# 𝔑ational Institute of Standards & Technology

# Specifications

## Standard Reference Instrument Series 6000

### Programmable Josephson Voltage Standard

**Description:** The Programmable Josephson voltage standard (PJVS) is an instrument that generates stable, quantum-accurate, direct-current (DC) voltages that are programmable over the range from −10 volts to +10 volts. The quantum accuracy of these voltages is derived from the Josephson Effect such that every superconducting Josephson junction in the PJVS circuit produces a voltage precisely proportional to the frequency of the applied microwave bias signal.

The PJVS with its quantum accurate dc voltages can serve as a primary voltage standard with accuracy of parts in $10^{10}$ (determined through intercomparison with another quantum voltage standard) or as a stable, programmable source for precision measurements, metrology experiments or calibrations. For example, the PJVS can be used to calibrate Zener references (typically within few parts in $10^8$ relative accuracy depending on the measurement instruments and Zener noise) as well as the amplitude-dependent gain and linearity of digital voltage meters.

The PJVS is also capable of generating stepwise-approximated waveforms or sine waves with a 10 % to 90 % transition duration between voltage steps that is less than 6 microseconds. The AC voltage of the stepwise waveforms do not have quantum accuracy because the transitions between the steps are bias dependent. A differential-sampling measurement technique with an integrating sampling digital voltmeter is used with the step-wise waveforms to calibrate the ac voltage of commercial voltage calibration sources at frequencies up to a few hundred hertz with a typical measurement uncertainty of a few parts in $10^7$, depending on the phase and amplitude stability of the source.

Design, assembly and technical measurements leading to the production of this SRI were performed by Superconductive Electronics Group members from the NIST RF Technology Division.

Support aspects involved in the issuance of this SRI were coordinated through the NIST Office of Reference Materials.

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**Specifications:** NIST provides the PJVS as Standard Reference Instrumentation (SRI) with performance that is equivalent to that of NIST systems in terms of quantum accuracy and precision measurement capability, provided that operators follow recommended best practices and perform intercomparisons with comparable quantum-based voltage sources. The NIST PJVS SRI is offered in a range of different configurations, from individual 10 V or 2 V PJVS cryopackaged chips that contain the superconducting integrated circuit to fully integrated PJVS systems where the chip is cooled by either liquid-helium or a cryocooler refrigerator to the operating temperature at which the PJVS circuit becomes superconducting. The PJVS chips are fabricated and packaged by NIST in accordance with existing and established fabrication protocols. All the system configurations of the PJVS SRI are constructed primarily from commercially available components and include software that optimizes the system performance and ensures that it produces quantum-accurate voltages.

NIST researchers continue to develop and improve the PJVS systems and measurement techniques. The PJVS circuits and systems and associated measurement capabilities are identical to those of NIST systems at the time of acquisition. NIST is providing the PJVS through the SRI program with prices derived such that NIST is reimbursed for all costs associated with duplicating the current versions of NIST systems. Prices do not include support, training, or on-site installation and qualification. The customer should contact the Standard Reference Instrument office (srminfo@nist.gov) for costs for these services.

The PJVS circuits and systems have the following specifications and features.[1]
A) A cryopackaged chip that is tested and demonstrated to produce stable, quantum-accurate, programmable voltages over the range from $-10$ volts to $+10$ volts with a minimum current range of 1.0 mA that is determined with a 3 $\mu$V measurement threshold.
B) The capability to generate stepwise-approximated voltage waveforms such that the transition duration between steps is less than six microseconds. Differential sampling measurements may be performed with the SRI 6000 system but require additional hardware and software. Interested parties should contact NIST for further details.
C) A majority of system components that are commercially available.
D) Operating frequency between 15 GHz and 22 GHz. 230 $\mu$V minimum voltage resolution of the least significant bit of 6 Josephson junctions, and 1 nV voltage tuning through 2 Hz frequency resolution (for output voltages larger than 200 mV).
E) A leakage resistance to ground of at least 50 G$\Omega$ and automated leakage resistance to ground measurement module. System delivered with shielded bias cables; custom made for low leakage current performance. Uncertainty due to leakage may be bounded by multiplying the leakage current ($\sim$ 10 V/Leakage resistance) by the lead resistance ($\sim$1 Ohm). Thus for $>$10 G$\Omega$ leakage resistance, the uncertainty due to leakage is $<$ 1 nV.
F) NIST-designed custom dc current bias electronics, electronic and hardware integration components, cables, wrenches, and equipment rack.
G) A single-node license of the "PJVS-Core" system software that automatically evaluates and optimizes the performance of the chip and the system electronics in order to ensure that the voltages are quantum accurate and have the largest current range.

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[1] Certain commercial equipment, instruments or materials are identified in this certificate to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

H) "ZENERcal" application software that provides dc calibrations of various voltage sources such as Zener references.

I) "DVMcal" application software that provides dc gain and linearity calibrations of various volt meters, such as Keysight 3458A, Keysight 34420A, Fluke 8508A, Fluke 8588A, Fluke 8558A, Keithley 2182, and Keithley 2002. DVMcal also includes a ratio calibration function for the Fluke 8508A, Fluke 8588A, and the Keysight 3458A.

J) The capability to externally control of the PJVS through an Ethernet connection (LabVIEW$^{TM}$ data socket) with user commands in order to enable the PJVS to be integrated with customer software for other applications.

**Delivery:** Delivery and installation dates will be determined on a case-by-case basis in coordination with the customer and based on the availability of components and NIST staff.

**Shipping:** Unless otherwise agreed by the parties, shipping terms shall be EXW (Incoterms 2010). NIST will prepare packaging for shipment of the PJVS SRI. Shipping crate dimensions and weight will be included in each quote. Customers are responsible for arrangement of shipping pickup at NIST as well as all customs duties and import fees (HTC 9030.33.0040).

**Technical requirements at installation site:** Customers must provide the following:

A) A 10 MHz reference signal whose frequency is accurate to a part in $10^{10}$ or better.

B) Customs related clearances, documents, payments, and fees.

C) Liquid helium for the on-site qualification.

D) Appropriate power and utilities for compressors (for cryo-cooled systems only), including power and connectors for RDK-205D: 3-phases, 200 V, 4.6-5.6 kW at 60 Hz (3.6-4.8 kW at 50 Hz) power, and cooling water: (4-9) L/min at (5-25) °C (for the water-cooled compressor only).

E) Acquiring the commercial instruments and components that are to be integrated into the PJVS system (as specified in the PJVS configuration descriptions).

F) Providing, as the customer deems necessary, the following additional instruments that are typically used for calibration measurements and are currently supported by existing PJVS software:

   a. A dedicated nanovoltmeter (in addition to the Keysight 34420A voltmeter provided with the PJVS system), such as either Keysight 34420A (preferred), Keysight 3458A, Fluke 8588A, or Keithley 2182A are recommended.

   b. Customer's Zener dc reference standard or standards.

   c. A DATAPROOF scanner (with GPIB module E installed), if the customer chooses to implement automated simultaneous calibration of multiple Zener voltage standard references.

*Users of this SRI should ensure that the Specifications Certificate in their possession is current.  This can be accomplished by contacting the Office of Reference Materials:  telephone (301) 975-2200; e-mail srminfo@nist.gov; or via the Internet at http://www.nist.gov/sri.*

# Programmable Josephson Voltage Standard (PJVS) System Configurations
## SRI 6000 series

**SRI 6000e:** Cryo-cooled 10V PJVS, with water-cooled compressor
a. DS instrument SG22000PRO microwave synthesizer with frequency up to 22 GHz
b. Sumitomo RDK-205D-F-40
c. Cryopackaged 10V PJVS chip
d. Mini-circuits ZVE-3W-183+ or DSI PA20000 or equivalent microwave amplifier
e. Keysight 34420A nanovoltmeter
f. SRS CTC100 temperature controller
g. NIST-designed JVS-700 dc current bias electronics with National Instruments: cDAQ-9178, NI 9403, 2 each NI 9264, NI 9238, GPIB-USB HS+, external computer and monitor

**SRI 6000h:** Cryo-cooled 10V PJVS, with water-cooled compressor, without synthesizer
a. Customer provides one of the recommended microwave synthesizers, either the Keysight E8257D or E8257N or an equivalent
b. Sumitomo RDK-205D-F-40
c. Cryopackaged 10V PJVS chip
d. Mini-circuits ZVE-3W-183+ or DSI PA20000 or equivalent microwave amplifier
e. Keysight 34420A nanovoltmeter
f. SRS CTC100 temperature controller
g. NIST-designed JVS-700 dc current bias electronics with National Instruments: cDAQ-9178, NI 9403, 2 each NI 9264, NI 9238, GPIB-USB HS+, external computer and monitor

**SRI 6000i:** Cryo-cooled 10V PJVS, with air-cooled compressor
a. DS instrument SG22000PROmicrowave synthesizer with frequency up to 22 GHz
b. Sumitomo RDK-205D-FA-40
c. Cryopackaged 10V PJVS chip
d. Mini-circuits ZVE-3W-183+ or DSI PA20000 or equivalent microwave amplifier
e. Keysight 34420A nanovoltmeter
f. SRS CTC100 temperature controller
g. NIST-designed JVS-700 dc current bias electronics with National Instruments: cDAQ-9178, NI 9403, 2 each NI 9264, NI 9238, GPIB-USB HS+, external computer and monitor

**SRI 6000l:** Cryo-cooled 10V PJVS, with air-cooled compressor, without synthesizer
a. Customer provides one of the recommended microwave synthesizers, either the Keysight E8257D-528 or E8257N or an equivalent
b. Sumitomo RDK-205D-FA-40
c. Cryopackaged 10V PJVS chip
d. Mini-circuits ZVE-3W-183+ or DSI PA20000 or equivalent microwave amplifier
e. Keysight 34420A nanovoltmeter
f. SRS CTC100 temperature controller
g. NIST-designed JVS-700 dc current bias electronics with National Instruments: cDAQ-9178, NI 9403, 2 each NI 9264, NI 9238, GPIB-USB HS+, external computer and monitor

**SRI 6000m:** Cryopackaged 10V PJVS chip

**SRI 6000n:** Cryopackaged 2V PJVS chip