DEVELOPMENT AND INVESTIGATION OF INTRINSICALLY SHUNTED JUNCTION SERIES ARRAYS FOR AC JOSEPHSON VOLTAGE STANDARDS

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Abstract

Different types of intrinsically shunted Josephson junctions have been developed and investigated for ac voltage standard applications at PTB. The first type, for generation of voltages up to 10 V, is driven by a 70 GHz sinusoidal microwave signal and consists of 69,632 series-connected junctions, where the number of junctions per segment follows a binary sequence. The second type, which is driven by short current pulses, contains up to 5,000 junctions and enables the synthesis of intrinsically accurate ac waveforms.

Introduction

The increasing demand for highly precise ac voltages has stimulated different attempts to develop measurement tools based on Josephson junction series arrays for these applications. Two approaches are presently being investigated. First, series arrays of overdamped Josephson junctions, in which the number of junctions per segment follows a binary sequence, are used mainly for applications at frequencies from dc to about 1 kHz [1], [2]. The second approach, which works best for applications at frequencies from about 100 Hz up to 1 MHz, is based on series arrays of overdamped Josephson junctions that are biased with a high-speed digital sequence of short current pulses [3], [4].

Both types of ac voltage standards have advantages and limitations. Binary-divided arrays consisting of about 70,000 junctions for a 70 GHz drive, are available for output voltages up to 10 V [5]. The array is operated as a multi-bit digital-to-analog (D/A) converter, which allows a sine waves to be synthesized as a step-approximated waveforms that exhibits harmonics in addition to the fundamental frequency. The synthesis of spectrally pure waveforms is enabled by pulse-driven arrays, which are typically operated in the frequency range from 5 GHz to 15 GHz. RMS voltages up to 275 mV were realized [3]; however the generation of RMS voltages of 1 V or more will be very challenging.

The first overdamped Josephson junction technologies that proved useful were superconductor-normal metal-superconductor (SNS) junctions using various barrier materials, e.g., AuPd [6] or HfTi [4]. Recently, highly resistive, amorphous metal-silicide, Nb_xSi_{1-x} barriers have proven useful for both pulse- and sine wave-driven ac voltage standards [3], [5]. These junctions are robust and enable the fabrication of large series arrays with sufficient reproducibility and yield. The characteristic voltage of the junctions is tuned so that the arrays can be used at different drive frequencies. Junctions with the highly resistive barrier materials have proven especially useful, and with very high yield, for 70 GHz junctions [5].

10 V binary-divided series arrays

The 69,632 junctions of the binary-divided arrays for operation at 70 GHz are embedded into a low-impedance microstrip line. This configuration ensures a compact design as well as a homogeneous microwave bias to all junctions by splitting it into 128 parallel microwave paths each containing up to 582 junctions. The Nb content and the thickness of the Nb_xSi_{1-x} barrier layer were adjusted to about 6 % and 11 nm, respectively, to reach the targeted characteristic voltage of about 150 µV, which is suitable for the 70 GHz drive [5].

The Nb-Nb_xSi_{1-x}-Nb trilayers were optimized and deposited at NIST. The patterning process, by use of electron-beam lithography, and junction measurement were performed at PTB. Fig. 1 shows the

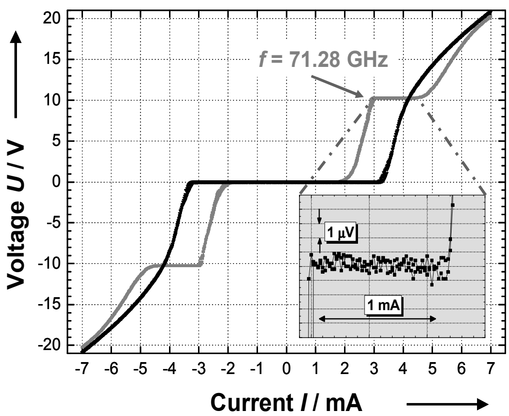

Fig. 1: Current-voltage characteristic of a 10 V SNS series array consisting of 69,632 junctions with and without microwaves at 71.28 GHz. The inset shows the 10 V step with high resolution.

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current-voltage characteristic of a 10 V array with and without the 70 GHz microwave bias. The current range of the constant-voltage step at the 10 V level is greater than 1 mA. These 10 V arrays are well suited for both dc and step-wise ac voltage applications.

Pulse-driven series arrays

The junctions for pulse-driven arrays are integrated into the middle of a 50 Ω coplanar waveguide transmission line. PTB has investigated a compact lumped-circuit design in which the junctions are arranged in a meander-like structure [7]. Pulse-driven arrays require a broadband microwave bias signal because of the large harmonic content of the digital pulse waveform. The small dimensions of these sub-micrometer SNS junctions consisting of Nb/HfTi/Nb require electron-beam lithography and chemical-mechanical polishing [4]. The characteristic voltage of the junctions is presently limited by the highly conductive HfTi layer. The use of highly resistive barriers is planned at PTB for the future; a promising material could be Nb_xSi_{1-x} utilized at NIST [3].
The width of the constant-voltage steps is measured over a wide frequency range as a first test of the broadband microwave behavior of the arrays. Fig. 2 shows the steps, which are represented by flat valleys in the plot of the derivative, d*U*/d*I* versus both frequency and dc bias current. The first step (1.SS) is present over the whole frequency range. The setup

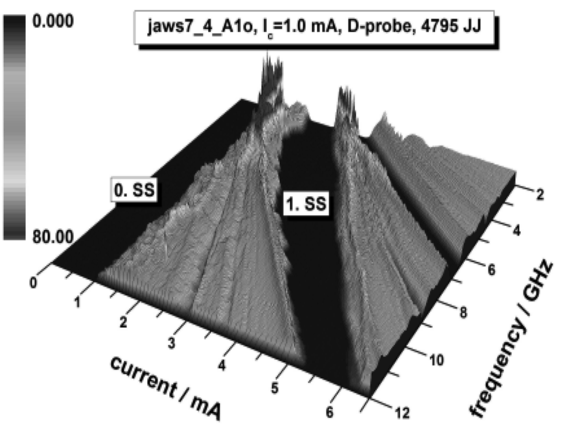

Fig. 2: Formation of constant-voltage steps as a function of microwave frequency *f* and dc bias *I* for an extended array of 4795 Josephson junctions. The vertical axis shows the grey-scale coded derivative d*U*/d*I*. Flat regions mark constant-voltage steps. The critical current (0.SS) was kept constant by adjusting the microwave power.

for pulse operation and investigations of array performance under pulse-drive will also be presented at the conference [8], [9].

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