PROGRAMMABLE 1 VOLT DC VOLTAGE STANDARD

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Abstract

We have developed a Josephson voltage standard that produces intrinsically stable voltages that are programmable from −1.1 V to + 1.1 V. The standard uses a binary array sequence of 32 768 SNS (superconductor-normal-superconductor) Josephson junctions. The output can source or sink up to 2 mA and thus has high noise immunity.

Introduction

This paper describes a new Josephson voltage standard (JVS) in which the output voltage $V = Nf / K_{J\text{-}90}$ is defined by digitally programming the step number N. In this programmable JVS, an array of nonhysteretic junctions is divided into a binary sequence as shown in Fig. 1. The microwave excitation for each junction is set to equalize the amplitude of the $n = 0$ and $n = 1$ steps as shown in the inset. Each segment of the array can be set to the $n = -1$, 0, or +1 steps by applying bias current ($-I_s$, 0, $+I_s$) at the appropriate nodes. The combined step number N for the whole array can thus be set to integer values between $-M$ and $+M$, where M is the total number of junctions in the array [1, 2].

The rapid settling time, inherent step stability, and large operating current margins of the JVS in Fig. 1 make it superior to a conventional JVS for many dc measurements. (We define a dc measurement to be one in which the transient associated with changing N can be excluded from the measurement.) This improved performance is made possible by a new integrated circuit technology using intrinsically shunted SNS (superconductor-normal-superconductor) Josephson junctions. These junctions operate at lower excitation frequencies (10 to 20 GHz) than a conventional JVS and have 100 times larger step amplitudes (2 to 4 mA) [3].

The new JVS chip contains 32 768 Josephson junctions that are distributed such that the device functions as a 9-bit (including sign) digital-to-analog converter (DAC). [4] The microwave drive is split 8 ways and delivered to 8 array segments of 4096 junctions each. The first segment is further divided into arrays of 128, 128, 256, 512, 1024, and 2048 junctions. Limiting the largest segment to 4096 junctions allows the bias currents to compensate for critical current variations between individual 4096 junction segments. The microwave drive frequency is near 16 GHz, which makes the voltage generated by each junction

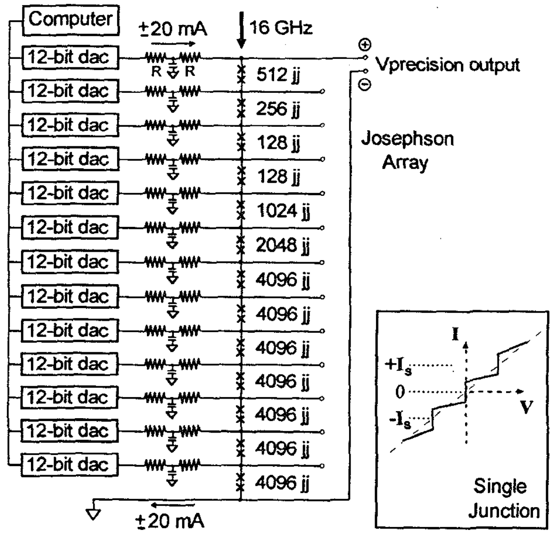

Fig. 1. Bias schematic of the 1 Volt Programmable JVS.

$V = f / K_{J\text{-}90} \approx 33\ \mu V$. The smallest cell in the device consists of 128 junctions, which makes the least-significant-bit (LSB) resolution about 4 mV. The output voltage can be set to any arbitrary value within the ±1.1 V range by selecting appropriate values of N and f.

Bias Circuit Design

As shown in Fig. 1, each node of the Josephson array is connected to a 12-bit DAC voltage source. These voltages are converted to currents by two series resistors ($R = 100\ \Omega$). The bias current to a typical array segment is about 15 to 20 mA. To set the Josephson array to any of its 511 quantized output levels, the computer calculates the voltage at each DAC output based on the bias current required by each array segment. After the 13 DAC input buffers have been loaded by the computer, the DAC outputs are simultaneously updated with a common trigger signal. The Josephson chip settles to the new voltage within a few microseconds.

The computer controls the bias electronics through an ordinary PC parallel port. Programming the array to a new output level takes about 500 µs. To ensure that noise from the computer and the environment is not coupled into the Josephson array biases, each signal wire from the parallel port is passed through a 1 MHz low pass filter. Additionally, the analog bias circuit is powered from rechargeable batteries and optically isolated from the digital logic. This not only reduces the potential for ground loops and unwanted RFI coupling, but it also allows the

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Josephson array to float with respect to ground, allowing greater flexibility when the JVS is connected to other measurement systems.

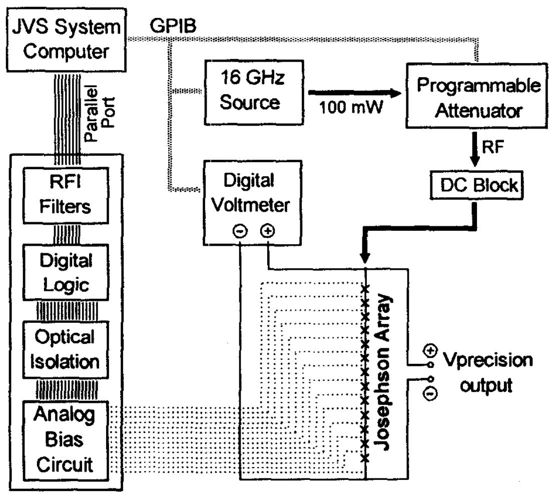

Fig. 2. Block diagram of the 1 Volt Programmable JVS.

System Overview

Figure 2 shows the overall configuration of the 1 V programmable JVS. The system computer controls the microwave frequency and power through GPIB connections to the 16 GHz source and the programmable attenuator. The output from the array is connected independently to both the precision output leads and the system digital voltmeter (DVM). This allows the system computer to continually monitor the array output with a resolution of a few microvolts (a few parts in 10^6 at 1 V).

Under control of the system computer, chip testing and diagnostic procedures are performed automatically. The individual I-V (current-voltage) curves of each array segment are measured to confirm functionality and to select the optimum bias points for the -1 and +1 steps. The chip operating margins for both dc bias currents and microwave power are measured, and the output voltage step flatness is verified over the full step height with sub-micro-ohm resolution.

Applications

The 1 V programmable JVS makes possible a number of dc measurements that take advantage of its rapid programmability, intrinsic output stability, and large operating margins (noise immunity). Some of these measurements have already been reported, including fast characterization of D/A and A/D converters, comparison against conventional SIS voltage standards, Zener reference calibrations using null voltages of 1 μV or less, etc. [2, 4]

The latest application of the 1 V programmable JVS is the watt balance experiment [5] which requires a stable, reversible voltage reference with high noise immunity. In the first mode of this experiment, a servo system controls the velocity of an induction coil moving in a magnetic field such that the voltage across the coil is equal to the 1 V reference from the JVS. In the second mode, the current in the induction coil is controlled in order to balance the gravitational force of a 1 kg mass. This current is precisely measured by passing it through a resistance standard and comparing the resulting voltage to the JVS with a null-meter. The new JVS operated successfully as a direct reference in both modes of the experiment, thereby eliminating two voltage transfers and the associated noise and uncertainty contributions. These experiments show that the large step height and floating output of the Josephson array makes it ideal for use in an experiment of this complexity. A system dedicated to this application is in the final stages of construction.

Another experiment that combines the advantages of fast switching and stable output voltage of the programmable JVS is the precise characterization of capacitors used in electron counting experiments. When a nearly perfect step function generated by a Josephson array is applied to the capacitor, measurement of the charging current yields information on the low-frequency dependence of the capacitance.

References

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