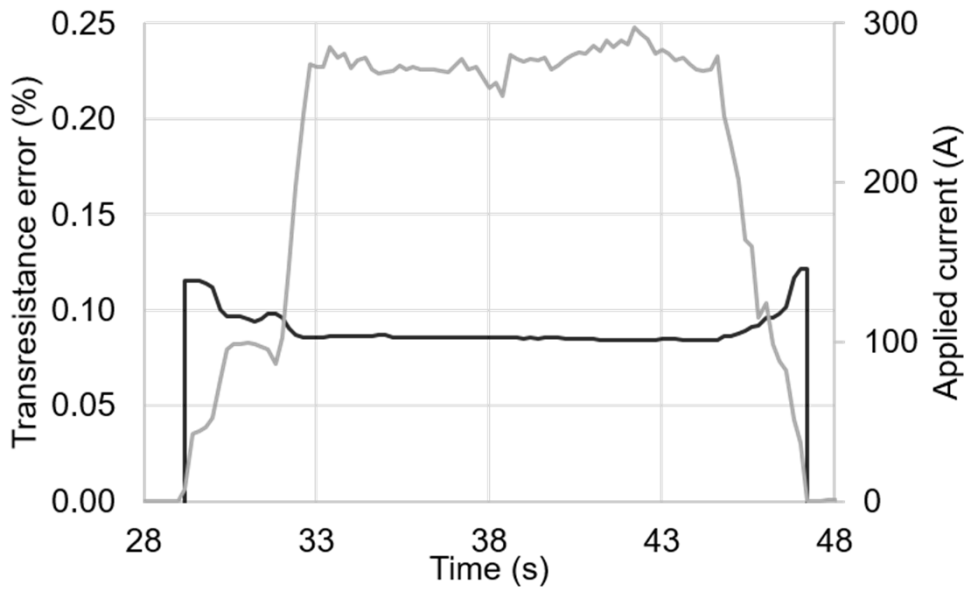
Dutch Metrology Institute

Realistic current patterns



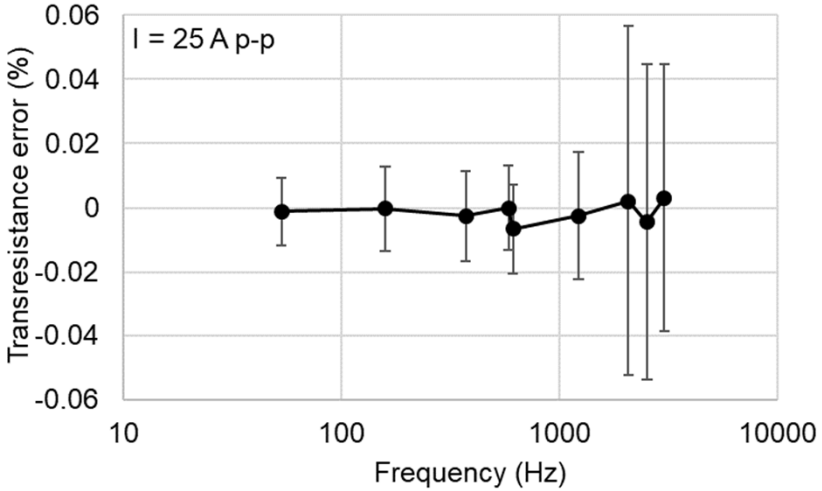
Current profiles recorded on board an underground traction unit from Metro de Madrid

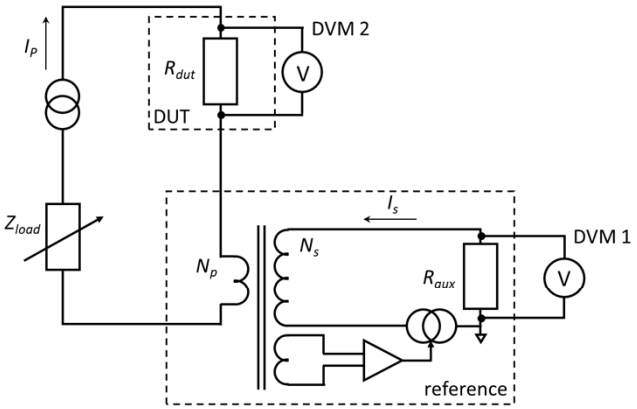


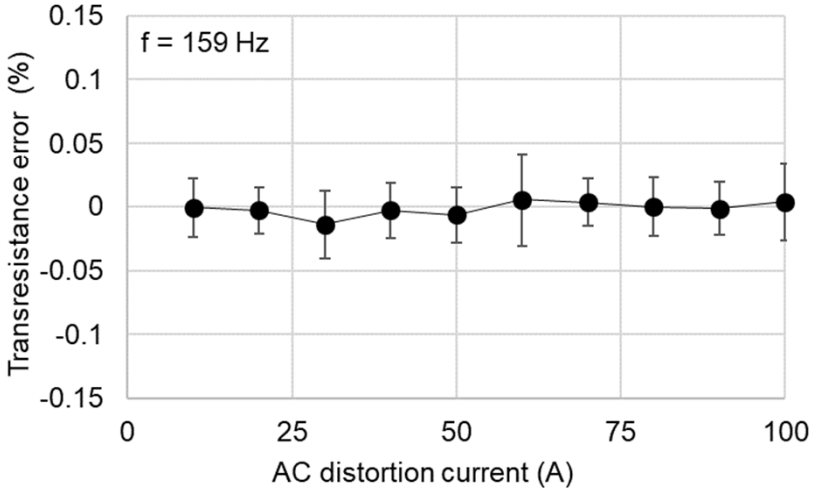


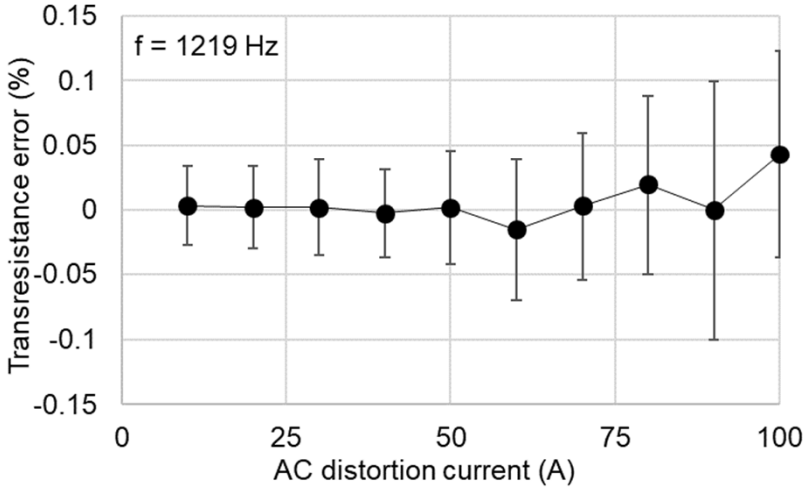
Dutch Metrology Institute

AC ripple distortion at 270 A DC





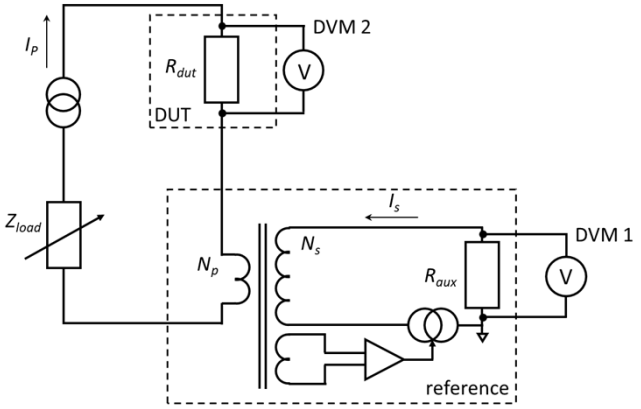


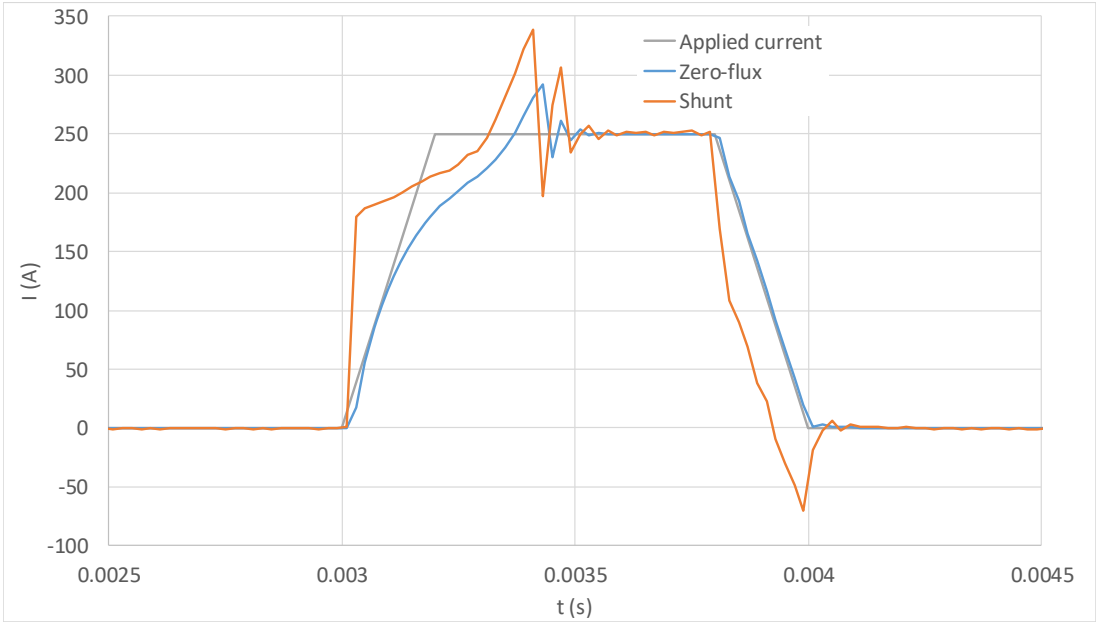


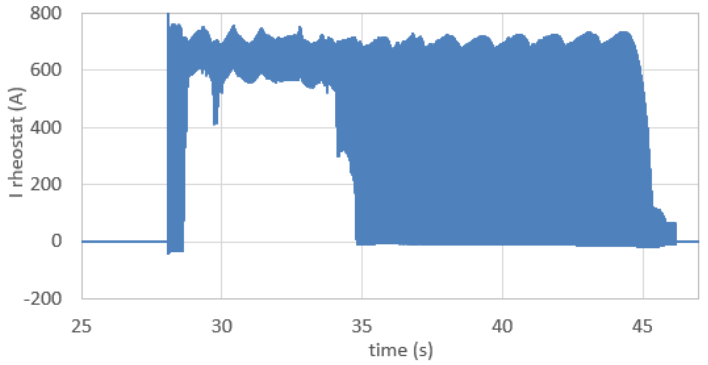
Dutch Metrology Institute

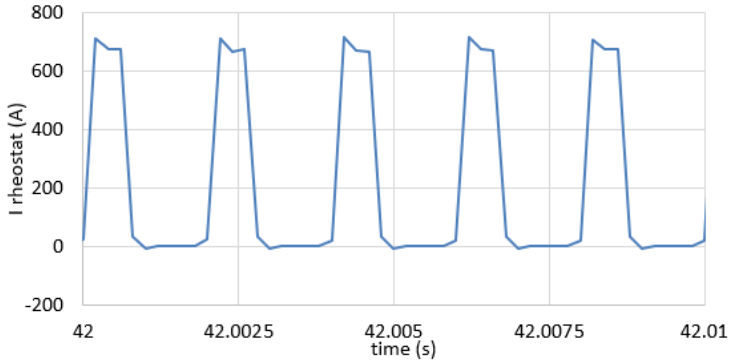
Chopped rheostat waveforms

Chopped waveforms as from HRI, 500 Hz
Measurements shunt vs zero-flux



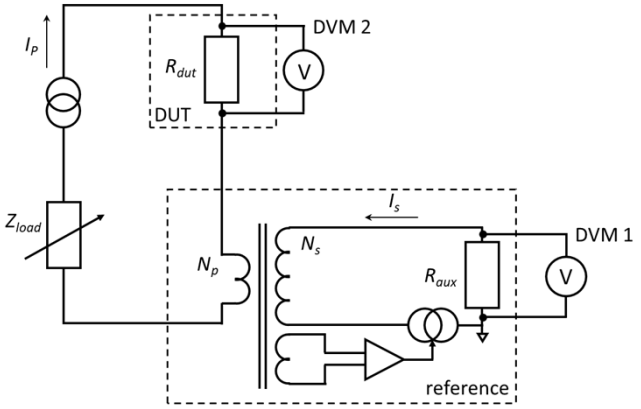




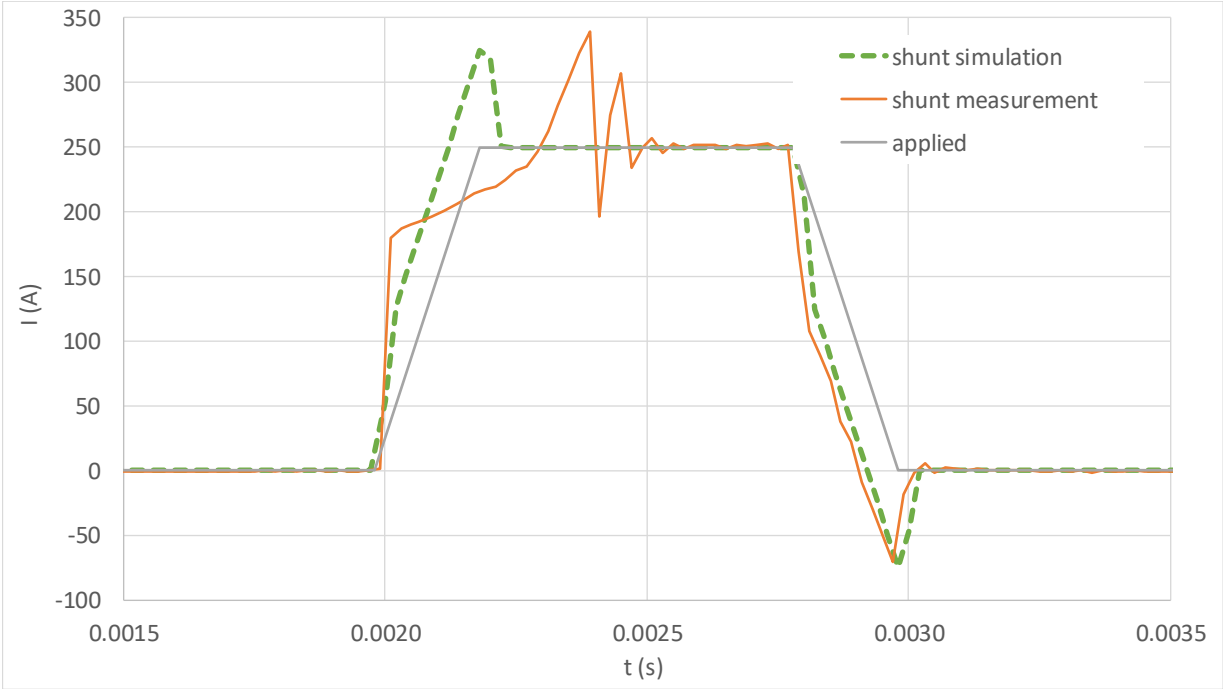


Dutch Metrology Institute

Chopped rheostat waveforms



Simulate shunt as R with series L and parallel C:
assume perfect applied current

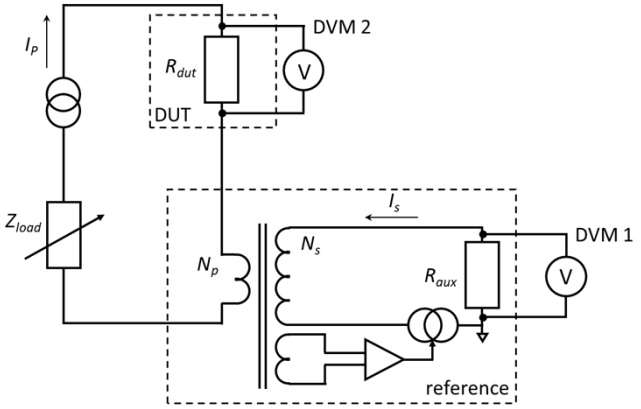


Either simulation,
or measurement,
or the assumption
is wrong…

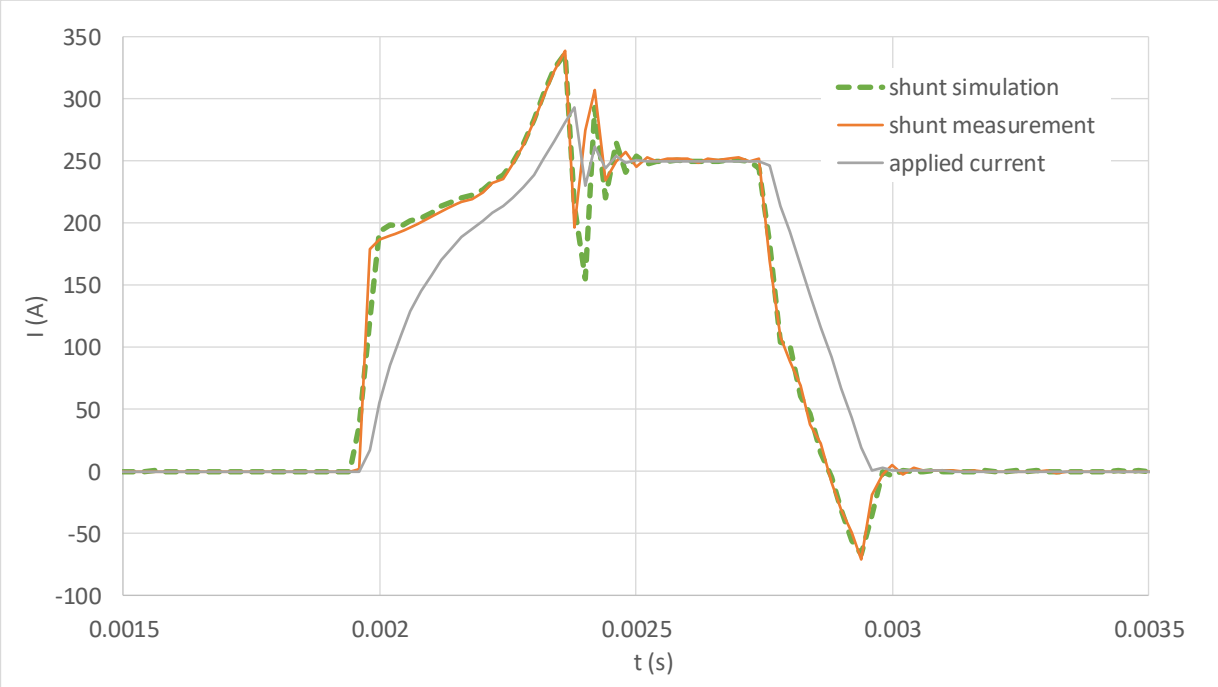
→ zero-flux was
right after all?

Dutch
Metrology
Institute

Chopped rheostat waveforms



Simulate shunt as R with series L and parallel C:
assume perfect applied current

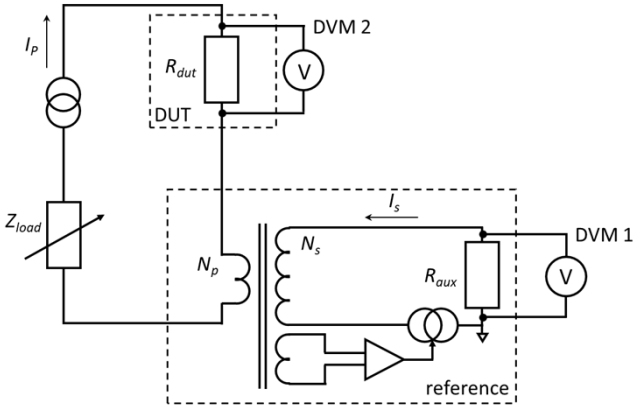


Measurement and simulation agree
→ Zero-flux was right after all!

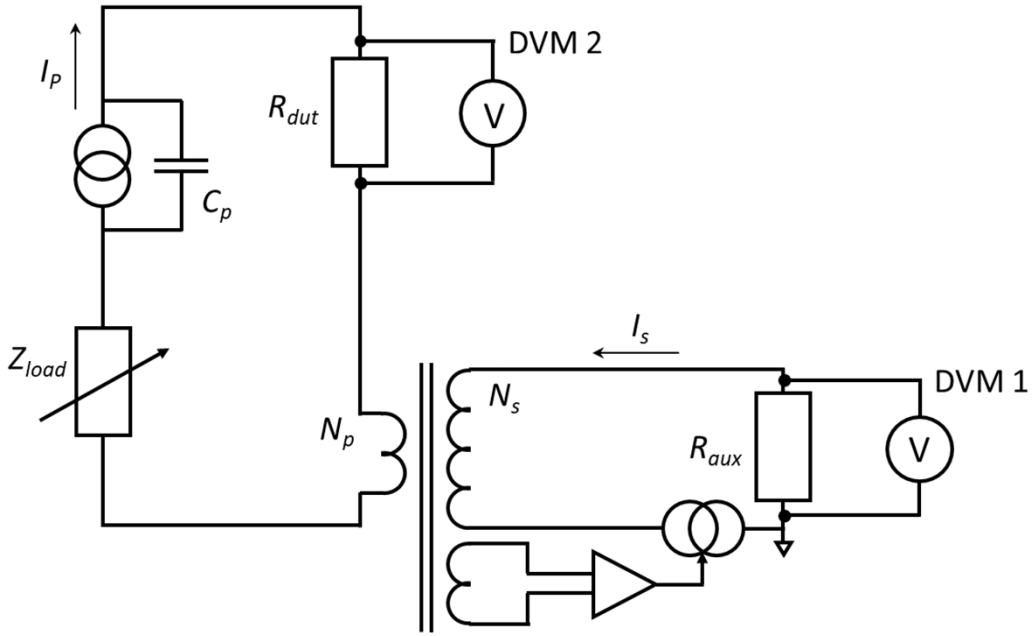
Current source cannot follow

Dutch Metrology Institute

Chopped rheostat waveforms

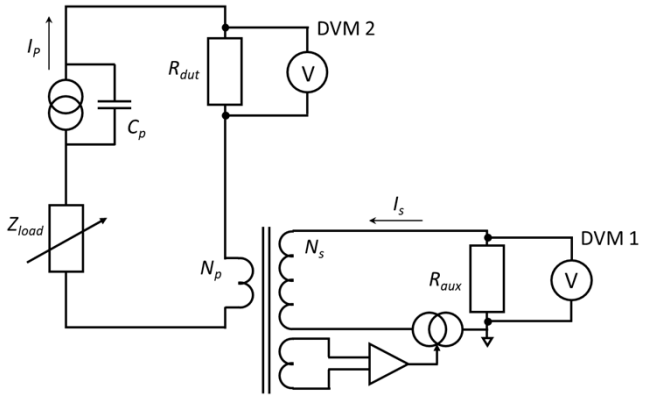


Add capacitor to increase slew rate of current source

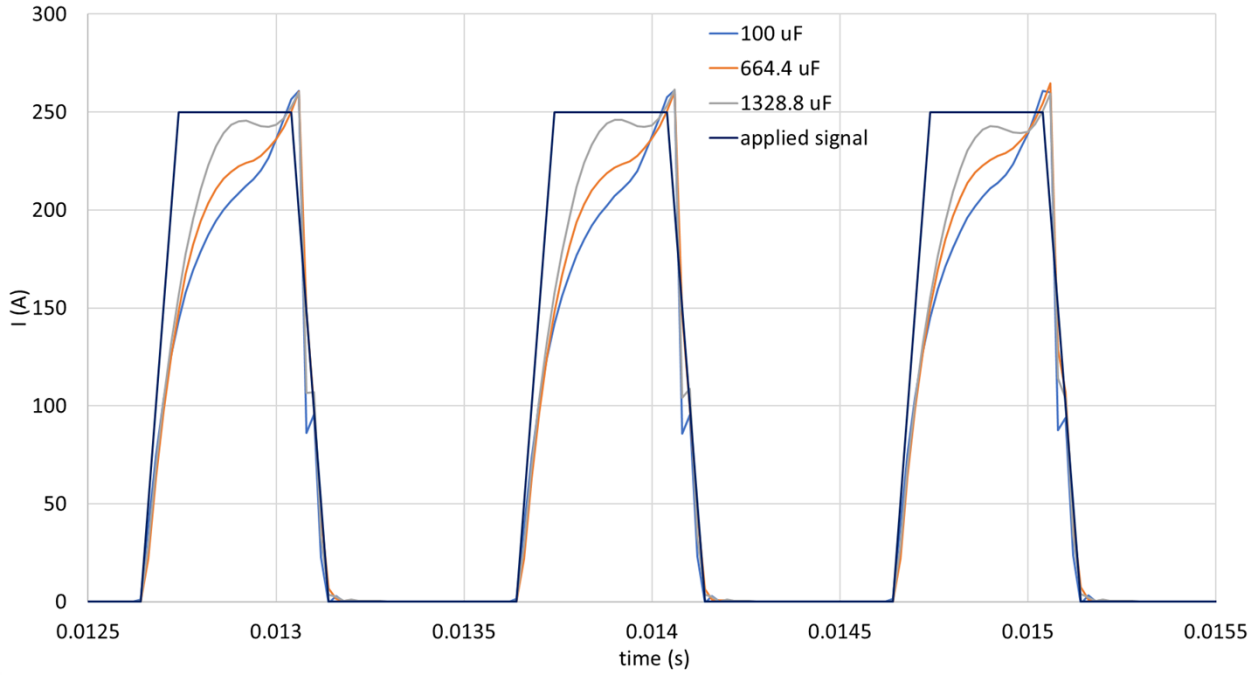


Dutch Metrology Institute

Chopped rheostat waveforms



Chopped waveforms, 500 Hz, 0 – 250 A:
Measurements with added capacitor



Dutch Metrology Institute

Summary and conclusion

- Designed, built and tested a setup for characterization of DC current sensors for railway applications mimicking real distorted operating conditions

- Characterized a zero-flux reference sensor
  - Excellent DC behavior
  - No effect of AC distortion to within a few ppm
  - Excellent behavior under highly distorted waveforms

- Characterized measurement sensor (shunt)
  - Drift of 0.03 % in half an hour due to dissipative heating
  - Intrinsic current dependence of 0.03 %
  - No effect of AC distortion to within a few ppm
  - Stable within 0.05 % under dynamic test signal from real underground
  - Cannot follow highly distorted waveforms due to internal inductance

Dutch Metrology Institute

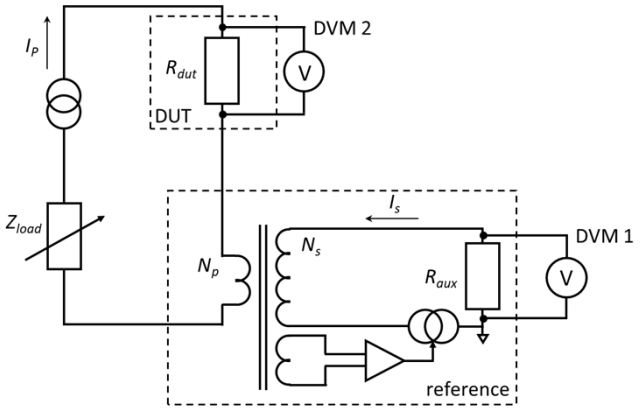
Future work

- Future work will focus on:
  - Different sensors, other waveforms
  - Increase dynamic capabilities of current source
  - Measure CMF including current/voltage readout
  - Apply DC voltage of 600 V, 750 V, 1.5 kV or 3 kV
  - Measure VMF and complete EMF

→ Calibration facility for DC current, voltage and energy under highly distorted conditions

→ Similar setup for AC

→ Testing facility for 50463-2 compliance



Thank you for your attention!