Automated setup to accurately calibrate electrical dc voltage generators

AUTOMATED SETUP TO ACCURATELY CALIBRATE ELECTRICAL DC VOLTAGE GENERATORS

Flavio Galliana, Pier Paolo Capra, Roberto Cerri and Marco Lanzillotti

***Abstract*—**At National Institute of Metrological Research (INRIM), an automated setup to calibrate dc voltage generators, mainly top-level calibrators, from 1 mV to 1 kV has been developed. The heart of the setup is an INRIM-built automated precision fixed ratios dc voltage divider. It can be interconnected to a DMM characterized in linearity, to a dc voltage standard and to a dc voltage generator under calibration to manage automatically the calibration process. Novelty of the system is the employment of the divider being such an instrument not commercially available. Main results are the improvement of the reliability and the increasing of the accuracy of the calibration process saving a lot of time. In addition, it is possible to avoid several standards (still manually operating) carrying out the whole process without changing the setup configuration and without the presence of operators. The expanded uncertainties of the system span from 6.0×10^{-7} to 1.3×10^{-4} improving the previous capabilities of the INRIM laboratory for calibration of multifunction instruments. The setup concept can be transferred to secondary high-level electrical laboratories to improve and expedite their calibrations.

Index Terms—Dc voltage, generator, calibration, multifunction calibrator, dc voltage standard, multi-meter, dc voltage divider, measurement uncertainties.

1. INTRODUCTION

In low frequency electrical measurements, programmable multifunction generating and measuring instruments as calibrators (MFCs) and multi-meters (DMMs) [1] are widespread in primary,

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the other ranges, being both much smaller than the DMM Accuracy specifications. The second step is the quick calibration of the 10:1 and 100:10 divider ratios and the calculation of the 100:1 ratio value [6]. Final step (described in next paragraph) is the calibration of generators from 1 mV to 1 kV, using the divider and the DMM as standards. This step is made according to the ranges of the generators under calibration as shown in Fig. 2.

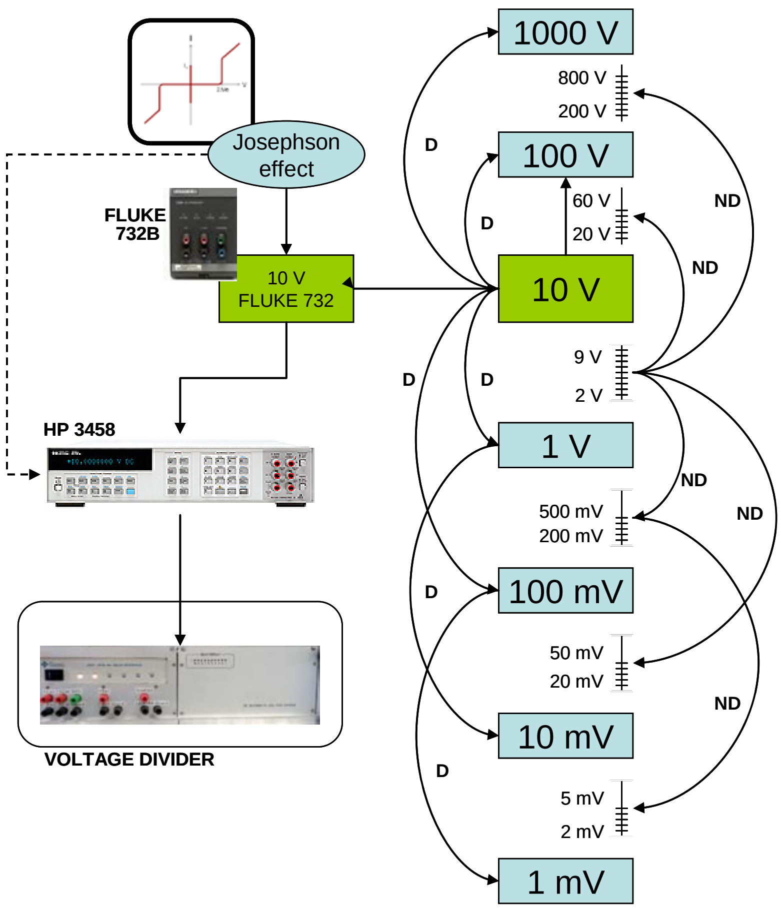

Fig. 2. Diagram of the calibration process. The value of the 10V is the key point of the traceability from a high precision Zener dc voltage standard calibrated vs. the Josephson effect. The calibration steps are symbolized with D for decade values and with ND for not-decade values.

Fig. 3, 4 and 5 shows the block scheme, the electrical scheme and a photo of the measurement setup respectively.

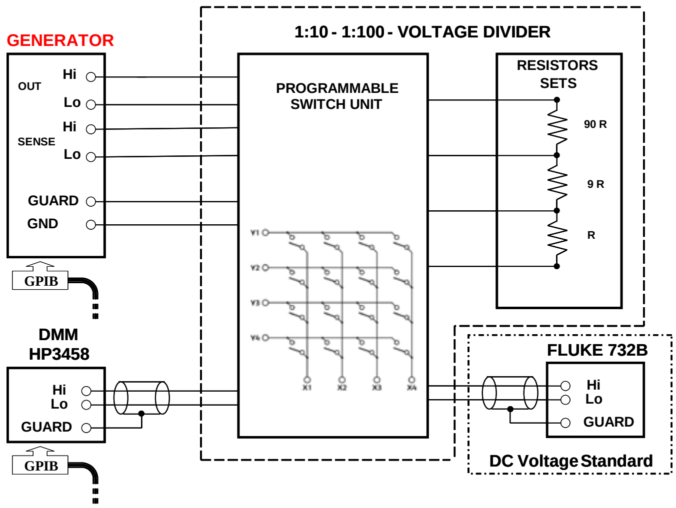

Fig. 3. Setup to calibrate dc voltage generators: the divider can be connected to the generator, to the DMM and to the dc voltage standard. The generator is set on internal guard (whenever available), while the generator ground terminal is connected to to the low and guard terminals (connected togheter) of the divider. The DMM is set to "guard open" and its guard terminal is connected to the divider guard terminal.

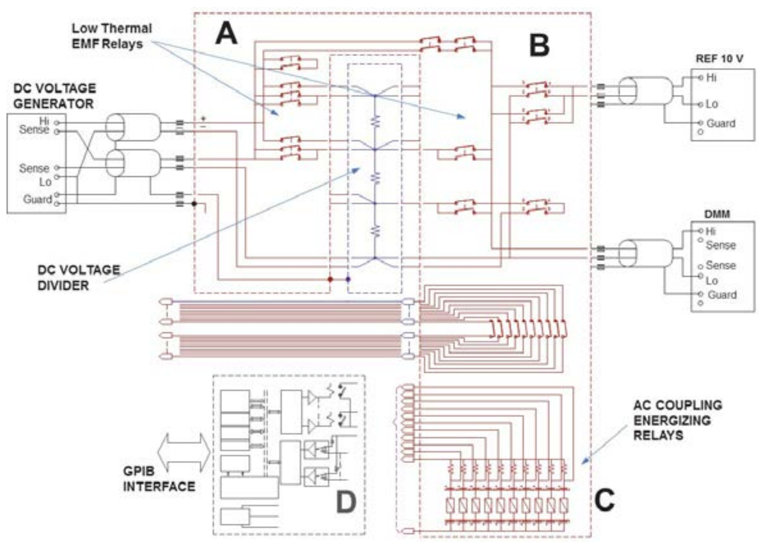

Fig. 4. Simplified scheme of the divider connected to the measurement setup. The whole calibration process is allowed by means of a relays network witch sets the divider ratio, configure the device under measurement and include or exclude the voltage reference. In particular, the relay sets A and B invert both the voltage of the generator and of the 10 V standard. The last relays group controls the resistors sets of the divider. C - the relays coils are pulse-controlled through two electrolytic capacitors to decouple the relays from the control circuit. D - commercially available GPIB to digital I/O interface.

DMM noise	Normal A	40
Emf	Rectangular B	17
Temp. eff. on generator	Rectangular B	0.9
RSS → DMM at 10 mV		**44**
Divider 1:1	Rectangular B	0.02
DMM noise	Normal A	40
Transfer. accuracy 10 mV	Rectangular B	32
Emf	Rectangular B	17
RSS → Generator at 10 mV		**70**

Table 4
Relative standard uncertainties budget of the calibration of a generator at 5V and at 0.5 V.

Component	type	1 σ ($\times 10^{-7}$)
DMM calibration at 10 V	Normal B	3.1
DMM cal. drift at 10 V[c]	Normal A	0.1
Divider 1:1	Rectangular B	0.02
DMM noise	Normal A	0.5
Linearity error[4]	Rectangular B	0.5
RSS →Generator at 5 V		**3.3**
Divider 10:1	Rectangular B	2.7
DMM noise	Normal A	1.0
Emf	Rectangular B	0.6
Temp. eff. on generator	Rectangular B	0.9
RSS → DMM at 0.5 V		**4.5**
divider 1:1	Rectangular B	0.02
DMM noise	Normal A	1.0
Transfer. accuracy 0.5 V	Rectangular B	2.9
Emf	Rectangular B	0.6
RSS → Generator at 0.5 V		**5.5**

Table 5
Relative standard uncertainties budget of the calibration of a generator at 50mV and at 5 mV.

Component	type	1 σ ($\times 10^{-7}$)
Generator calibrated at 5 V	Normal B	3.3
Divider 100:1	Rectangular B	3.8
DMM noise	Normal A	10
Emf	Rectangular B	12
Temp. eff. on generator	Rectangular B	0.9
RSS →DMM at 50 mV		**16**
Divider 1:1	Rectangular B	0.02
DMM noise	Normal A	10
Transfer. accuracy 50 mV	Rectangular B	5.8
Emf	Rectangular B	12
RSS → Generator at 50 mV		**23**
Generator calibrated at 0.5 V	Normal B	5.5
Divider 100:1	Rectangular B	3.8
DMM noise	Normal A	80
Emf	Rectangular B	17
Temp. eff. on generator	Rectangular B	1.3
RSS → DMM at 5 mv		**82**
Divider 1:1	Rectangular B	0.02
DMM noise	Normal A	80
Emf	Rectangular B	17
Transfer. accuracy 5 mV	Rectangular B	61
RSS → Generator at 5 mV		**131**

Table 6

Relative standard uncertainties budget of the calibration of a generator at 50V and at 500 V.

Component	type	1 σ ($\times 10^{-7}$)
Divider 10:1	Rectangular B	2.7
DMM noise	Normal A	0.6
DMM calibration 10 V	Normal B	3.1
DMM calibration drift[c]	Rectangular B	0.1
Emf	Rectangular B	1.2
Linearity error[d]	Rectangular B	0.5
RSS →Generator at 50 V		**4.3**
Divider 100:1	Rectangular B	3.8
DMM noise	Normal A	0.4
DMM calibration 10 V	Normal B	3.1
DMM calibration drift[c]	Rectangular B	0.1
Emf	Rectangular B	0.2
Linearity error[d]	Rectangular B	0.5
RSS → Generator at 500 V		**4.9**

In Table 7 the relative expanded uncertainties (i.e. the best measurement capabilities) of the INRIM-Lab for the calibration of generators from 1 mV to 1 kV before and after the introduction of this setup, are listed.

Table 7

Relative expanded uncertainties of the calibration of generators from 1 mV to 1 kV. The table is referred to the calibration of a J. FLUKE 5700A calibrator. The uncertainties are grouped in measurement ranges according to the publication criteria of the CIPM-MRA database[e].

Dc voltage ranges	Previous capabilities (μV/V)[f]	New capabilities (μV/V)[f]
± 1 mV	192	127
±1 mV to ± 3 mV	65	47
± 3 mV to ± 5 mV	42	26
± 5 mV to ± 10 mV	23	13.9
± 10 mV to ± 30 mV	11	5.1
± 30 mV to ± 50 mV	8.5	4.8
± 50 mV to ± 200 mV	2.2	1.5
± 200 mV to ± 300 mV	1.9	1.3
± 300 mV to ± 500 mV	1.7	1.1
± 500 mV to ± 1 V	0.9	0.9
± 1 V to ± 2 V	1.2	0.7
± 2 V to ± 3 V	0.9	0.7
± 3 V to ± 4 V	0.8	0.7
± 4 V to ± 5 V	0.8	0.7
± 5 V to ± 6 V	0.7	0.7

[e] The CIPM Mutual Recognition Arrangement (CIPM MRA) is the framework through which National Metrology Institutes demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The outcomes of the Arrangement are the internationally recognized (peer-reviewed and approved) Calibration and Measurement Capabilities (CMCs) of the participating institutes.

[f] For same measurement values in consecutive ranges (as the last value of a range and the first of the following range, excluding the 1 mV) the better uncertainty value should be considered.

± 6 V to ± 7 V	0.7	0.7
± 7 V to ± 8 V	0.7	0.7
± 8 V to ± 9 V	0.7	0.6
± 9 V to ± 10 V	0.6	0.6
10 V to ± 12 V	0.8	0.6
± 12 V to ± 20 V	0.9	0.9
± 20 V to ± 30 V	0.9	0.9
± 30 V to ± 40 V	1.1	0.9
± 40 V to ± 50 V	1.2	0.9
± 50 V to ± 60 V	1.4	0.9
± 60 V to ± 80 V	1.7	0.9
± 80 V to ± 100 V	0.8	0.8
± 100 V to ± 200 V	1.6	1.0
± 200 V to ± 300 V	1.4	1.0
± 300 V to ± 400 V	1.4	1.0
± 400 V to ± 500 V	1.4	1.0
± 500 V to ± 600 V	1.3	1.0
± 600 V to ± 800 V	1.3	1.0
± 800 V to ± 1000 V	1.3	1.0

6. MEASUREMENT RESULTS

Fig. 6 shows the positive and negative dc voltage readings of the DMM at the output of the fixed-ratios divider calibrating a generator. Calibration values are obtained averaging the DMM measurements, acquired after a suitable delay to stabilize the readings.

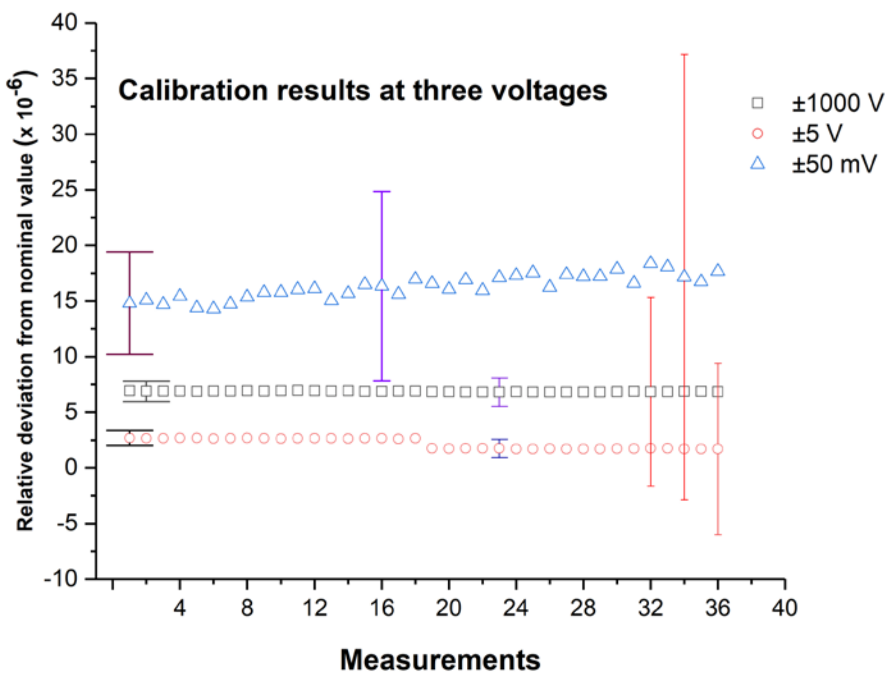

Fig. 6. Calibration results at three dc voltage values of a calibrator [5]. The bars with small caps indicate the one-year accuracy specifications of the calibrator, those with medium caps indicate the old system uncertainties while those with large caps indicate the new setup uncertainties.

CONCLUSIONS

From Table 7 it is possible to see that the relative uncertainties (best measurement capabilities) of the INRIM-Lab for the calibration of dc voltage generators from 1 mV to 1 kV, after the introduction of the new setup, improved. Other achievements are the time saving and the measurement reliability as the calibration process can run without the presence of operators. The dc voltage results of a measurement comparison between the INRIM-Lab and a high level secondary electrical laboratory made with the new system [10] were re-calculated with the new uncertainties[g] maintaining the agreement with this laboratory. This exercise represents a first validation of the setup. In future, further comparisons will be made to check the reliability of the system. For example, the calibration of the INRIM-built selectable-value transportable high dc voltage standard (THVS) [11] with this setup will be compared with the calibration system of the THVS itself. Other aims are the updating the INRIM capabilities in the CIPM MRA database and the transfer of the setup concept to secondary calibration laboratories or to other National Metrology Institutes.

Acknowledgment

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