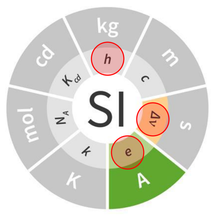
IMPACT OF THE NEW GENERATION OF JOSEPHSON VOLTAGE STANDARDS IN AC AND DC ELECTRIC METROLOGY

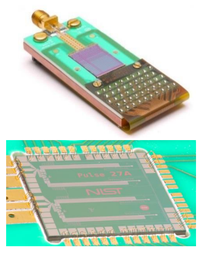
Alain Rüfenacht, Nathan E. Flowers-Jacobs, Paul D. Dresselhaus, Anna E. Fox, Justus A. Brevik, Charles J. Burroughs, and Samuel P. Benz

National Institute of Standards and Technology, Boulder, CO 80305, USA



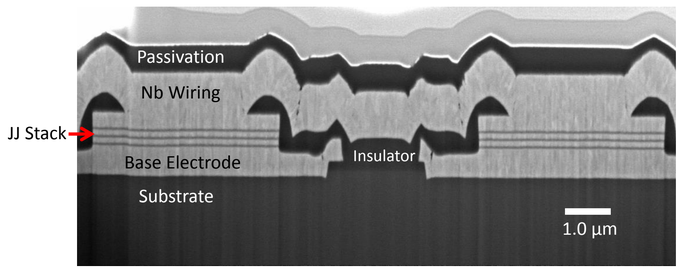
With the 2018 redefinition of the SI, Josephson voltage standards will directly realize the unit volt

$$U_J = n\frac{f}{K_J}, \qquad K_J = \frac{2e}{h}$$



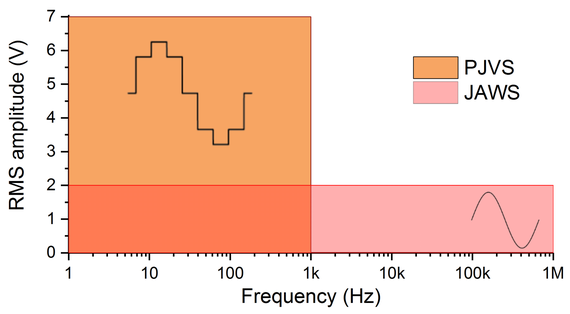
Standards	Bias RF Frequency	Generator	Microwave	# of JJs	Applications
Programmable Josephson Voltage Standard (**PJVS**)	18 GHz – 22 GHz	Synthesizer + coaxial cable	Continuous	265,116 n=0, ±1 (10 V)	DC + stepwise approximated AC
Josephson Arbitrary Waveform Synthesizer (**JAWS**)	14.4 GHz - 15 GHz (Pulse pattern frequency)	Pulse generator + Coaxial cable	Pulsed	51,240 n=0, ±1, (±2) (1 V rms)	DC + AC (1 Hz to 1 MHz)

$Nb/Nb_xSi_{1-x}/Nb$ Josephson Junction (JJ) Technology



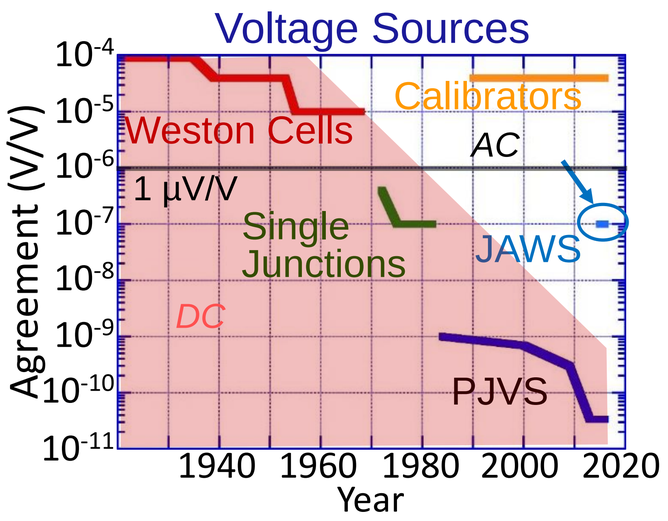
Cross-section along microwave coplanar waveguide

JVS currently available frequency and voltage range



Fully automated cryogen liquid free Josephson voltage standards

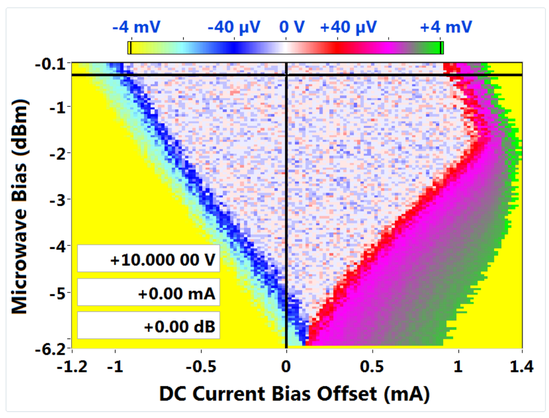
Weston Cell, Electrochemical Battery

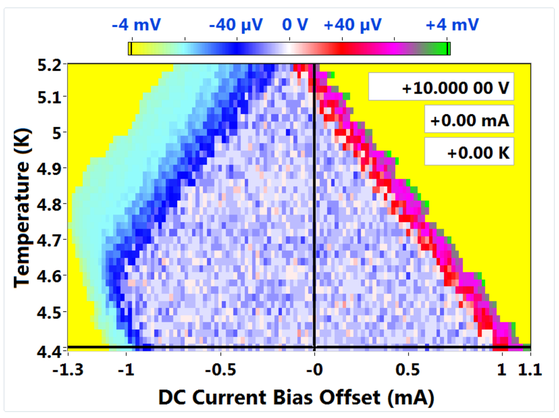


Commercial Voltage Calibrators

Both systems are available as Standard Reference Instruments (SRI)
https://www.nist.gov/sri PJVS: 6000 & JAWS: 6011

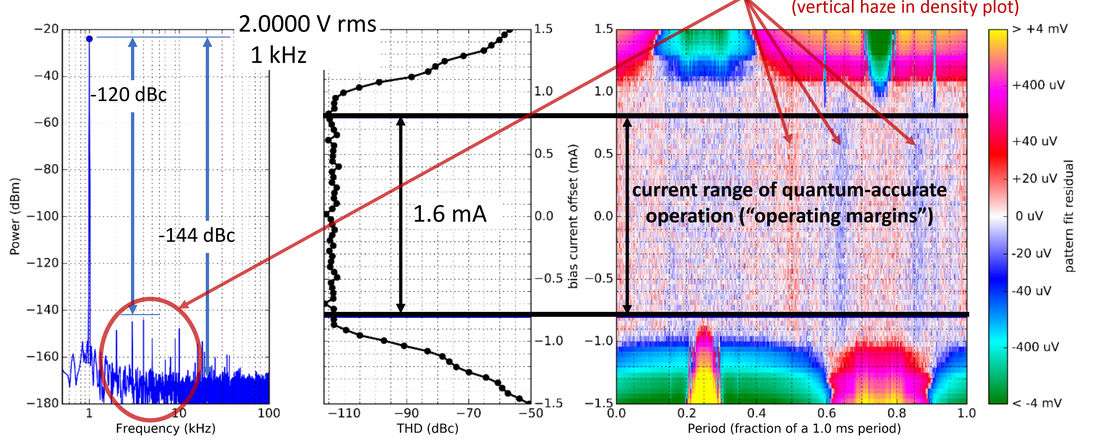
Quantum locking range verification (intrinsically accurate operating domain)





10 V DC (PJVS output measured with Keysight 3458A)

Non-linearities of ADC/Digitizer (vertical haze in density plot)



Nathan Flowers-Jacobs et al., IEEE Trans. Appl. Supercond., Feb 2016, Art. ID 1400207

Applications

Standards	DC calibrations	AC Calibrations	Others
PJVS	Zener reference DVM linearity Calibrator	Stepwise reference waveform for rms source calibration*	"Electrical triangle" Kibble balance Joule balance Quantum Watt (electric power)*
JAWS	Nanovoltmeter	Sine source* AC voltmeter†/Digitizer† Thermal transfer standard†	Impedance bridge

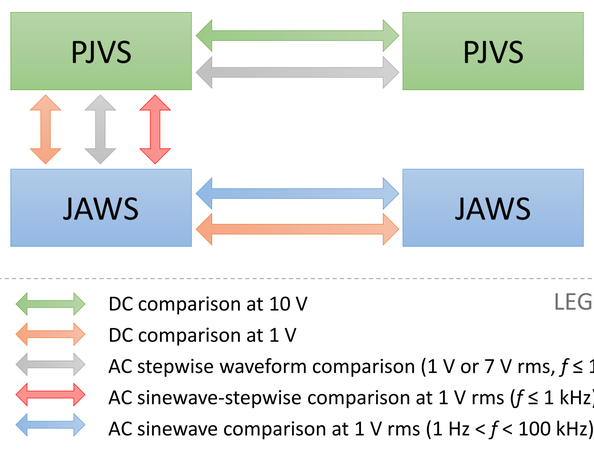
*) with the use of differential sampling method
†) High impedance load connected to the JAWS or PJVS output

"Artifact" Detectors vs "Quantum" Sources

- Conventional AC standards are RMS Detectors
  - Thermally compare AC and DC voltage signals
  - Different "artifact" standards have similar performance, but are NOT identical
- Replace detectors with "quantum" sources: **PJVS, JAWS**
  - Must verify correct "quantum" operation
  - Systematic errors must be characterized
  - Intrinsically accurate, identical

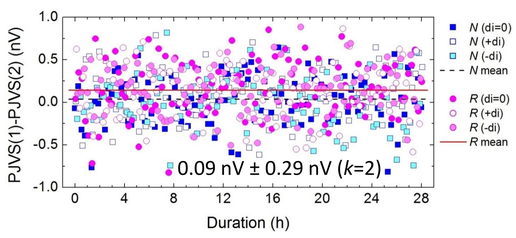
Traceability

With the new redefinition of the SI traceability is intrinsic. The agreement between two systems can be verified with direct or indirect comparison of JVS standards.

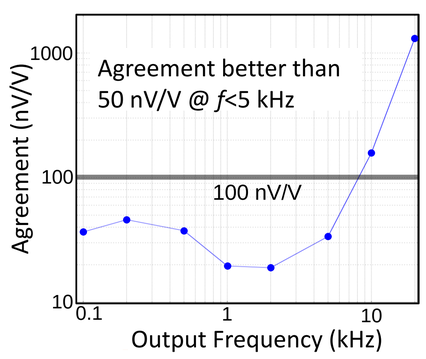


Direct comparison results

10 V DC (PJVS difference measured with EM N-11)



1 V rms JAWS (JAWS comparison versus frequency)



Present and Future Challenges

- Switch the AC voltage metrology field from detector based to source based
  - Direct traceability to the SI
  - Provide quicker and more accurate calibration process
  - Requires stable ac source artifact standards for the dissemination (Zener standard equivalent for ac voltage metrology)
- Develop new measurement method to drive accurately low impedance loads
- Characterize all the systematic errors associated with each system
  - Transmission line errors and corrections (JAWS)
  - Develop zero-compensation method to minimize errors (JAWS)
  - Error due to leakage currents (PJVS and JAWS)
- Disseminate PJVS and JAWS beyond national metrology institute
  - Full automation (turn-key system operated on cryocoolers)
  - Long term reliability of the system
  - User friendly applications

CONCEPT
DEVICE FABRICATION
SYSTEM DESIGN
AUTOMATION AND SELF CHECK
METROLOGY APPLICATIONS
TRACEABILITY