Rapport BIPM-2005/14

Comparison of the Josephson Voltage Standards of the BEV and the BIPM

(part of the ongoing BIPM key comparison BIPM.EM-K10.b)

D. Reymann and S. Solve, Bureau International des Poids et Mesures
F- 92312 Sèvres Cedex, France

W. Waldmann, G. Heine, P. Scheibenreiter and J. Pribil,
Bundesamt für Eich- und Vermessungswesen
A-1160 Vienna, Austria

Comparison of the Josephson Voltage Standards of the BEV and the BIPM

(part of the ongoing BIPM key comparison BIPM.EM-K10.b)

D. Reymann and S. Solve, Bureau International des Poids et Mesures
F- 92312 Sèvres Cedex, France

W. Waldmann, G. Heine, P. Scheibenreiter and J. Pribil,
Bundesamt für Eich- und Vermessungswesen
A-1160 Vienna, Austria

Abstract. A comparison of the 10 V Josephson array voltage standard of the Bureau International des Poids et Mesures (BIPM) was made with that of the Bundesamt für Eich- und Vermessungswesen (BEV), Vienna, Austria, in November 2005. The results are in excellent agreement and the overall uncertainty is about 3.5 parts in 10^{10}.

1. Introduction

In 2004, the BIPM sent a questionnaire to the national laboratories to propose, among different options, a new type of comparison, where a stable reference voltage produced across the BIPM Josephson array is measured using the laboratories' Josephson array voltage standards (JAVS). This would allow direct comparison using the routine measurement technique used for calibrations in the laboratories, requiring only the BIPM array, but not both arrays, to maintain a perfectly stable output throughout the measurements. This article describes the comparison of the BIPM 10 V standard with that of the Bundesamt für Eich- und Vermessungswesen (BEV) that was carried out at the BEV in November 2005.

2. Comparison equipment

2.1 The BIPM JAVS

The part of the BIPM JAVS used in this comparison comprises the cryoprobe with a Hypres 10V SIS array, the microwave equipment and the bias source for the array. The Gunn diode frequency is stabilised using an EIP 578 counter and an ETL/Advantest stabilizer. To visualize the array characteristic, while keeping the array floating from the ground, an optical isolation amplifier is placed between the array and the oscilloscope; during the measurements the array is disconnected from this instrument. To verify the step stability, a HP 34401 A digital voltmeter (DVM) is used to measure the voltage between the array voltage leads. The series resistance of the measurement leads is 4 Ω and the value of the thermal electromotive forces (EMFs) is less than 50 nV. The leakage resistance between the measurement leads is larger than 10^{11} Ω.

2.2 The BEV JAVS

The BEV JAVS is routinely used to calibrate Zener diode based standards. The BEV's working standards and some customer standards are directly measured against the JAVS, thereby significantly reducing the traceability chain. The array and the bias source were produced by the PTB and have been in service since 1997. Step biasing, array monitoring and the connection of the Zener under test are manually operated. The array is connected to ground via the bias source. At the BEV a measuring program based on Testpoint was developed which allows all the results from the measurement instruments to be read automatically, especially the frequency from the EIP counter and the voltage from the detector, a Keithley 2182 instrument. In particular it should be mentioned that any instability of the microwave frequency is therefore included in this calculation and in the Type A uncertainty. The GPIB interface for reading the measurement instruments is optically isolated from the computer; also the 10 MHz reference signal for the EIP counter is electrically isolated from the signal which is connected to the BEV caesium clock.

- Type of array: 10 V SIS, produced by the PTB s/n M10-9/2;
- Detector: Keithley 2182, scale used 10 mV;
- Bias source: PTB 11/95, produced by the PTB;
- Array: connected to bias source during measurements;
- Software used: JAVSMES_20051111.TST, BEV-produced measurement program based on Testpoint, modified on 11 November 2005;
- Frequency source stabilizer: counter EIP 578B, locking device produced by the PTB, stability better than 5 Hz;
- Measurement reversing switch: manual switch, produced by the PTB;
- Thermal EMFs approximately 600 nV;
- Impedance of measurement leads approximately 5.5 Ω;
- Leakage resistance approximately 1.25×10^{10} Ω.

3. Comparison procedures

Preliminary and test measurements carried out on 10 and 15 November 2005 are described in Appendix A. Only those carried out on November 11 and 14 are taken into consideration for the comparison.

During the measurements, the BIPM array was disconnected from its bias source. The two arrays were connected in series opposition via the BEV's reversing switch and a BIPM low thermal EMF-reversing switch. In this new procedure (option "B"), the BEV's JAVS is used to measure the BIPM array voltage as if it were a Zener voltage standard. In fact, in BEV Zener measurements, the polarity of the output voltage is reversed using the switch whereas in the main part of the Josephson comparison, only the bias of the array was reversed and no switch reversal was made. The "low" of the BEV detector was connected to ground via the bias source.

4. Description of the measurements

The following is a brief description of the procedure used by the BEV software to obtain a single measurement of the voltage of the BIPM array. One set of 25 readings of the voltage difference between the two arrays were carried out, in the positive polarity of the bias of the two arrays. Then two sets of 25 such readings were carried out, in the negative polarity and again one set of 25 readings in the positive polarity. The complete measurement took about five minutes. The result is the mean of the positive measurements and of the negative measurements.
The readings were corrected by the software to take into account the value of the DVM gain. This value was measured by biasing the BEV array on different steps and measuring the JAVS voltage directly connected to the DVM.
Individual data for the difference between the value measured by the BEV and the theoretical value of the BIPM array voltage are plotted in Fig. 1, together with their Type A uncertainties.

5. Uncertainties and results

The sources of Type B uncertainty (Table 1) are the absolute value of the frequency measured by the EIP counter, and the measurement leakage resistance, detector gain and linearity. The effect of the uncertainty of the frequency and the leakage resistance of the measurement circuit are the main sources of Type B uncertainty, most of the effects of non linearity and frequency stability being already contained in the Type A uncertainty. As both array polarities were reversed during the measurements, the effect of the residual thermal EMFs is already contained in the Type A uncertainty of the measurements. (The standard Type A uncertainty was 1.7 nV)

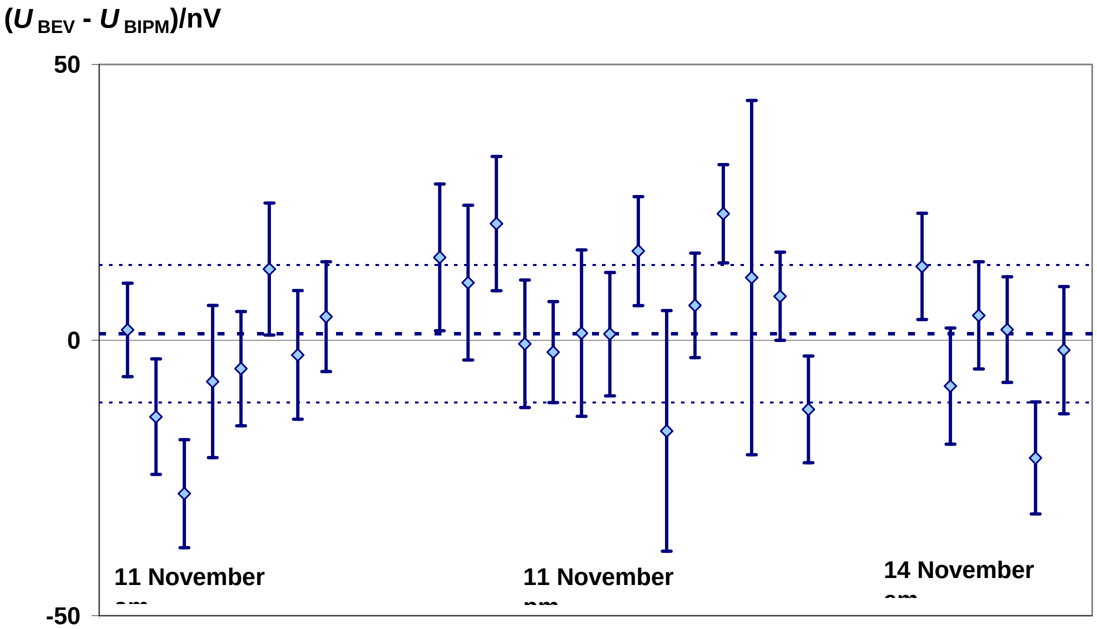

Fig. 1. Difference between the measured values and the theoretical value of the BIPM array voltage. Vertical bars are the 1σ Type A uncertainties of each measurement. The dotted lines are for the mean and the 1σ Type A uncertainties of a single measurement.

Table 1. Estimated Type B standard uncertainty components.

	Type	Uncertainty/nV BIPM	BEV
Frequency	B	0.2	1.3
Leakage resistance	B	0.4	2.6
Detector (*)	B		0.6
Total (RSS)	B	0.4	3.0

(*) As the BEV array was biased on different steps and as the detector gain was taken into account, a large part of the detector uncertainty is already contained in the Type A uncertainty of the measurements.

The result is expressed as the relative difference between the values that would be attributed to the 10 V Josephson array standard by the BEV (U_{BEV}) and its theoretical value (U_{BIPM}).

$(U_{BEV} - U_{BIPM}) / U_{BIPM} = 1.1 \times 10^{-10}$ $u_c / U_{BIPM} = 3.5 \times 10^{-10}$

where u_c is the combined standard uncertainty.

6. Discussion and conclusion

This comparison is the fifth of a new series where the host laboratory uses its own Josephson equipment to measure the voltage of the BIPM array, considered as the “transfer” instrument. The main feature of this new measurement technique is that it requires only the BIPM array, but not both arrays, to maintain a perfectly stable and reproducible 10 V output throughout the measurements.

The BIPM equipment was installed and preliminary measurements were performed on the day after arrival; during the first two days, adjustments were made to various parts of the BEV measurement set-up. The comparison itself was then carried out with these improved conditions.

The results of the comparison demonstrate the ability of BEV in 10 V measurements. This comparison allowed the laboratory to study various problems, and to improve the measurement conditions by applying DVM calibration corrections.

It should be pointed out that the BEV system as it was at the beginning of the comparison, was already suitable for Zener measurements; as the observed deviations were of only a few parts in 10^9, the limiting parameters could not have been determined without a direct Josephson comparison.

Appendix A

Preliminary measurements

The first measurement day at the BEV revealed various minor problems.

1 – After having assembled the BIPM equipment, it appeared that when both JAVS were connected together no steps could be observed on the BEV array, despite the fact that the BIPM array was floating from ground. To get rid of this problem, the only possibility was to remove the ground from the helium Dewar flask containing the BIPM array. At the BEV, as well as at the BIPM, the mains voltage is about 230 V between a "neutral" and a "phase". As the Austrian mains plugs are symmetric, few instruments had been connected in the wrong position. Nevertheless, even after having connected all instruments in the right position, it was not possible to connect the BIPM helium Dewar to ground.

2 – The dispersion of the results and the Type A uncertainty of the preliminary measurements were larger than expected. This was partly due to the fact that no correction was applied to take into account the detector calibration. The BEV software was then modified to apply the necessary correction.

3 – The number of data for a single determination of the voltage of a Zener in a single polarity was equal to 100, and about two minutes were necessary for this measurement. Hence, the duration of the four sets of measurements in a single series was much too long. Although such a large number of data may be necessary to integrate the noise when measuring a Zener, it was not so when measuring a Josephson array. For these two reasons, the number of data was reduced to 25. This had two advantages: it reduced the risk of a step jump of the BIPM array; and it made it possible to increase the number of measurements.

Complementary measurements

In the measurements, the mean of the standard deviation of a single observation within a run was 12 nV. In order to try to reduce this value, another detector (Keithley 182) was tested. After a new modification of the acquisition software and a calibration of the detector, a few measurements were carried out. No significant reduction of the standard deviation was obtained, but complementary measurements were suggested.

DISCLAIMER

Certain commercial equipment, instruments or materials are identified in this paper in order to adequacy specify the environmental and experimental procedures. Such identification does not imply recommendation or endorsement by the BIPM, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.