



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 parts in 10^7 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 rise time between voltage steps that is less than 2 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 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 S.P. Benz NIST Quantum Electronics and Photonics Division.

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

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Gaithersburg, MD 20899
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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 (SRI 6000a – SRI 6000u), from individual 10V or 2V 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 also include support, training, and on-site qualification.

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 μ V measurement threshold.
- B) The capability to generate stepwise-approximated voltage waveforms such that the rise time between steps is less than two microseconds.
- C) A majority of system components that are commercially available.
- D) Operating frequency between 18 GHz and 22 GHz. 230 μ V minimum voltage resolution of the least significant bit of 6 Josephson junctions, and 1 nV voltage tuning through 1 Hz frequency resolution (for output voltages larger than 250 mV).
- E) A leakage resistance to ground of at least 25 G Ω .
- F) A NIST-designed custom dc amplifier, a Dell Ultrasharp 24-inch widescreen flat panel monitor, electronic and hardware integration components, cables, wrenches, and a 24U x 24”W x 30”D 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.
- H) Application software that provides dc and linearity calibrations of various voltage sources and meters such as Zener references, voltage standards, and volt meters.
- I) The capability to externally control of the PJVS through an Ethernet connection (LabviewTM data socket) with user commands in order to enable the PJVS to be integrated with customer software for other applications.

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.

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).

Installation: At the customer's location, NIST staff will complete final assembly of the system and perform the system qualification. Qualification is defined as follows: When measured on the smallest voltage range of the nanovoltmeter and the system is configured to bias half the junctions to +5 V and the other half to -5Vs, the resulting combined voltage step is quantized over a current range of at least 1.0 mA as determined by a 3 μ V voltage measurement threshold.

Training: NIST staff will provide up to 24 hours of training to customer staff on PJVS operation, maintenance, and precision measurements.

Support: NIST staff will provide up to 60 hours of technical assistance, consultation and support for a two-year period beginning on the system qualification date. If the circuit no longer achieves the qualification condition, then NIST will provide up to three replacement chip cryopackages or repairs (as determined by NIST) during the two-year period of support.

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 liquid-helium-cooled systems only) for both the on-site qualification as well as for daily operation.
- D) Appropriate power and utilities for compressors (for cryo-cooled systems only), including power and connectors for single-phase 15.5 A, 208 V, 60 Hz (or 13 A, 200 V, 50 Hz) power, and cooling water (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 support by existing PJVS software:
 - a. A dedicated nanovoltmeter, such as either Agilent 34420A, Agilent 3458A, 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; fax (301) 948-3730; 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

6000a Liquid helium-cooled 10V PJVS

- a. Agilent E8257D-528 microwave synthesizer with frequency up to 31.8 GHz
- b. Cryofab CMSH-100 dewar with auxiliary 0.5 inch-diam. fill port, and helium level meter
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip
- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000b Liquid helium-cooled 10V PJVS (US GSA Authorized)

- a. Agilent E8257N microwave synthesizer with frequency up to 40 GHz (US GSA Authorized)
- b. Cryofab CMSH-100 dewar with auxiliary 0.5 inch-diam. fill port, and helium level meter
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip
- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000c Liquid helium-cooled 10V PJVS, with compact microwave synthesizer

- a. PhaseMatrix FSW-0020 microwave synthesizer with frequency up to 20.7 GHz
- b. Cryofab CMSH-100 dewar with auxiliary 0.5 inch-diam. fill port, and helium level meter
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip
- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000d Liquid helium-cooled 10V PJVS, without synthesizer

- a. *Customer provides* one of the recommended microwave synthesizers, either the Agilent E8257D-528 or E8257N or an equivalent
- b. Cryofab CMSH-100 dewar with auxiliary 0.5 inch-diam fill port, and helium level meter
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip
- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000e Cryo-cooled 10V PJVS, with water-cooled compressor

- a. Agilent E8257D-528 microwave synthesizer with frequency up to 31.8 GHz
- b. Sumitomo SRDK-101DP-HC4E2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000f Cryo-cooled 10V PJVS, with water-cooled compressor (US GSA Authorized)

- a. Agilent E8257N microwave synthesizer with frequency up to 40 GHz (US GSA Authorized)
- b. Sumitomo SRDK-101DP-HC4E2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000g Cryo-cooled 10V PJVS, with water-cooled compressor, with compact source

- a. PhaseMatrix microwave synthesizer with frequency FSW-0020 up to 20.7 GHz
- b. Sumitomo SRDK-101DP-HC4E2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000h Cryo-cooled 10V PJVS, with water-cooled compressor, without synthesizer

- a. *Customer provides* one of the recommended microwave synthesizers, either the Agilent E8257D-528 or E8257N or an equivalent
- b. Sumitomo SRDK-101DP-HC4E2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000i Cryo-cooled 10V PJVS, with air-cooled compressor

- a. Agilent E8257D-528 microwave synthesizer with frequency up to 31.8 GHz
- b. Sumitomo SRDK-101DP-HC4A2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000j Cryo-cooled 10V PJVS, with air-cooled compressor (US GSA Authorized)

- a. Agilent E8257N microwave synthesizer with frequency up to 40 GHz (US GSA Authorized)
- b. Sumitomo SRDK-101DP-HC4A2
- c. Cryopackaged 10V PJVS chip

- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000k Cryo-cooled 10V PJVS, with air-cooled compressor, with compact source

- a. PhaseMatrix microwave synthesizer with frequency FSW-0020 up to 20.7 GHz
- b. Sumitomo SRDK-101DP-HC4A2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000l Cryo-cooled 10V PJVS, with air-cooled compressor, without synthesizer

- a. *Customer provides* one of the recommended microwave synthesizers, either the Agilent E8257D-528 or E8257N or an equivalent
- b. Sumitomo SRDK-101DP-HC4A2
- c. Cryopackaged 10V PJVS chip
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000m Cryopackaged 10V PJVS chip

6000n Cryopackaged 2V PJVS chip

6000o Upgrade existing NIST-installed Liquid-helium-cooled PJVS to Cryocooler with water-cooled compressor

- a. Sumitomo SRDK-101DP-HC4E2

6000p Upgrade existing NIST-installed Liquid-helium-cooled PJVS to Cryocooler with air-cooled compressor

- a. Sumitomo SRDK-101DP-HC4A2

6000q Liquid helium-cooled 10V PJVS without dewar

- a. *Customer provides* a CMSH-100 Dewar or other dewar and fixtures compatible with cryoprobe
- b. Agilent E8257D-528 microwave synthesizer with frequency up to 31.8 GHz
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip
- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000r Liquid helium-cooled 10V PJVS (US GSA Authorized) without dewar

- a. *Customer provides* a CMSH-100 Dewar or other dewar and fixtures compatible with cryoprobe
- b. Agilent E8257N microwave synthesizer with frequency up to 40 GHz (US GSA Authorized)
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip

- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000s Liquid helium-cooled 10V PJVS, with compact microwave synthesizer without dewar

- a. *Customer provides* a CMSH-100 Dewar or other dewar and fixtures compatible with cryoprobe
- b. PhaseMatrix FSW-0020 microwave synthesizer with frequency up to 20.7 GHz
- c. HPD JVS-650B cryoprobe
- d. Aldetec ALS04541 microwave amplifier
- e. Agilent 34420A nanovoltmeter
- f. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000t Liquid helium-cooled 10V PJVS, without synthesizer or dewar

- a. *Customer provides* one of the recommended microwave synthesizers, either the Agilent E8257D-528 or E8257N or an equivalent
- b. *Customer provides* a CMSH-100 Dewar or other dewar and fixtures compatible with cryoprobe
- c. HPD JVS-650B cryoprobe
- d. Cryopackaged 10V PJVS chip
- e. Aldetec ALS04541 microwave amplifier
- f. Agilent 34420A nanovoltmeter
- g. National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000u Liquid helium-cooled 10V PJVS, without synthesizer, dewar, amplifier, cryoprobe, nanovoltmeter, bias electronics and controller

- a. Cryopackaged 10V PJVS chip
- b. *Customer provides* one of the recommended microwave synthesizers, either the Agilent E8257D-528 or E8257N or an equivalent
- c. *Customer provides* a CMSH-100 Dewar or other dewar and fixtures compatible with cryoprobe
- d. *Customer provides* an HPD JVS-650B cryoprobe
- e. *Customer provides* an Aldetec ALS04541 microwave amplifier
- f. *Customer provides* an Agilent 34420A nanovoltmeter
- g. *Customer provides* the following from National Instruments: PXI-1042Q chassis, PXI-8101 Windows 7 controller and 4 GB RAM, 6 each PXI-6230 DAC cards, 6 each DB37M-DB37F-EP 37-Pin Shielded Cables, 6652 timing card, 0.5m, 1m, and 2m GPIB cables, & GPIB-USB HS (EC)

6000v Cryopackaged 1V ACJVS chip

- a. Cryopackaged ACJVS chip having four arrays of Josephson junctions capable of synthesizing ac waveforms of 1V rms amplitude while operating in either liquid helium or in a dry cryostat.
- b. *Customer provides* all other systems components, including software, bias electronics, cryoprobes, cryostats, cryocoolers, dewars

6000w ACJVS Software

- a. Core software compatible with HSCC arbitrary waveform generator model ABG-2 and used for tuning the bias conditions of each array so as to optimize the quantum states (maximize the operating margins) of customer selected waveforms
- b. Measurement software for performing ac-dc measurements of customer supplied devices, such as transfer standards, which works with the core software