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Research paper

Achievement of Traceability for DC Voltage and Current Measurements up to 5 kV and 1 A

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Abstract

National Institute of Standards is the National Metrology Institute of Egypt, which realizes units of measurements according to the Inter-na-tional System of Units. The DC Josephson Voltage Standard is used as a primary standard to reproduce the unit of volt and provide tracea-bility of measurements to the SI units. JVS, Zener diode reference standards, standard resistors, multifunction calibrators and volt-age divid-ers of NIS maintain the DC voltage & current and provide the traceability to all Egyptian industrial governmental and private sectors. In this paper, the measurements' traceability of DC voltages from 10 mV up to 5 kV and DC currents from 100 µA up to 1 A has been achieved. In this method, the Fluke 5720A multifunction calibrator has been calibrated in its DC voltage and current functions to cover the range of 1 kV and 1 A. To extend the voltage range to 5 kV, a universal high voltage divider has been used. The DC voltage calibrations have been performed using a Fluke 732B Zener diode reference standard, which is traceable to International System of Units via the NIS DC voltage primary standard. Relevant DC voltage and current measurements, associated with their expanded uncertainties, are presented in this work.

Keywords: *DC Voltage and Current Measurements; Multifunction Calibrator; Voltage Divider; Traceability; JVS; Expanded Uncertainty.*

1. Introduction

National Metrology Institutes (NMIs) maintain the measurement standards and provide traceability to the International System of Units (SI). In the fields of practical electrical metrology, accurate measurements of electric voltages and currents are motivating. National Institute of Standards (NIS) is the unique NMI in Egypt that maintains the national standards of the country and provides traceability to SI units for different electrical parameters. In the fundamental and practical metrology realm, the accurate electrical measurements are interesting. In addition, for application purposes, there is an essential need for electrical measurements and calibrations [1]. Ampere is one of the seven SI base units that represents the electric current. The electric voltage is realized through the primary standard of voltage while current comes from voltage drop across the standard resistors [2-3]. NIS electrical quantities division is responsible for maintaining the electrical quantities and the realization of the unit of voltage is based on the Josephson Voltage Standard (JVS), which is based on arrays of SIS tunnel junctions [4]. It is commonly used as a primary DC voltage standard. Applying it, secondary voltage standards can be calibrated with the highest level of accuracy. Consequently, NIS's JVS is used to maintain a group of Zener diode reference standards. Using these standards, the accuracy of the Josephson voltage is transferred to the working standards of the laboratory and then to customer devices by means of calibration [5-7]. Traceability for DC current measurements is achieved using DC voltage and resistance standards. The reliability of measurements performed is demonstrated through participation in DC voltage and resistance international comparisons. Details about these comparisons can be found in BIPM KCDB database [8, 9]. This work has been done to support the establishment of dissemination process of DC voltage and current from JVS and standard resistors to achieve NIS self-assured traceability. Through this research, unbroken chain traceability on DC voltage from 10 mV up to 1 kV has been built using the JVS as a primary standard, a Zener diode as a secondary standard and a multifunction calibrator as working standard using the DEKAVIDER esi RV-722 Kelvin Varley Voltage Divider. In order to extend the DC voltage traceability to the high voltage region, the 5 kV range calibration has been added to this chain. Furthermore, the traceability of the DC current from 100 µA to 1 A has been achieved by applying the obtained voltage measurements on appropriate reference standard resistors. In this work, the traceability as maintained at NIS for DC parameters has been discussed. All the calibration results uncertainties have been estimated as per ISO GUM document at coverage factor k = 2 with approximately 95% confidence level [10, 11].

2. Calibration setup of DC voltage

The conventional 'National Standard' of DC voltage is maintained using the NIS JVS and a group of eight Fluke 732B Zener diode reference standards. NIS JVS is a fully automated system manufactured by Supracon AG – Germany called supraVOLT-control [4]. The Fluke 732B Zener diode is a direct voltage secondary standard with 10 V and 1.018 V outputs. It is a highly accurate and stable solid state DC voltage reference standard [5-7]. In order to achieve traceable Zener diodes, JVS is frequently used for calibrating them at 10 V and 1.018 V. One of these traceable10 V Zener diodes in combined with voltage dividers has been used to calibrate the DC voltages from 10 mV up to 5 kV. This Zener has been also used in conjunction with standard resistors and voltage divider to calibrate the DC current from 100 µA to 1 A.

The 10 V DC of the Fluke 5720A calibrator has been directly calibrated against the traceable 10 V of the Fluke 732B Zener diode. Applying DEKAVIDER esi RV-722 Kelvin Varley voltage divider with appropriate dividing ratios, the ranges of 10 mV, 100 mV, 1 V, 100 V and 1000 V have been completed. The RV-722 is a highly accurate, stable, and linear ratio standard voltage divider using Kelvin Varley circuit. It is appropriate for use in many voltage ratios applications. Before using the RV-722 voltage divider in DC voltage calibration process, this divider has been calibrated at the used dividing ratios 1:10, 1:100 and 1:1000 using the traceable Fluke 732B Zener diode and a traceable Fluke 8508A digital multimeter (DMM).
Figure 1 shows the divider calibration setup. Table 1 lists the uncertainty budget for this calibration at 1:100 dividing ratio and Table 2 illustrates the actual dividing ratio with their uncertainties. Afterwards, this calibrated voltage divider has been used in calibration setup of the Fluke 5720A calibrator to obtain the actual values of DC voltages (10 mV, 100 mV, 1 V, 100 V and 1000 V). The DC voltage differences between the traceable Zener and the calibrator readings have been measured using a traceable keithley-182 digital voltmeter (DVM). Figure 2 shows the calibration setup for DC voltage ranges from 10 mV to 1000 V. Then 10 V range of Fluke 5720A calibrator has been directly calibrated via 10 V of the standard Zener as shown in Figure 2-a. For calibration of 10 mV, 100 mV and 1 V, the 10 V of the Zener has been connected to the esi RV-722 voltage divider at 0.001, 0.01 and 0.1 dividing ratios respectively, as shown in Fig. 2-b. Fluke 5720A calibrator has been connected to the voltage divider at ratios of 0.1 and 0.01 to calibrate its 100 V and 1000V respectively against the Zener 10 V, as shown in Fig. 2-c. To get the 5 kV range calibration, the universal resistive/capacitive voltage divider with 500:1 dividing ratio has been used.
The same value of 10 V reference Zener diode has been used to calibrate the 5 kV DC range. The 5 kV was applied from a high voltage DC source (Haefely Trench 100 kV DC Source & 140 kV half-wave rectifier) to the universal high voltage divider to get 10 V. Then, the10 V has been calibrated against the traceable 10 V of the reference Zener.
The actual dividing ratio of the universal voltage divider has been attained by calibrating this divider via a reference Phenix high voltage divider [12] that is traceable to the NIS JVS [13].
Figure 3 shows the calibration setup of DC voltage at 5 kV. All calibrations' uncertainties have been evaluated as per ISO/GUM document. The measurements' uncertainties have been evaluated at k = 2 for 95% confidence level. Uncertainty budget for calibrating DC Voltage at 100 V is given in Table 3. Table 4 lists the actual values of DC voltages from 10 mV up to 5 kV associated with the relevant uncertainties.

3. Calibration setup of DC current

Using Ohm's law, DC current has been calibrated from 10 µA to 1 A using standard DC voltage source and standard resistors. In order to get the actual values of the DC currents from 100 µA up to 1 A, the corrected values of the DC voltages have been multiplied by the standard resistors actual values. Figure 4 shows the calibration setup block diagram of the DC currents. The voltage drop across a 100 Ω standard resistor has been calibrated compared with the reference standard 10 V Fluke 732B zener diode to get the actual values of the 100 µA, 1 mA, 10 mA and 100 mA as shown in Fig. 4-a and 4-b. A 100 mΩ standard resistor has been used to get the actual value of 1 A, as shown in Fig. 4-c.

Fig. 1: Calibration Setup of ESI RV-722 Voltage Divider.

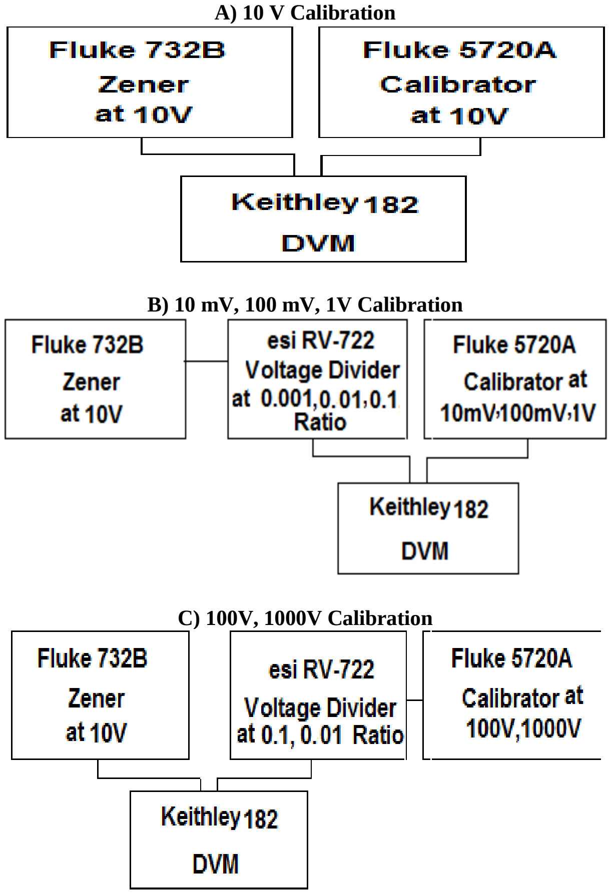

Fig. 2: DC Voltage Ranges' Calibration Setup.

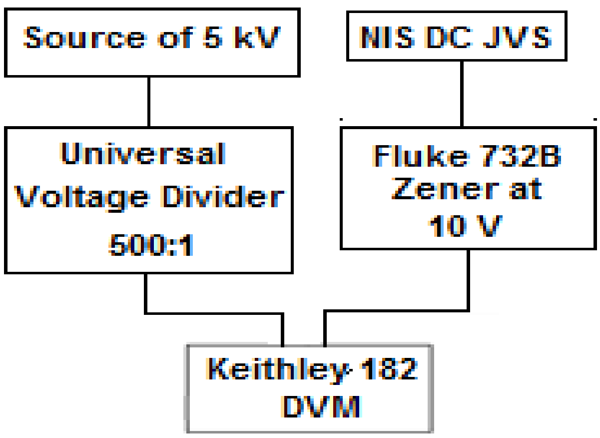

Fig. 3: Calibration Setup of DC Voltages of 5 KV at NIS.

Table 1: Uncertainty Budget for Calibration of Devider ESI Rv-722 Kelvin Varley Voltage Divider at 1:100 Dividing Ratio

Uncertainty sources	Standard uncertainty	Probability distribution	Divisor	Ci	Uncertainty contribution
Repeatability of Fluke 8508A DMM readings	7.748E-08 V	Normal	1	1	7.75 E-08 V
Uncertainty of Fluke 8508A DMM from its calibration certificate	1.700E-07 V	Normal	2	1	0.85 E-07 V
Drift of the Fluke 8508A DMM since the last calibration	0.099E–6 V	Rectangular	$\sqrt{3}$	1	0.06 E–6 V
Uncertainty of Fluke 732B zener diode reference standard from its calibration certificate	1.035E-07 V	Normal	2	1	0.52 E-07 V
Temperature deviation of the 732B zener diode reference standard	0.083E-06 V	Rectangular	$\sqrt{3}$	1	0.05 E-06 V
Drift in Fluke 732B zener diode reference standard	0.102E-06 V	Rectangular	$\sqrt{3}$	1	0.06 E-06 V
Thermal EMF due to the cables used	0.0987E-06 V	Rectangular	$\sqrt{3}$	1	0.06 E-06 V
Combined standard uncertainty					1.6 E-07 V
Effective degrees of freedom					∞
Expanded uncertainty at confidence level 95% (k=2)					3.2 E-07 V

Table 2: Actual Dividing Ratio

Nominal Dividing Ratio	Actual Dividing Ratio	± Expanded Uncertainty (µv/v)
0.1	9.9999E-02	1.3
0.01	1.0000E-02	0.3
0.001	9.9950E-04	0.3

Table 3: Uncertainty Budget for Calibrating DC Voltage at 100 V

Uncertainty sources	Standard uncertainty	Probability distribution	Divisor	Ci	Uncertainty contribution
Repeatability of keithley182 DVM readings	1.51 E-04 V	Normal	1	1	1.51 E-04 V
Uncertainty of keithley182 DVM from its calibration certificate	3.00 E-07 V	Normal	2	1	1.50 E-07 V
Uncertainty of Fluke 732B zener diode reference standard from its calibration certificate	1.04 E-07 V	Normal	2	1	0.52 E-07 V
Uncertainty of voltage divider from its calibration certificate	6.35 E-07 V	Normal	2	1	3.2 E-07 V
Combined standard uncertainty					1.50 E-04 V
Effective degrees of freedom					∞
Expanded uncertainty at confidence level 95% (k=2)					3.0 E-04 V

Table 4: Actual Values of DC Voltages from 10 MV Up To 5 KV

Nominal Voltage	Actual Voltage	± Expanded Uncertainty
10 mV	10.01023 mV	30 µV/V
100 mV	100.03875 mV	4.8 µV/V
1 V	1.0000266 V	3.1 µV/V
10 V	10,0002388 V	2.2 µV/V
100 V	100.000038 V	3.0 µV/V
1000 V	999.94038 V	3.0 µV/V
5 kV	5.106043 kV	1 mV/V

Table 5: Uncertainty Budget for Calibrating DC Current at 1A

Uncertainty sources	Standard uncertainty	Probability distribution	Divisor	Ci	Uncertainty contribution
Repeatability of keithley182 DVM readings	7.5 E-01 ppm	Normal	1	1	7.5 E-01ppm
Uncertainty of keithley182 DVM from its calibration certificate	1.0 E+01 ppm	Normal	2	1	0.5 E+01 ppm
Uncertainty of Fluke 732B zener diode reference standard from its calibration certificate	1.04E-02 ppm	Normal	2	1	0.50 E-02 ppm
Uncertainty of voltage divider from its calibration certificate	2.41E+01 ppm	Normal	2	1	1.2 E+01 ppm
Uncertainty of standard resistor from its calibration certificate	3.57 E-01 ppm	Normal	2	1	1.78 E-01 ppm
Combined standard uncertainty					1.30 E-05A
Effective degrees of freedom					∞
Expanded uncertainty at confidence level 95% (k=2)					2.6 E-05 A

Table 6: Actual Values of DC Currents from 100 MA Up to 1 A

Nominal Current	Actual Current	± Expanded Uncertainty
100 µA	100.09284 µA	24 µA/A
1 mA	1.00029296 mA	26 µA/A
10 mA	9.99932095 mA	13 µA/A
100 mA	99.9929375 mA	13 µA/A
1 A	1.00032442 A	26 µA/A

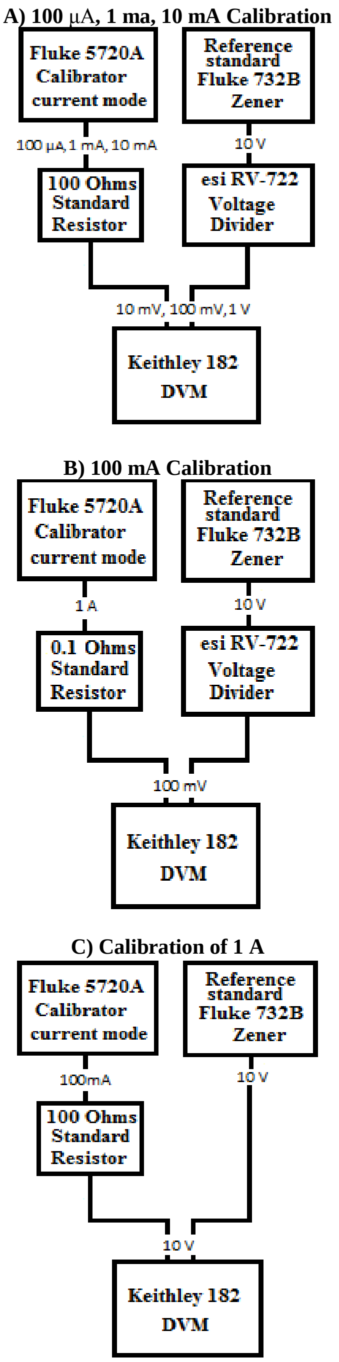

Fig. 4: Calibration Setup of DC Current Ranges.

4. Conclusion

The traceability of DC voltage up to 5 kV and current up to 1A at NIS has been achieved. Unbroken chain traceability on DC voltage from 10 mV up to 1 kV has been built using the JVS as a primary standard, a Zener diode as a secondary standard and a multifunction calibrator as working standard using the DEKAVIDER esi RV-722 Kelvin Varley voltage divider. DC voltage traceability has been extended to 5 kV range using the universal high voltage divider. Traceability for DC current measurements from 100 µA up to 1A has been obtained. The relevant results of the measurements are presented and sources of uncertainty are estimated.

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