Voltage Divider for 10 V – JVS Transference

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Abstract: We have designed and characterized a voltage divider to calibrate 1 V Josephson voltage standard (JVS) with the 10 V output of solid state voltage standards (zeners). This voltage divider is based on tetrahedral junctions and sealed oil-filled commercial resistance elements. The Hamon series-parallel method is used to obtain the divider ratio. This method allows to measure the 10 V zener output in a direct way with the JVS system.

The zener calibration showed high stability during measurements and the results have been found consistent with the expected values within the uncertainty.

Keywords: JVS, voltage divider, tetrahedral junction, zener calibration

1. INTRODUCTION

The Josephson voltage standard system of our laboratory has been used for more than eighteen years. This system allows the zener calibration only at their 1.018 V output. Since then, the calibration of 10 V output is made with a high accuracy DVM, correcting its 10 V range with the previously calibrated zener 1.018 V output [1]. In this way this method depends on the multimeter linearity and 1.018 V output of the zener, which has the poorest long term specifications [2]. This method has a typical expanded uncertainty of U = 0.5 μV/V.

To improve the 10 V output zener calibration we developed a voltage divider to measure the 10 V output against 1 V JVS. The divider is based on the Hamon series-parallel method and tetrahedral junctions. To know the divider ratio we have measured it using a high accurate potentiometric method and a direct current comparator system (DCC).

2. EXPERIMENTAL ARRANGEMENT

2.1. Design

The divider is based on the Hamon series-parallel transfer method [3] and takes advantage of tetrahedral junctions

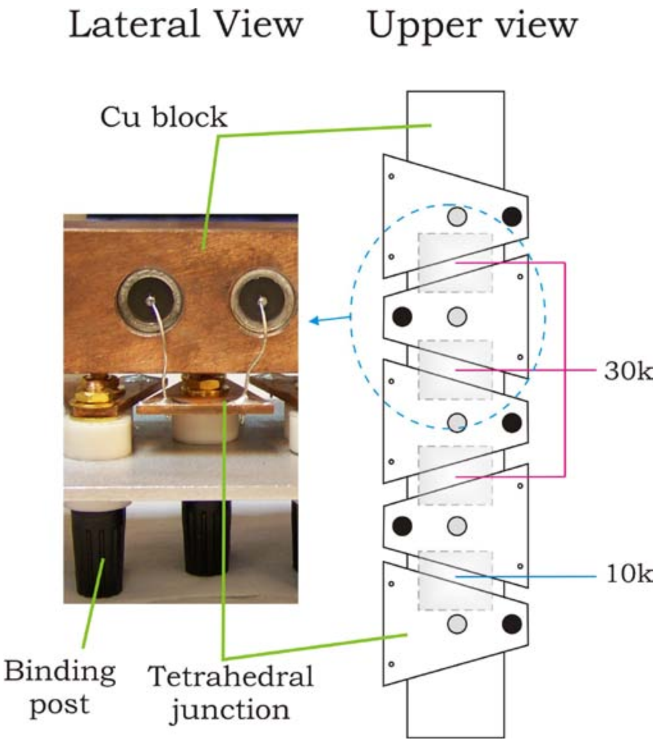

Fig. 1. Lateral view of the divider without aluminum cover, on the left. Upper schematic view of elements disposition, on the right.

properties [4]. To design it we took into account that the divider should have 1:10 ratio and it should not load the 10 V zener output.

We selected a set of three 30 kΩ and one 10 kΩ resistors, permanently connected in series through tetrahedral junctions. The selected nominal values are a commitment to reduce leakage currents and contact resistance effects.

We chose oil-filled and sealed Vishay resistors which have a temperature coefficient of resistance ≤ 0.05 ppm/ºC and a tolerance ≤ 0.005% [5]. Low thermal emf Cu -Te golden plated binding post connectors isolated with PTFE were used to make external connections, see figure 1. The resistors were selected after studying their stability and resistance value.

To increase specific heat and thermal stability of the surrounding medium, the resistors were allocated into a cooper block and each resistor case was greased with thermal conducting grease before mounting.

The resistors are permanently connected in series by tetrahedral cooper junctions. Thus, each element conforms a four-terminal resistor. To characterize the divider the three 30 kΩ resistors are connected in parallel and compared with the 10 kΩ resistor [4], fig. 2. Junction resistances have been measured being less than 1 μΩ.

2.1. Divider calibration

We called $\alpha_{i\text{-}j} = R_i / R_j$ the ratio of resistances i and j. R_P and R_S are the equivalent resistance value in parallel and series connections of the three 30 kΩ resistors of the divider. To obtain R_p we short-circuit A-B and C-D terminals by connecting cooper bars (dotted lines in fig. 2). Two extra cooper bars are used to perform four-terminal resistor ratio measurement.

Two measurements have to be performed in order to determine $\alpha_{P\text{-}4}$. R_P and R_4 are measured using a dummy high stability 10 kΩ resistor. We obtain

$$\alpha_{P-4} = \frac{\alpha_{P-dummy}}{\alpha_{4-dummy}} \tag{1}$$

with $\alpha_{P\text{-}4}$ independent of R_{dummy} at first order. The calibration procedure takes less than thirty minutes so is feasible to assume that R_{dummy} does not change during the calibration.

Kirchoff's laws applied to the circuit of figure 2 determines:

$$V_Z = V_J\left(\frac{R_S + R_4}{R_4}\right) = V_J\left(1+\alpha_{S-4}\right) \tag{2}$$

where current through the DVM and leakage currents have been neglected.

At first order R_s is related to R_p as, see [4]:

$$\alpha_S = 9\alpha_{P-4} \tag{3}$$

then the 10 V zener output can be determined from (2) and (3).

3. RESULTS

Several resistors had been tested using a high resolution DVM configured on four terminal resistance measurement function for a day before the assembly. No differences on resistance stability could be determined. We selected the four closest to its nominal value. They showed a deviation from their nominal value less than 9 μΩ/Ω.

After the assembly we measured the resistors again and we found a change in their values < 1.5 μΩ/Ω in all cases.

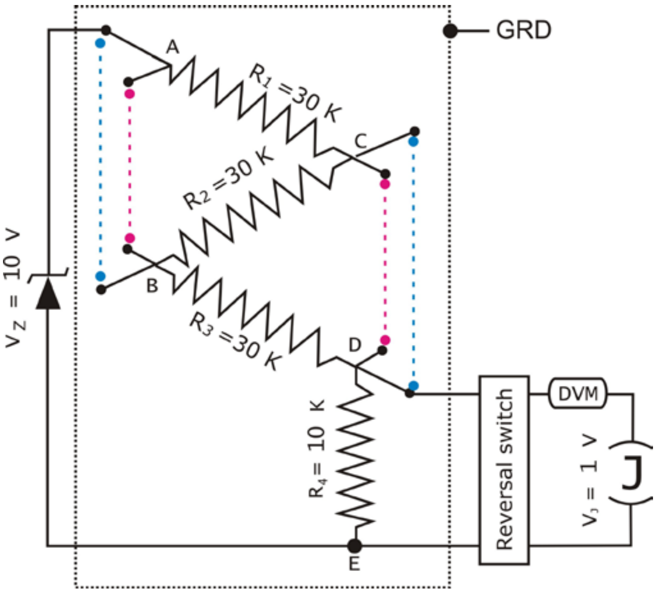

Fig. 2 Schematic diagram of the 10 V zener output calibration with 1 V JVS. The parallel connection is made by shorting terminals A-B and C-D (dotted lines) to measure the divider ratio.

The standard deviation was less than 0.5 μΩ/Ω during measurements.

The isolation showed lower values than expected (~ 10^{10} Ω). We thought that triboelectric effects during connectors mounting could decrease the PTFE effective resistance. Therefore, the top aluminum cover (see figure 1) was replaced by a cover of PTFE, which has increased the isolation to more than 5 10^{12} Ω in all cases.

We measured the stability of ratio relation on the final design. We could establish a variation of 0.1 ppm during a 20 hs measurement. This result allow us to expect no significant change on divider ratio during zener and divider calibrations.

We performed the zener calibration using the multimeter range correction method and the voltage divider method. We could establish that the 10 V zener values are consistent within uncertainty as is showed in table 1. It should be pointed out that 10 V zener measurements presents a great stability as indicated on sencond column of table 1. The computed standard deviation was lower than 0.06 μV/V.

Ratio calibration was made with our potentiometric system which has good specifications on 10 kΩ comparations [6]. Voltage drop tests had been made on measurement conditions using a high accuracy DVM. In this way we obtained independent testing on 9:1 ratio relation and could avoid paralleling resistors with short circuits. Good agreement was obtained between measurements.

Table 1. Results corresponding to two days of measurement.

V_J [V]	σ [μV/V]	α_{P-4}	Divider method [V]	DVM method [V]	Difference between methods [μV/V]
0.999985304	0.003	1.0000070	9.999917	9.999922	0.6
0.999985506	0.010	1.0000074	9.999922	9.999925	0.4

4. CONCLUSION

The divider system initially showed noise and interference. Replacing the aluminum top cover with a PTFE new one the isolation resistance was increased and noise and interference were reduced.

Divider ratio showed to be stable within 0.1 ppm during 20 h measurements.

This divider allows to calibrate the 10 V zeners output directly to the 1 V Josephson voltage standard avoiding the poor stability and dependence on the 1.018 V output as in the DVM method.

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