Preparation for future inter-comparison of ACJVS between two National Metrology Institutes

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Towards the propagation of AC Quantum Voltage Standards

Preparation for future inter-comparison of ACJVS between two National Metrology Institutes

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Contents

Introduction

This document presents some considerations on the future inter-comparison of AC Programmable Josephson Voltage Standards (ACJVS) between two National Metrology Institutes. Namely Türkiye Bilimsel ve Teknolojik Araştirma Kurumu (TUBITAK) and Czech Metrology Institute (CMI) are considered as candidates.

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In this document a type of ACJVS, Programmable Josephson Voltage System (PJVS), is understood as a whole measurement system with Josephson chip, bias, null meter or digitizer, controlling computer and operating software able to measure or generate DC or stair-case AC voltage.

The comparison of DCJVS was already tested by many institutes, usually with conventional JVS. Two types of DC comparisons are commonly used [1]:

- Direct comparison [1]: Josephson chips of both systems are connected into one circuit. In the case of Conventional JVS (zero crossing steps), bias source of one of systems can be used to set quantum level of both chips. Next bias sources are disconnected and one system is used to measures voltage of the chip of other system. In the case of PJVS bias sources of both systems are used.

- Indirect comparison: Comparison using transfer standard: A Zener voltage reference (secondary electronic voltage standard) is alternately measured by both systems. Thus the Zener voltage reference serves as a transfer standard. Main requirements for the transfer standard is short time noise and stability.

A comparison of AC systems is not yet common in metrological institutes. BIPM has conducted 4 full pilot studies from September 2015 to February 2018 for AC comparison (62.5 Hz, 1 V and 7 V RMS). Up to now the AC comparison of PJVS is still under development in BIPM.

The document focus on comparison of ac voltage at 53 Hz and 1 kHz because of the need for power and impedance measurements. The target RMS amplitude is 7 V.

1 Methods of comparison

Following methods can be considered for comparison of two PJVS:

1. Direct comparison.

[1] Direct comparisons of JVS will be the basis of the uniformity of the future realization of the volt unit after the SI redefinition in May 2019.

2. Indirect comparison using a transfer standard.

3. LF impedance bridge methods.

1.1 Direct comparison

Because PJVS is basically a DCJVS system switching to a new voltage very often, a comparison seems to be easy[2]. A quantum step is set on both PJVS and value is compared. Next the same is proceeded on different step according generated stair-case waveform simulating sine waveform. However because of the stair-case waveform, it is not really an AC comparison but a DC comparison although the systems are compared very quickly. Thus only direct DC comparison of two PJVS was carried out till today ([2], [3]).

1.2 Comparison using transfer standard

An AC voltage source or voltmeter act as a transfer standard. Thus to carry out such a comparison some AC transfer standard have to be selected.

Three methods of comparison using transfer standard can be considered:

– Two PJVS measuring AC source one after another.

– Two PJVS measuring AC source at once.

– Two PJVS are measured by an AC voltmeter.

1.2.1 Measuring AC source one after another

In this comparison a transfer standard is alternately measured by both systems.

This method can be done in two ways:

1. on-site comparison,

2. long-distance comparison.

On-site comparison: One PJVS has to be moved to the participating laboratory. Connecting cables to the transfer standard must sometimes be changed from one measurement setup to the other, each time a measurement is completed. However the use of a low-thermal switch to connect the AC transfer to one setup to the other is possible in some cases [4]. In that case, there's relaxing time required for the thermals to stabilize and the comparison process is faster. The 10 MHz reference signal also needs to

[2]Easy with the aim of relative uncertainty 10^{-10}.

be moved from one setup to the other to prevent from any ground loop between the two measurement setups.

Long-distance comparison: The transfer standard is sent from one laboratory to another. The stability of the transfer standard needs to be considered up to several months. The advantage is no PJVS has to be transfered but a higher uncertainty is expected compared to the previous method, typically one order of magnitude [5].

1.2.2 Measuring AC source at once

The second method was never tested but should be possible due to high impedance input of the digitizers used in the PJVS setups. However a severe grounding, synchronization and common mode voltage problems can be expected. It would benefit if one PJVS would not need to be grounded. The grounding scheme of the samplers have also to be considered. The cryocooled systems are typically grounded by the cryocooler, thus this type of comparison of two cryocooled systems seems to be very problematical.

1.3 Comparison using ac voltmeter

Because PVJS can act as a generator of the stair-case waveform, the output can be measured by a voltmeter. Therefore a voltmeter can be also used as a transfer standard. The main issue of this method is the stair-case waveform is composed of a large number of harmonics. Such a voltmeter has to either measure RMS value or a whole stair-case waveform has to be analyzed or lock-in voltmeter has to be used. However every stair-case waveform generated by PJVS is undefined when the voltage is changed. Therefore the precision of this type of comparison can probably never be better than error caused by this effect.

1.4 LF impedance bridge methods

Based on the experience of PTB, the impedance bridges using PJVS are possible but very hard to build and comparison would lead to many problems.

1.5 Evaluation of comparison methods

For the needs of considered NMIs, the long-distance comparison using transfer standard seems to be the best one. When this type of comparison is mastered, NMIs can test the on-site comparison using transfer standard.

The next chapter considers available transfer standards.

2 Selection of the transfer standard

Main requirements for the transfer standard are voltage amplitude stability (value and noise), frequency stability (value and jitter). If a typical calibration of AC source by PJVS takes few minutes, the required stability of the transfer standard needs to be considered up to ten minutes.

Very important ability of the transfer standard is to be referred to an external timebase signal. The analog waveform produced by the transfer standard and the approximated waveform produced by the PJVS must have a common timebase (e.g. 10 MHz external reference).

So the transfer standard should be able to:

- Generate sine waves of frequency up to 5 kHz amplitude up to 10 V.
- The voltage amplitude stability (value and noise) and frequency stability (value and jitter) should be as low as possible. Stability should be better than comparison uncertainty in the time frame of one change of transfer standard between both compared PJVS.
- The harmonic distortion should be as low as possible.
- The transfer standard must be able to be referred to an external timebase signal.

Devices considered in this document are:

1. Calibrator Fluke 5720A Series II or 5730A.
2. DualDAC 2.

2.1 Fluke 57X0A

The advantage using the calibrator as a transfer standard is almost all metrological laboratories have such calibrator already available, therefore participants can test the calibration of such a device before the comparison itself.

Calibrators Fluke 5720 Series II and 5730 has the same specifications. Following values are based on the datasheets [6].

freq., ampl (RMS).	7 V, 55 Hz	7 V, 1 kHz
24 hours stability (±1 °C)	92 µV	
Distortion (10 Hz – 10 MHz)	±3.15 mV (67 dB)	
CMRR	140 dB	

Calibrator Fluke 5700 has the same stability specifications but increased absolute uncertainties.

From the experience of metrological laboratories the calibrators often have much better stability than specifications. The stability of Fluke 5700 as measured:

Observation period	1 to 12 s	up to 100 s	up to 23 days
Allan dev. (7 V RMS, 375 kHz) [7]	6 µV	3 µV	
Max. deviation (6 V RMS, 1 kHz) [8]			±69 µV
Max. deviation (7 V RMS, 1 kHz) [7]			±24 µV

2.2 DualDAC 2

Full scale amplitude of the DualDAC 2 is 7.15 V.

Stability of the output signal is determined by reference dc source. According the datasheet, with a Fluke 5700 calibrator as a reference voltage source (with an internal Zener), sine wave amplitude stability is about 1 ppm for days.

The distortion of the output signal [9] is in ideal conditions about −80 dBc, noise floor is about −100 dBc, this is in agreement to used 16 bit DAC [10].

Because the ac waveform of the DualDAC 2 is governed by the reference dc source, both NMIs should be already compared at dc voltages with uncertainties smaller than target uncertainty of AC comparison.

However the claimed uncertainties couldn't be reached operating the prototype tested in [5] at 1 V (62.5 Hz and 125 Hz). This is probably effect of glitches found in the output of some DualDAC 2 pieces. Also influence of 10 MHz on the output was found.

2.3 Evaluation of transfer standards

Based on the experience gained in the comparisons of PTB-BIPM and NPL–BIPM, the Fluke 57X0A seems to be the most suitable transfer standard for the long-distance comparison. The next chapters considers needed actions to accomplish the comparison.

3 Definition of measurand

A measurand that will be measured during the comparison must be specified properly. For the case of AC voltage metrology following is typically measured:

- root mean square (RMS) amplitude,
- amplitude of main signal component,
- amplitudes of all harmonic components.

RMS amplitude is dependent on bandwidth because of the noise in the signal. Thus to measure RMS amplitude a bandwidth of the PJVS must be specified so it can be compared to other PJVS with possibly different bandwidth (based on the used digitizers).

Because PJVS cannot measure whole waveform in a single period, an assumption about distortion in the signal must be made, because non-repetitive distortion or distortion in the neglected part of the waveform would be a source of error. The possibility is to check DUT by other means that no unwanted distortion appears in the measured signal.

Amplitude of main signal component or harmonic components have to be calculated by advanced algorithms from the data sampled by null meter of a PJVS system. Such an algorithm can introduce yet additional error and has to be included in uncertainty [11].

However RMS value is the measurand used in AC-DC metrology for many years and there is a lot of experience in this field. Therefore it is preferable to measure RMS value, although it will be advantageous to test both measurement of RMS and amplitude of main signal component.

4 Actions needed to accomplish the comparison

The future actions can be divided into 4 stages:

1. Preparation stage: Both future participants will test and routinize the calibration of the type of transfer standard at their own institutes.
2. Long distance stage: Selected transfer standard (STS) will be sent between participants by post service and a comparison based on long term stability of STS carried out.
3. On site stage: One of PJVS systems will be moved to the institute of the second participant and a comparison based on short term stability of STS carried out.
4. On site stage experimental: A simultaneous calibration of the STS will be tested after successful completion of the previous stage.

4.1 Time plan

Time of all actions T+x is described as a number of months after both participants acquire fully working PJVS system.

T+0 participants train the calibration of the STS.

T+3 Participant 1 makes a calibration of STS.

T+4 Participant 1 sends STS to Participant 2.

T+5 Participant 2 makes a calibration of STS.

T+6 Participant 2 sends STS to Participant 1.

T+7 Evaluation of results.

T+10 Transfer of PJVS of Participant 1 to the laboratory of Participant 2.

T+11 On site comparison of two PJVS at the laboratory of Participant 2.

T+10 Transfer of PJVS of Participant 1 to the laboratory of Participant 2.

T+12 Evaluation of results.

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