DESIGN OF THE NIST 10 V PROGRAMMABLE JOSEPHSON VOLTAGE STANDARD SYSTEM

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Abstract

NIST has developed and implemented a new Programmable Josephson Voltage Standard (PJVS) that operates at 10 V. This next-generation system is optimized for both dc metrology and stepwise-approximated ac voltage measurements for frequencies up to a few hundred hertz. The non-hysteretic Josephson junctions in these 10 V PJVS systems, which produce intrinsically stable voltages, provide a number of advantages and additional features as compared to conventional JVS systems.

Introduction

Since the demonstration of uniform series arrays of intrinsically shunted Josephson junctions starting in the mid 1990's [1-2], continued research and development has led to many Programmable Josephson Voltage Standards (PJVS) worldwide. In recent years, the output voltage of PJVS circuits has increased beyond the original 1 V maximum voltage and reached the 10 V benchmark [3-5], which was set over twenty years ago by conventional dc Josephson Voltage Standard (JVS) systems.

This enables PJVS technology to replace conventional JVS technology in the coming years for those who wish to utilize its advantages, which include: (a) Comprehensive automation and the ability to fully characterize all operating margins of the device without operator participation, (b) Inherent voltage-step stability and large current margins (0.7 mA), which eliminate the need for output filters, thus enabling applications not previously possible with conventional JVS, (c) Short settling time (200 ns), which enables the generation of both dc and stepwise-approximated ac voltages, which are metrologically useful up to a few hundred hertz.

Because PJVS systems directly "program" the output voltage, they require completely different bias electronics (both dc and microwave) and wiring, and therefore are not a "drop-in replacement" for existing conventional JVS systems. The realization of 10 V PJVS devices has given us the opportunity to completely redesign each component of the PJVS system, including microwave generator, audio-frequency bias electronics, control software, cryoprobe, cryopackaging, etc. The system design improvements for the new PJVS circuits are essential for extending the capabilities and features beyond the conventional application of dc metrology, and into ac metrology applications through use of the intrinsically stable and rapidly programmable voltages. Complete details of the new system design will be presented at the CPEM conference.

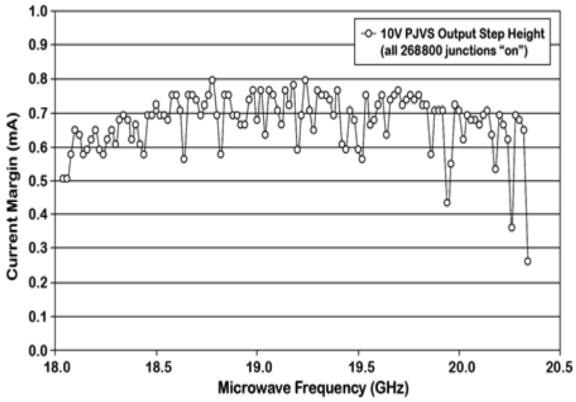

Figure 1. Measured operating current range for a 10 V PJVS circuit (with all 32 sub-arrays biased at nonzero voltage steps) at numerous microwave frequencies over a 2.3 GHz range.

DC Operation

Details of NIST SNS (superconductor normal-metal superconductor) PJVS circuits, systems, and bias methods have been described elsewhere [6-8], and in recent years numerous technological improvements have enabled the successful development of 10 V PJVS circuits with practical operating margins [9-11]. The culmination of those efforts is illustrated in Fig. 1, which shows the operating-current margins over a wide range of microwave frequencies for these 10 V devices. The broad frequency response of these circuits is primarily due to an improved microwave design of the PJVS circuits. This PJVS circuit operates with a current margin greater than 0.55 mA for all frequencies between 18.2 GHz and 19.8 GHz.

These current margins are smaller than the typical 2 mA margins of our lower-voltage 2.5 V devices. The lower current range is due partially to the lower critical current of the junctions in the 10 V chip (roughly half the crucial current of the 2.5 V devices), which was intentionally chosen to reduce the circuit's total power dissipation, so that its heat load would be more compatible with cryocooler operation.

Fig. 2 shows that the PJVS output voltage step is perfectly "flat" (i.e., constant voltage within the noise

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of the measurement) over the full range of bias current with all junctions biased at a nonzero voltage. Half of the junctions are biased on the positive voltage step and the other half on the negative step, which, in combination, produces a small net voltage that can be measured on a low voltage range. The microwave drive frequency is 19.3 GHz for this measurement. The total usable step height is 0.7 mA, and the “dither” bias current flows simultaneously through all cells. The calculated slope is -9 nV/mA ± 41 nV/mA (*k=2*), which is an uncertainty of ± 1 part in 10^9 for a bias current setpoint accuracy of ± 0.2 mA. The measurement uncertainty could be reduced further by use of a lower voltage range and averaging more data.

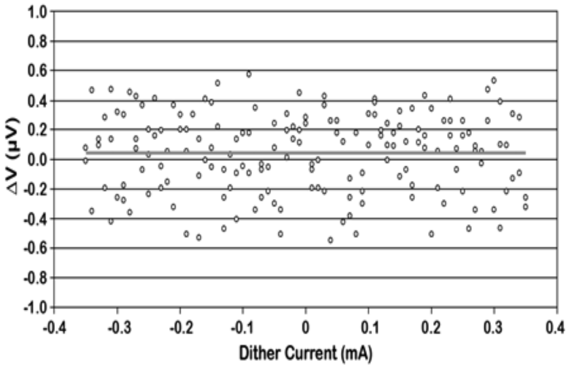

Figure 2. Measured output voltage deviation from the expected quantized dc voltage vs. dither current for a 10 V PJVS with all sub-arrays active.

AC Operation

There has been extensive research over the past decade into the use of PJVS systems for stepwise approximated ac waveform synthesis. This method of synthesis cannot approach the unprecedented low distortion and high-spectral purity that pulse-driven ac Josephson voltage standards (ACJVS) have demonstrated [12]. However, since ACJVS systems are presently limited to 250 mV rms, PJVS stepwise ac synthesis is worth exploring because it can produce voltages up to 7 V rms, as depicted in Fig. 3.

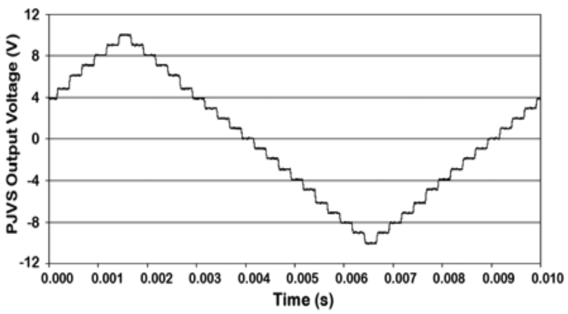

Figure 3. Digital oscilloscope measurement of a 10 V (zero-to-peak) 100 Hz triangle wave generated by the 10 V PJVS system. These first design 10 V chips consist of equally sized sub-arrays, giving a “digital” resolution around 400 mV. The second design of 10 V devices, which are presently being developed, will have a LSB of approximately 200 μV, which will enable significantly higher-resolution arbitrary waveforms.

Stepwise ac metrology with PJVS systems has been most successfully implemented through the use of digital sampling techniques [13-14], with the best uncertainties achieved at frequencies of 50 Hz to 60 Hz, for power applications [15-16]. Recent research efforts and specialized measurement methods suggest that useful stepwise-ac voltage measurement techniques may be extended up to audio frequencies. However, as we have previously reported [17-18], there are significant challenges that must be circumvented in order to accomplish this.

Conclusion

NIST has developed a PJVS system at 10V for both dc metrology and stepwise approximated synthesis. All system components have been redesigned and optimized so that these systems are a long-term alternative to “conventional” 10V JVS for users that desire the additional measurement capabilities.

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