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MEASURING CAPABILITIES OF BIM

Workshop on Power and Power Quality Metrology

10th June 2016

CMI, Brno, Czech Republic

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- Short history of metrology in Bulgaria
- Metrology in Bulgaria now
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- NCM capabilities in the field of power quality measurements
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- NCM capabilities in the field of DC Resistance measurements
- NCM capabilities in the field of DC voltage measurements

Short history of metrology in Bulgaria

<u>Legislation</u>:

- 1888 – First Bulgarian Law on Measures and Weights;
- 1910 – Second Bulgarian Law on Measures and Weights;
- 1948 – Third Law on Measures and Weights;
- 1998 - Law on Measurements;
- **2002 - Law on Measurements (with amendment from 2005).**

<u>Structure</u>:

- 1910 – Established the metrological service in Bulgaria;
- 1944 – Transformation in department "Measures and Weights" with 11 sections and 2 main labs for electrical, mechanical and physical measurements;
- 1948 – Rename in "Measures and Measuring Instruments". Established the government metrological offices;
- 1963 - Established the Institute of Standardization, Measures and Measuring Instruments;

Short history of metrology in Bulgaria

Structure:

- 1970 – Committee of Quality, Standardization and Metrology (CQSM);
- 1976 – Established of National Metrological Center to CQSM;
- 1998 – National Center of Metrology and directorate “Measures and Measuring Instruments” as a part of State Agency for Standardization and Metrology;
- 2002 - State Agency for Metrology and Technical Surveillance;
- **2005 – Bulgarian Institute of Metrology.**

Standards:

- 1911 – Bulgaria had 2 measuring standards – for mass (1 kg) and for length (1 m);
- 1972 – Standard for resistance (Ohm);
- 1974 - Standard for voltage (Volt);

Short history of metrology in Bulgaria

Standards:

- 1977 – Established and confirmed 53 national measuring standards;
- 1991 - Established and confirmed 17 national measuring standards;
- up to 2014 – more 8 national measuring standards (the last one for current and voltage ratios at 50 Hz – decision of council of ministry № 430/ 26.06.2014).

<u>Membership in International Organizations</u>:

- 1911 – Bulgaria signed Meter Convention and became a Member State of BIPM;
- 1956 - Bulgaria became a Member State of OIML;
- 1991 - Bulgaria became a Member State of Euro-Asian Cooperation of National Metrological Institutions (COOMET);
- 2003 - Bulgaria became a Member State of EUROMET (now EURAMET)

METROLOGY IN BULGARIA - NOW

Legislation - Law on measurements (2002, amendment of Law 2005)

Responsible institution – Bulgarian Institute of Metrology (BIM)

Scientific Metrology:

- General Directorate National Center of Metrology (NCM)

Legal Metrology:

- General Directorate Measures and Measuring Instruments (MMI) – verification and expertise of measuring instruments
- Directorate for tests – type approvals of MIs, EMC, gaming mashines and fiscal devices

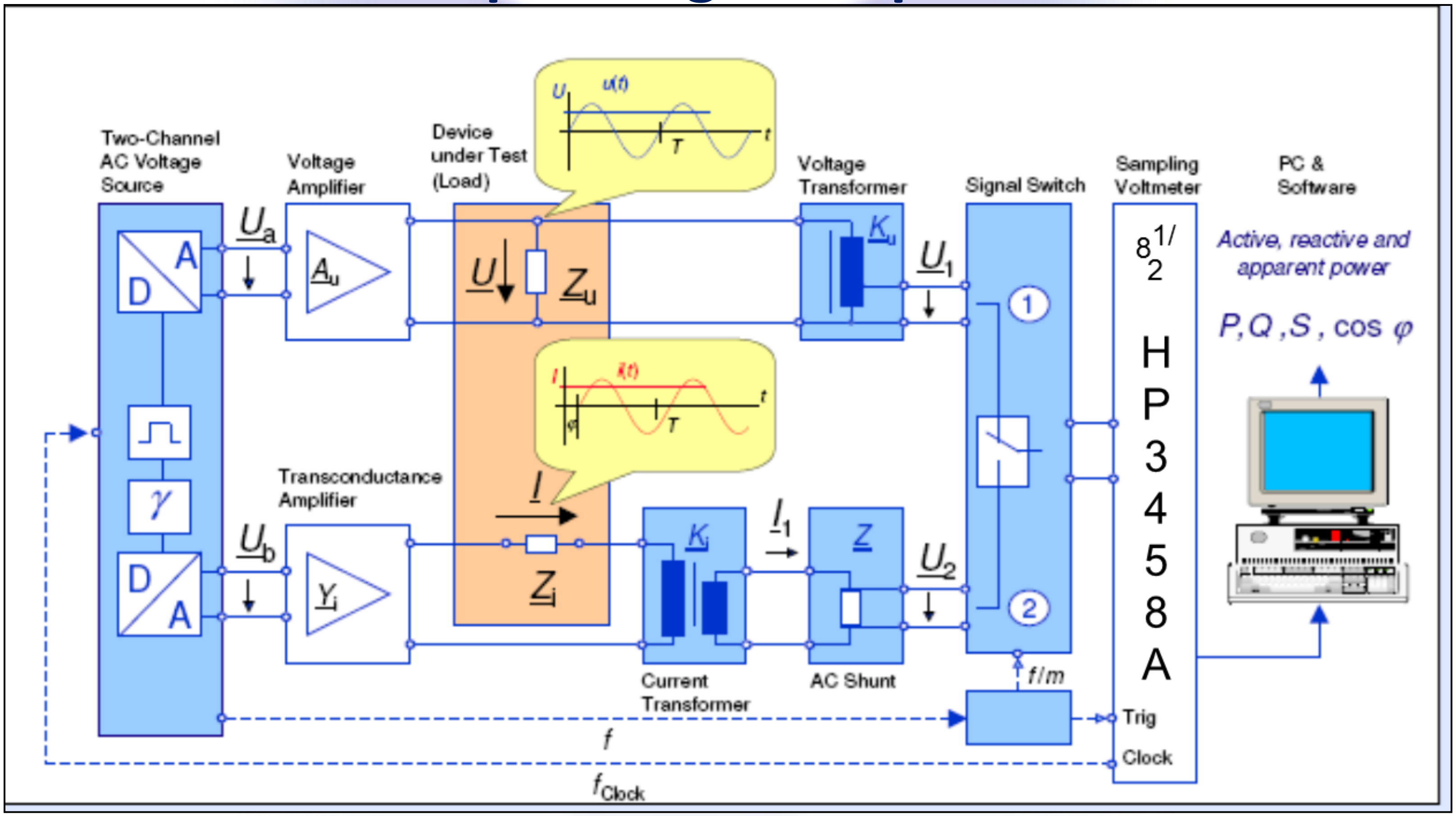
NCM capabilities in the field of power measurements

Precision Power Calibration system PPCS

- This system & concept is originally developed by the scientists from PTB, Germany (Dr. Günther Ram, Harald Moser, Dr. Andreas Braun and other team members)
- This know-how transferred to ZERA GmbH to further design, develop, produce, market & sale.
- In this presentation is used the information, given to BIM's experts from ZERA's specialists during Training on PPCS at NCM Sofia, 23-26.09.2008.

NCM capabilities in the field of power measurements - PPCS

Operating Principle



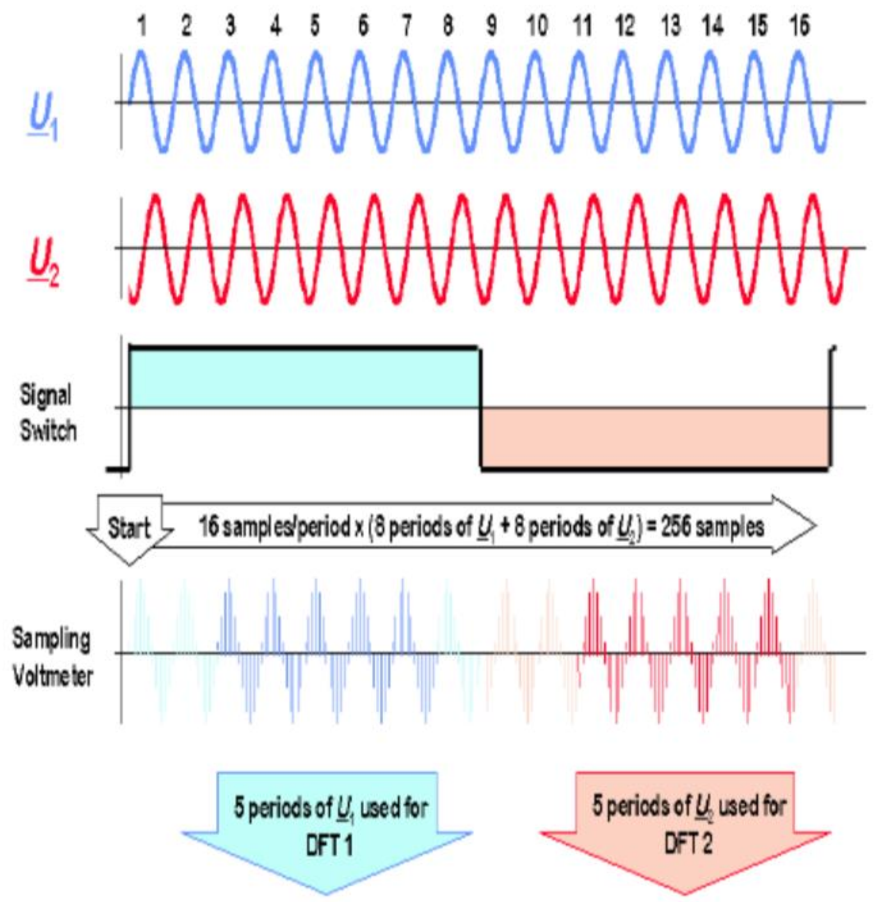
NCM capabilities in the field of power measurements – PPCS. Operating Principle

- The operating principle is based on synthesized AC voltages, the use of a single sampling voltmeter, and on computerized evaluation by means of the Discrete Fourier transformation.
- The traceability to SI units DC voltage & DC resistance is ensured by the RMS voltmeter and the AC shunt with small & well know frequency characteristics, both calibrated against national standards.
- The reduction of the measurement uncertainty is achieved by using a single clock signal for the generation of the required voltage and also for the measurement of these signals. These significantly reduces the
  - Synchronization errors with sampling methods
  - Unavoidable differences between different sampling voltmeters.

NCM capabilities in the field of power measurements – PPCS. Operating Principle

- A Two channel AC voltage source generated from clock signal ƒclock, the sinusoidal voltages Uc & Ub, where the phase shift y between Uc & Ub can be chosen to have any value between 0 ° and ±180 °.
- A voltage amplifier supplies the voltage U1 (e.g. 240 V) to be applied to device under calibration (DUC), and in parallel to the voltage transformer SVT480-120, where secondary of transformer connected to DMM through signal switch.
- A current amplifier generate the test current and to be supplied to DUC & primary of precision current transformer SCT100-120. Secondary of this current transformer burdened with high precision shunt HPR10. The voltage drop across shunt is measured by DMM through signal switch.
- The signal switched is used to supply the sampling alternatively to DMM.

NCM capabilities in the field of power measurements – PPCS. Operating Principle



- Sampling scheme
  - The signal switch has a switching rate of m periods of the signal frequency f.
  - The sampling voltmeter is triggered at the beginning of the m periods and take n samples for each period with an amplitude resolution of at least 21 bits.
  - Synchronizing error is eliminated due to same source- the master clock of the sampling voltmeter.
  - Good result obtained for m=8, n=16 yielding 128 samples for U1 & U2
  - To avoid settling problem first samples after switching are excluded

NCM capabilities in the field of power measurements – PPCS. Operating Principle

- Voltage $\underline{U}$, current $\underline{I}$ and phase shift φ can be calculated

$$\underline{U} = \underline{U}_1 \cdot \underline{K}_\mathrm{u} \,, \qquad \underline{I} = \underline{I}_1 \cdot \underline{K}_\mathrm{i} = \frac{\underline{U}_2}{\underline{Z}} \cdot \underline{K}_\mathrm{i}$$

$$\varphi = \arctan \frac{\mathrm{Im}\{\underline{I}/\underline{U}\}}{\mathrm{Re}\{\underline{I}/\underline{U}\}} \text{ with } \frac{\underline{I}}{\underline{U}} = \frac{\underline{U}_2}{\underline{U}_1} \cdot \frac{\underline{K}_\mathrm{i}}{\underline{K}_\mathrm{u}} \cdot \frac{1}{\underline{Z}}$$

  - $\underline{U}_1$ is the complex output voltage of the voltage transformer
  - $\underline{U}_2$ is the complex voltage drop on the AC shunt with the impedance $\underline{Z}$
  - $\underline{K}_\mathrm{u}$ and $\underline{K}_\mathrm{i}$ are the complex transformation ratios of the voltage- and the current transformer

NCM capabilities in the field of power measurements – PPCS. Operating Principle

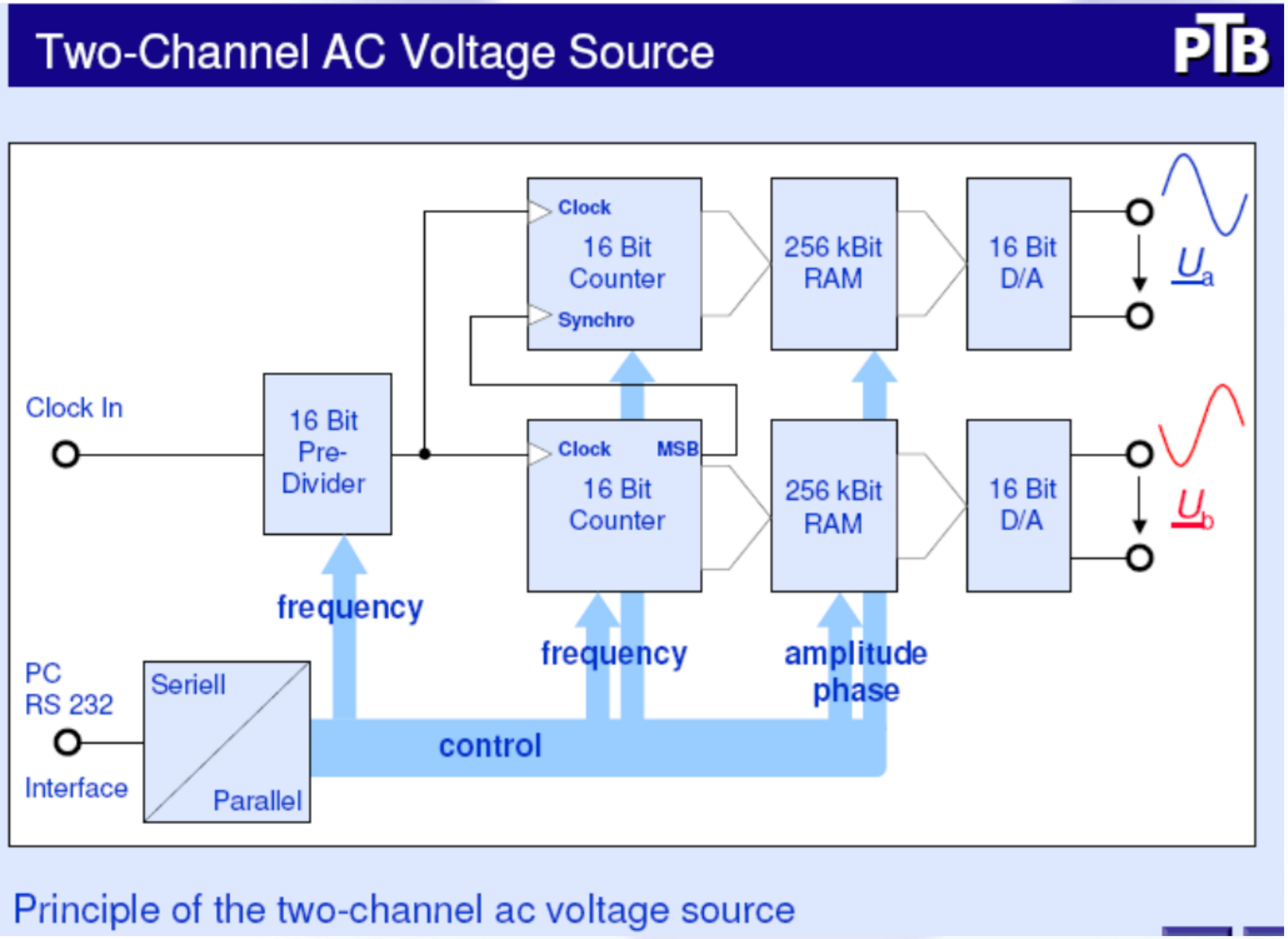
- If the in-phase and quadrature errors of the voltage- and the current transformers and the time constant of the ac shunt are neglected, the equations can be simplified:

$$U = U_1 \cdot K_{nu}, \quad I = U_2 \cdot \frac{K_{ni}}{R_n}$$

$$\varphi = \arctan \frac{\mathrm{Im}\{\underline{U}_2 / \underline{U}_1\}}{\mathrm{Re}\{\underline{U}_2 / \underline{U}_1\}}$$

  - U1 is the rms value of $\underline{U}1$
  - U2 is the rms value of $\underline{U}2$
  - K_{nu} and K_{ni} are the nominal values of $\underline{K}u$ and $\underline{K}i$
  - R_n is the nominal value of the resistance of $\underline{Z}$

NCM capabilities in the field of power measurements – PPCS. Operating Principle



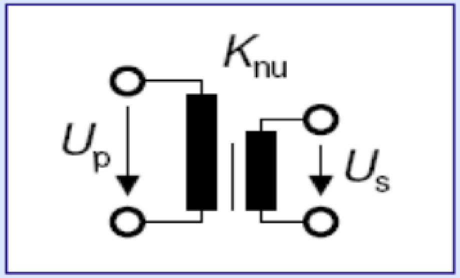
Concept on which DAC 5329

+ ADC 5331 function is based

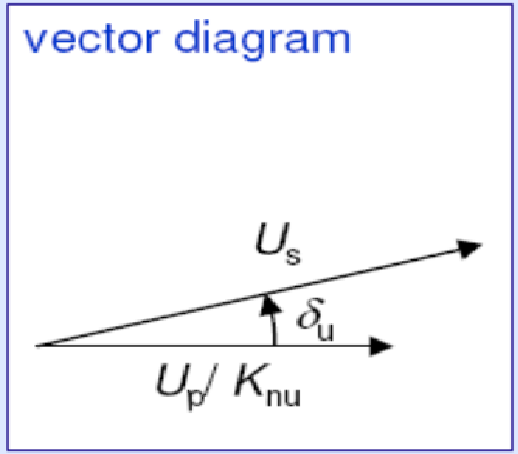
NCM capabilities in the field of power measurements – PPCS. Operating Principle

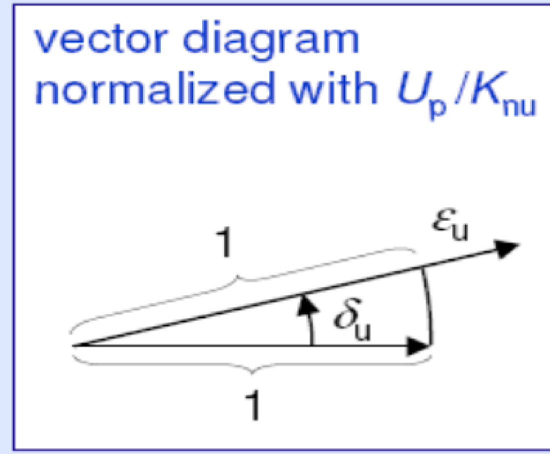
Voltage Transformer

Principle of the voltage transformer



$$\varepsilon_u = \frac{K_{nu} \cdot U_s - U_p}{U_p}$$





$$\varepsilon_u \approx (100 \ldots 300)\cdot 10^{-6} \pm (10 \ldots 30)\cdot 10^{-6}$$

- U_p primary voltage
- U_s secondary voltage
- K_{nu} nominal transformation ratio
- ε_u ratio error (voltage error)
- δ_u phase displacement

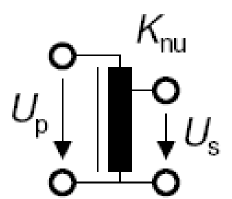
NCM capabilities in the field of power measurements – PPCS. Operating Principle

Inductive Voltage Divider (Auto-Transformer)

PTB

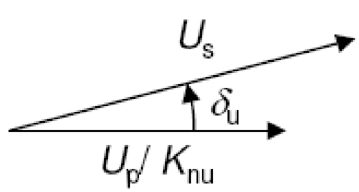
Principle of an inductice voltage divider

(auto-transformer, only one tapped winding, no electrical insulation between primary and secondary voltage)

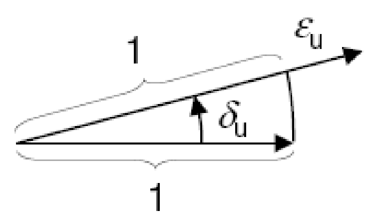


$$\varepsilon_u = \frac{K_{nu} \cdot U_s - U_p}{U_p}$$

vector diagram



vector diagram normalized with U_p / K_{nu}

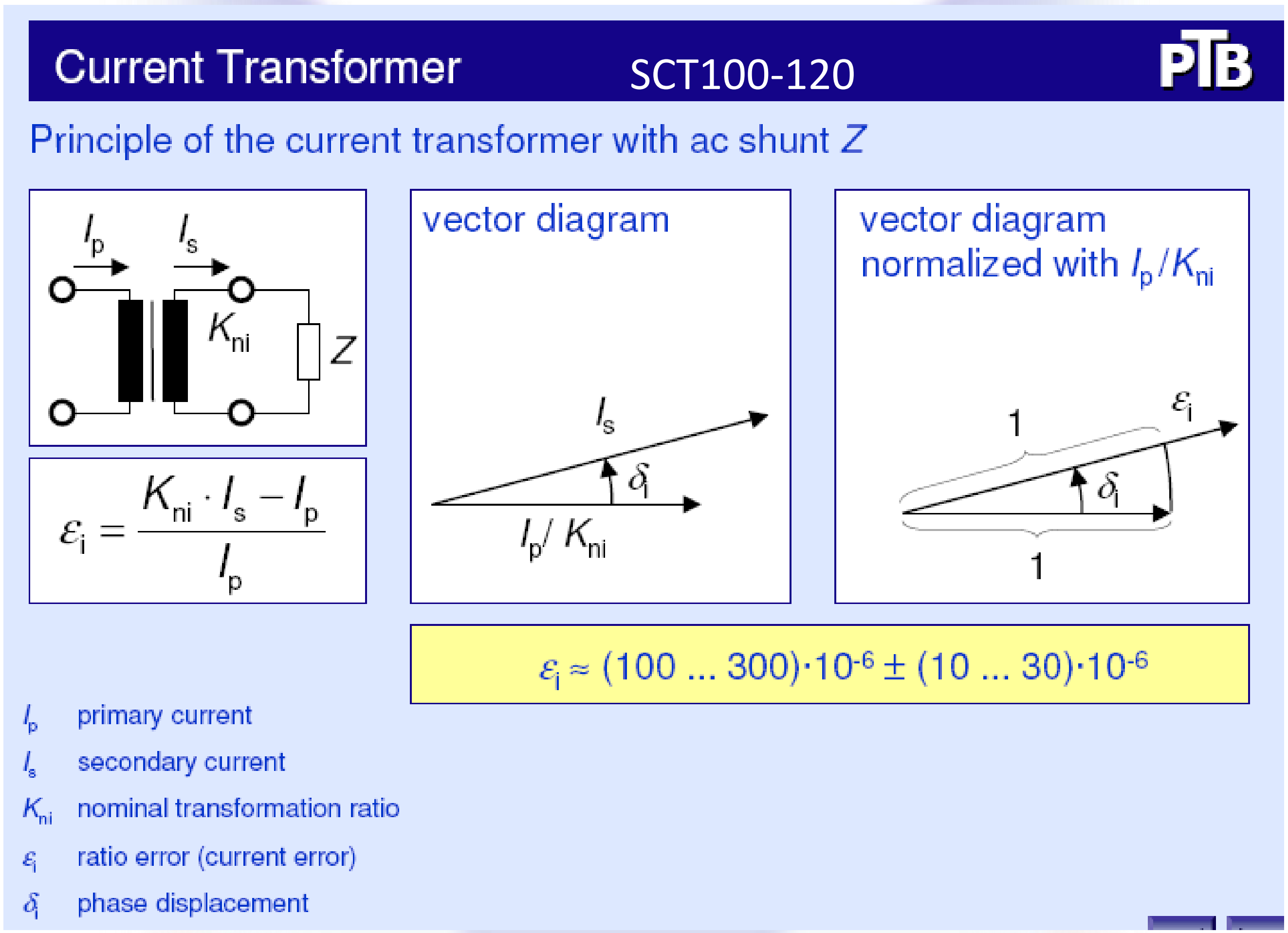


$\varepsilon_u \approx (10 \ldots 50) \cdot 10^{-6} \pm (1 \ldots 5) \cdot 10^{-6}$

- U_p primary voltage
- U_s secondary voltage
- K_{nu} nominal transformation ratio
- ε_u ratio error (voltage error)
- δ_u phase displacement

Concept on which SVT 480-120 is based

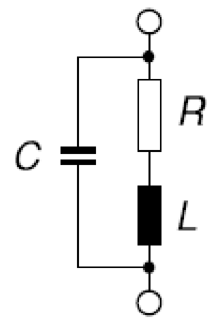
NCM capabilities in the field of power measurements – PPCS. Operating Principle



NCM capabilities in the field of power measurements – PPCS. Operating Principle

AC Shunt **HPR 10** PTB

Simplified equivalent circuit of an ac shunt



$$\underline{Z} = R \cdot (1 + \mathrm{j} \cdot \omega \cdot \tau)$$

$$\tau = \frac{L}{R} - R \cdot C$$

$$\varphi = \arctan(\omega \cdot \tau) = \arctan \omega \cdot \left(\frac{L}{R} - R \cdot C \right)$$

$\tau \approx$ (-100 ... +100) ns ± (1 ... 10) ns

$\underline{Z}$ impedance of the ac shunt (with resistance R, inductance L and capacitance C)

τ time constant of the ac shunt

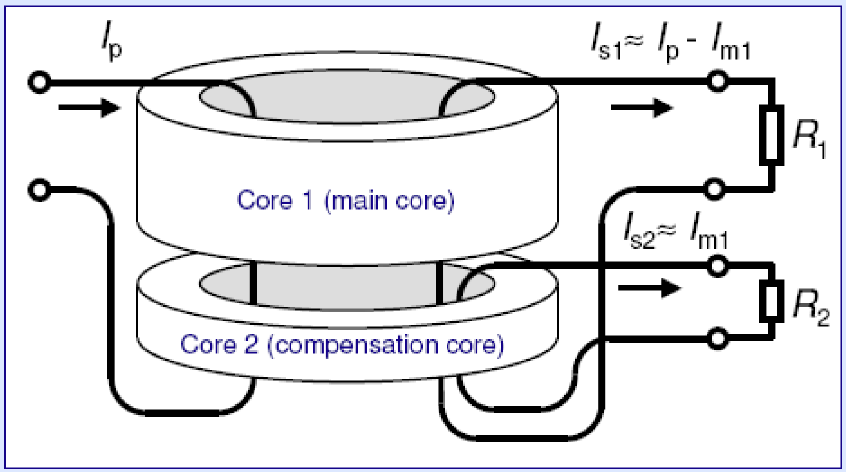
φ phase angle between current and voltage

NCM capabilities in the field of power measurements – PPCS. Operating Principle

Two-stage Current Transformer

PTB

Principle of a two-stage current transformer of high accuracy (shown for $K_{ni} = 1$)



$$\varepsilon_i = \frac{K_{ni} \cdot (I_{s1} + I_{s2}) - I_p}{I_p}$$

$$\varepsilon_i \approx (1 \ldots 5) \cdot 10^{-6} \pm (1 \ldots 5) \cdot 10^{-6}$$

I_p primary current (encloses both cores)

I_{s1} secondary current of main winding

I_{m1} magnetizing current of main core

I_{s2} secondary current of compensation core (approximatly equal to I_{m1})

(magnetizing current of compensation core neglected)

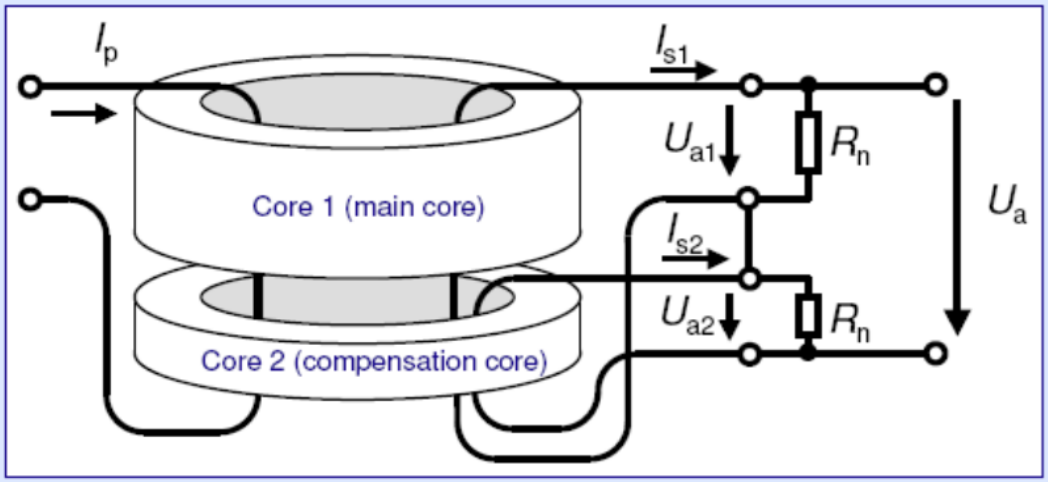
Concept on which SCT100-120 is based

NCM capabilities in the field of power measurements – PPCS. Operating Principle

Precise Current-to-Voltage Transducer

PTB

Principle of a precise current-to-voltage transducer based on a two-stage current transformer and two ac shunts



The phase displacement δ_{iu} between input current and output voltage is not shown in this simplified presentation. δ_{iu} is caused by the phase displacement of the current transformer and by the time constants of the ac shunts and amounts to about 10 µrad with best possible uncertainties of about 1 µrad.

- I_p primary input current
- U_a output voltage
- K_{iu} current-to-voltage transformation ratio
- ε_{iu} current-to-voltage ratio error

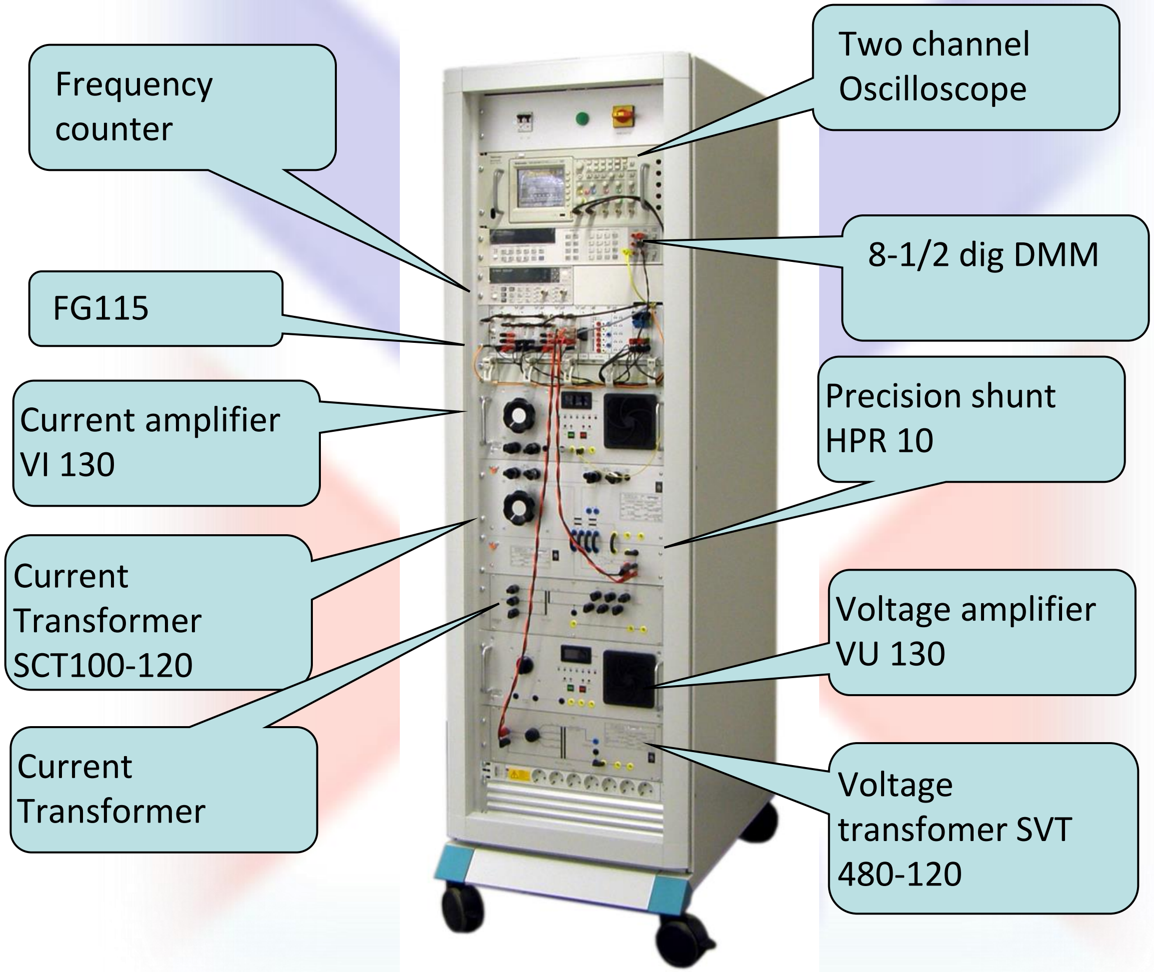
$$K_{iu} = \frac{U_{a1} + U_{a2}}{I_p} = \frac{U_a}{I_p} = \frac{R_n}{K_{ni}} \cdot (1 + \varepsilon_{iu})$$

$$\varepsilon_{iu} \approx (1 \ldots 10) \cdot 10^{-6} \pm (1 \ldots 10) \cdot 10^{-6}$$

SCT100-120

With HPR10

NCM capabilities in the field of power measurements – Components of PPCS



CMC

AC power and energy: single phase (frequencies below or equal to 400 Hz): **active; reactive & apparent power**. Power meter, power converter, power comparator, wattmeter, power calibrator,

0 W (var; VA) to 48000 W (var; VA)

Relative expanded uncertainty (k = 2, level of confidence 95 %) in µW/VA (µvar/VA; µVA/VA): **16 to 150**

Direct comparison

Voltage: 10 V to 480 V

Current: 0.002 A to 100 A

Power factor: 1 to 0 inductive or capacitive

Frequency: 46 Hz to 65 Hz

Approved on 06 August 2013

Internal NMI service identifier: BIM/52; BIM/84; BIM/85

Uncertainty table

CMC

AC power and energy: three phase: active, reactive & apparent power. Power meter, power converter, power comparator, wattmeter, power calibrator,

0 W (var; VA) to 144000 W (var; VA)

Relative expanded uncertainty (k = 2, level of confidence 95 %) in µW/VA (µvar/VA; µVA/VA): **16 to 170**

Direct comparison

Voltage: 10 V to 480 V

Current: 0.002 A to 100 A

Power factor: 1 to 0 inductive or capacitive

Frequency: 46 Hz to 65 Hz

Approved on 06 August 2013

Internal NMI service identifier: BIM/87, BIM/88, BIM/89

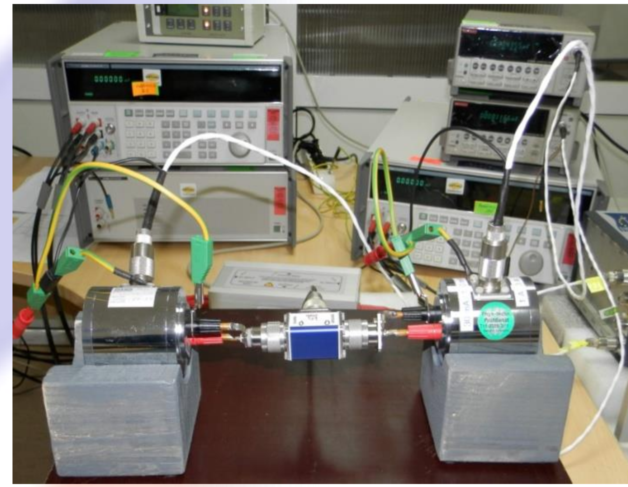
Uncertainty table

NCM capabilities in the field of power quality measurements

<u>Fully configured 4-phase Electrical Power Standard system – 6140, FLUKE</u>

- Voltage range: from 1 V to 1000 V;
- Current range: from 10 mA to 80 A;
- Phase angle between voltage and current: from 0 ° to ±180 º;
- Frequency range; from 16 Hz to 500 Hz;
- Generation of harmonics and interharmonics (up to 5 kHz);
- Generation of flicker according to EN 61000-4-15;
- Voltage dips and swells.

NCM capabilities in the field of AC current measurements



AC-DC current measurements

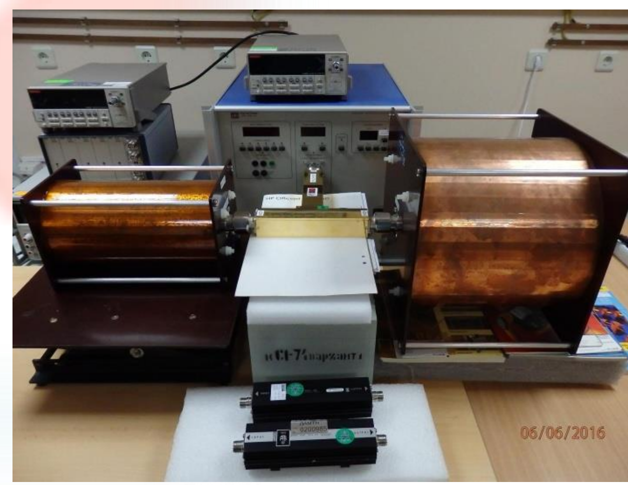
Step-up procedure

Fluke calibrators 5720A, Transcpnductance amplifier C&H 8100, Nanovoltmeters Keithley 2182A,

Marian Kampic's AC-DC switching system

Set of Fluke shunts A40 and A40A

from 2 mA to 20 A , from 10 Hz to 100 kHz



Future work: extended to 100 A

Shunts: V16/80A/8 и V16/40A/8

NCM capabilities in the field of AC current measurements- CMCs

AC-DC current measurements

Based on results in EURAMET-EM-K12 CMCs will be improve to:

from 2 mA to 20 A , from 10 Hz to 100 kHz

Uncertainty: from 5 to 42 μA/A

In the range from 50 A to 100 A shunts are measured in BEV

Uncertainty: from 13 to 80 μA/A

NCM capabilities in the field of DC Resistance measurements

Resistance ratio bridge based on DCC

High accuracy automated system MI 6010C

Resistance bridge 6010C

Extender 6011C(100 A)

DC current source 6100A (100A)

Resistance: from 0,000 1 Ω to 10 kΩ

Automated high resistance bridge MI 6000B

DC source 1000 A for 100 V

Air bath MI 9300

Resistance : from 10 kΩ to 1 GΩ

NCM capabilities in the field of DC Resistance measurements -CMCs

Resistance, fixed resistors: from 0,000 1 Ω to 1 Ω
Uncertainty: from 0,2 to 9 μΩ/Ω

Resistance, fixed resistors : from 10 Ω to 1 MΩ
Uncertainty: from 0,3 to 1,8 μΩ/Ω

Resistance, fixed resistors : from 10 MΩ to 1 GΩ
Uncertainty: from 3,2 to 110 μΩ/Ω

Resistance, fixed resistors : from 10 GΩ to 100 TΩ
Uncertainty: from 1000 to 6000 μΩ/Ω

NCM capabilities in the field of DC voltage measurements

Hot news for DC voltage capabilities:

Three-channel microprocessor controlled system 10 Volt Josephson Voltage standard including mechanical cryocooler, developed by IPHT Jena was implemented

at 10 V difference to primary JVS system at IPHT

$U_{no.13} - U_{IPHT} = -0{,}9$ nV , or $U_{no.13}/U_{IPHT} - 1 = 9\text{x}10\text{-}11$

relative combined uncertainty (k=1)

$u_c/u_{no.13} = 2{,}75 \text{ x}10^{-10}$

THANK YOU FOR YOUR ATTANTION!