Bilateral Comparison of 1.018 V and 10 V Standards between the KRISS (Republic of Korea) and the BIPM, February 2008

(part of the ongoing BIPM key comparison BIPM.EM-K11.a & b)

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Introduction

As a part of the ongoing BIPM key comparison BIPM.EM-K11.a & b, a comparison of the 1.018 V and 10 V voltage reference standards of the BIPM and the Korean Research Institute for Standards and Science, Daejeon, Republic of Korea, was carried out from 23 February to 01 March 2008. A KRISS Zener diode (Fluke 732A S/N 4645006), was measured alternatively by the BIPM Josephson Array Voltage Standard (JAVS) setup and with the KRISS JAVS measurement chain.

Comparison procedure

The comparison procedure is different from the traditional protocol for those comparisons for which the transfer standards are shipped. The main reason is that a direct on-site Josephson comparison at the level of 10 V was already planned with KRISS. We took this opportunity to also carry out BIPM.EM-K11.a & b comparisons at the same time on-site, at the KRISS. The complete BIPM measurement chain was shipped to Korea.

The comparison was thus performed according to the following procedure:

1- A KRISS Zener diode (Fluke 732A S/N 4645006) was chosen as the only transfer standard. The CHASSIS GROUND was connected to the GUARD and to the ground. Both JAVS were floating from ground. The Zener was disconnected from the ac power at least two hours before the measurements.

2- The transfer standard was measured every day at 1.018 V and 10 V following the scheme:
   a. Transfer standard calibrated by the BIPM JAVS ("before");
   b. Transfer standard calibrated by the KRISS JAVS;
   c. Transfer standard calibrated by the BIPM JAVS ("after").

3- Each calibration step consists of 6 successive measurement points. The first KRISS point was systematically removed and the mean value of the following 5 other served for the calculation of one daily measurement point;

4- For each day, a least squares fit was applied to the BIPM calibration points and the voltage difference attributed by both JAVS was calculated at the mean time of the KRISS measurements (common reference date) as the voltage difference between the mean value of the KRISS values and the calculated value of the BIPM least squares fit (Cf. Figure 1).

This procedure was repeated during the 6 days of the comparison period.

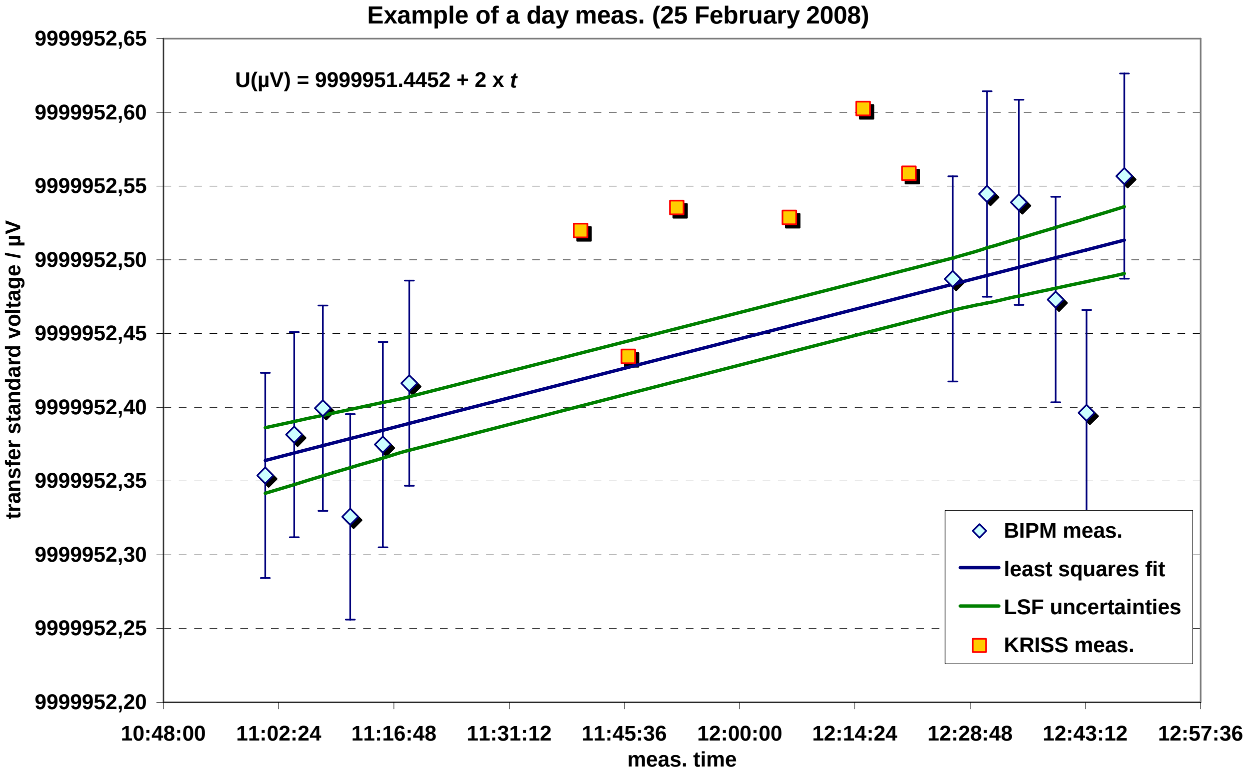

Figure 1: Example of one measurement day at the level of 10 V. The equation is the result of the least squares fit adjustment giving the output voltage in terms of the time *t* in seconds. LSF uncertainties are at *k* = 1.

Environmental parameters

By performing the measurements in the same laboratory in an alternating way, the pressure, temperature and humidity effects on the voltage output of the Zener standard are minimized. The meteorological parameters were measured (Cf. Table 1) even if no corrections for pressure, temperature and humidity were applied to the measurements.

	T(°C)	**P(hPa)**	**H (rel. %)**
23/02/2008	21,6	1015	35,6
25/02/2008	23,8	1019	37,1
26/02/2008	23,7	1009,5	37,5
27/02/2008	23,8	1008	35,6
28/02/2008	23,9	1010	37,6
29/02/2008	24,0	997	37,2
01/03/2008	22,7	1011	39,5

Table 1: Environmental parameters recorded during the comparison period.

Comparison results and uncertainty budget

Tables 2a and 2b list the results of the comparison and the uncertainty contributions for the comparison KRISS/BIPM respectively at 1.018 V and 10 V. Figures 2a and 2b are the corresponding graphs of the voltage difference over the period of the comparison. Experience has shown that flicker or 1/*f* – noise ultimately limits the stability characteristics of Zener diode standards and it is not appropriate to use the standard deviation divided by the square root of the number of observations to characterize the dispersion of measured values. Instead, we consider that the flicker noise limit is of the order of 1 part in 10^8 [1, 2]. In the case that the standard deviation divided by the square root of the number of observations is higher than the considered noise floor, we use the expanded standard deviation of the mean to characterize the dispersion of the measured values.

As it was mentioned in the precedent paragraph, the BIPM value attributed to the transfer standard was calculated from a least squares fit adjustments of the two BIPM series of measurements at the mean time of the KRISS measurement but we also calculated the simple mean of the BIPM data. From Figures 2a and 2b where both methods are shown, we can conclude that the difference between these two methods is non significant. In other words, within the time needed to carry out a daily measurement, the observed drift was taken into account for the calculation of the final result. The linear fit and the mean of both groups take the drift into account in a very similar way.

Furthermore, no uncertainty contributions related to the stability of the standards during transportation needs to be considered for this comparison.

In Tables 2a and 2b, the following elements are listed:

(1) the voltage difference (U_{KRISS} — U_{BIPM}) in nV, computed using a linear least-squares fit to all of the data from the BIPM and referenced to the mean time of the KRISS's measurements;

(2) the voltage difference (U_{KRISS} — U_{BIPM}) in nV, computed using a simple mean of the two BIPM measurement series; The mean value of the 6 days of measurements is considered as the final result.

(3) the Type A uncertainty (in nV) due to the instability of the Zener, computed as the standard deviations of the mean of the daily series of 6 measurements according to the following formulas:

$$\sigma^2_{\mathrm{m}}(\mathrm{BIPM}) = [\sigma^2_{\mathrm{m}}(\mathrm{BIPM\ -\ before}) + \sigma^2_{\mathrm{m}}(\mathrm{BIPM\ -\ after})]/4,$$

$$\text{and } \sigma_{\mathrm{m}} = \sqrt{\sigma_m^2(BIPM) + \sigma_m^2(KRISS)}$$

(4) the uncertainty component arising from the BIPM measurement chain.

(5) the uncertainty component arising from the maintenance of the volt at KRISS.

(6) Type A uncertainty calculated as the standard deviation of the mean of the 6 points calculated with the simple mean method and which corresponds to the complete measurement period.

We consider that this component can't be lower than the relative 1/f – noise floor assumed to be equal to 1 part in 10^8.

Results at 1.018 V

Nominal Voltage (1.018 V)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
23/02/2008	73	137	15	2.3	3.0	26
25/02/2008	74	82	9			
26/02/2008	-18	-23	4			
27/02/2008	117	115	9			
28/02/2008	90	156	5			
01/03/2008	84	93	4			
Mean	**70**	**93**	**4**	**2.3**	**3.0**	**26**

Table 2a : Individual voltage difference between the measurement result of the transfer standard based on the KRISS and the BIPM JAVS and their related uncertainties, at the level of 1.018 V, expressed as (U_{KRISS} — U_{BIPM}) in nV.

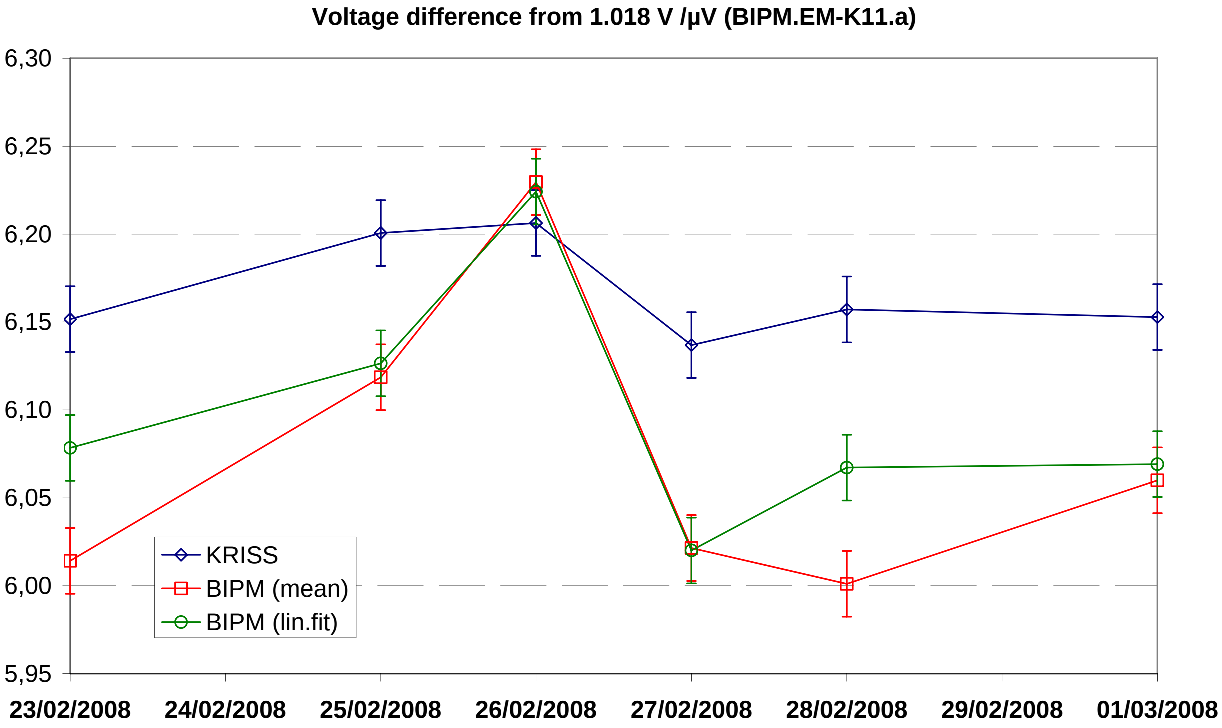

Figure 2a : Individual voltage difference between the measurement result of the transfer standard from 1.018 V carried out by KRISS and BIPM expressed in µV. Uncertainty bars represent only the Type A uncertainty.

Results at 10 V

Nominal Voltage (10 V)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
23/02/2008	-199	-198	42	2.6	2.4	49
25/02/2008	-75	-92	71			
26/02/2008	-52	+118	43			
27/02/2008	+6	17	47			
28/02/2008	37	19	55			
29/02/2008	99	101	64			
Mean	**-31**	**-6**	**135**	**2.6**	**2.4**	**100***

Table 2b :Individual voltage difference between the measurement result of the transfer standard based on the KRISS and the BIPM JAVS and their related uncertainties, at the level of 10 V, expressed as (U_{KRISS} — U_{BIPM}) in nV.

*: **We consider that this component can't be lower than the relative 1/f – noise floor assumed to be equal to 1 part in 10^8.**

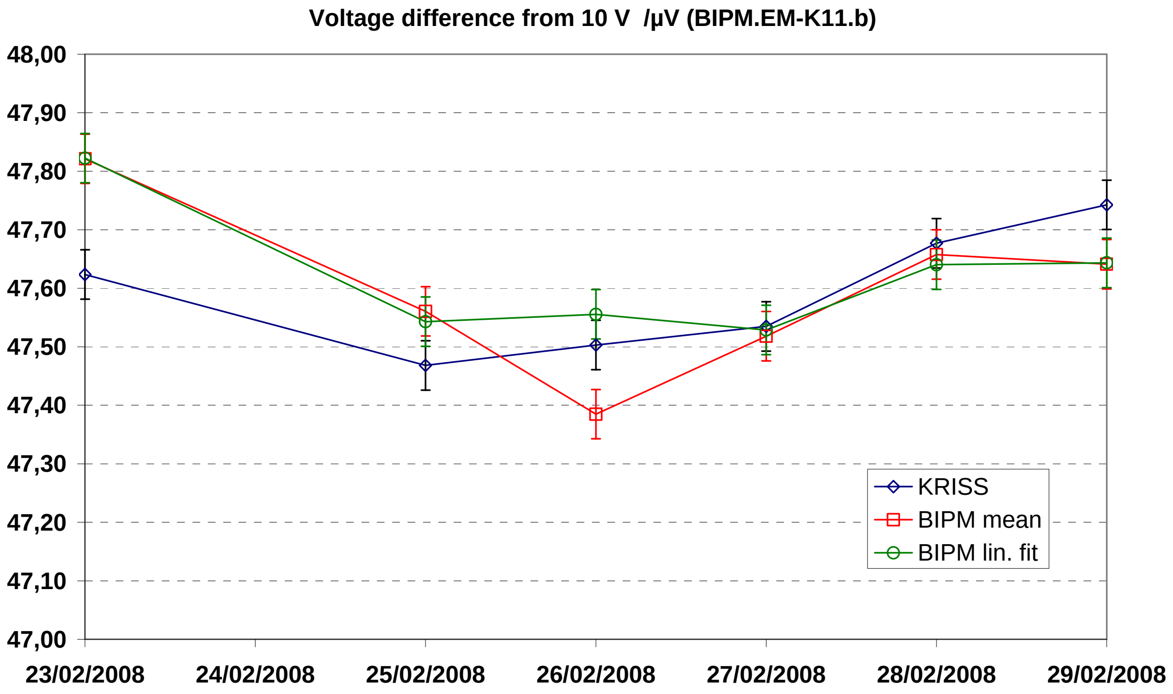

Figure 2b : Individual voltage difference between the measurement result of the transfer standard carried out by KRISS and BIPM from 10 V expressed in µV. Uncertainty bars represent only the Type A uncertainty.

Table 3 summarizes the relative uncertainties related to the calibration of a Zener diode against the BIPM Josephson array voltage standard at the KRISS (*k* = 1).

Uncertainty component	**Type**	**Contribution at 1.018 V /nV**	**Contribution at 10 V /nV**
Noise in the measurement loop*	A	2.3	2.6
Bias of the detector	A	0	0
Temperature and Pressure correction coefficient**	B	0	0
Zener noise	A	See tables 2a	See tables 2b
JAVS frequency source accuracy	B	0.11	1.15
JAVS Leakage resistance	B	0.02	0.17
Total (except Zener noise)		**2.3**	**2.6**

* The relative uncertainty of the detector noise (2.10^{-10}) is already included in this component.

** Fluke zener equipped with a Motorola© chip have very low temperature and humidity correction factors [3]. No corrections were applied for the environmental parameters.

Table 4 lists the uncertainties related to the maintenance of the volt and the Zener calibration at the KRISS.

Uncertainty component	1.018 V	10 V
Microwave freq. (1 Hz/75 GHz)	0.013 nV	0.13 nV
Probe leakage (DWG) (0.3 Ω/10 GΩ @ 0.5 min)	0.03 nV	0.3 nV
Circuit leakage (1 k Ω/1 T Ω for 1.018 V Zener 40 Ω/1 T Ω for 10 V Zener)	1 nV	0.4 nV
Rev. Sw. Thermal Repeatability	0.5 nV	0.5 nV
Digital nanovoltmeter (0.5 mV reading w/Keithley 2182)	2.2 nV	2.2 nV
RSS Type B	**2.5 nV**	**2.3 nV**

It should be noted that the above table refers to the KRISS normal practice, where the Zener CHASSIS and GUARD are floated from the ground.

Final comparison result

At KRISS, the CHASSIS and GUARD are usually both floating from ground during the measurement of a Zener against the JVS. In this comparison the CHASSIS and GUARD were grounded. When the CHASSIS-GUARD connection is grounded, a leakage path to the KRISS Josephson system ground can lead to an error at 1.018 V as this output voltage is produced by an internal divider inside the Zener. This effect was experimentally evaluated from a series of alternate measurements; with the CHASSIS GROUND - GUARD connected to the ground and with the CHASSIS GROUND - GUARD floated from ground. The correction value was -152 nV with standard uncertainty of 40 nV (cf. Appendix A).

The final result of the comparison is presented as the difference between the value assigned to a 1.018 V and a 10 V standard by the KRISS, U_{KRISS} and that assigned by the BIPM, at the KRISS, U_{BIPM}:

At 1.018 V, $\boldsymbol{U_{\mathrm{KRISS}} — U_{\mathrm{BIPM}}}$ **= 70 nV;** $\boldsymbol{u_{\mathrm{c}}}$ **= 48 nV**

At 10 V, $\boldsymbol{U_{\mathrm{KRISS}} — U_{\mathrm{BIPM}}}$ **= - 31 nV;** $\boldsymbol{u_{\mathrm{c}}}$ **= 100 nV**

Where u_{c} is the combined standard uncertainty associated with the measured difference including the uncertainty of the representation of the volt at the BIPM based on $K_{\mathrm{J-90}}$ and the uncertainty on the representation of the volt at KRISS and the uncertainty related to the comparison.

Conclusion

This comparison protocol is different from the one usually used to carry out BIPM.EM-K11 a & b comparisons in different manners. The major differences from the traditional BIPM.EM-K11 a & b protocol lie in the following points:

1- We have chosen a Fluke 732A Zener standard as the only transfer standard; these instruments are known to have very low temperature and pressure coefficients, thus no corrections for temperature nor pressure variations were applied to the measurement.

2- Furthermore this type of standard shows a lower intrinsic noise compared to the transfer standards normally involved in the framework of BIPM.EM-K11a &b comparisons (Fluke 732B).

3- As the comparison was carried out on-site, there was no uncertainty component due to transportation of the transfer standard. This component is usually a predominant one in the uncertainty budget.
4- The transfer standard was measured by the participant and the pilot laboratory within a few hours. We showed that within this context, it is possible to get rid off any effect of the natural drift of the voltage output of the Zener.

The uncertainty contributions associated with Zener non-ideal behavior, such as non-linear drift, impact due to shipping, and environmental effects from atmospheric pressure, temperature, and relative humidity, therefore are largely eliminated.

The comparison result shows that the calibration results of a zener voltage standard, based on the JAVS of the KRISS and the BIPM were equivalent within their stated expanded uncertainties on the mean date of the comparison.

References

[1] Witt T. J., *Maintenance and dissemination of voltage standards by Zener-diode-based instruments*, IEE Proc.-Sci. Meas. Technol., vol. 149, pp. 305-312, 2002.
[2] Hamilton C. A. , et al., *Josephson Volt Interlaboratory Comparison at 10 V DC, Proccedings of the NCSL International Workshop and Symposium*, 2003.
[3] Witt T. J., *Pressure Coefficients of Some Zener Diode-Based Electronic Voltage Standards*, IEEE Transactions on instrumentation & measurement, vol. 48, pp. 329-332, 1999.

Appendix A: CHASSIS-GUARD to ground leakage effect on the KRISS measurement setup.

When the CHASSIS-GUARD is grounded to the KRISS Josephson system, a ground leakage occurs and the internal potential sense circuit of the Zener detects a potential decrease at the high potential part (~9 kΩ) of the internal divider and command to increase the current to compensate this potential decrease. This compensating feedback current from the Zener stabilizer circuit results in an increase of the voltage at the lower part (1 kΩ), that is equivalent to an increase of the voltage of the 1.018 V output voltage (cf. Fig. 3)

The ground leakage resistance of KRISS system is estimated to be about 50 GΩ (through cryoprobe filter). The expected voltage change at 1.018 V for estimated leakage resistances (Zener leakage between output terminals and CHASSIS-GUARD was estimated as 10 GΩ) is 0.9 x 10 V x 9 kΩ / (10 GΩ + 50 GΩ) = 135 nV. This theoretical correction agrees well with the experimental value of 152 nV (Cf. Fig. 4). The ground leakage resistance estimation has a range from 30 GΩ to 80 GΩ which gives correction value range of ± 70 nV around the experimental value 152 nV.

The 70 nV is taken as half range of the rectangular distribution.

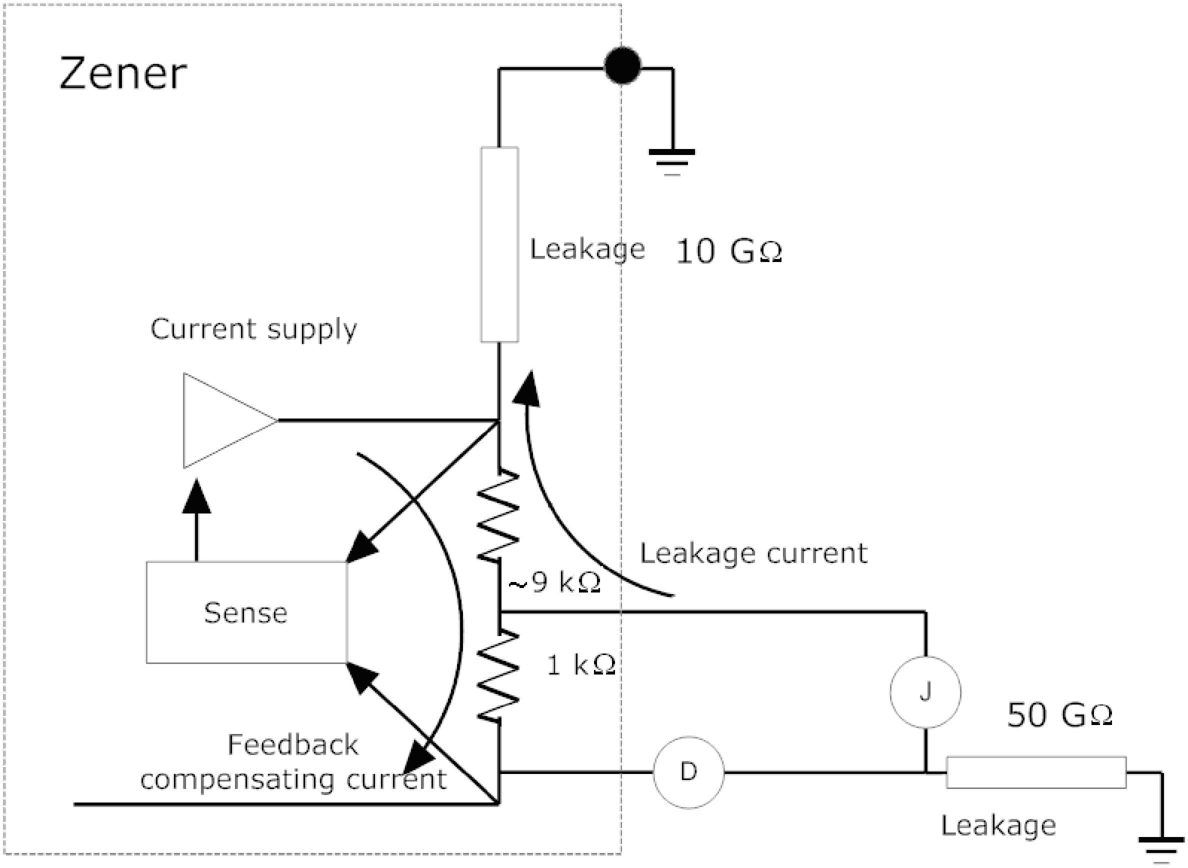

Fig. 3: Schematic of the setup for the measurement of 1.018 V Zener voltage output with the KRISS Josephson system

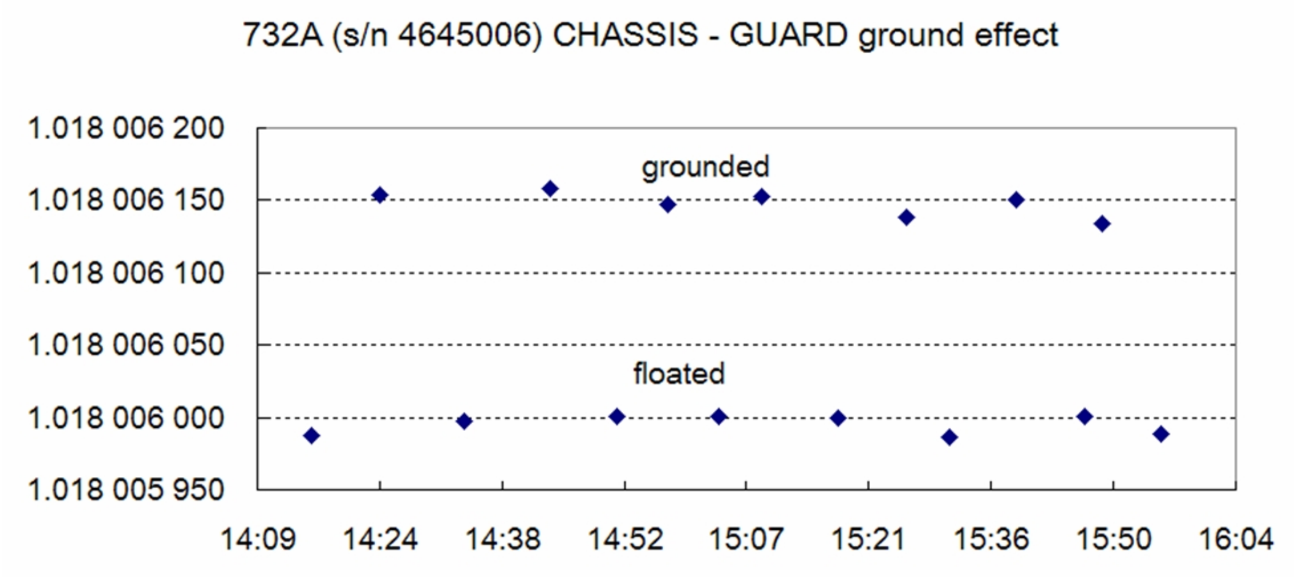

Fig.4: Measurement data of 732A-4645006 1.018 V output; with CHASSIS and GUARD grounded (upper) and with CHASSIS and GUARD floated (lower).