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Investigastions on a Selectable-Value, High Dc Voltage Standard

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***Abstract* – At National Institute of Metrological Research (INRIM) a Selectable Value High DC Voltage Standard operating in the range from 10 V to 100 was realized to cover the absence of high level DC Voltage Standards at voltages upper than 10 V to employ both as Laboratory Standards or traveling Standards for Interlaboratory Comparisons. It A novel ground-mobile electronic technique was utilized. In the first tests the developed Standard showed better noise and stability of the same order of top level DC Voltage and Multifunction Calibrators, widely employed in Electrical Calibration Laboratories. The project is also upgradable up to 1000 V.**

I. INTRODUCTION

The national DC Voltage Standard is today reproduced from the National Standard of Time, through the Josephson effect [1]. The maintenance of the National Standard is granted by groups of Zener-diode-based Dc Voltage Standards whose values are periodically updated repeating the Josephson effect [1–3]. Besides this important role, these standards are excellent transport standards due to their resistance to physical shock, temperature changes and possibility to operate in battery mode. For this reason they are involved in a particular process called “artifact calibration” with which electrical instruments as Digital Multimeters (DMMs) and Multifunction Calibrators (MFCs), widely employed as Electrical Standards in Secondary Calibration Laboratories, are periodically calibrated and adjusted. This process requires only a small number of reference standards including a 10 V Zener-Dc Voltage Standard [4, 5]. In addition for their easy transportability, they are also involved in Interlaboratory comparisons (ILCs). Zener-Dc Voltage Standards were involved both in International and National ILC’s. [6–10]. A lack in availability of high performance DC Voltage Standards also for ILC’s exists at voltages upper than 10 V. DC Voltage calibrators and MFC’s are now the most employed Reference Standards for DC Voltages up to 1000 V. They have significant advantages as their high stability and accuracy, remote control and commercial availability. The disadvantages are their noise problems at the input stage [11] and their unsuitability to be transported and act for example as traveling standards for ILCs due to the their dimensions and sensitivity to mechanical stresses. To cover this lack, at National Institute of Metrological Research (INRIM) a prototype modular Multi Value High DC Voltage Standard (HVS), operating from 10 V to 100 V was realized, with the possibility to operate in floating battery mode avoiding noises due to connection to the mains and with a novel ground mobile electronic developmnent technique. This paper shows the main features of the HVS and its characterization results obtained comparing it with the main commercial top class DC Voltage calibrators and MFC’s at its more critical operating value (100 V).

II. DESCRIPTION OF THE HVS

Although DC Voltage calibrators and MFC’s are top class instruments, in some applications noise problems can arise. For example, when in a measurement circuit other sensitive instruments are involved besides them, common mode and power supply noises may lead to significant measurement errors. In particular at higher voltages DC Voltage calibrators and MFC’s noises and disturbs can be significant due to the presence of many internal circuits [11]. An attempt to reduce noise and these problems of commercial calibrators was realized with the employed technique for the realization of the HVS that was projected to operate disconnected from the mains as all its circuits are supplied by means of a set of 12 V lead batteries that are recharged when the device is not under measure. The HVS is equipped with two voltage outputs as shown in Fig. 1.

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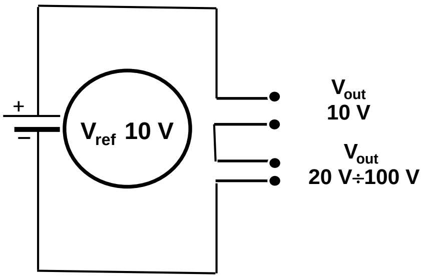

Fig. 1. Block scheme of the HVS.

The HVS is a Voltage source providing a DC settable Voltage ranging from 20 V to 100 V. It has an internal commercial high performance Zener 10 V Dc Voltage Standard acting as Reference for the device. The 10 V output of this Standard is also available as shown in Fig. 1. A principle scheme of the actual realization and an external view of the HVS are respectively shown in Fig.2 and 3.

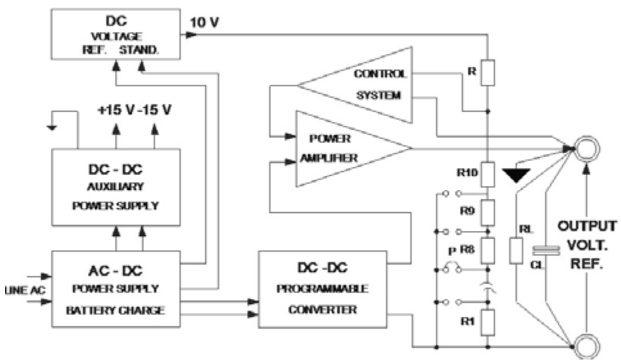

Fig. 2. HVS principle scheme.

The HVS, to provide the desired voltages, receives the correct supply voltages by means of precision low ripple programmable DC-DC converters that supply their output stage with proper voltages to obtain the desired output voltage. Two additional DC-DC converters generate auxiliary voltages to control the output stage providing the voltages from 20 V to 100 V. This stage employs high voltage P-channel MOS components as power buffer. The control circuits was made with precision operational amplifiers with very low offset and low temperature dependence. The reference resistors are hermetically sealed ultra-high-precision Z–Foil with temperature coefficient less than 0.4×10^{-6}/°C. The output stage is equipped with a protection system for maximum voltage and current. A novel assembly method, based on a ground-mobile technique shown in Fig. 2 where it is visible that the ground potential is in this case driven to the high potential, was adopted allowing to control the generated voltages with active components normally used for low voltages available at lower cost. The project is also suitable to be upgraded in future adding to the actual realization a module with a Voltage source providing a DC settable Voltage ranging from 200 V to 1000 V.

Fig. 3. HVS external view.

A. Main features of the HVS

The resistors involved in the HVS are Vishay VSRJ type 10 kΩ with tolerance of ± 0.05 %), temperature coefficient (TCR) less of 0.4×10^{-6}/°C, thermal EMF of ± 0.05 μV/V, power at 70°C ≅ 0.3 W. The main electronic component is a MOSFET VISHAY mod. IRFR220, $V_{drain\text{-}Source(DS)}$: 200 V, $R_{DS\ on}$: 0.8 Ω, $I_{DS\ on}$: 3A.

The specifications of the HVS are:

- Output voltages: 10 V and from 20 V to 100 V selectable by means of an internal switching system; output currents ≥ 5 mA;
- Output noise at 100 V of about 106 μV rms vs. 155 μV and 153 μV of a top class DC Voltage Calibrator and a top class MFC as declared by the manufacturers;
- Detected 24h mean stability of 2.1×10^{-7} at 100 V to compare with the 24h detected mean stability of 2.0×10^{-7} and 4.8×10^{-7} for two top class DC Voltage Calibrators and two MFCs;
- possibility to operate in floating mode disconnected from mains;

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III. COMPARISON WITH DC VOLTAGE CALIBRATORS AND MFC'S

Three alternative tests were carried out to compare the HVS at 100 V with high accuracy DC Voltage Calibrators and MFC's in their DC Voltage mode. In a first test the HVS, a DCV Calibrator and a MFC were compared connecting them alternatively to the same high accuracy DMM in its 100 V range. DMM measurements at 100 V were computed nulling its 0 V readings. The measurements were made in a shielded laboratory thermoregulated at (23 ± 0.3) °C and relative humidity of (40 ± 10) %. The 12h measurement obtained results of the three standards are shown in Fig. 4. In this case the HVS was fed by a generator connected to the mains. The measurements spreads, evaluated as standard deviations of the measurements were 5.8×10^{-8}, 1.0×10^{-7} and 8.3×10^{-8} respectively for the HVS, for the DCV

Calibrator and for the MFC. These values included the DMM contribution that was considered stable in the three evaluations as the better available one was selected. The lowest drift was obtained by the DCV Calibrator.

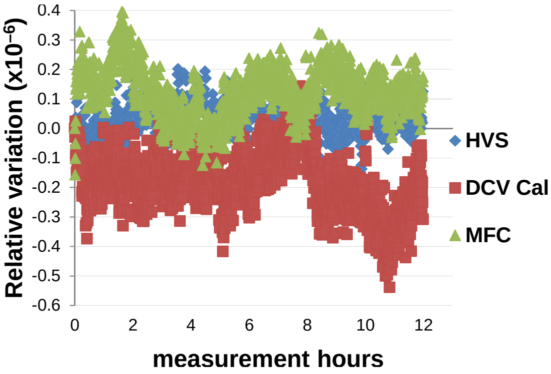

Fig. 4. 12h spread and drift comparison among the HVS, a DCV Calibrator and a MFC.

A second test was carried out with the measurement setup shown in Fig. 5 comparing the short-time stability and drift of the three standards at 100 V for 12h and 2 h (Fig. 6 and 7). The three standards were successively measured with an opposition method connecting them to the 100 V input of a high accuracy INRIM Voltage Divider [12] set in 100:10 ratio and comparing them with the 10 V of a INRIM Zener DC Voltage Standard connected through a DMM in its 100 mV range to the 10V output of the Divider. The 2h measurements were made disconnecting the HVS from the mains and only battery fed.

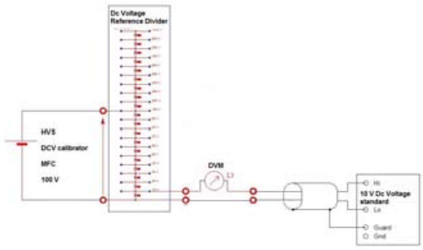

Fig. 5. More accurate measurement setup to compare the HVS with DCV Calibrators or MFC's.

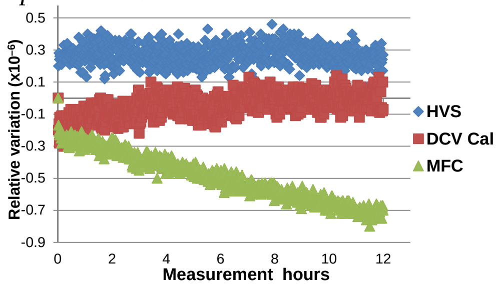

Fig. 6. 12h spread and drift comparison at 100 V among the HVS, a DCV Calibrator and a MFC with the measurement setup of Fig. 5.

The 12h spreads were 5.8×10^{-8}, 7.6×10^{-8} and 1.5×10^{-7} respectively for the HVS, the DCV Calibrator and the MFC. These values included the Divider and Voltage Reference contribution that were considered stable in the three evaluations. The 2h spreads were 6.0×10^{-8}, 6.2×10^{-8} and 4.5×10^{-8} respectively for the HVS, the DCV Calibrator the MFC while the lowest drift was obtained in this case by the HVS. In these last measurements the HVS was equipped with a voltage battery regulator to stabilize its feeding.

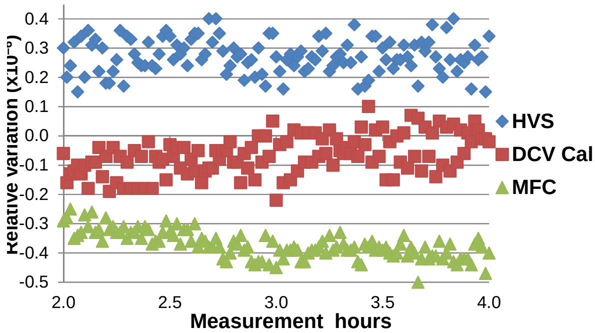

Fig. 7. 2h noise and drift comparison of the HVS at 100 V with a DCV Calibrator and a MFC evaluated with the measurement setup of Fig. 5.

In a third test three DMM's with similar noise were selected. This selection was made connecting them at the same time, in their DC Voltage mode, to a high stability same DCV source, and evaluating their measurements repeatability. Then, the HVS, two top class DCV calibrators and MFC's were compared at 100 V in a 65h time-period. The measurements were carried out during the weekend to avoid disturbs due to presence of the operators. In this case the three instruments under comparison were undergone to the same environmental fluctuations. Figs 8–10 show the obtained results. the HVS was fed with the voltage battery regulator.

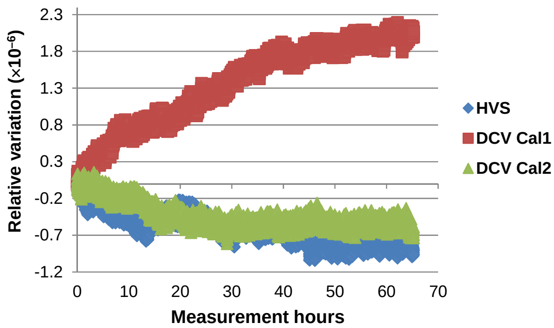

Fig. 8. 65h spread and drift comparison of the HVS at 100 V with two DCV Calibrators with the three DMM's test.

The 65h spreads were 2.1×10^{-7}, 5.7×10^{-7} and 1.8×10^{-7} respectively for the HVS and for the two DCV

Calibrators including the DMM'noises, similar for the three DMM's. Analyzing the measurements drifts of the devices, an environmental change occurred in the middle measurement period. For this reason the measurements in the last 24 h were highlighted in the next figure.

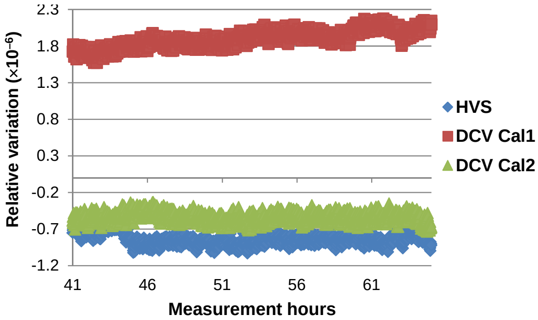

Fig. 9. Last 24h spread and drift of the HVS at 100 V with two DCV Calibrators with the three DMM's test.

In the last 24h measurements the spreads were 9.5×10^{-8}, 1.2×10^{-7} and 6.9×10^{-8} respectively for the HVS and for the two DCV Calibrators. Fig. 10 shows the results of the the same 65h test comparing the HVS with two high performance MFC's in their voltage mode.

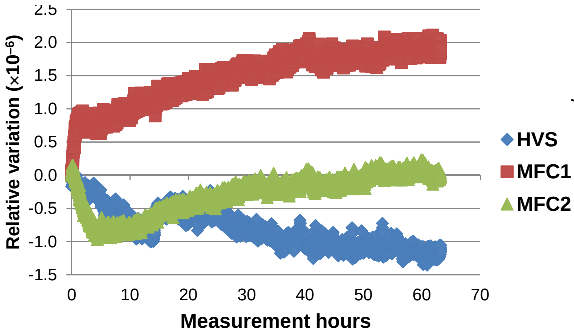

Fig. 10. 65h spread and drift comparison of the HVS at 100 V with two MFCs with the three DMM's test.

The 65h measurements spreads were 2.9×10^{-7}, 3.9×10^{-7} and 2.9×10^{-7} respectively for the HVS and for the two MFCs.

IV. CALIBRATION OF THE HVS

The measurement setup shown in Fig. 5 is also used for the HVS calibration (for example at 100 V) connecting it to the 100 V input of the INRIM Voltage Ratio Standard set and calibrated in 100:10 ratio, and compared with a 10 V DC Voltage high performance INRIM Zener Standard calibrated vs. the INRIM National Standard Voltage applied through the DMM to the 10V output of the Divider. The HVS 100 V value is then:

$$V_{HVS} = \frac{V_s + v}{D} \quad (1)$$

Where V_s is the 10 V DC Voltage of the 10 V Standard, v the voltage unbalance and D the Divider Voltage Ratio.

V. TEMPERATURE COEFFICIENT AND MID-TERM STABILITY OF THE HVS

A. Temperature coefficient

To investigate the temperature behaviour of the HVS in the temperature range typically of Eelectrical Calibration Laboratories that is normally (23 ± 1) °C, the HVS was measured, after suitable stabilization, at (22, 23 and 24) °C in a settable temperature laboratory to evaluate its temperature coefficient around 23 °C, that resulted $\cong -8.3\times10^{-8}$/°C.

B. Mid-term stability and drift of the HVS.

Since its assembly the HVS was also measured at 100 V with the measurement setup of Fig. 5 about every week to evaluate its mid-term stability (about 110 days) The results are shown in Fig.11. The HVS showed a smooth linear increasing drift since its assembly of 1.2×10^{-6} (about 1.3×10^{-8}/day). The drift behaviour seems justified as the complete stabilization of the HVS internal components has not yet reached. The measurements will continue to detect its regimen drift and its long-term stability.

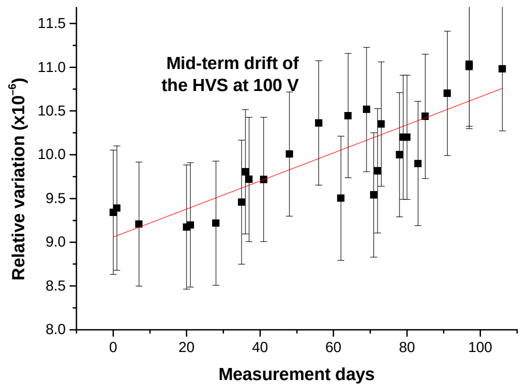

Fig. 11. Measurement at 100 V of the HVS since its assembly. The bars correspond to the HVS calibration 2σ uncertainties as stated in the next paragraph.

In Fig. 12 a view of the experimental setup for the HVS calibration is given.

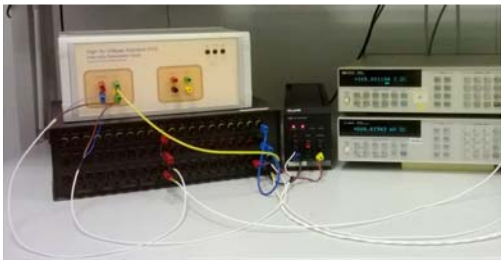

Fig. 12.View of the measurement setup for the calibration of the HVS. Besides the HVS, a 10 V reference standard, the Voltage Divider, the DMM to measure the voltage unbalance and another DMM to direct monitor the HVS's output voltage are shown.

VI. UNCERTANTY EVALUATIONS

A. HVS Calibration uncertainty

According to the paragraph IV and to (1) in Table 1 an uncertainty budget for the calibration of the HVS at 100 V is given.

Table 1. HVS calibration uncertainty budget at 100 V.

Source	type	1σ ($\times10^{-7}$)
Ref 10 V calibration	B	0.25
Ref drift	B	1.2
Ref temp dependence	B	0.2
Ref humidity dependence	B	0.1
Ref pressure dependence	B	negl.
Voltage unbal.	B	negl.
DMM accuracy	B	0.2
DMM calib.	B	negl
Repeatability	A	0.2
Divider Ratio	B	1.0
Divider drift	B	1.2
Divider temp. dependence	B	1.2
Total RSS		3.6

For a 95 % confidence level the calibration uncertainty of the HVS at 100 V is then about 7.1×10^{-7}.

B. HVS use uncertainty at 100 V

Use uncertainty can be defined as the best uncertainty that the HVS can assure in the time period between two calibrations. in Table 2 a preliminary uncertainty budget of the HVS use uncertainty at 100 V is given. It was assumed to use the HVS as DC Voltage Standard for 90 days without recalibration.

Table 2. HVS mid-term use uncertainty budget at 100 V.

Source	type	1σ ($\times10^{-7}$)
calibration	B	3.6
drift	B	8.1
temp dependence	B	1.0
Total RSS		8.9

For a 95% confidence level the use uncertainty of the HVS at 100 V is then about 1.8×10^{-6}. This uncertainty budget has to be updated as uncertainty components due for example to possible pressure, humidity and transport dependence of the HVS have to be investigated and successively added.

VII. CONCLUSIONS

In the first characterization and stability tests the realized HVS showed lower noise, short and mid-time stability and measurement repeatability on the order of top class DC Voltage calibrators and MFCs. This is a significant result as the HVS is not yet equipped with additional technical details to better shield it from environmental parameters fluctuations. This realization had the scope to verify if the principle of the HVS could act as DC top level Voltage Standard. Future aims are the evaluation of the HVS humidity, pressure and transport dependence to evaluate its attitude also as Transportable Voltage Standard for Interlaboratory Comparisons.

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