Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

MIKES METROLOGY

Measurement of Reactor and Capacitor Losses

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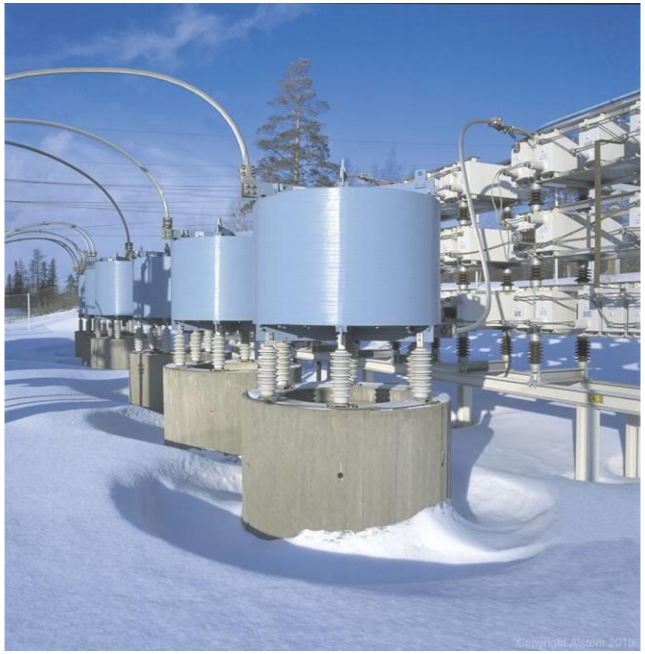


Joint open workshop
ENG61 FutureGrid
and 14IND08 ElPow

31th August 2016
PTB - Braunschweig

Overview

- Motivation
- Sampling system of VTT MIKES and PTB
- Calculation of losses
- Comparison (reactor, capacitor)
- Phantom power source (Future)
- Summary

<u>Motivation</u>: European Research Project „ELPOW“

→ **Developement of loss power sampling systems for:**

HV Reactors and Capacitors

- Precise on-site calibration of meas. systems in industrial environments
- Laboratory conditions (target 20 ppm)

Reason: Limited measuring range of capacitance bridge

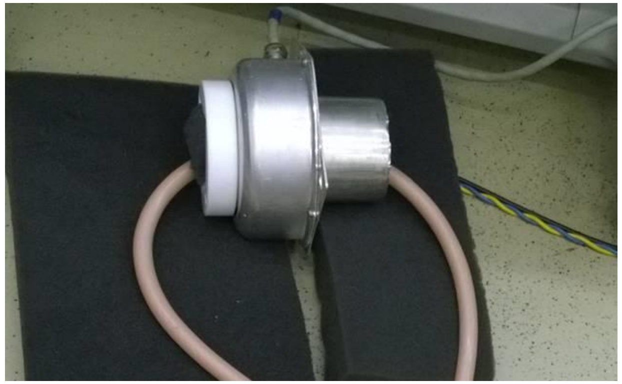
Sampling System of VTT MIKES

- Rogowski coil

  -> No integrator

  -> Frequency dependent output voltage

  -> Stable voltage ratio for inductance while measuring with variable frequency

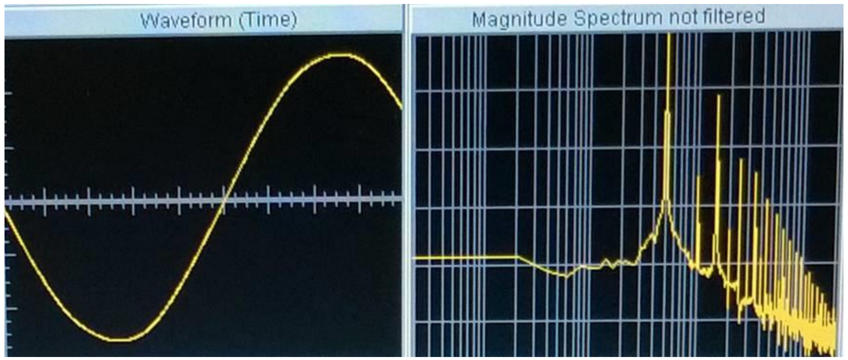


- High voltage capacitive voltage divider
- Current shunts

  -> Calibration of Rogowski coil

- Software

  -> DFT->Impedance and phase



Sampling System of VTT MIKES

- Two sampling DMMs (3458A)

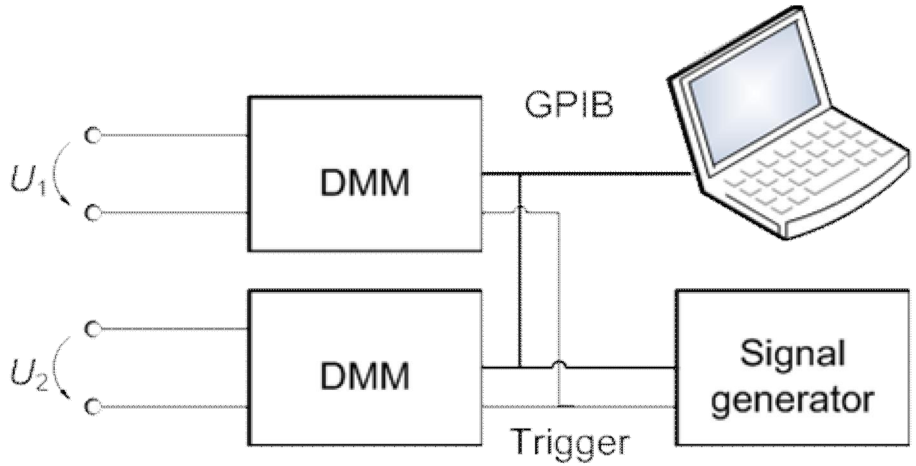
  -> Long integration time 120 µs

  -> Sampling rate 4.1 kS/s

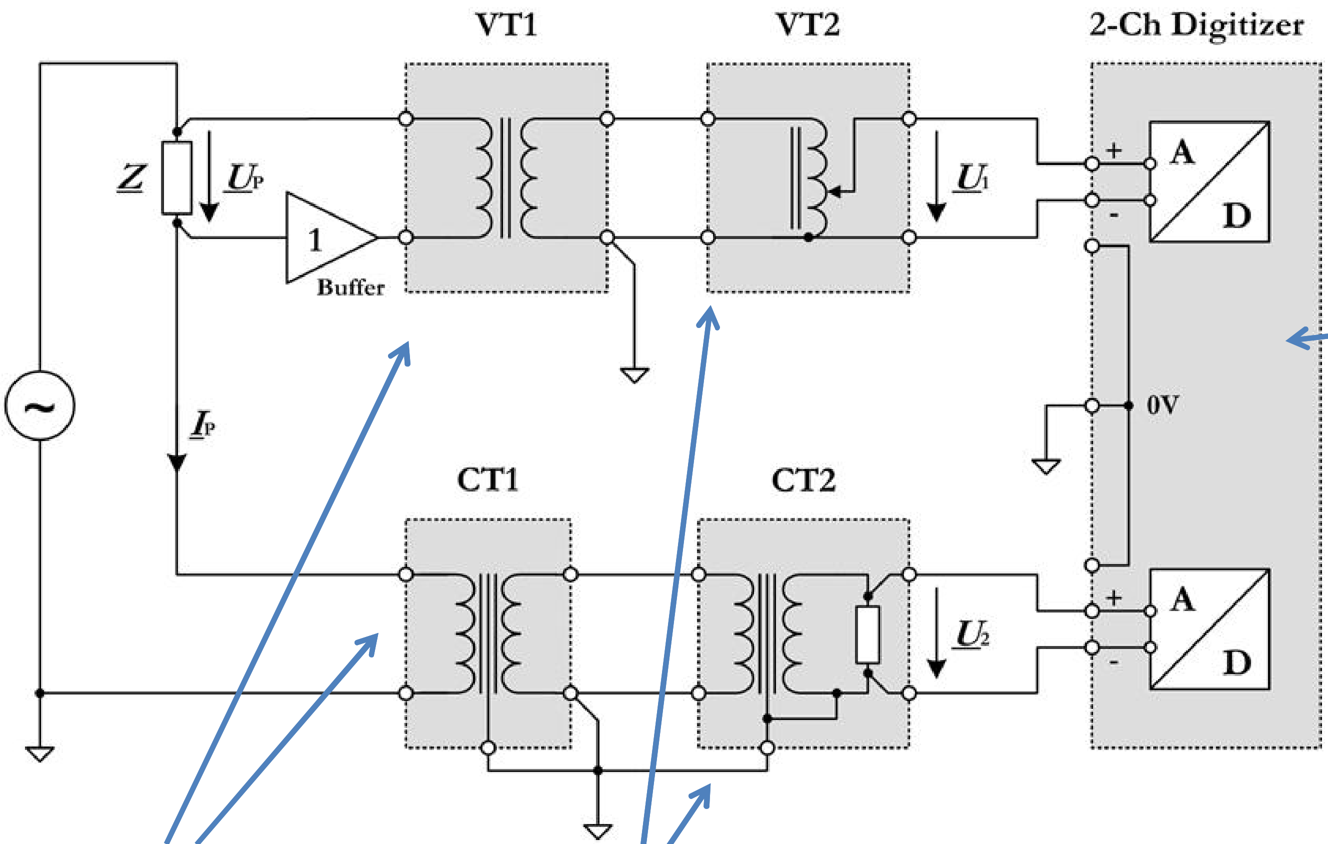
- External trigger unit

  -> simultaneous triggering

  -> Phase error between DMMs & ranges measured and corrected



Sampling System of PTB



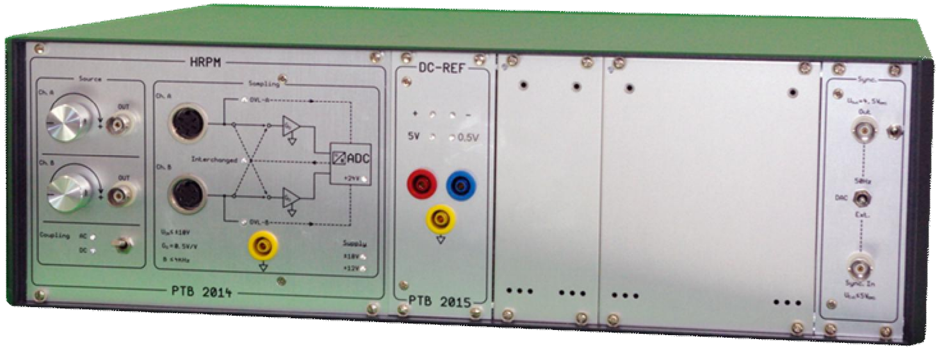
Sampling System
***U* = 2… 10 ppm**

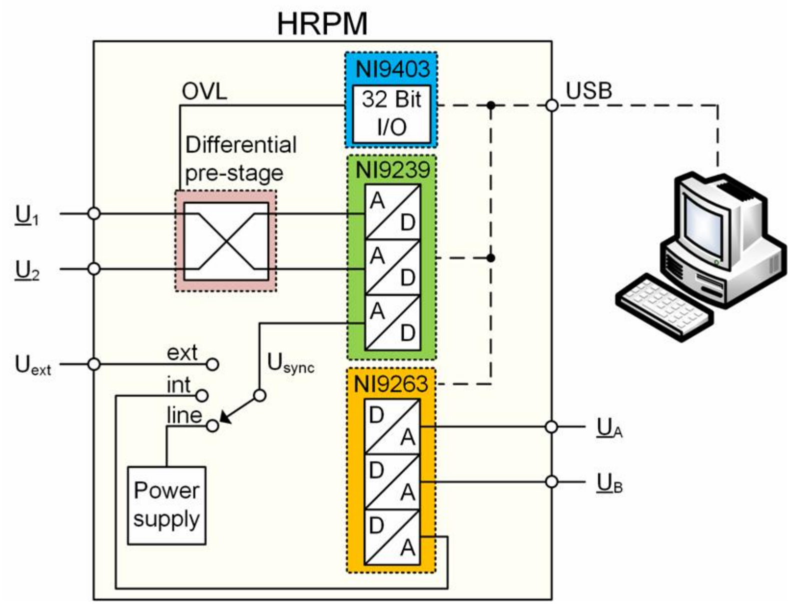
HV / HC standard transformers
***U* = 10… 20 ppm**

range transformers
***U* = 2… 5 ppm**

Combined uncertainty
U = 20... 50 ppm

Sampling System of PTB





2-channel-sampling system

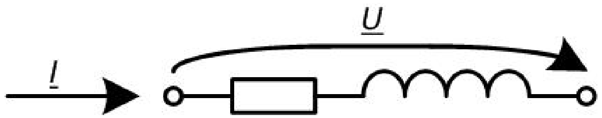
- Based on NI cards (24 bit, 50 kHz)
- U_{pk} = ±1 V; ±10 V
- Measurement uncertainty 2… 10 ppm / µrad for ratio measurements
- Software-synchronization (resampling)
- Processing of the measurement results on PC (LabView Software)
- Fast measurement rate (5 / s is attainable)

Calculation of losses:

$$\underline{S} = \underline{U} \times \underline{I}^* = \underline{U}^2 \times \frac{1}{\underline{Z}^*}$$

1) Optimization of the sampling system for impedance measurement

$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{\underline{U}_1 \times \underline{F}_U}{\underline{U}_2 \times \underline{F}_I} = \frac{1}{\underline{\Gamma}} \times \frac{\underline{F}_U}{\underline{F}_I}$$



2) Split Z in real and imaginary part

Actual frequency from sampling process

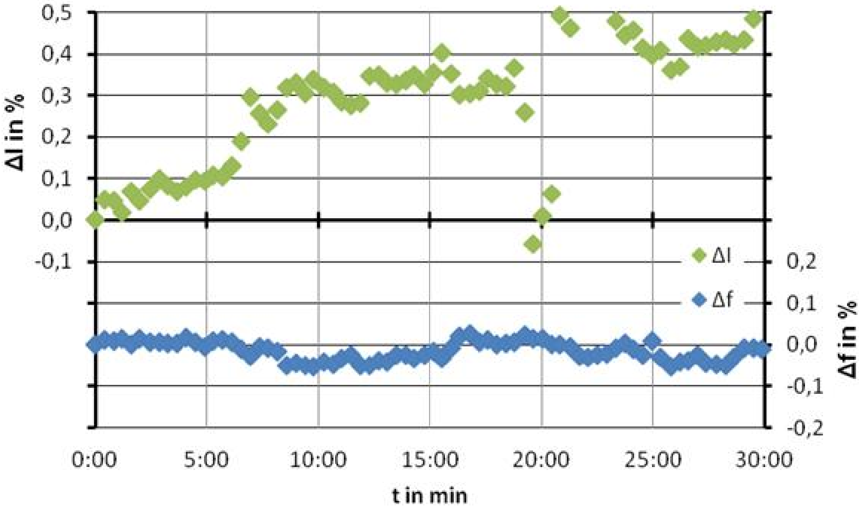
3) Calculation of the equivalent circuit (R-L, R-C, series, parallel)

4) Rated Losses based on

Series equivalent: $P_r = I_r^2$ x R or

Parallel equivalent: $P_r = U_r^2$ / R

<u>Calculation of losses</u>: Advantage of Z determination



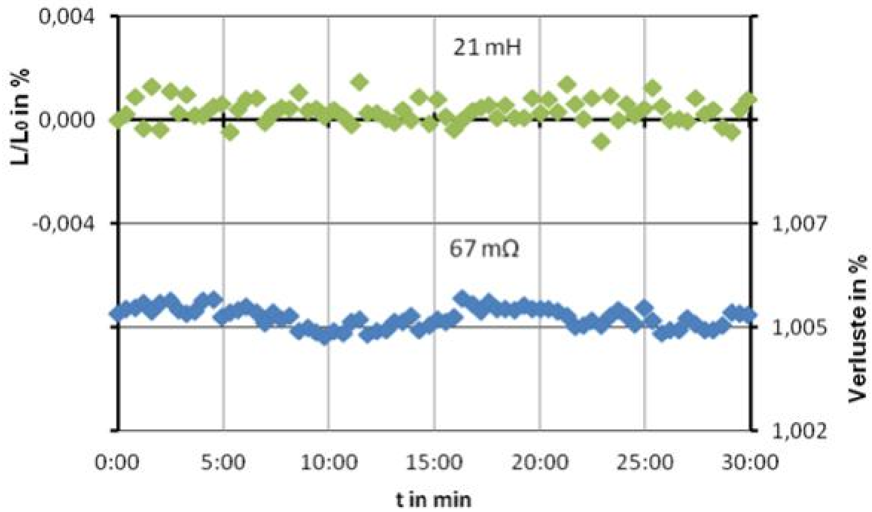
- **Current / Voltage not stable**
- **frequency is not stable**

↓

Measurement of Power is not stable (Type A uncertainty is high)

- **calculated inductor and**
- **calculated resistor**

are stable within ± 20 ppm (Type A uncertainty is low)



Comparison VTT MIKES – PTB:

1) against power standard of PTB with

- **100 V / 5 A**
- **52 Hz**
- **several phase angles within ± 90°**

Both sampling systems agree within ± 10ppm (voltage, current, phase angle, power)

necessary pre-condition for accurate HV measurements

Comparison: Air core reactor (15kVAr)

Inductance: 4,6 mH
Impedance: 1,45 ohm
Rated current: 100 A

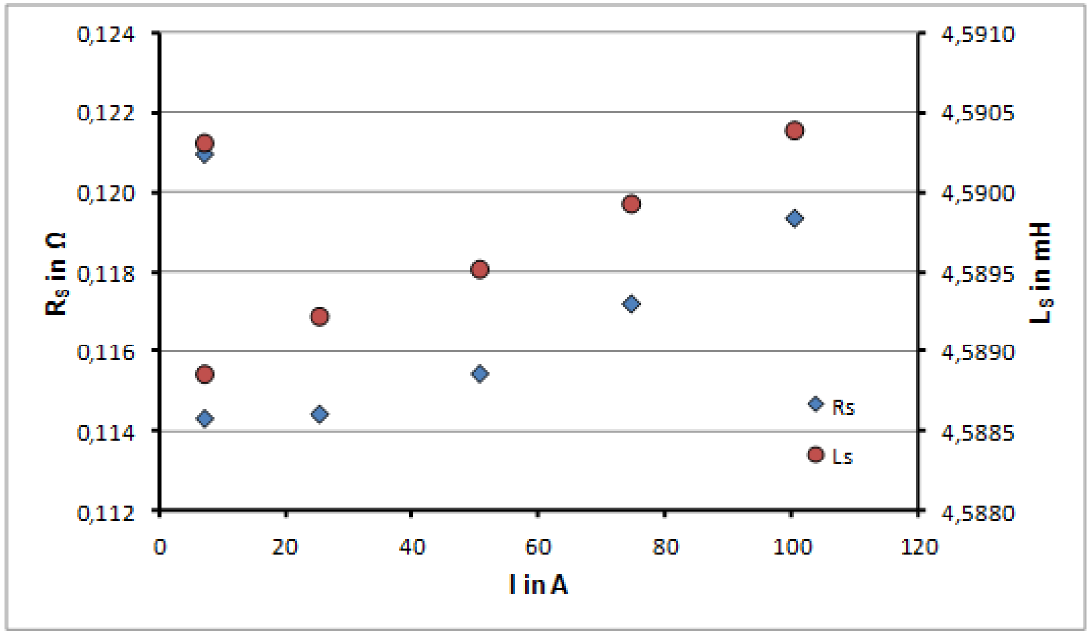
Comparison with	U_P in V	I_P in A	$\Delta\tan\delta$ in 10^{-6}	$s(\Delta\tan\delta)$ in 10^{-6}	ΔL in µH/H
with Rogowski (50Hz) 4,6 mH	36	25	-93	10	83
	73	51	-111	36	72
	108	75	-120	79	189
	145	100	-60	184	168
	10	7	-67	36	7
with shunt (50Hz) 4,6 mH	10	7	-13	8	14

1. Finding: meas. with VTT MIKES Shunt agree better

→ RC calibration prior to the calibration requires more care

Comparison: Air core reactor

2. Finding: self-heating causes change of resistance (here 7%)
→ Higher standard deviation
→ Synchronization of both meas. systems imperfect (to around 2s in 60s)



Comparison: Shunt reactor (50kVAr)

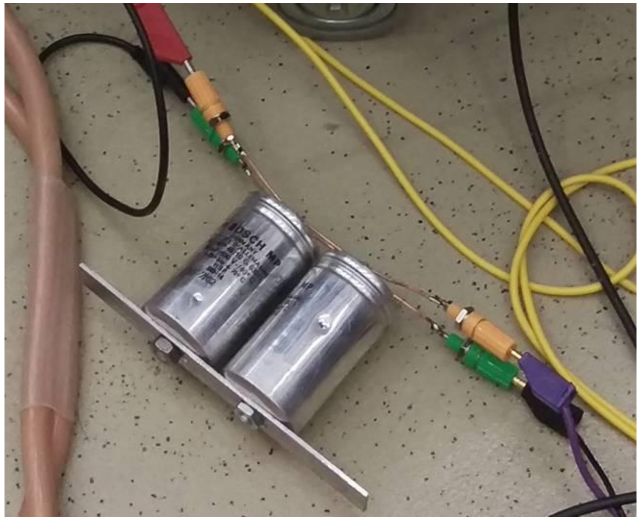
Comparison with	U_P in V	I_P in A	$\Delta\tan\delta$ in 10^{-6}	$s(\Delta\tan\delta)$ in 10^{-6}	ΔL in µH/H
with Rogowski (50Hz) 7 mH	154	70	-83	7	105
	78	35	-99	5	46
with Rogowski (50Hz) 190 mH	176	4	-16	29	51
	65	1	-7	32	-9
with shunt (50Hz) 85 mH	188	6	-16	22	-28
	36	1	1	60	4

Finding: meas. with VTT MIKES Shunt agree better

→ same as with air core inductor

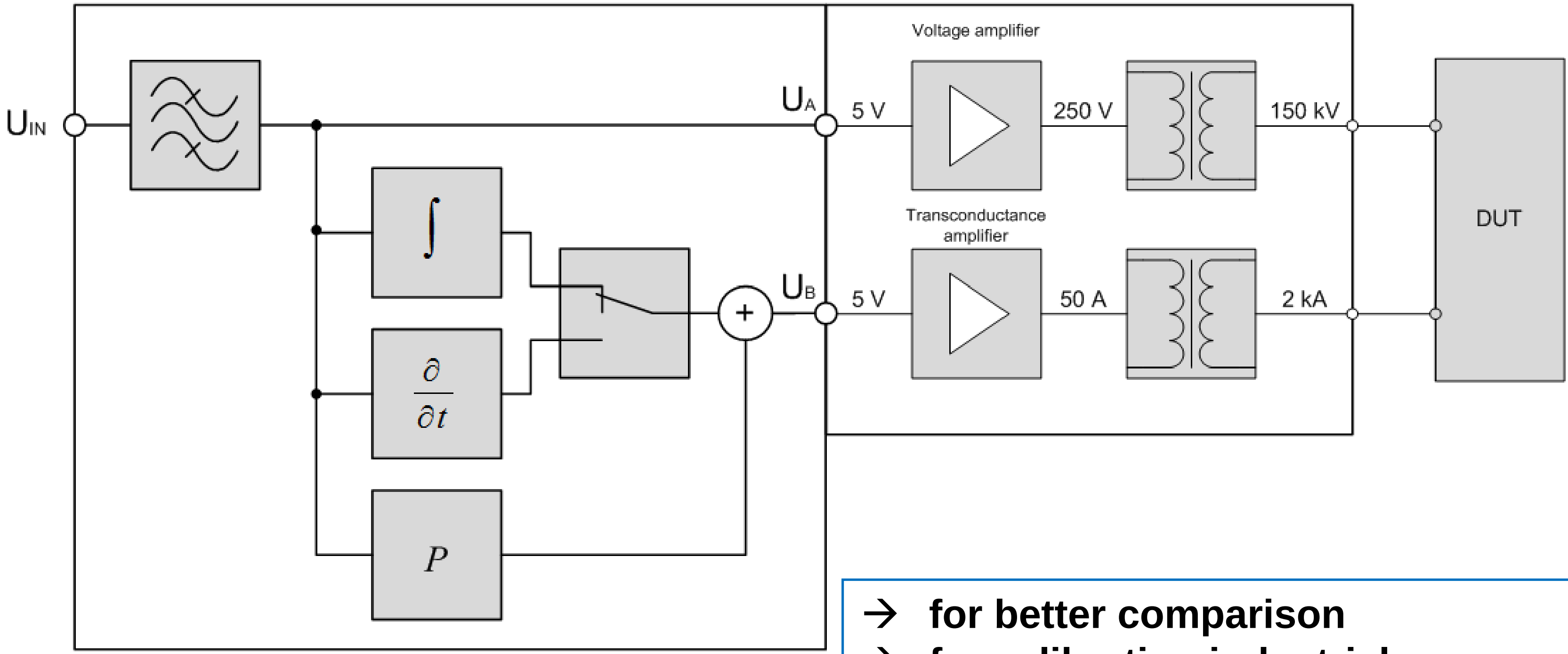
<u>Comparison:</u> Capacitor

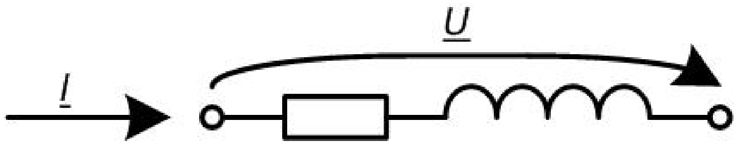
Comparison with	U_P in V	$\Delta \tan\delta$ in 10^{-6}	$s(\Delta \tan\delta)$ in 10^{-6}	ΔC in µF/F
emulated capacitor (53Hz) 50µF; $\tan\delta$=0,001	50	-7	6	16
	100	-9	4	20
	300	-11	9	11
	480	-16	5	21
emulated capacitor (50Hz) 50µF; $\tan\delta$=0,001	50	35	16	-41
	100	8	7	-37
	300	-4	7	13
	480	-11	9	18
low voltage capacitor (50Hz) 20µF; $\tan\delta$=0,004	8	-15	18	113
	80	-8	5	26
	190	1	9	-13



→ good agreement within ± 35 ppm

Phantom Source: Emulator for Reactors and Capacitors





$$u(t) = R \cdot i(t) + L \cdot \frac{di(t)}{dt}$$

→ **for better comparison**
→ **for calibrating industrial meas. systems**

→ **prototype tested**
→ **expected power source in 2016/2017**

Summary:

- Two sampling-based high power measuring systems presented
- First comparison at low voltages and low currents (< 500 V; < 100 A)
- Results show some weaknesses with real compensation components

Future work to be done (→ 2018):

- Establishing a phantom power source for 150 kV and 2 kA
- Repeating the comparison at high voltage / high current

THANKS FOR YOUR ATTENTION

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