Comparison of 1.018 V and 10 V DC Voltage References

Technical protocol for BIPM.EM-K11.a and .b comparisons

1. Introduction

The Mutual Recognition Arrangement among National Metrology Institutes (NMIs) places particular importance on key comparisons to demonstrate a NMI's ability to measure certain critical quantities. The Consultative Committee for Electricity and Magnetism has identified comparisons of 1.018 V and 10 V standards, including Josephson array voltage standards (JAVS), as key comparisons. These standards are considered as primary voltage standards. To take advantage of the high accuracy of JAVS, on-site direct comparisons have been carried out by the BIPM since 1991 (BIPM.EM-K10.a/b).

Another way that NMIs check the coherence of JAVS standards is to use Zener diode-based references (Zeners) as travelling standards in international comparisons. Such comparisons are most demanding of the performance of Zeners. Nevertheless, provided that corrections are made for the effects of atmospheric pressure and internal temperature (thermistor measurement) on the Zener outputs, it is possible to reach the 1 part in 10^8 level of uncertainty.

The NMIs that do not posses JAVS often rely on Zeners as travelling standards to assure traceability to Josephson standards via calibrations and comparisons with other NMIs or with the BIPM. Over the years, some NMIs have participated in regular calibrations of their national voltage standard by the BIPM. Consequently, they have established accurate values and drift rates of their standards.

2. Purpose

The purpose of this comparison is to link the voltage reference of the laboratory* (acronym), country, to that of the BIPM in the frame of the BIPM.EM-K11.a and .b key comparisons.

Technical changes to this protocol need to be approved by the CCEM WGLF (low frequency working group).

3. The standards

* The text appearing in red color in the present document needs to be updated for each new comparison.

The travelling standards or transfer standards (TS) are two Zeners (Fluke 732B type) identified by a name (Zi and Zj) where “i” and “j” are a letter or a number. The standards are therefore referred as:

Zi s/n serial number 1
Zj s/n serial number 2

Those Zeners have two output voltages, nominally 1.018 V and 10 V. Within this comparison, one output or both outputs can be measured according to the choice made by the participant.

4. Powering the Zeners

During the transport the Zeners are powered by their internal battery and with an extra external battery in parallel. These external batteries must be disconnected as soon as the Zeners are in the laboratory and be fully charged before the return travel by using an external charger. They must not be connected to the Zeners when powered by the mains nor charged by the internal charger of the Zeners.

For long distance shipment, typically outside Europe, the Zeners are powered through the “BIPM Voltage Stabilizer” equipped with 14 Ah lead batteries which offers the possibility to safely supply the two transfer standards for up to 14 days [2]. This device is delivered with a charger and corresponding user manual. It needs to be properly recharged before the return travel.

Transport Safety Regulation: The transfer standards and their additional power units are allowed to air freight under the IATA Dangerous Good Regulations identified as **UN2800, Batteries, wet, Nonspillable; Not restricted as per Special Provision A67**.
These batteries are subject to the Hazardous Materials Regulations as, as well as being plainly and durably marked either “NONSPILLABLE” or “NONSPILLABLE BATTERY” on the outer packaging.
The internal Zener battery and all additional power supply during transportation meet the conformance with the standard 49 CFR 173.159a which is mandatory.

The additional batteries with BIPM rules are prepared for transport so as to prevent short circuit.. The battery and package should be marked “NONSPILLABLE” or “NONSPILLABLE BATTERY.”

The Zeners shall be disconnected from the mains at least two hours before the beginning of the measurements and be reconnected to the mains at most 10 hours later. If the front panel LOW BAT indicator starts blinking the Zeners must be immediately connected to the mains for recharging the battery.

When the Zeners are not in the process of measurements, they must be permanently connected to the mains (front panel AC PWR lighted).

5. Measurements schedule

At the BIPM, there will be at least five series of measurements over a period of one to two weeks before AND after the measurements at laboratory. At the laboratory, one series of, at least, five consecutive measurements shall be performed.
If necessary (and justified) the first measurements after the transportation will be considered as preliminary (not taken into account for the final calculation).

The Zeners will be sent to and from country on the first working day of the week following the measurements. In organizing the transportation it needs to be ensured that the total transport time is shorter than the battery hold time.

6. Temperature and pressure coefficients, environment conditions

The resistance of the oven temperature thermistor of the BIPM Zeners transfer standards , which is an indicator for the temperature of the internal voltage reference , must be measured via the connector (DE9 type) at the rear panel of the standard. A special cable is supplied with the standards to measure the two-terminal thermistor resistance. To avoid self-heating of the thermistor, the test current produced by the selected ohmmeter for this measurement should **not exceed 10 µA**.

The atmospheric pressure and the internal thermistor resistance shall be measured and reported for each measurement of an output voltage. The measurement results of the laboratory shall be given without applying any correction for temperature or atmospheric pressure. These corrections for temperature or atmospheric pressure will be applied by the BIPM* using the following formula and the coefficients in the table:

$$U_0 = U_m \times (1 - C_T \times (T_m - T_0) - C_P \times (P_m - P_0))$$

where U_0 is the corrected value, U_m the measured value, C_T and C_P the temperature and pressure coefficients, T_m and P_m the values of the thermistor resistance and atmospheric pressure at the time of the measurement, T_0 the thermistor reference value and P_0 the reference atmospheric pressure 1013.25 hPa.

The measurement results shall be provided in the format presented in Table1:

Standard	Output	Date (dd/mm/yyyy)	Measured Voltage / µV	Zener Temperature /kΩ	Atmospheric Pressure /hPa	Lab. Temperature /°C	Lab. Relative Humidity Level /%
Zi	1.018 V	value	value	value	value	value	value
	10 V	value	value	value	value	value	value
Zj	1.018 V	value	value	value	value	value	value
	10 V	value	value	value	value	value	value

Table 1. Format of the presentation of the results which must be sent to the pilot laboratory.

The ambient temperature and relative humidity shall be measured and indicated in the results form as a useful additional piece of information. However, no correction of the voltage output of the Zeners will be applied for those quantities.

* The sensitivity coefficients of the BIPM secondary voltage standards were determined for the first time in 2000 [1] and have been re-determined in 2016 for the temperature) and 2017 for the pressure) [3,4]

7. Connections

The binding posts “GUARD” and “CHASSIS” will be connected together and connected to the ground in a single point which is usually the reference potential of the laboratory.

During the measurements, the mains plug at the rear of the Zeners shall remain disconnected unless the LOW BATT indicator blinks. In that case, the measurement is interrupted immediately and the Zener must be plugged back to the mains power supply.

8. BIPM Uncertainty budget

In addition to the uncertainty on the realisation of the volt through the operation of the BIPM primary voltage standard (JAVS) based on the Josephson Effect, BIPM provides the following uncertainty components on the measurement of the transfer standards:

1- Type A uncertainty calculated as the standard deviation of the mean of the measurements performed at BIPM. This uncertainty can’t be lower then the Zener intrinsic noise level which is considered, at the BIPM, at the level of 1 part in 10^8.

2- The uncertainty on the pressure and temperature corrections evaluated from the uncertainty on the correction coefficients applied to the voltage measurements and the difference of the mean atmospheric pressure and mean internal Zener temperature difference measured at BIPM and at the participation laboratory.

3- Uncertainty on the transfer of the standards: we compare the internal consistency (*a priori* uncertainty, std. unc. of the mean) and external consistency (*a posteriori* uncertainty, std. dev. of the two results). If the external consistency is significantly larger than the internal consistency, it is included in the uncertainty budget as a measure of potential changes of the standards during the comparison.

9. Participant report

The laboratory report must be sent to the BIPM within one month from the completion of his measurements.

This report shall contain:

The measurement method description and the results presented as shown in Table 1:

for each reported value, it will be reported:

- identification of Zener
- date and time of measurement
- measured voltage
- thermistor resistance
- ambient temperature, humidity, and pressure

an uncertainty budget with the different sources of uncertainty and their values, as:

- the Type A standard uncertainty;
- realisation or maintenance of the voltage reference
- detector (gain, bias current, offset, input impedance, nonlinearity, etc.)
- leakage resistance
- thermal electromotive forces
- electromagnetic interference
- thermistor and pressure measurements;

10. Final report

The draft version of the final report (identified as Draft A within the CIPM MRA terminology) will be issued within two months after completion of the comparison. It will be sent to the laboratory for discussion and approval. The final report (identified as Draft B) will then be submitted to the chairman of CCEM WGLF for approval. Once the approval formalized, the report will be published in the KCDB and as a paper in the *Metrologia Technical Supplement*.

11. Share of costs

The BIPM covers the transport of the equipment to the NMI. The NMI is engaged to arrange and pay the shipment of the equipment back to the BIPM.

12. Contact persons

Pilot Laboratory Dr Stéphane Solve
Bureau international des poids et mesures (BIPM)
Pavillon de Breteuil
F 92312 Sèvres Cedex France
Tel.: + 33 1 45 07 70 26
Fax : +33 1 45 07 62 62
E-mail: stephane.solve@bipm.org

Participant contact details

13. References

[1] T.J. Witt, Maintenance and dissemination of voltage standards by Zener-diode-based instruments, IEE Proc.-Sci. Meas. Technol., vol. 149, pp. 305-312, 2002.

[2] A.Tonina, R.Iuzzolino, M.Bierzychudek , M.Real, S. Solve, R. Chayramy and M. Stock Bilateral Comparison of 1.018 V and 10 V Standards between the INTI (Argentina) and the BIPM, August to October 2009, (part of the ongoing BIPM key comparison BIPM.EM-K11.a and b),*Metrologia*, 2010, 47, *Tech. Suppl.*, 01002

[3] S. Solve, R. Chayramy and O. Power, Temperature sensitivity coefficients of the BIPM secondary voltage standards, 10.1109/CPEM.2016.7540702

[4] S. Solve, R. Chayramy and S. Yang, Pressure sensitivity coefficients of the BIPM secondary voltage standards, accepted for publication in the CPEM 2018 proceedings (Paris).

13. Revision History

Version number	Date of Issue/Review	Summary of change
Ver 1.0		Final version 1.0
Ver. 2.0	5/4/2012	Attribution of QMS identifier: BIPM/ELEC-T-16, V2.0 New section 11: charging policy
Ver. 2.1	9/8/2014	text of different sections clarified
Ver. 2.2	13/12/2017	New BIPM logo
Ver. 2.3	18/05/2018	Following misunderstandings with a participant, clarifications and new information added