17NRM01 TrafoLoss
Final Stakeholder Workshop

Active voltage divider with small phase error

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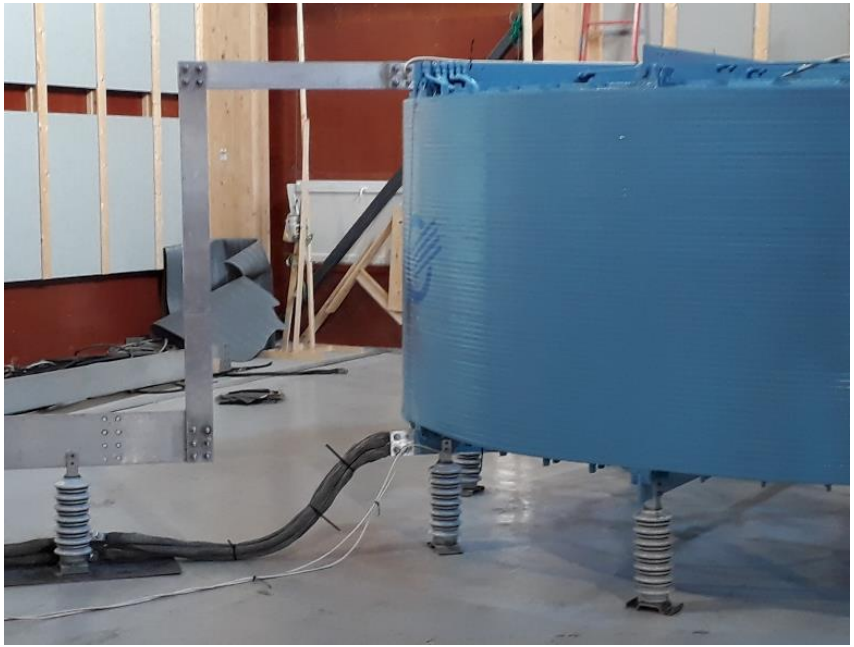
Introduction

- Accurate loss measurements are increasingly needed.
- Phase accuracy is a challenge when the power factor is low

$$P = U \cdot I \cdot \boxed{\cos \varphi}$$



Target and approach

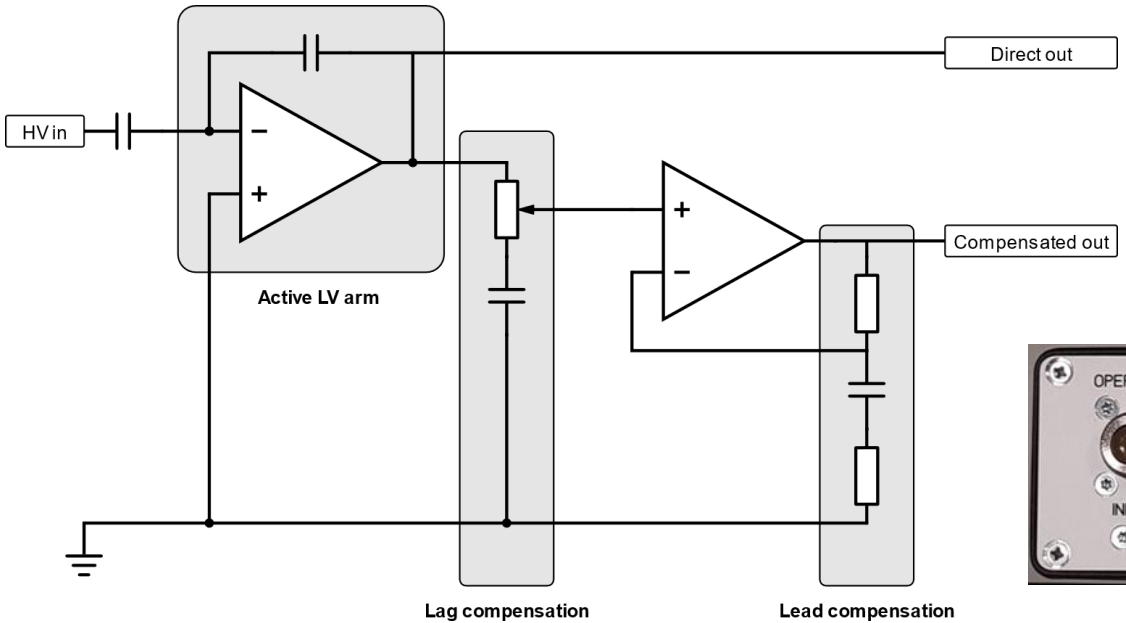
- Target: To design and build a capacitive voltage divider to meet the following specifications for industrial requirements

Range	Ratio uncertainty	Phase displacement uncertainty
100 kV	40 µV/V	25 µrad

- Approach: Active loss voltage arm
  - Any low-loss (compressed gas) capacitor can be used as high voltage arm
  - Based on original design by PTB [1]
  - Two independent circuits with different capacitance value

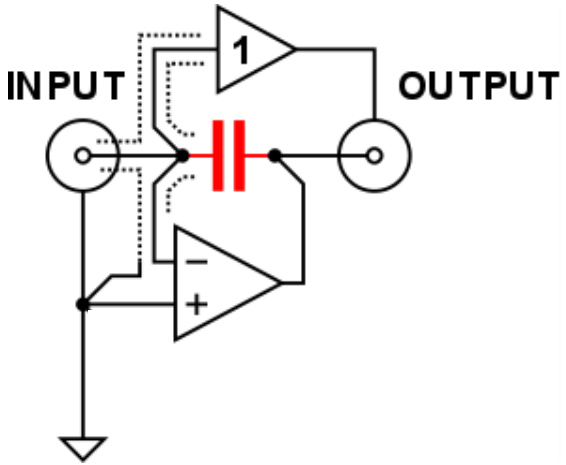
[1] E. Mohns, et al., "An Active Low-Voltage Capacitor for Capacitive HV Dividers," CPEM 2018, https://ieeexplore.ieee.org/document/8501238.

Active capacitive divider low voltage arm with zero phase displacement



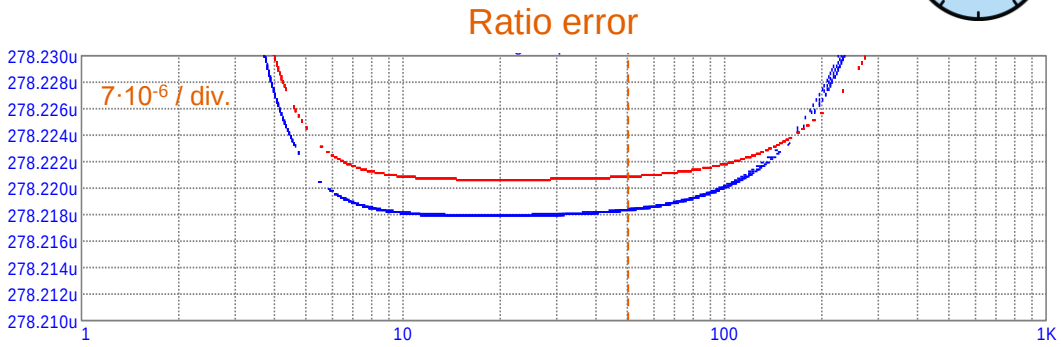
Active low voltage arm

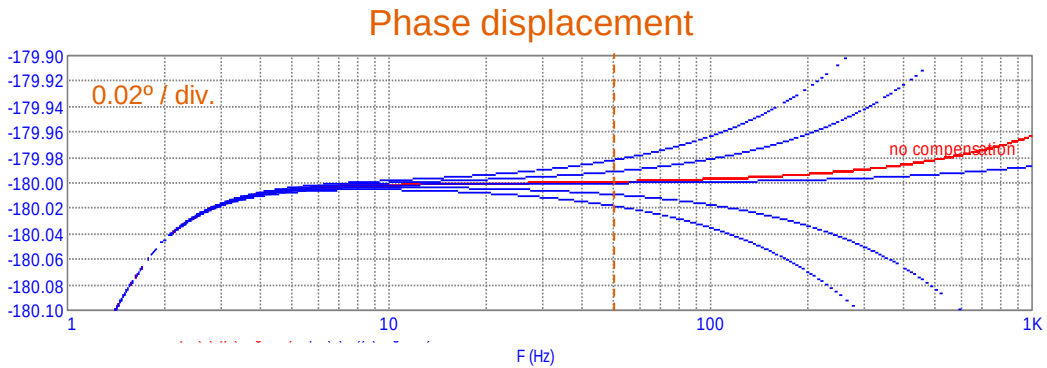
- Low loss ceramic capacitors on the feedback loop of a buffer amplifier
- Ground is also buffered to avoid ground loop
- Load independent output
- Small phase displacement in power frequency due to characteristics of the high voltage and feedback capacitors



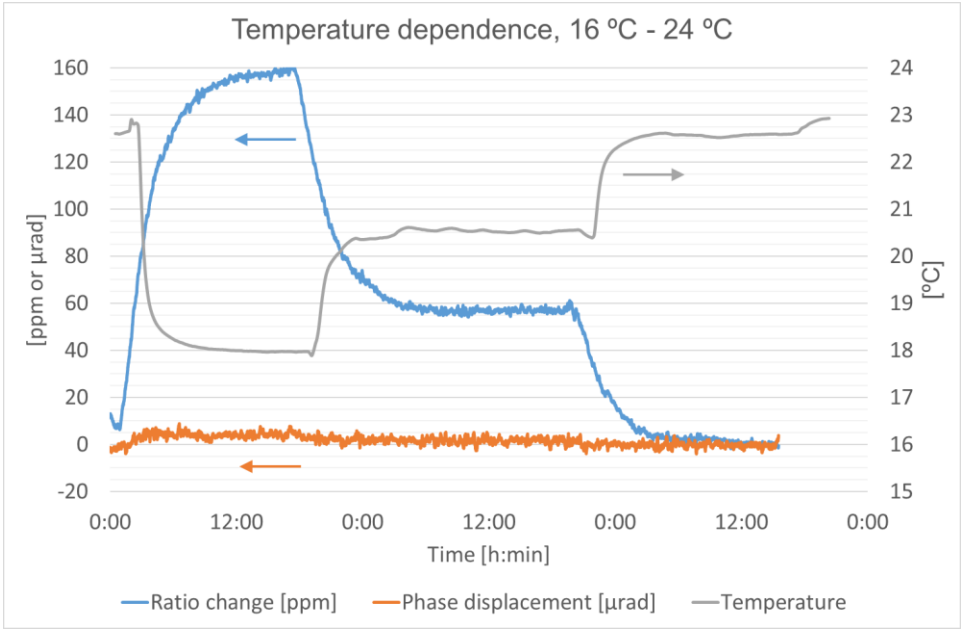
Compensation of phase displacement

- Phase displacement can be adjusted to zero
- Phase displacement adjustment range
  - ± 0.03º (± 500 µrad)





Performance with 20 kV capacitor



Specifications

- Low voltage arm
  - Output
    - Inverting, ± 10 V
  - Nominal LV capacitances
    - 0.4 µF, 2.7 µF
  - Gain flatness
    - ± 10 ppm from 5 Hz to 100 Hz

- With the applied 20 kV capacitor
  - Long time constant, c. 4 h
  - Temperature coefficients:
    - Scale factor: $-36 \cdot 10^{-6}$ /K
    - Phase displacement: 0.4 µrad/K
  - Calibration @ 50 Hz, 21 ºC, 12 kV:
    - Scale factor: 3913.80 ± 30 ppm
    - Phase displacement: (0 ± 10) µrad

Outside calibration laboratory…

- Loss measurement of an air-core shunt reactor [2]
  - 4 kV, 1200 A, 11.7 mH
  - Steady state reached in c. 6 hours
  - PF 0.001, uncertainty 5 % (k = 2)
  - Measured loss increase (c. 1.5 mΩ) was slightly higher than obtained with calculation according to IEC 60076-6 [2]
- Two-channel low voltage arm sold to a Finnish test laboratory

[2] J. Havunen et al., *Measuring Losses of an Air-Core Shunt Reactor with an Advanced Loss Measuring System* ISH2019, Budapest, Hungary, https://zenodo.org/record/3521194

Conclusions

- The low voltage arm with phase compensations allows adjustment of voltage channel phase displacement to zero.
  - Below 10 µrad even the lengths measurement cables have to be taken into account…
- Tested in industrial environment
- Temperature coefficient of the HV capacitor limits the amplitude uncertainty
- Phase displacement error is limited by the accuracy of the available phase reference.

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