NIST National Institute of Standards and Technology U.S. Department of Commerce

National Institute of Standards & Technology

Specifications

Standard Reference Instrument Series 6011

Josephson Arbitrary Waveform Synthesizer

Description: The Josephson arbitrary waveform synthesizer (JAWS) is an instrument that synthesizes ac voltage waveforms and dc voltages whose metrological accuracy results from pulse biasing thousands of series-connected superconducting Josephson junctions into their identical quantum states. The quantum accuracy of these voltages is derived from the Josephson Effect, such that every junction in the JAWS circuit produces the integer number and polarity of quantized voltage pulses at precisely determined time.

The JAWS system is essentially a digital-to-analog converter that generates time-dependent voltage signals that serve as a primary ac voltage standard. It is the only ac voltage standard source directly derived from quantum effects. Waveforms such as sine waves or arbitrary waveforms may be synthesized with frequencies and harmonics ranging from four hertz to a few megahertz frequencies. As a result of circuit and output lead impedances, the accuracy of the waveforms provided to test instruments will depend on the frequency, with lower audio frequencies having the lowest uncertainty. For example, a 1 kHz, 1 V rms sine wave has a uncertainty (k=1) of one part in 10^7, whereas a 100 kHz sinewave will has a uncertainty (k=1) of one part in 10^5 at the output leads. The uncertainty is limited by ac leakage paths and is expected to decrease as more advanced measurement techniques are refined. System software characterizes and accounts for the largest of these errors. Contributions to the uncertainty include extrinsic effects such as transmission line errors, and quadrature errors from the compensation currents, as well as intrinsic errors from the delta-sigma code and phase noise. A detailed study is available on request.

Design, assembly and technical measurements leading to the production of this SRI were performed by P.D. Dresselhaus of the NIST Quantum Electromagnetics 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
Certificate Issue Date: 30 January 2019

Specifications: NIST provides the JAWS 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 JAWS SRI is offered in a range of different configurations (SRI 6011a – SRI 6011c), from individual 1V JAWS cryopackaged chips that contain the superconducting integrated circuit to fully integrated JAWS systems in which the chip is cooled by a cryocooler refrigerator to the operating temperature at which the JAWS circuit becomes superconducting. The JAWS chips are fabricated and packaged by NIST in accordance with existing and established fabrication protocols. All the system configurations of the JAWS SRI are constructed primarily from commercially available components and include software that optimizes the system performance and ensures that it produces quantum-accurate waveforms.

NIST researchers continue to develop and improve the JAWS systems and measurement techniques. The JAWS circuits and systems and associated measurement capabilities are identical to those of NIST systems at the time of acquisition. NIST is providing the JAWS 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 technical division for costs for these services.

The JAWS circuits and systems have the following specifications and features.[1]

A) A cryopackaged chip that is tested and demonstrated to produce stable, quantum-accurate waveforms up to 1 V rms with a minimum current range of 1.0 mA that is determined by a Total Harmonic Distortion better than -100 dBc.

B) The capability to generate voltage waveforms with frequency components from 4 Hz up to 1 MHz.

C) A majority of system components that are commercially available.
   a. Keysight M8195A high-speed signal generator
   b. Keysight 33522B low-speed signal generator for compensation
   c. Optilab 2-channel MD-50 GHz bandwidth amplifier
   d. Zurich Instruments MFLI digitizer for analysis and margins testing
   e. HSCC AWG-2 4-channel isolated, programmable amplifier custom-made for NIST

D) Patterns will use a standard pulse frequency of 14.4 Giga-pulses/sec with user-defined waveforms or a standard set of NIST-generated waveforms for standard voltages and frequencies: 0.1, 0.2, 0.5, 0.75, and 1 V rms at 100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, 10 kHz, 20 kHz, 50 kHz, and 100 kHz. Combined uncertainties (k=2) in parts in 10^6 (220 mV range at 200 mV output voltage) are:

100 Hz	400 Hz	1 kHz	2 kHz	5 kHz	10 kHz	20 kHz
2	2	2	2	2	4	12

from “Uncertainty Analysis for the Army Primary Standards Laboratory”, J. Underwood, 2017.

E) Electronic and hardware integration components, cables, wrenches, and a 24U x 24”W x 30”D equipment rack.

[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.

F) A single-node license of the JAWS 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.
G) Application software that provides ac-dc difference measurements and calibrations of various voltage sources and meters

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 JAWS 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) A Windows-based computer system (Windows 7 or higher) with at least 16 GB of RAM for data analysis and system operation. At least four(4) USB-2 ports are required.
C) Customs related clearances, documents, payments, and fees.
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) Providing, as the customer deems necessary, the following additional instruments that are typically used for calibration measurements and are currently support by existing JAWS software:
    a. A Fluke 792A thermal transfer standard
    b. A Fluke 5790 ac voltmeter for rms voltage measurement
F) Liquid helium (for liquid-helium-cooled systems only) for both the on-site qualification as well as for daily operation.

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.

Josephson Arbitrary Waveform Synthesizer (JAWS) System Configurations
SRI 6011 series

6011a Cryo-cooled 1V rms JAWS, with water-cooled compressor

a. Keysight M8195 2-channel 65 GSa/s waveform synthesizer
b. Keysight 33522B Low-speed AWG for signal generation
c. Optilab 2-chan MD-50 2-channel broadband 50 GHz amplifier
d. HSCC AWG-2 Differential amplifier module
e. Sumitomo SRDK-101DP-HC4E2
f. Cryopackaged 1V rms JAWS chip
g. Zurich Instruments MFLI digitizer, 60 MSa/sec, 16-bit
h. NIST JAWS software

6011b Cryo-cooled 1V rms JAWS, with air-cooled compressor

a. Keysight M8195 2-channel 65 GSa/s waveform synthesizer
b. Keysight 33522B Low-speed AWG for signal generation
c. Optilab 2-chan MD-50 2-channel broadband 50 GHz amplifier
d. HSCC AWG-2 Differential amplifier module
e. Sumitomo SRDK-101DP-HC4A2
f. Cryopackaged 1V rms JAWS chip
g. Zurich Instruments MFLI digitizer, 60 MSa/sec, 16-bit
h. NIST JAWS software

6011c Cryopackaged 1V rms JAWS chip (standalone)

6011d Cryopackaged 2V rms JAWS chip (standalone)

6011e 1V JAWS Cryopackage with Liquid Helium Cryoprobe

6011f Cryocooled 2V JAWS System, with water-cooled compressor

a. Keysight M8195 2-channel 65 GSa/s waveform synthesizer
b. 2x Keysight 33522B Low-speed AWG for signal generation
c. Optilab 2-chan MD-50 2-channel broadband 50 GHz amplifier
d. 2x HSCC AWG-2 Differential amplifier module
e. Sumitomo SRDK-101DP-HC4E2
f. Cryopackaged 2V rms JAWS chip
g. Zurich Instruments MFLI digitizer, 60 MSa/sec, 16-bit
h. NIST JAWS software

6011g Cryocooled 2V JAWS System, with water-cooled compressor, no synthesizer

a. 2x Keysight 33522B Low-speed AWG for signal generation
b. Optilab 2-chan MD-50 2-channel broadband 50 GHz amplifier
c. 2x HSCC AWG-2 Differential amplifier module
d. Sumitomo SRDK-101DP-HC4E2
e. Cryopackaged 2V rms JAWS chip
f. Zurich Instruments MFLI digitizer, 60 MSa/sec, 16-bit
g. NIST JAWS software