High-precision pulse-driven AC Josephson voltage standard up to 1 V at PTB

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Abstract — The increasing demand for generation of high precision AC voltages providing pure frequency spectra and the capability of synthesizing even complex arbitrary waveforms for metrological applications lead to the extension of the well established DC Josephson Voltage Standard to AC voltages. To achieve this goal, the pulse-driven Josephson Voltage Standard, also called "Josephson Arbitrary Waveform Synthesizer" (JAWS), has been developed for many years at PTB. Recently, a major milestone was reached: the JAWS output RMS voltage exceeded the important limit of 1 V. This voltage level is very essential, because it opens many new applications in electrical metrology.

For use in the JAWS, Josephson junction arrays are operated by short current pulses with a non-constant pulse repetition frequency. The maximum repetition frequency is limited by commercial available pulse pattern generators (PPG) to about 15 GHz (return-to-zero pulses). Bipolar waveforms can be synthesized due to the fact that ternary pulses (+1, 0, -1) are delivered by the PPG. Therefore, it is possible to use the plus and minus Shapiro step and hence the output voltage of the JAWS is doubled. DC voltages and arbitrary waveforms are synthesized by adjusting the pulse sequence and coding the waveform with a higher-order sigma-delta simulation. This fundamental approach delivers spectrally pure waveforms – i.e. higher harmonics can be suppressed by more than 120 dBc, which is normally below the noise floor of common spectrum analyzers.

The fabrication of arrays for JAWS circuits is performed at the PTB clean room in a complex multilayer thin-film process. Overdamped Josephson junctions with non-hysteretic current voltage characteristics are used. At PTB we recently focused on SNS like junctions (S: superconductor, N: normal metal) with Nb_xSi_{1-x} as barrier material. This material has the advantage that the characteristic voltage and the critical current density can be adjusted nearly independently in a wide range by tuning the barrier thickness (d) and the barrier composition (x). For the JAWS these parameters are typically: d = 30 nm and x = 0.2. The extremely stable and reproducible deposition conditions ensure an extraordinary low intra-chip and run-to-run parameter spread and therefore we were able to fabricate even triple-stacked Josephson junction series arrays with a high yield. This means a sophisticated multilayer process with 11 layers in total (5 x S-layer, 3 x N-layer, 3 x other layer). On a single chip of 10 mm x 10 mm two JAWS circuits with up to 9 000 Josephson junctions each can be integrated. By a superconducting on-chip connection a total number of 18 000 junctions is available at the chip output voltage leads.

Recently, by combining eight circuits on four different chips, we could connect in series the total number of 63 000 Josephson junctions thus increasing the output voltage of the JAWS to an effective value of 1 V (1.4 V_{peak}). For this purpose a novel PPG with 8 ternary output channels was integrated in the JAWS setup. High quality waveforms were synthesized with a signal-to-noise ratio better than 120 dBc.

In a worldwide unique precision comparison with an AC quantum voltmeter (based on the programmable Josephson voltage standard), an excellent agreement of (3.5 ± 11.7) nV/V could be demonstrated at a frequency of 250 Hz.

For the future, effective voltages of 1 V open up a great number of new application possibilities for the JAWS in the field of electrical AC voltage metrology, e.g. calibration of AC voltages, AD-/DA-converters, thermal converters, voltage dividers, and impedance references. At the QM 2016 conference we presented the features of the new 1 V JAWS system in detail and introduced some applications performed at PTB.

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Keywords (Index Terms) — Josephson Arbitrary Waveform Synthesizer, JAWS, SNS Josephson junction, AC Josephson Voltage Standard, pulse-driven Voltage Standard.