

# Metrology Applications of Josephson Junction Circuits

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There has been much impressive progress in the past two decades in devices, systems and applications of Josephson voltage standards for precision metrology. Because the ac Josephson equation fundamentally links frequency to voltage, modern ultra-stable frequency sources may be used in conjunction with arrays of Josephson junctions to create significant voltages and waveforms which are used to calibrate instruments.

The three main classes of metrology involving Josephson junction circuits: dc voltage metrology, ac voltage metrology, and temperature scale definition. For dc voltage metrology, circuits with over 500,000 Josephson junctions have been made to produce step-wise and dc voltages up to  $\pm 20$  V<sup>1</sup>. Similar systems are in common use worldwide for the calibration of Zener voltage references, ac-power standards, and Watt-balance experiments. Ac voltage metrology (10 Hz to 100 kHz) has been performed using pulse-driven arrays (the Josephson Arbitrary Waveform Synthesizer or JAWS) of up to 100,000 Josephson junctions for voltages up to 2 V<sub>rms</sub>. The JAWS system may be used for thermal transfer standard calibration or as a precision ac voltage source<sup>2</sup>. A special case of the JAWS system is used to make small, pseudo-white noise waveforms which are used in Johnson noise thermometry metrology to help re-define the temperature scale<sup>3</sup>.

[1] H. Yamamori, T. Yamada, H. Sasaki, and A. Shoji, "10V programmable Josephson voltage standard circuit with a maximum output voltage of 20V", *Supercond. Sci. Technol.* 21 (2008), 105007; F. Müller, T. Scheller, R. Wendisch, R. Behr, O. Kieler, L. Palafox, and J. Kohlmann, "NbSi Barrier Junctions Tuned for Metrological Applications up to 70 GHz: 20 V Arrays for Programmable Josephson Voltage Standards", *IEEE Trans. Appl. Supercond.*, vol. 23, pp 1101005, Jun. 2013

[2] Nathan E. Flowers-Jacobs, Alain Rufenacht, Anna E. Fox, Paul D. Dresselhaus, Samuel P. Benz, "2 V Pulse-Driven Josephson Arbitrary Waveform Synthesizer", <https://dx.doi.org/10.1109/CPEM.2016.7540601>, and Frederic Overney, Nathan E. Flowers-Jacobs, Blaise Jeanneret, Alain Rufenacht, Anna E. Fox, Jason M. Underwood, Andrew D. Koffman, Samuel P. Benz, "Josephson-Based Full Digital Bridge for High-Accuracy Impedance Comparisons", <https://dx.doi.org/10.1109/CPEM.2016.7540628>.

[3] Samuel P. Benz, Alessio Pollarolo, Jifeng Qu, Horst Rogalla, Chiharu Urano, Weston L. Tew, Paul D. Dresselhaus, D. R. White, "An electronic measurement of the Boltzmann constant", *Metrologia*, Volume 48, Number 3