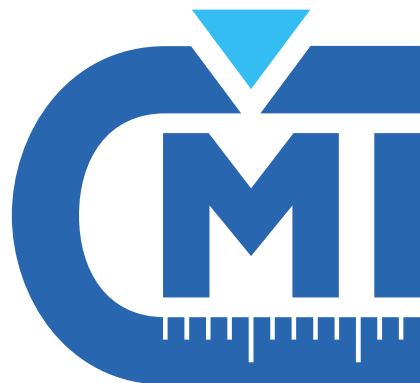


Informace z konference CPEM a o projektech ČMI

*Martin Šíra
Český Metrologický Institut, Brno*

57. Konference ČKS se
zaměřením na akreditaci a
autorizaci metrologických
pracovišť, tachografů, ...
7.11. a 8.11. 2018
HOTEL Skalský Dvůr
Lísek u Bystřice nad Pernštejnem



Conference on Precision Electromagnetic Measurements



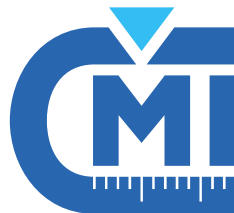
Místo konání:
Paříž

- 8. – 13. 7. 2018
- 500 účastníků
z 50 zemí
- 481 příspěvků:
 - 168 přednášek
 - 313 posterů



Témata konference

1. Fundamental Constants and universality tests
2. Redefinition of the SI and its implementation
3. Realisation and dissemination of the kilogram in the revised SI
4. Time and frequency
5. Quantum electrical standards I
6. Quantum electrical standards II
7. Photonics and optical metrology
8. Novel Sensors and Measurements
9. Current
10. Voltage
11. DC Resistance
12. Impedance
13. Magnetics
14. Power and Energy
15. High voltage and current
16. Radio Frequency / Microwave



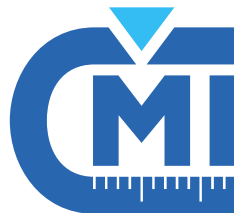
Revize SI

- Problému se týkalo přes 20 příspěvků, z toho 3 klíčové přednášky (historie SI)
- CODATA (Committee on Data of the International Council for Science): speciální vydání k revizi SI
- O nové SI bude rozhodnuto na 26. konferenci o váhách a mírách (General Conference on Weights and Measures, CGPM) **16. 11. 2018.**
- Z konference bude přímý přenos, viz **bipm.org.**

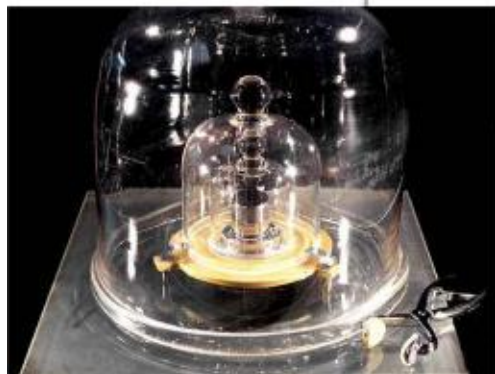
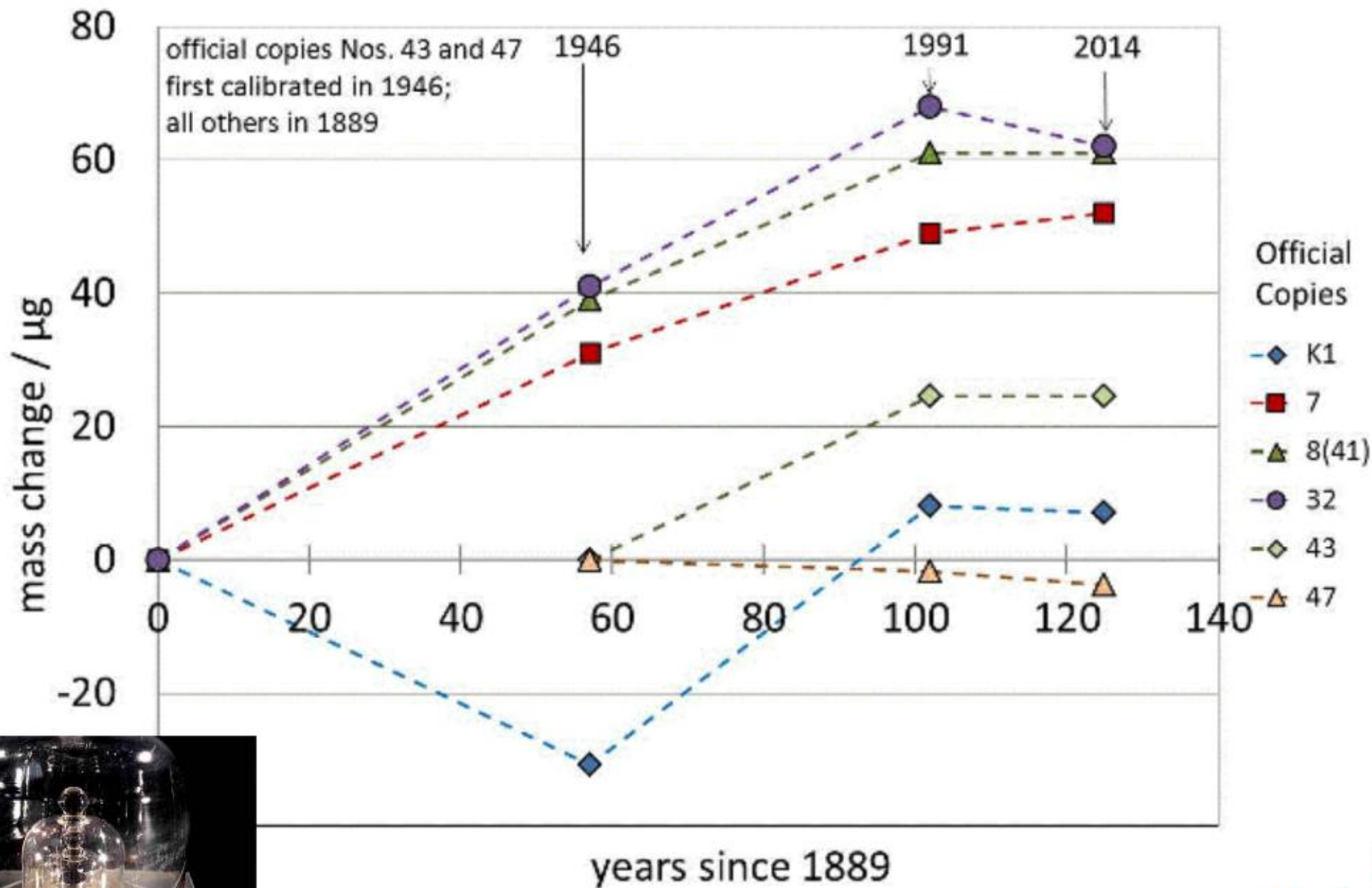


Proč revize SI?

- IPK je poslední artefakt v SI
- měření malých hmotností má velkou nejistotu
- elektrické veličiny jsou používány mimo SI
(protože nejistoty h a e jsou příliš velké)
- definice K je závislá na vlastnostech vody
(čistotě, okolních podmínkách)
- mol je závislý na kg
- nestabilita IPK
(IPK ztrácí svou hmotnost)



Stabilita IPK



Princip změny SI

Nyní:



Princip změny SI

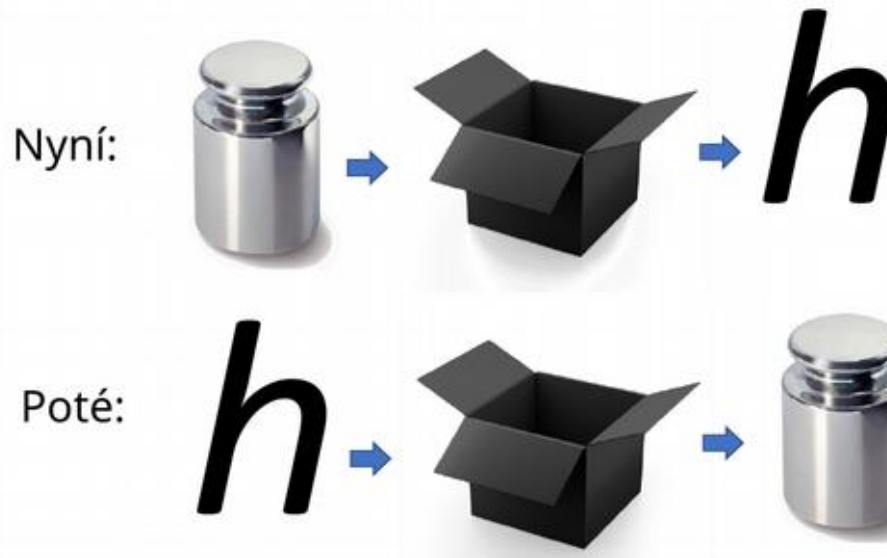
Nyní:



Poté:



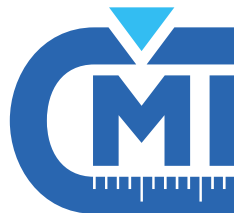
Princip změny SI



www.bipm.org

Nyní
definované artefakty
nulová nejistota c
nenulová nejistota h
nulová nejistota ϵ_0
nulová nejistota IPK

Po revizi
definované hodnoty konstant
nulová nejistota c
nulová nejistota h
nenulová nejistota ϵ_0
nenulová nejistota IPK

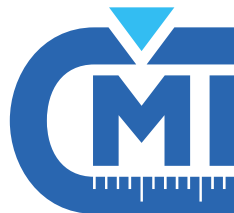


Hodnoty konstant pro novou SI

Quantity	Value	Rel. stand. Uncert u_r
h	$6.626\,070\,150(69) \times 10^{-34} \text{ J s}$	1.0×10^{-8}
e	$1.602\,176\,6341(83) \times 10^{-19} \text{ C}$	5.2×10^{-9}
k	$1.380\,649\,03(51) \times 10^{-23} \text{ J K}^{-1}$	3.7×10^{-7}
N_A	$6.022\,140\,758(62) \times 10^{23} \text{ mol}^{-1}$	1.0×10^{-8}

Quantity	Value
h	$6.626\,070\,15 \times 10^{-34} \text{ J s}$
e	$1.602\,176\,634 \times 10^{-19} \text{ C}$
k	$1.380\,649 \times 10^{-23} \text{ J K}^{-1}$
N_A	$6.022\,140\,76 \times 10^{23} \text{ mol}^{-1}$

D. B. Newell, 'The CODATA 2017 Special Adjustment for the revision of the SI', presented at the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018), Paris, France, 2018.



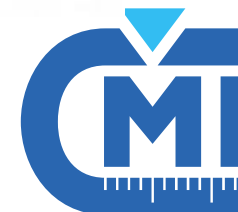
Revize SI: klíčová data

Identification ^a	Quantity ^b	Value	Rel. stand. Uncert u_r
NIST-15	h	$6.626\,069\,36(38) \times 10^{-34} \text{ J s}$	5.7×10^{-8}
NRC-17	h	$6.626\,070\,133(60) \times 10^{-34} \text{ J s}$	9.1×10^{-9}
NIST-17	h	$6.626\,069\,934(88) \times 10^{-34} \text{ J s}$	1.3×10^{-8}
LNE-17	h	$6.626\,070\,40(38) \times 10^{-34} \text{ J s}$	5.7×10^{-8}
IAC-11	N_A	$6.022\,140\,95(18) \times 10^{23} \text{ mol}^{-1}$	3.0×10^{-8}
IAC-15	N_A	$6.022\,140\,70(12) \times 10^{23} \text{ mol}^{-1}$	2.0×10^{-8}
IAC-17	N_A	$6.022\,140\,526(70) \times 10^{23} \text{ mol}^{-1}$	1.2×10^{-8}
NMIJ-17	N_A	$6.022\,140\,78(15) \times 10^{23} \text{ mol}^{-1}$	2.4×10^{-8}
NIST-88	R	$8.314\,470(15) \text{ J mol}^{-1} \text{ K}^{-1}$	1.8×10^{-6}
LNE-09	R	$8.314\,467(23) \text{ J mol}^{-1} \text{ K}^{-1}$	2.7×10^{-6}
NPL-10	R	$8.314\,468(26) \text{ J mol}^{-1} \text{ K}^{-1}$	3.2×10^{-6}
LNE-11	R	$8.314\,455(12) \text{ J mol}^{-1} \text{ K}^{-1}$	1.4×10^{-6}
LNE-15	R	$8.314\,4615(84) \text{ J mol}^{-1} \text{ K}^{-1}$	1.0×10^{-6}
INRIM-15	R	$8.314\,4743(88) \text{ J mol}^{-1} \text{ K}^{-1}$	1.1×10^{-6}
LNE-17	R	$8.314\,4614(50) \text{ J mol}^{-1} \text{ K}^{-1}$	6.0×10^{-7}
NPL-17	R	$8.314\,4603(58) \text{ J mol}^{-1} \text{ K}^{-1}$	7.0×10^{-7}
NIM-17	R	$8.314\,459(17) \text{ J mol}^{-1} \text{ K}^{-1}$	2.0×10^{-6}
PTB-17	$A_e(^4\text{He})/R$	$6.221\,140(12) \times 10^{-8} \text{ m}^3 \text{ K J}^{-1}$	1.9×10^{-6}
NIM/NIST-17	k/h	$2.083\,6630(56) \times 10^{10} \text{ Hz K}^{-1}$	2.7×10^{-6}

D. B. Newell, 'The CODATA 2017 Special Adjustment for the revision of the SI', presented at the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018), Paris, France, 2018.

^a IAC: International Avogadro coordination; INRIM Istituto Nazionale di Ricerca Metrologica, Torino, Italy; LNE: Laboratoire national de métrologie et d'essais, Trappes and La Plaine-Saint-Denis, France; NIM: National Institute of Metrology, Beijing, PRC; NIST: National Institute of Standards and Technology, Gaithersburg, MD, and Boulder CO, USA; NMIJ: National Metrology Institute of Japan, Tsukuba, Japan; NPL: National Physical Laboratory, Teddington, UK; NRC: National Research Council Canada, Ottawa, Canada; PTB: Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Germany

^b h : Planck constant; N_A : Avogadro constant; R : molar gas constant; $A_e(^4\text{He})/R$: molar polarizability of ^4He gas to the molar gas constant quotient; k/h : Boltzmann constant to Planck constant quotient



Metody měření h

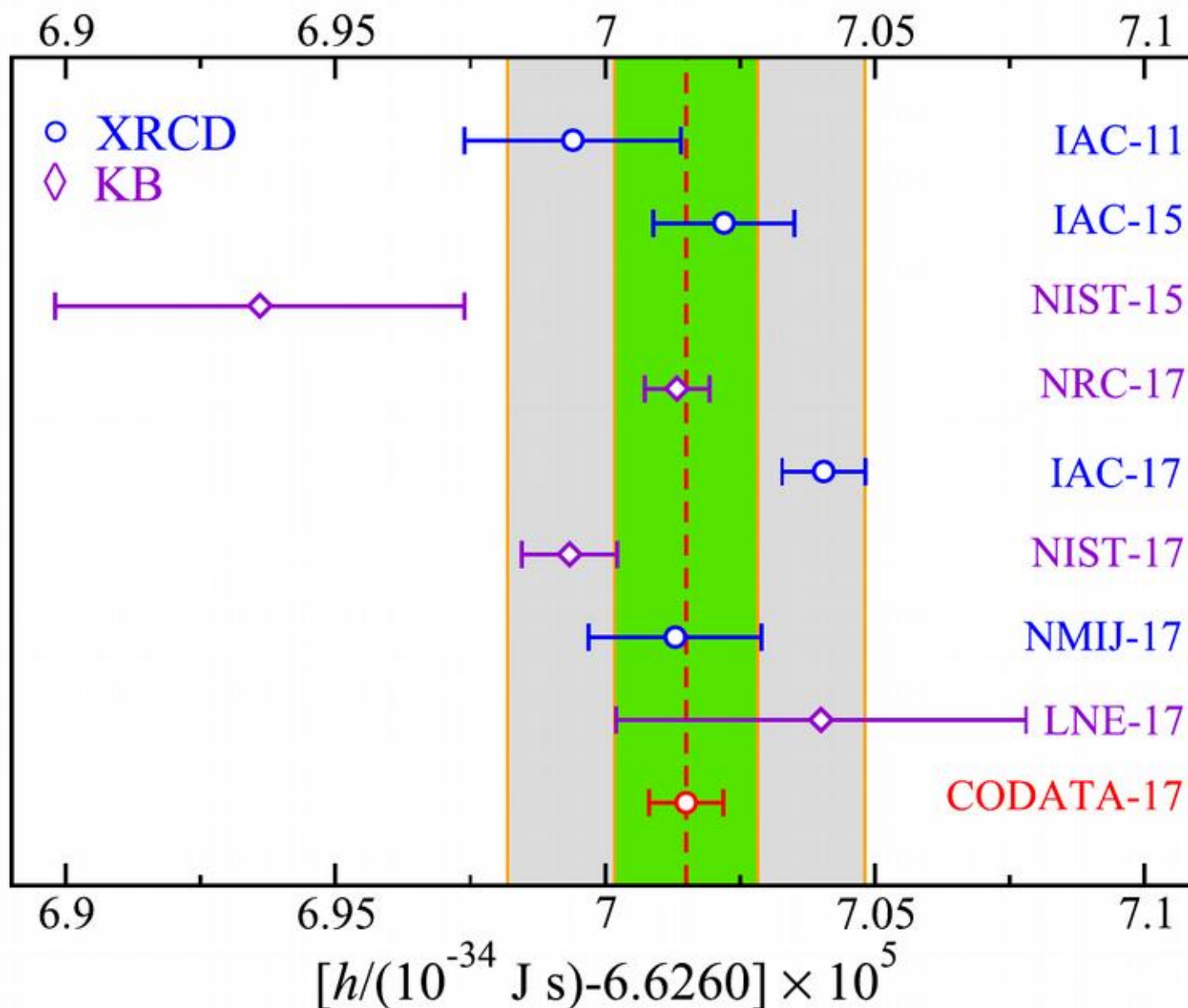


Kibble balance
Elektromagnetické váhy

XRCD
Počítání atomů v kouli z ^{28}Si



Revize SI: měření h



Metody měření k



**AGT – Acoustic gas
thermometry**
Rychlost zvuku vs teplota

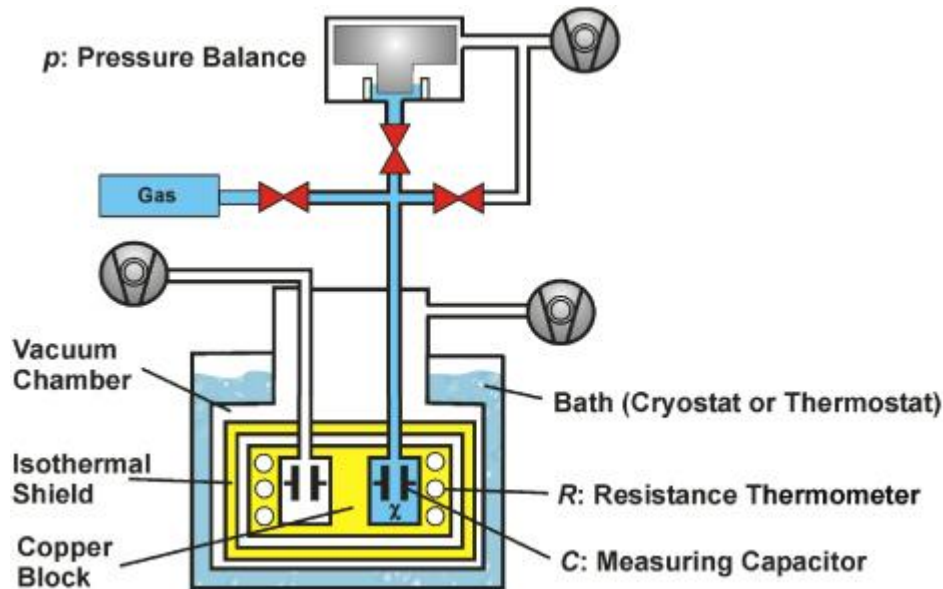
Michael R. Moldover, Weston L. Tew, Howard W. Yoon, *Advances in thermometry*, Nature Physics, **12**, pages 7–11 (2016)

Metody měření k



AGT – Acoustic gas thermometry

Rychlost zvuku vs teplota



DCGT – Dielectric Constant Gas thermometry

Dielektrické vlastnosti plynu

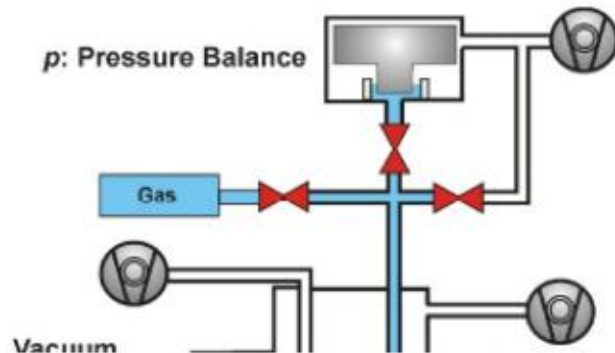
Christof Gaiser, Thorsten Zandt, Bernd Fellmuth,
Dielectric-constant gas thermometry, Metrologia, **52**,
Number 5, 2015

Metody měření k



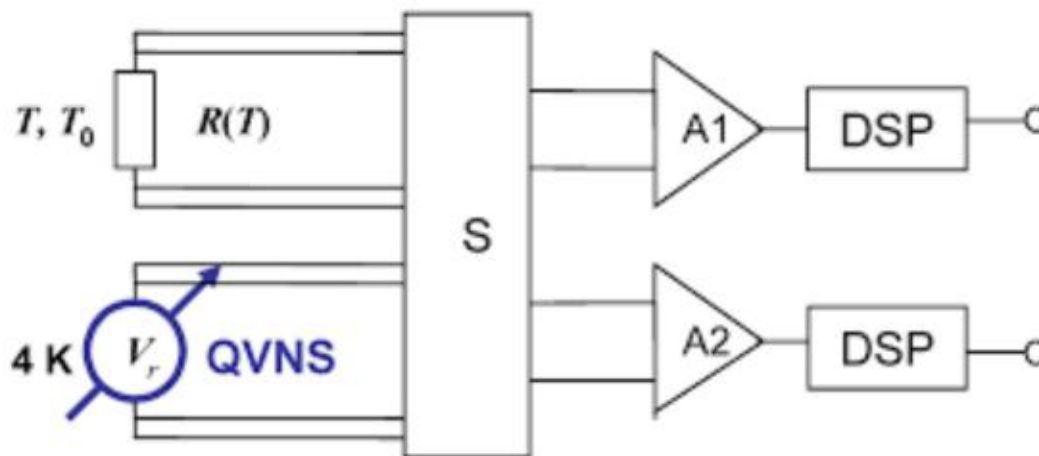
AGT – Acoustic gas thermometry

Rychlost zvuku vs teplota



DCGT – Dielectric Constant Gas thermometry

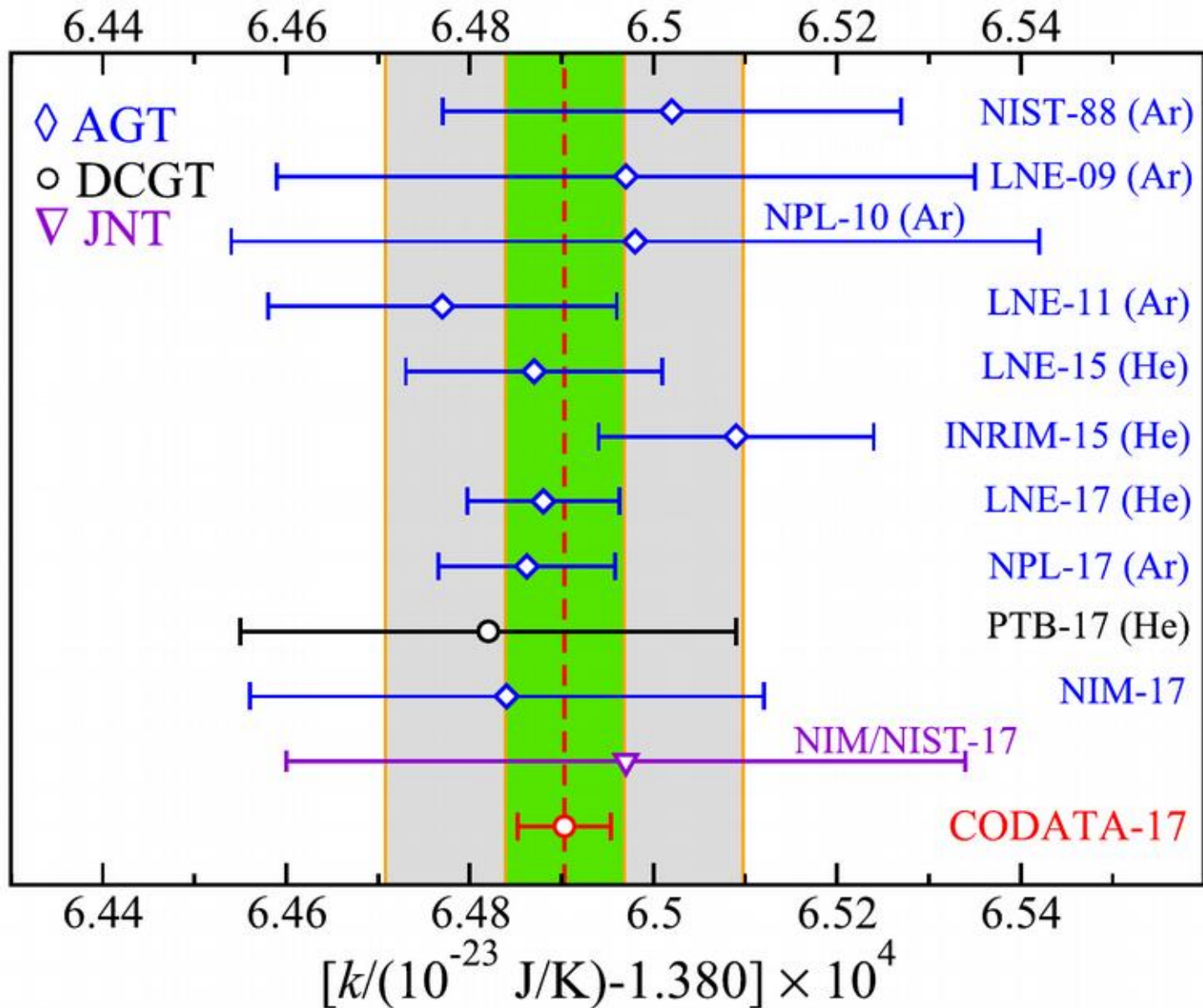
Dielektrické vlastnosti plynu



JNT – Johnson Noise Thermometry

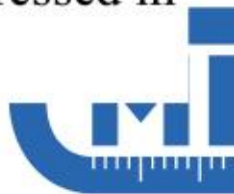
Josephsonův jev jako simulátor teplotního šumu odporu

Revize SI: měření k



Nové definice jednotek: s, m, k, A

- The **second**, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{\text{Cs}}$, the unperturbed ground-state hyperfine transition frequency of the caesium 133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1} .
- The **metre**, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299 792 458 when expressed in the unit m/s, where the second is defined in terms of $\Delta\nu_{\text{Cs}}$.
- The **kilogram**, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be $6.626\,070\,15 \times 10^{-34}$ when expressed in the unit J s, which is equal to $\text{kg m}^2 \text{s}^{-1}$, where the metre and the second are defined in terms of c and $\Delta\nu_{\text{Cs}}$.
- The **ampere**, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge e to be $1.602\,176\,634 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{\text{Cs}}$.



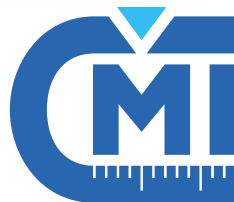
Staré definice jednotek: s, m, k, A

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.

The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

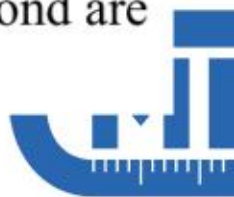


Nové definice jednotek: K, mol, cd

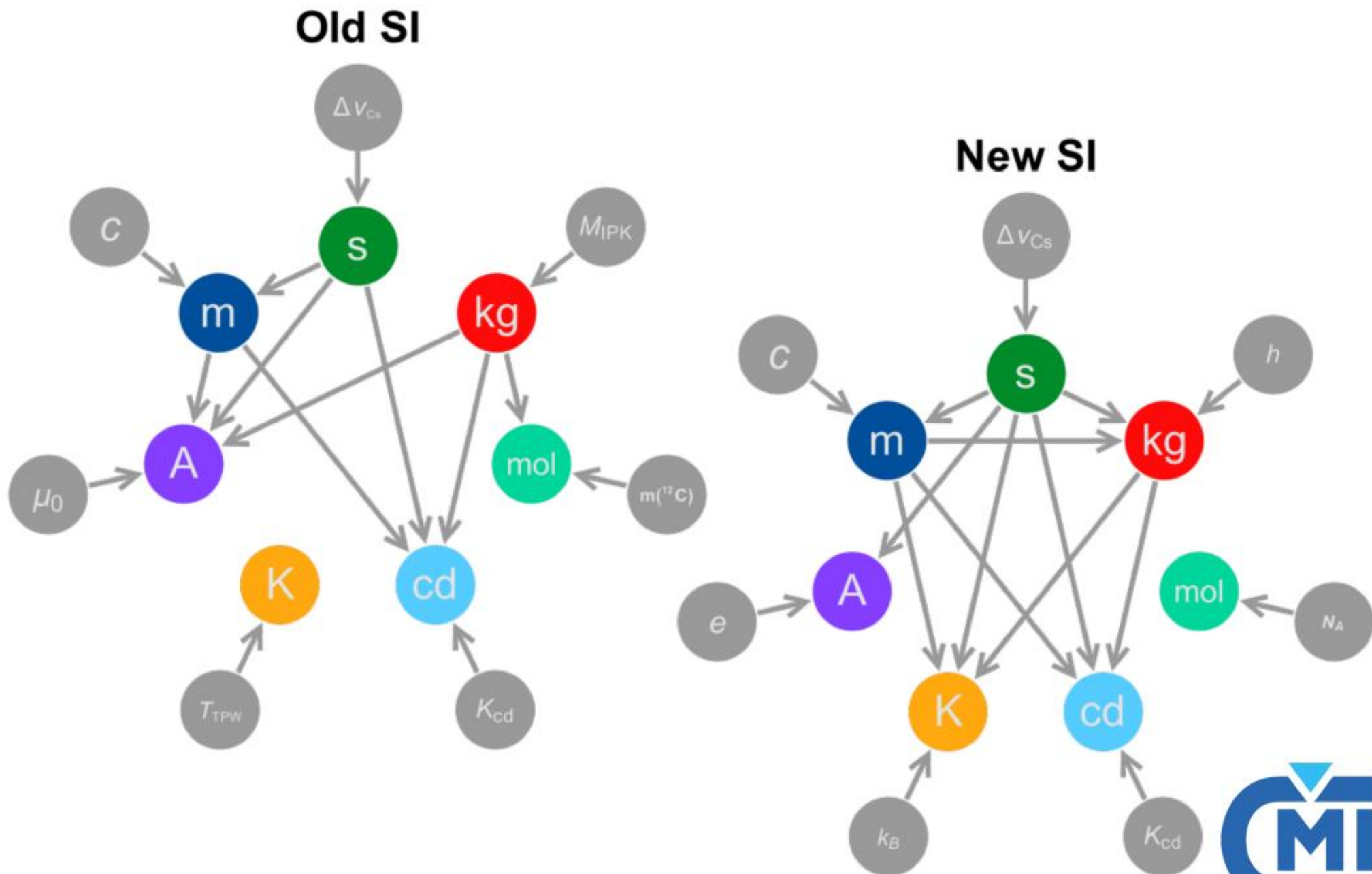
- The **kelvin**, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.380\,649 \times 10^{-23}$ when expressed in the unit J K^{-1} , which is equal to $\text{kg m}^2 \text{s}^{-2} \text{K}^{-1}$, where the kilogram, metre and second are defined in terms of h , c and $\Delta\nu_{\text{Cs}}$.
- The **mole**, symbol mol, is the SI unit of amount of substance. One mole contains exactly $6.022\,140\,76 \times 10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant, N_{A} , when expressed in the unit mol^{-1} and is called the Avogadro number.

The amount of substance, symbol n , of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.

- The **candela**, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd} , to be 683 when expressed in the unit lm W^{-1} , which is equal to cd sr W^{-1} , or $\text{cd sr kg}^{-1} \text{m}^{-2} \text{s}^3$, where the kilogram, metre and second are defined in terms of h , c and $\Delta\nu_{\text{Cs}}$.



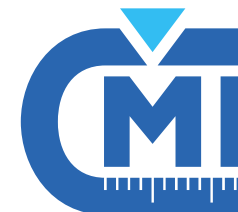
Závislosti v nové SI



Vliv revize SI na jednotky

jednotka	$(2018/1990 - 1) \times 10^{-9}$
Volt (V)	107
Ohm (Ω)	18
Ampér (A)	89
Coulomb (C)	89
Watt (W)	-196
Farad (F)	-18
Henry (H)	18

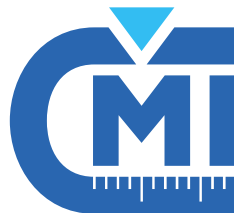
D. B. Newell, 'The CODATA 2017 Special Adjustment for the revision of the SI', presented at the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018), Paris, France, 2018.



Pokračující experimenty

Odvozování kg nekončí:

- Ian A. Robinson et. all. *Developing the next generation of NPL Kibble balances*
- Z. Li et. all. *The Status of the NIM-2 Joule Balance*, NIM, Čína
- Chao et. all. *The Design and Development of a Tabletop Kibble Balance at NIST*
- Bettin et. all. *New Silicon Crystals for a Redefined Kilogram and Mole: Isotopic Composition of the First Two Crystals*, PTB
- Ahmedov: *Preliminary Planck Constant Measurements in the UME Kibble Balance*, Turecko

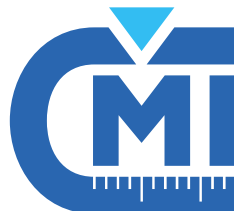


Lehrmann, PTB: Status of the realization and dissemination of the kilogram via silicon spheres

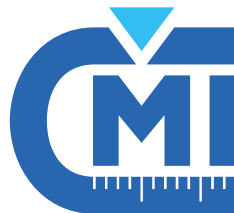
- Různé třídy etalonů z Si:

	^{28}Si	$^{\text{nat}}\text{Si}_{\text{qp}}$	$^{\text{nat}}\text{Si}_{\text{sc}}$
category	primary	“quasi-primary”	secondary
$u_{\text{rel}}(k=1)$ of mass	$2 \cdot 10^{-8}$	$3 \cdot 10^{-8}$	$3 \cdot 10^{-8}$
form error RONt	< 30 nm	< 20 nm	< 80 nm
average roughness Ra	< 0.3 nm	< 0.5 nm	< 1 nm
expected price	> 1 Mio. €	> 100 k €	> 10 k €
availability	limited, PTB	PTB/ industrial supplier	industrial supplier

- Projekt Si-kg k zavedení výroby a prodeje křemíkových koulí v privátní sféře.
- Studium dlouhodobých vlastností Si při použití v automatizovaných vážících systémech.



Další příspěvky z CPEM



Nová kniha o HP/Agilent/Keysight 3458

Sampling with 3458A

understanding, programming, sampling and signal processing

Autor: Rado Lapuh

ISBN 978-961-94476-0-4

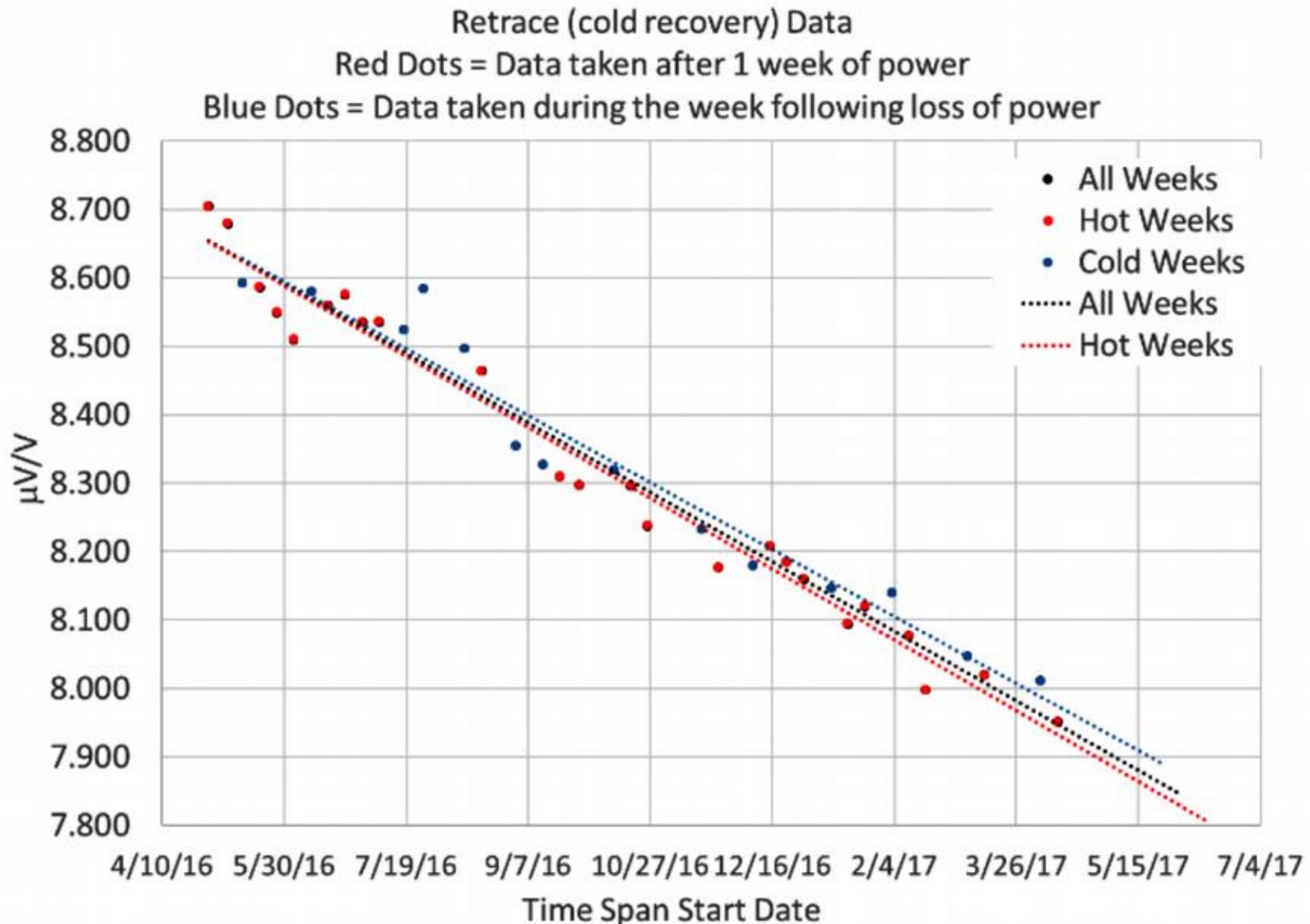
Cena ~100 €



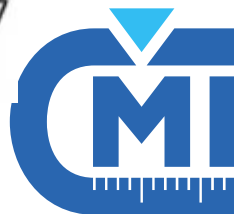
- popis práce
- příklady programování
- rozbor chyb
- algoritmy výpočtu veličin
- pěkný úvod do vzorkování



Jeff Gust: Experiments to Extend the Retrace Specification of Fluke Zener Reference Standards



Jeff Gust, 'Experiments to Extend the Retrace Specification of Fluke Zener Reference Standards', presented at the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018), Paris, France, 2018.



Jeff Gust: Experiments to Extend the Retrace Specification of Fluke Zener Reference Standards

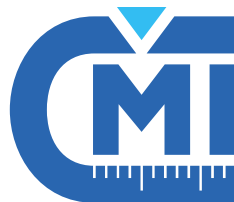
- Nová Zenerova reference 732C
- místo 1,018 V je 1 V
- nově 0,1 V
- menší závislost na vlhkosti



fluke.com

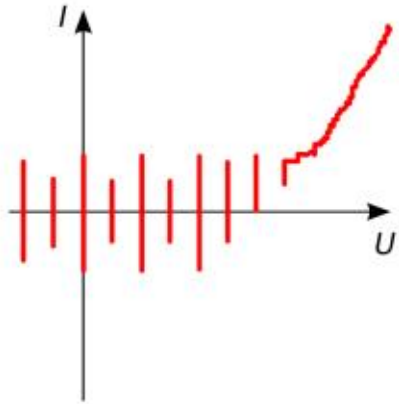
Period that Power is Turned Off	Change in 10 V Output Value ($\pm\mu\text{V/V}$)
$\leq 10\text{min}$	0.1
10min to 24hr	0.25
24hr to 14days	0.25

Jeff Gust, 'Experiments to Extend the Retrace Specification of Fluke Zener Reference Standards', presented at the 2018 Conference on Precision Electromagnetic Measurements (CPEM 2018), Paris, France, 2018.

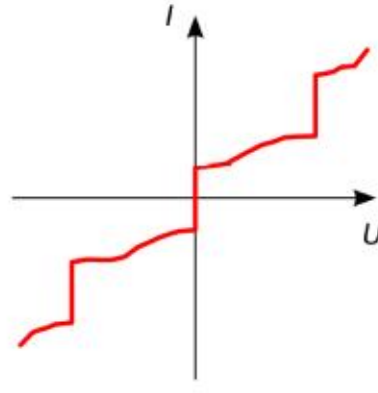


Pokrok ve vývoji kvantových etalonů napětí

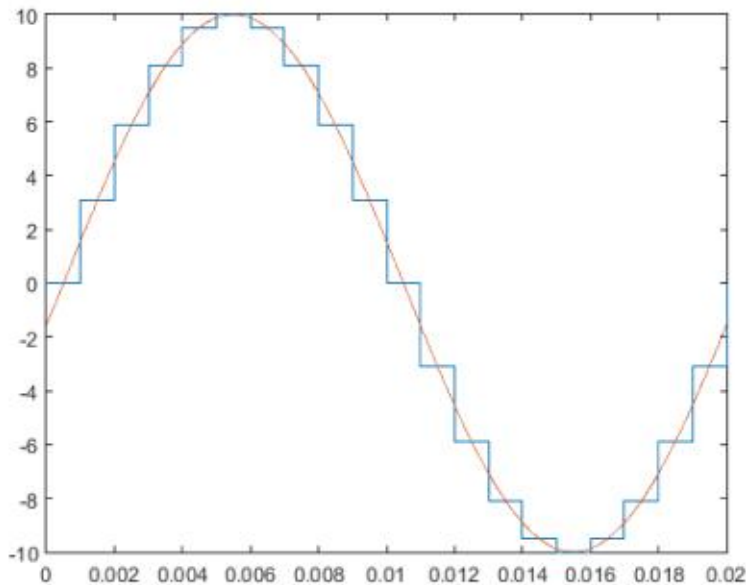
Stejnoseměrné JVS:



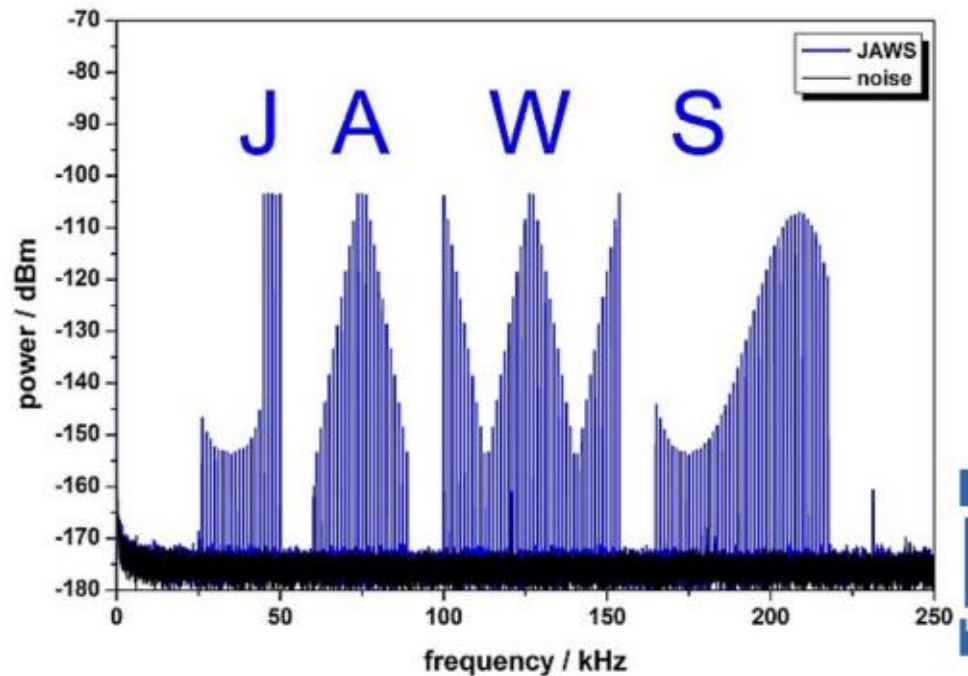
Střídavé JVS:



Programovatelný JVS:



Pulzní JVS:



Pokrok ve vývoji kvantových etalonů napětí

- PTB dokázalo vyrobit 5 Josephsonových přechodů na sobě

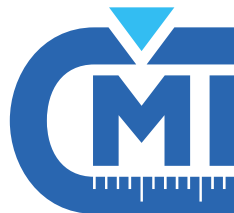
Kohlmann: Development and Fabrication of Improved Josephson Series Arrays with NbSi Barrier for AC Voltage Standards

- MIKES vyvíjí buzení JAWS pomocí fotodiod

Nissilä: Driving a Josephson junction array with a mode-locked laser and a photodiode

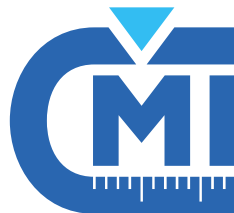
- BIPM již provedlo testovací porovnání programovatelných střídavých kvantových etalonů napětí, shoda 10^{-7}

Solve: Towards a BIPM on-site comparison program for AC voltages based on the differential sampling technique



Přspěvky ČMI

- Comparison of Sampling Voltage Measurements of Multi-tone Signals
- A novel method for calibration of ADC using JAWS
- Uncertainty of ROCOF calculated by means of Monte Carlo method
- Uncertainty of Phasor Measurement Unit calculated by means of Monte Carlo method
- Accurate Measurements of Energy, Efficiency and Power Quality in the Electric Railway System
- Comparison of VoltRef and New CMI Software for Zener Standards Maintenance
- Four Terminal Pair Digital Sampling Impedance Bridge up to 1 MHz
- Precision Buffer with Low Input Capacitance
- Bridging the LF-RF gap for calibration of the RLC meters
- Digital sampling setup for calibration of strain gauge bridge calibration unit BN100
- Progress on Simple Resistance Standard with Calculable Time Constant



Projekty ČMI



TracePQM: Traceability Routes for Electrical Power Quality Measurement

EMPIR projekt na diseminaci měření elektrického výkonu



Cíle:

1. vyvinout a validovat modulární měřidlo el. výkonu na metrologické úrovni
2. vyvinout a validovat sw s otevřeným zdrojovým kódem pro řízení a zpracování výsledků
3. vytvořit příručku (Good Practice Guide) o práci s měřidlem, sw a kalibraci

<http://tracepqm.cmi.cz/>

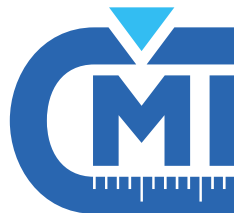
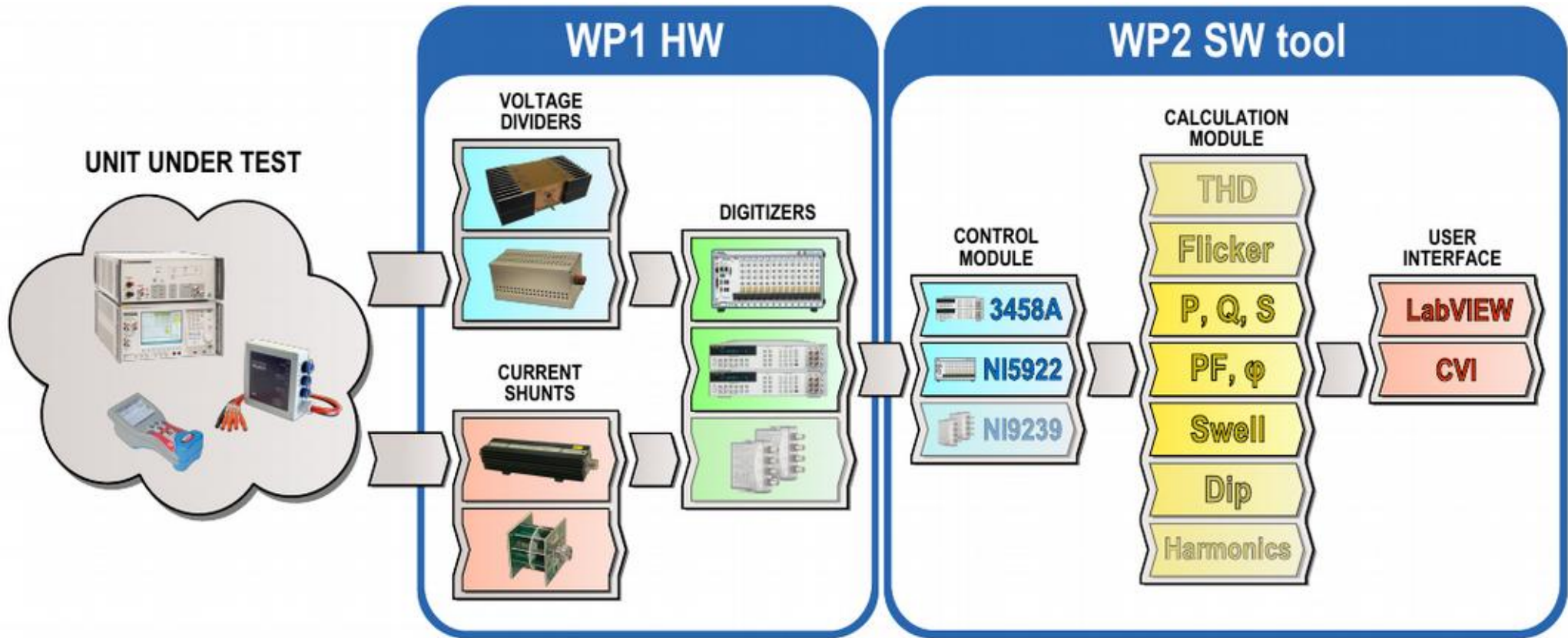
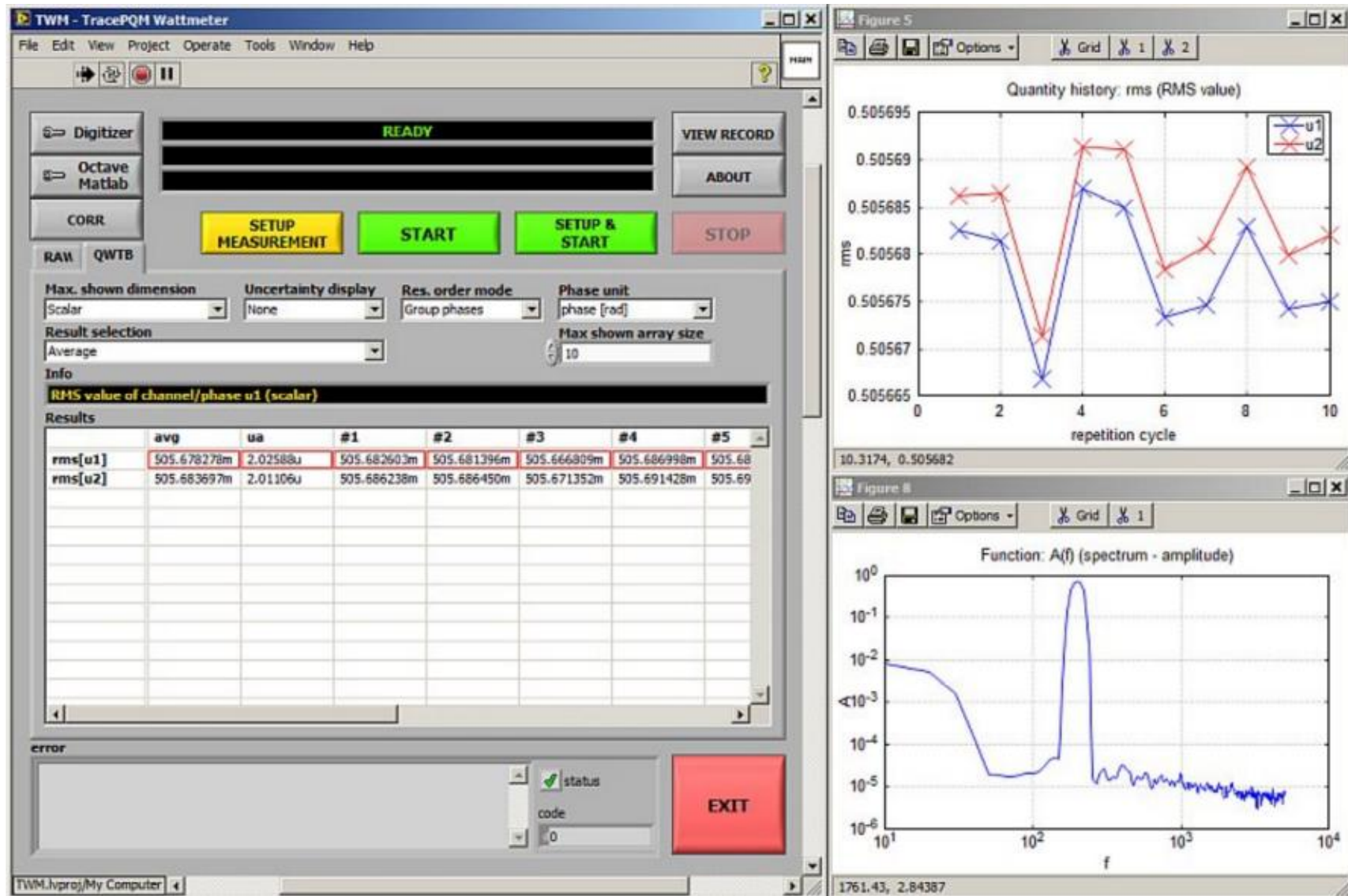


Schéma projektu TracePQM



TWM - TracePQM Wattmeter



<https://github.com/smaslan/TWM>

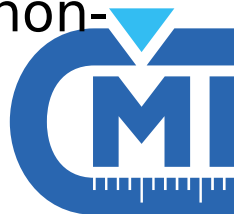


QWTB – Software Toolbox for Sampling Measurements

- Algorithmy: ADEV, CCC, FPNLSF, FourPSF, INL-DNL, MADEV, OADEV, PSFE, SFDR, SINAD-ENOB, SP-WFFT, ThreePSF, flicker_sim, iDFT2p, iDFT3p
- Algorithmy pro TWM:
 - MFSF: Multi-harmonic fitting for non-coherent sampling.
 - MODTDPS: Amplitude modulation parameters for sine and rectangular modulation for non-coherent sampling.
 - THDWFFT: Total Harmonic Distortion calculator and harmonics analyser for non-coherent sampling.
 - PWRTDI: Four quadrant power meter by time-domain integration method for non-coherent sampling.
 - HCRMS: Half-cycle RMS calculator for PQ event detection according IEC 61000-3-40 for non-coherent sampling.
 - InDiSwell: PQ event detection according IEC 61000-3-40 for non-coherent sampling.



<https://qwtb.github.io/qwtb/>

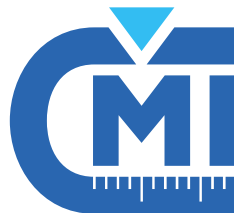


RoCoF: Standard Tests and Requirements for Rate-of-Change of Frequency (ROCOF) Measurements in Smart Grids

EMPIR projekt

Účastní se: NPL, VSL, CMI a Strathclyde University

- Podpora IEC/IEEE standardů pro měření ROCOF
- Vývoj nových algoritmů
- Vývoj referenční architektury pro měření ROCOF
- Odhad nejistot



QuADC: Waveform metrology based on spectrally pure Josephson voltages

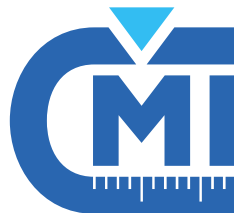
EMPIR projekt

Účastní se: PTB, CEM, CMI, INRIM, JV, NPL, SP, TUBITAK, VSL, VTT, Applicos, esz, HSN, INTI, SC, METAS

- Vývoj kvantového voltmetru ss. – 1 MHz,
- Přímá návaznost na SI
- Rozsah až 1 kV

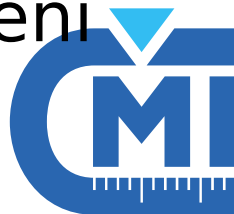
- ČMI vyvíjí buffer, řízení systému a zpracování naměřených dat

<https://github.com/smaslan/QuADC-buffer>

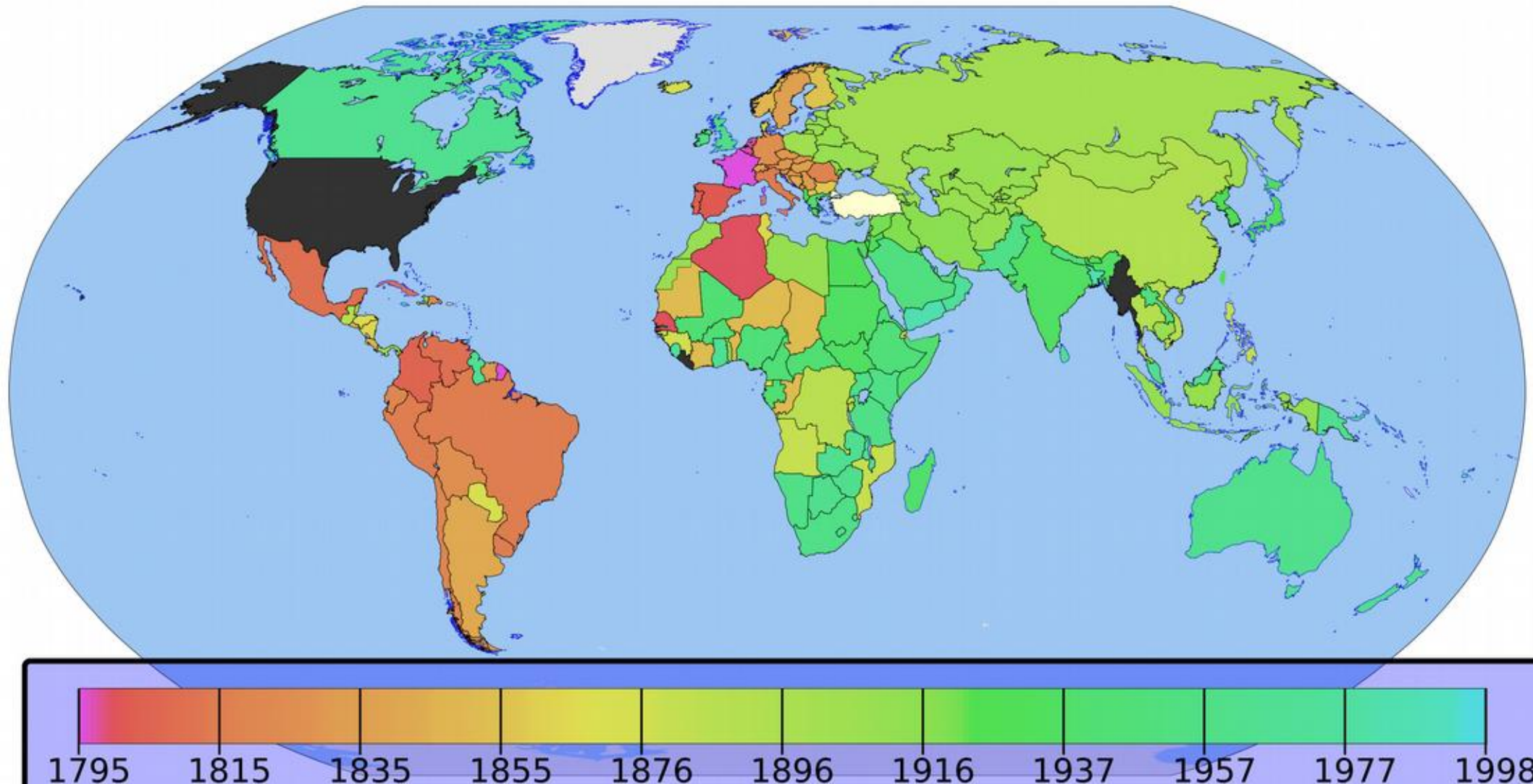


Nové projekty EMPIR s účastí ČMI

- **MyRails** – metrologie/měření elektrického výkonu v železničních systémech
- **DIG-AC** – návaznost měření založených na vzorkovacích metodách:
 - vývoj vzorkovacích step-up/step-down metod, algoritmy pro dynamická měření, validace návaznosti
- **Liion** – metrologie Li-ion baterií:
 - vývoj protokolů pro testování životnosti, měření kapacity impedančními metodami

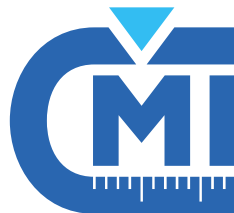


USA a SI: Země podle data přijetí metrické konvence



Zaostalé země: USA, Libérie, Myanmar, Nezávislý stát Samoa, Federativní státy Mikronésie, Republika Palau, Marshallovy ostrovy.

H. Vera, 'The Social Life of Measures Metrication in the United States and Mexico', New School University, New York, N.Y., USA, 2012.



Děkuji za pozornost

