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ACCURATE COMPARISON BETWEEN INRIM AND A SECONDARY CALIBRATION LABORATORY USING A TOP-CLASS MULTIFUNCTION ELECTRICAL CALIBRATOR

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ABSTRACT

An accurate inter-laboratory comparison (ILC) concerning the electrical quantities in low frequency between the laboratory for the calibration of multifunction electrical instruments of the National Institute of Metrology Research (INRIM) and a secondary high level electrical calibration laboratory was performed with satisfactory results. The instrument involved in the ILC was a top class multifunction electrical calibrator, chosen for its wide measurement fields and its excellent definability requiring therefore very small uncertainties to calibrate it. This ILC was the first high accuracy comparison exercise at INRIM involving a grid of about one hundred and thirty measurement points. The ILC allowed to check adequately the measurement capabilities, techniques and uncertainties of this secondary laboratory. Attention was paid to evaluate the correlated terms between the two laboratories measurements. The calibrator showed high stability and resulted more appropriate than fixed standards or than a 8.5 digits multimeter to the aim of the ILC.

Key Words: Inter-laboratory comparison, measurement uncertainty, multifunction calibrator, correlation coefficient, calibration.

1. INTRODUCTION

Since decades, the measurement capabilities in the field of low frequency electrical quantities (DC and AC Voltage, DC and AC current and DC Resistance) among National Measurements Institutes (NMIs) have been verified by means of inter-laboratory comparisons (ILCs) regarding the calibration of fixed primary electrical standards as in [1–4]. These Institutes have the competence to correctly disseminate the low-frequency electrical units towards their working standards and instruments and towards secondary laboratories that operated with much higher measurement uncertainties than NMIs. Now, modern electrical secondary calibration laboratories operate with smaller measurement uncertainties than in the past as they are equipped with high accuracy and stability digital instrumentation as multimeters (DMMs) and multifunction calibrators (MFCs) operating in wide measurement fields [5]. The calibration of these instruments can be made at different uncertainty levels and with different measurement strategies. Some instruments can be calibrated by means of the “artifact calibration”, an easy method that requires only few reference Standards [6–9]. The reliability of these laboratories can be assured by means of their participation with satisfactory results to ILCs technically suitable to their capabilities and uncertainty levels. In this paper, an accurate and extensive ILC between the laboratory for calibration of multifunction electrical instruments of the National Institute of Metrology Research (INRIM-Lab) and a high level secondary electrical calibration laboratory (Cal-Lab) regarding the calibration of a top-class 8.5 digits MFC is presented. This was the first ILC carried out at INRIM with a secondary laboratory accredited with very small uncertainties involving more than one hundred measurement points and several measurement techniques in the field of the electrical quantities in low frequency. The described ILC was carried out also to verify the competence and capabilities of the participating Cal-Lab to maintain and improve its accreditation status.

2. CHOICE OF SUITABLE INSTRUMENTS FOR ILCs

NMIs and ILCs providers have to provide suitable ILCs to correctly verify the capabilities of secondary laboratories. ILCs concerning the calibration of only fixed electrical standards [1–4, 10–12] unfortunately don't cover the wide operating fields of modern secondary electrical calibration laboratories. An instrument covering wide fields and used by INRIM for several years in ILCs with these laboratories is the 8.5-digit high precision DMM. An ILC with this instrument ensures a suitable check of the capabilities of medium-high level secondary laboratories that are equipped with top-class multifunction instruments as reference standards. High level secondary calibration laboratories are instead equipped with complete sets of primary standards as reference standards to be calibrated at NMIs. These standards are for example a 10 V DC Voltage standard, DC Voltage dividers, standard resistors and shunts and an AC/DC transfer standard, (that can also be used as AC Voltage meter). With such instrumentation, these laboratories can internally calibrate with very small uncertainties their MFC(s) and DMM(s), then after utilized as working instruments. Till now, the capabilities of these laboratories have been verified by INRIM by means of ILCs concerning the calibration of a DMM and of some fixed standards as a 10 V or a 10 k Ω standards. Nevertheless, these ILCs don't allow to adequately verify the measurement capabilities and the uncertainties of these laboratories. In this ILC, a top-class MFC was chosen as instrument to be calibrated due to its wide measurement fields and its excellent definability (definitional uncertainty) [13], better than that of a DMM, requiring therefore very small uncertainties to calibrate it. For this reason, this kind of ILC can be adequate to correctly verify the capabilities of high level secondary electrical calibration laboratories.

3. THE INSTRUMENT TO CALIBRATE IN THE ILC

The instrument under calibration in the ILC was a J. Fluke 5700A MFC with associate a transconductance amplifier J. Fluke 5725A. The operating ranges of this MFC in DC and AC Voltage functions span from 1 mV to 1100 V and at frequencies from 10 Hz to 1.2 MHz in AC Voltage, in Resistance function span from 1 Ω to 100 M Ω , in DC and AC current functions span from 1 μ A to 10 A and at frequencies from 10 Hz to 10 kHz in AC current.

3.1 ILC instructions

The calibration of the MFC had to be performed with the instrument in thermal equilibrium with the environment at a temperature of $(23.0 \pm 1)^\circ \text{C}$, after a feeding period of at least 24 h. After the successfully execution of the SELF DIAG and CAL zero procedures, the MFC had to be calibrated in the measurement ranges reported in Table 1. For AC measurements the INRIM-Lab and the Cal-Lab had to calibrate the MFC with a measuring system with input impedance not less than 1 M Ω to avoid undesired load effects. All the measurement points involved in the ILC are reported in the following Tables 2 and 3 and in Fig. from 5 to 9.

Table 1.

Measurement ranges of the ILC with the MFC.

Quantity	Measurement range	Frequency range
DC Voltage	1 mV \div 1000 V	40 Hz \div 1MHz
AC Voltage	1 mV \div 1000 V	
DC Current	10 μ A \div 10 A	40 Hz \div 5 kHz
AC Current	100 μ A \div 10 A	
DC Resistance	1 Ω \div 100 M Ω	

Normally at the INRIM-Lab a complete calibration of a MFC is performed in three steps [5]. With an initial verification, a wide set of measurement points are compared with the reference measurement system. Successively the adjustment, as suggested by the manufacturer, is performed.

A final verification (as performed in the initial one) checks the effectiveness of the adjustment. For this ILC, only a verification (without adjustment) had to be performed.

4. TRACEABILITY TO NATIONAL STANDARDS OF THE INRIM-LAB AND OF THE CAL-LAB

The traceability chain of the INRIM-Lab from national standards is shown in Fig. 1. The INRIM-lab and the Cal-Lab both take their traceability from other INRIM laboratories as the DC Voltage, the DC Resistance and the AC Voltage laboratories that in Fig. 1 are schematically identified with “National Standards”. Among the primary references of the INRIM-lab there are a high precision DMM characterized in linearity and used as DC Voltage ratio standard [14, 15] and a INRIM-made automated DC Voltage fixed ratios standard divider [16]. The traceability chain of the Cal-Lab is similar to that of the INRIM-Lab with some common standards also calibrated at INRIM implying a partial correlation between the measurements of the two laboratories.

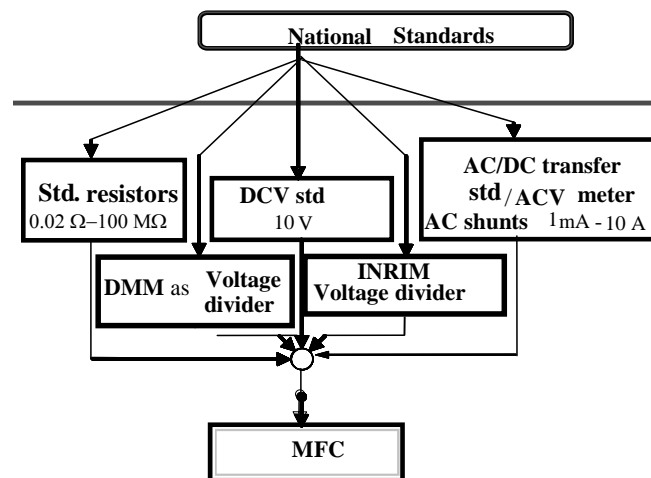


Fig. 1. Traceability chain of the INRIM-lab from national standards till down to the calibration of the MFC.

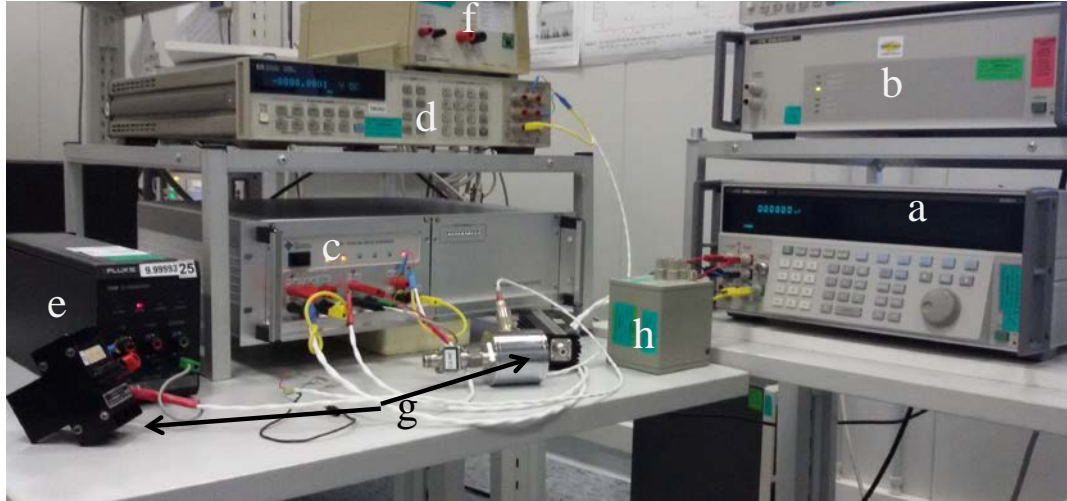


Fig. 2. View of the measurement setup at INRIM-Lab to calibrate the MFC. Are visible: a) the MFC, b) the transconductance amplifier, c) the automated DC Voltage fixed ratios divider, d) the DMM as DC Voltage divider, e) the 10 V Standard, f) a DC Resistance shunt, g) AC Resistance shunts and h) the 10 k Ω Standard. In the photograph are not visible the AC\DC Transfer Standard and the oil and air baths containing respectively the low value and high value standard resistors.

The measurement uncertainties of the two laboratories were respectively evaluated in calibration procedures respectively approved by INRIM as signatory of the CIPM MRA¹ and by the Italian calibration Accreditation body ACCREDIA. The uncertainties reported in the INRIM-Lab procedures were evaluated according to the criteria defined in [5]. The procedures of both laboratories, in particular for AC measurements, take into account the effects of the output impedance of the calibrator, of the impedance of cables and connectors and of the input impedance of the measuring system in order to correct the measurement values due to load effects. The evaluation of these impedances is made according to the expertise of the technicians of the two laboratories and to the manufacturer indications². Consequently, in the same procedures, uncertainty components due to the made corrections are added.

¹ 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.

² In the procedures, in particular for AC Voltage and current, for each MFC measurement range, the impedance value of a measurement circuit involving the output impedance of the MFC, the impedances of cables, connectors and the input impedance of the measuring systems, is estimated. This value allows a correction of the measurement results due to load effects.

4.1 Measurement setups for the calibration of the MFC J. Fluke 5700 A in AC Voltage and DC Resistance and their uncertainties.

The calibration of the MFC involves several measurement setups as the MFC operates on wide fields of the five electrical quantities in low frequency. Often, more than a setup is necessary for each quantity. The INRIM-Lab and Cal-Lab procedures are very complete documents reporting all the measurement setups for the calibration of the MFC with the corresponding uncertainties evaluations. To give all this information in the paper, besides to be impossible, goes beyond the scope of the paper. Nevertheless, In Fig. 3 and 4, the measurement setups for the calibration of the MFC J. Fluke mod. 5700A at the INRIM-Lab respectively in AC Voltage in the range from 0.5 V to 1000 V and in DC Resistance at 1 Ω are given. Uncertainties budget for the 10 V at 1 kHz and at 1 Ω are also added.

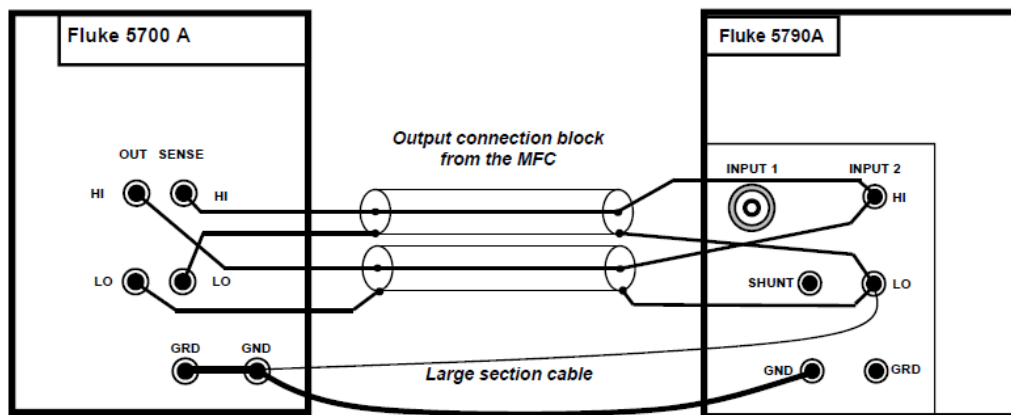


Fig. 3. View of the measurement setup at INRIM-Lab to calibrate the MFC in AC Voltage in the range from 0.5 V to 1000 V.

This calibration is made automatically, comparing the 5700A with the AC/DC transfer standard J. Fluke mod.5790A taking into account the transfer errors of the transfer standard. In a first phase, the calibrator applies DC voltages of both polarities, corrected according to its calibration in DC Voltage, used as reference values by the transfer standard. In a second phase, the calibrator applies the alternating voltages to be measured by the J. Fluke mod. 5790A. According to the 5790A calibrated transfer errors, the AC Voltage values provided by the MFC

are evaluated. In this case the transfer standard is used as AC Voltage meter. In Table 2 an uncertainty budget for the value 10 V at 1 kHz is given.

Table 2.
5700 Å calibration relative uncertainty budget at 10 V 1 kHz.

Uncertainty components due to:	type	1σ ($\mu\text{V/V}$)
Load, connections between 5700-5790	B	5.0
5700 applied reference DC voltage	B	7.6
5700 applied reference DC voltage drift	B	0.5
5790 AC/DC transfer error	B	7.0
Repeatability.-instability 5700 applied AC voltage	A	5.0
5790 AC/DC transfer error drift	B	4.0
5790 short-time stability	B	5.0
Total RSS		14

For a 95 % confidence level the calibration relative uncertainty of the 5700 Å at 10 V, 1 kHz is then 2.8×10^{-5} . The same value can be obtained in the range from 40 Hz to 20 kHz.

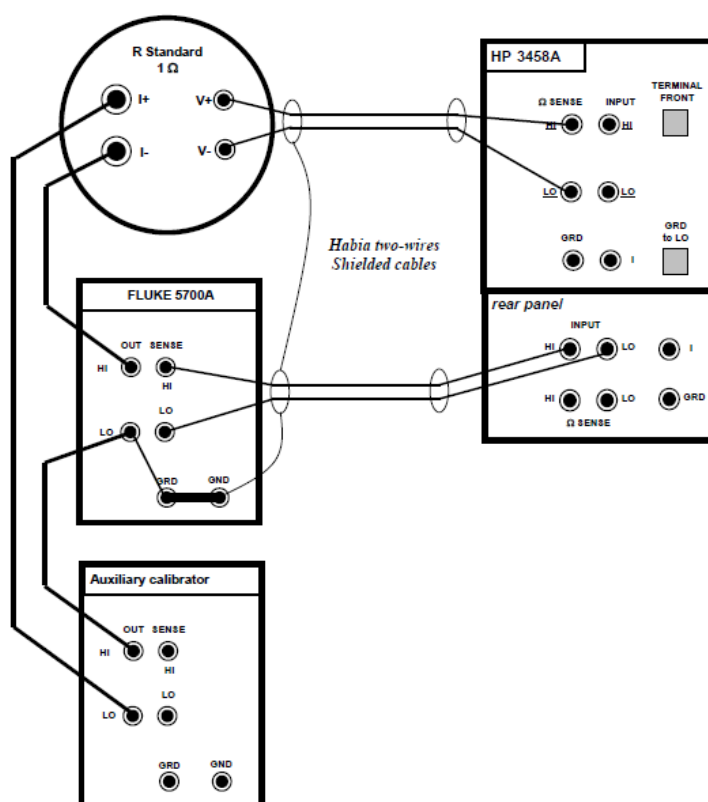


Fig. 4. View of the measurement setup at INRIM-Lab to calibrate the MFC in DC Resistance at 1 Ω .

For the calibration of the $1\ \Omega$ value, the measurement is made by means of a volt-ampere method with a current of 100 mA provided by an auxiliary calibrator. This current flows

through the series formed by a standard resistor R_s and the Fluke 5700 A set on the $1\ \Omega$ value R_x . The auxiliary calibrator provides a current of both polarities while a HP 3458 DMM measures the voltage drops on R_s and R_x , respectively on the front and the rear input terminals. The $1\ \Omega$ value provided by the 5700 A is then given by the following relation:

$$R_x = R_s \frac{(V_{x+}/V_{s+}) + (V_{x-}/V_{s-})}{2} \cong R_s \times r \quad (1)$$

where V_{x+} , V_{s+} , V_{x-} and V_{s-} are respectively the voltage values measured on the 5700A (x) and on R_s (s) respectively with positive (+) and negative polarity (-).

Table 3.

5700 A calibration relative uncertainty budget at $1\ \Omega$.

Uncertainty components due to:	type	1σ ($\mu\Omega/\Omega$)
R_s calibration	B	0.5
R_s drift	B	0.58
R_s temperature effect	B	0.017
r repeatability	A	2.0
Total RSS		2.1

For a 95 % confidence level the calibration relative uncertainty of the 5700 A at $1\ \Omega$ is then 4.2×10^{-6} . In the INRIM-Lab and Cal-Lab procedures, uncertainty budgets are made for each measurement point and field for the five electrical quantities in low frequency.

5. ANALYSIS OF THE RESULTS

The MFC was calibrated twice by the Cal-Lab, once before and once after its calibration at the INRIM-Lab. To minimize the effect of the possible drift of the MFC, the Cal-Lab mean values of its two calibrations were taken into account. For the evaluation of the ILC it was considered, as measurand, a MFC “relative error” E defined in (2) as:

$$E = (m - s) / s \quad (2)$$

where m indicate the value measured by a laboratory at a setting s of the MFC.

In the following (3) and (4) for each measurement point, the INRIM-Lab and Cal-Lab relative errors were respectively defined as:

$$E_I = (m_I - s) / s \quad (3)$$

$$E_L = \frac{(m_{L1} - s) + (m_{L2} - s)}{2s} \quad (4)$$

where m_I are the values measured by the INRIM-Lab at the settings s of the MFC, while m_{L1} and m_{L2} are the same values measured by the Cal-Lab at the same s before and after its calibration at the INRIM-Lab. For each measurement point, a new measurand as difference between E_L and E_I was introduced [10–12, 17].

$$d = E_L - E_I \quad (5)$$

whose standard uncertainty is:

$$u^2(d) = [u^2(E_I) + u^2(E_L) - 2u(E_L)u(E_I) \times r(E_L, E_I)] \quad (6)$$

where $u(E_L)$ and $u(E_I)$ are respectively the Cal-Lab and INRIM-Lab standard uncertainties, while $r(E_L, E_I)$ is the correlation coefficient between E_L and E_I . Criteria to evaluate $r(E_L, E_I)$ for each electrical quantity were introduced.

- DC Voltage: In each measurement point $r(E_L, E_I)$ was evaluated according to the following relation:

$$r(E_L, E_I) = \frac{u_B^2(std_{DCV})}{u(E_I) \times u(E_L)} \quad (7)$$

where $u_B(std_{DCV})$ is the type B component of the standard uncertainty of the calibration at INRIM of the 10 V standard inserted in the traceability chain of both laboratories. $u_B(std_{DCV})$ includes the uncertainties respectively due to the DC Voltage national standard and to the transfer to the INRIM 10 V standard. The corrections of the results for load effect were considered independent as the two laboratories utilize different instrumentation (DMM and dividers) for DC Voltage measurements.

- AC Voltage:

In each measurement point $r(E_L, E_I)$ was evaluated according to the following relation:

$$r(E_L, E_I) = \frac{u_B^2(std_{DCV} + u_B^2(corr_{load}) + u_B^2(\delta))}{u(E_I) \times u(E_L)} \quad (8)$$

Where $u_B(\delta)$ is the type B uncertainty of the AC/DC transfer standard calibrated at INRIM [18]³ and inserted in the traceability chain of both laboratories. As $u_B(\delta)$ depends by voltage and frequency, typical uncertainty values corresponding to frequency and voltage ranges were considered. $u_B(\text{corr_load})$ is the type B uncertainty of the measurements correction due to load effects. For this uncertainty component, higher values were considered for AC Voltages lower than 220 mV in which the MFC output impedance is about 50 Ω and for higher frequencies.

- DC Resistance: In each measurement point $r(E_L, E_I)$ was evaluated according to the following relation:

$$r(E_L, E_I) = \frac{u_B^2(\text{std}_{RES})}{u(E_I) \times u(E_L)} \quad (9)$$

where $u_B(\text{std}_{RES})$ is the type B standard uncertainty of the calibration at INRIM of the standard resistors inserted in the traceability chain of both laboratories.

$u_B(\text{std}_{RES})$ includes the uncertainties respectively due to the DC Resistance national standard and to the transfer to the DC Resistance scale. As the resistance measurements were made with a substitution method comparing the DC Resistance values given by the MFC with reference resistors of same nominal values through a DMM, measurements corrections due to load effect were considered unnecessary.

- DC current: In each measurement point $r(E_L, E_I)$ was evaluated according to the following relation:

$$r(E_L, E_I) = \frac{u_B^2(\text{std}_{DCV}) + u_B^2(\text{std}_{RES})}{u(E_I) \times u(E_L)} \quad (10)$$

where $u_B(\text{std}_{RES})$ is the type B standard uncertainty of the calibration at INRIM of the resistors or DC Resistance shunts inserted in the traceability chain of both laboratories and used to obtain the desired currents. The measurements corrections due to the load effect on the MFC were made

³ The two laboratories used the same AC/DC transfer standard but with different release.

taking into account the used resistors to obtain the requested currents. Therefore, the uncertainties of the correlated corrections of the two laboratories can be already included in $u_B(std_RES)$.

- AC current. In each measurement point $r(E_L, E_I)$ was evaluated according to the relation:

$$r(E_L, E_I) = \frac{u_B^2(std_DCV) + u_B^2(\delta) + u_B^2(corr_load) + u_B^2(std_RES)}{u(E_I) \times u(E_L)} \quad (11)$$

where $u_B(\delta)$ are the type B uncertainties of the calibration at INRIM of the complex constituted by the AC/DC transfer standard with its AC/DC transfer shunts. As $u_B(\delta)$ depends by current and frequency, typical uncertainty values corresponding to frequency and current ranges were considered. $u_B(corr_load)$ is the type B uncertainty of the correction of the AC Current measurements due to load effects. Higher values of $u_B(corr_load)$ were considered at higher frequencies. $u_B(std_RES)$ is the type B standard uncertainty of the calibration at INRIM of the resistors or DC Resistance shunts used in the calibration of the AC/DC shunts in DC current.

A further investigation of the correlation matter should be made, however, this goes beyond the scope of the paper and of the scope of the described ILC. Finally, the normalized error En with respect to INRIM-Lab for each measurement point was evaluated as:

$$En = \frac{d}{U(d)} \quad (12)$$

where $U(d) = 2u(d)$ at a 95% confidence level.

In Table 4 and 5 the results for DC and AC Voltage are respectively reported.

Table 4.Results of the ILC for DC Voltage. all the uncertainties are at 1σ confidence level.

Set value (mV)	E_I ($\times 10^{-6}$)	$u(E_I)$ ($\times 10^{-6}$)	E_L ($\times 10^{-6}$)	$u(E_L)$ ($\times 10^{-6}$)	d ($\times 10^{-6}$)	$u(d)$ ($\times 10^{-6}$)	En
1	-25.0	96	50.0	155	75.0	182.3	0.2
-1	-20.0	96	-50.0	155	-30.0	182.3	-0.1
3	5.0	32.5	16.7	55	11.7	63.9	0.1
10	5.5	11.5	5.0	24	-0.5	26.6	0.0
-10	4.0	11.5	-5.0	24	-9.0	26.6	-0.2
100	0.5	1.1	2.5	1.8	2.0	2.1	0.5
-100	0.5	1.1	0.0	1.8	-0.5	2.1	-0.1
(V)							
0.3	0.5	0.9	1.5	1.7	1.0	1.9	0.3
-0.3	0.2	0.9	-0.3	1.7	-0.5	1.9	-0.1
1	-0.2	0.4	0.7	0.5	0.9	0.6	0.7
-1	0.0	0.4	1.1	0.5	1.1	0.6	0.8
3	2.3	0.5	2.7	0.6	0.4	0.8	0.3
-3	2.3	0.5	1.8	0.6	-0.5	0.8	-0.3
7	2.3	0.4	2.2	0.4	-0.1	0.6	-0.1
10	2.2	0.3	2.1	0.5	-0.1	0.5	-0.1
-10	2.3	0.3	2.1	0.5	-0.2	0.5	-0.2
20	2.5	0.4	1.5	0.6	-1.0	0.7	-0.7
-20	2.5	0.4	2.0	0.6	-0.5	0.7	-0.3
30	1.7	0.5	0.9	0.8	-0.8	0.9	-0.4
-30	1.7	0.5	0.9	0.8	-0.8	0.9	-0.4
50	1.5	0.6	0.6	0.6	-0.9	0.8	-0.6
100	1.2	0.4	0.8	0.6	-0.4	0.7	-0.3
-100	1.2	0.4	1.1	0.6	-0.1	0.7	-0.1
300	1.7	0.7	1.3	0.7	-0.4	1.0	-0.2
-300	1.6	0.7	1.0	0.7	-0.6	1.0	-0.3
400	1.8	0.7	0.9	0.7	-0.9	1.0	-0.5
800	1.5	0.5	0.7	0.6	-0.8	0.9	-0.5
1000	1.2	0.5	0.5	0.6	-0.7	0.8	-0.5
-1000	1.1	0.5	1.0	0.6	-0.1	0.8	-0.1

Table 5.Results of the ILC for AC Voltage. all the uncertainties are at 1σ confidence level.

Set value (mV)	f (kHz)	E_I ($\times 10^{-6}$)	$u(E_I)$ ($\times 10^{-6}$)	E_L ($\times 10^{-6}$)	$u(E_L)$ ($\times 10^{-6}$)	d ($\times 10^{-6}$)	$u(d)$ ($\times 10^{-6}$)	En
1.0	1	843.7	487	100.0	1300	-743.7	1388.1	-0.3
10.0	1	59.8	52	-15.0	140	-74.8	148.6	-0.3
100	0.04	10.0	19	0.0	30	-10.0	32.2	-0.2
100	1	0.6	19	-10.0	30	-10.6	32.2	-0.2
10	10	-1.5	19	-10.0	30	-8.5	32.2	-0.1
200	1	2.6	19	0.0	27.5	-2.6	29.6	0.0
(V)								
0.3	1	17.1	18	1.7	23.3	-15.4	25.4	-0.3
0.5	1	5.3	15	-5.0	22.0	-10.3	21.7	-0.2
1	0.04	14.0	14	4.0	22.0	-10.0	21.3	-0.2
1	1	5.7	14	-3.0	22.0	-8.7	21.3	-0.2
1	100	-43.0	20	-35.0	55.0	8.0	56.4	0.1
1	300	-69.2	61	20.0	145.0	89.2	156.4	0.3
1	1000	-1208	178	-550	750	656.8	770.6	0.4
2	1	5.3	14	1.8	22.5	-3.5	21.8	-0.1
3	0.04	15.0	14	23.3	21.7	8.3	21.0	0.2
3	1	12.8	14	15.0	21.7	2.2	21.0	0.1
3	100	129.3	23	158.3	21.7	29.0	27.8	0.5
6	1	-2.1	14	10.8	25.0	12.9	24.1	0.3
10	0.04	13.1	14	20.0	20.0	6.9	18.9	0.2
10	1	4.5	14	15.0	20.0	10.5	18.9	0.3
10	20	2.8	14	10.0	20.0	7.2	18.9	0.2
10	100	-47.2	23	-10.0	50.0	37.2	53.0	0.4
10	300	-110.6	136	-45.0	125.0	65.6	184.1	0.2
10	1000	-1368.5	324	-850.0	750.0	518.5	816.9	0.3
20	1	5.0	14	20.0	20.0	15.0	19.3	0.4
30	0.04	20.6	18	30.0	21.7	9.4	23.8	0.2
30	1	16.6	18	28.3	21.7	11.8	23.8	0.2
30	100	120.0	50	156.7	58.3	36.6	75.4	0.2
60	1	8.5	18	200	20.8	11.5	23.1	0.3
100	0.04	25.5	18	300	21.0	4.5	23.2	0.1
100	1	17.1	18	250	21.0	7.9	23.2	0.2
100	20	7.0	18	200	21.0	13.0	23.2	0.3
100	100	-38.0	50	-55	60.0	-17.0	76.6	-0.1
200	1	17.0	19	350	20.0	18.0	22.7	0.4
300	0.04	6.0	20	200	21.7	14.0	25.4	0.3
300	1	11.2	20	200	21.7	8.8	25.4	0.2
300	20	-3.3	20	11.67	25.0	15.0	28.3	0.3
600	1	1.1	23	12.50	25.0	11.4	30.1	0.2
1000	0.04	3.1	29	100	25.0	6.9	34.8	0.1
1000	1	6.9	29	200	25.0	13.1	34.8	0.2
1000	20	-19.1	45	0.0	80.0	19.1	90.6	0.1
1000	30	-26.2	80	-10	80.0	16.2	112.1	0.1

In Figures from 5 to 9 the En values of the ILC in all the measurement points of the ranges of Table 1 are shown.

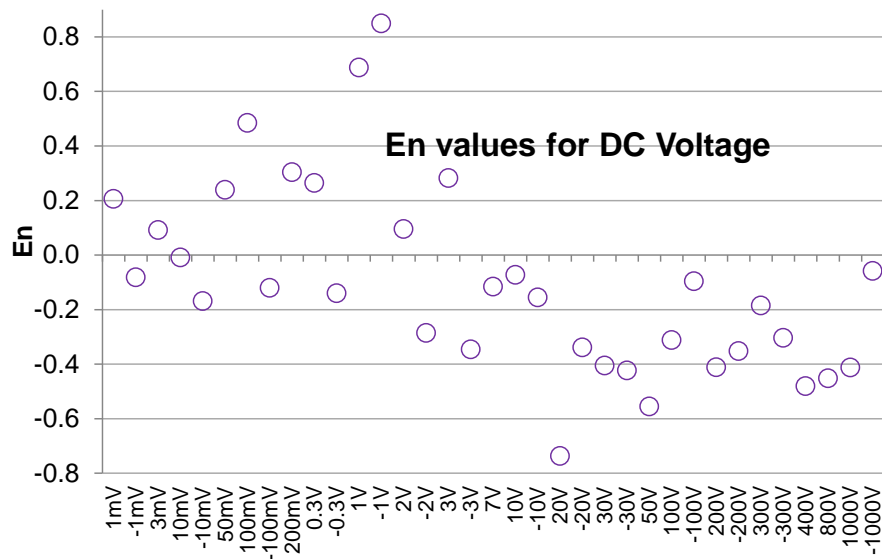


Fig. 5. *En* values for DC Voltage.

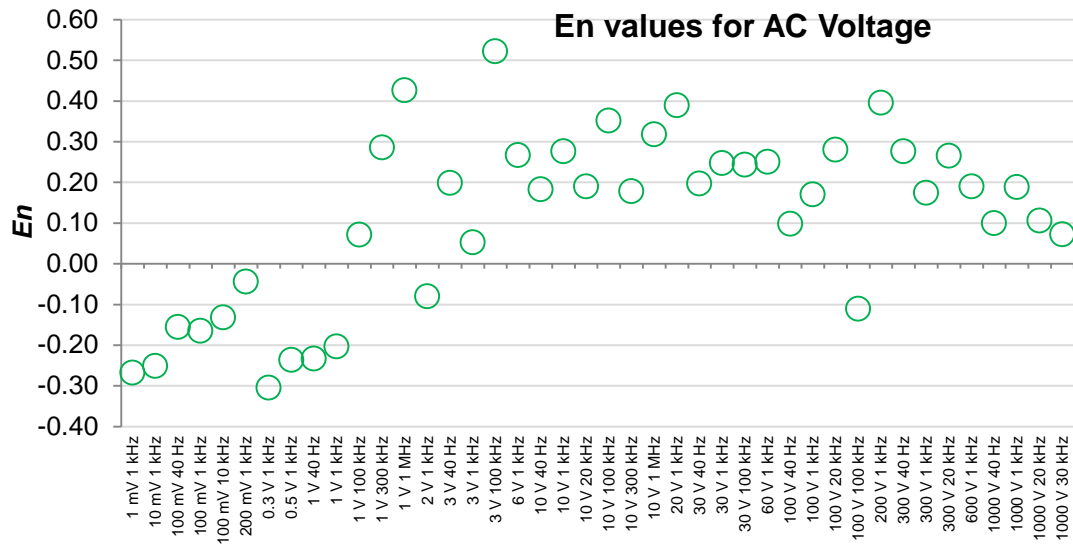


Fig. 6. *En* values for AC Voltage.

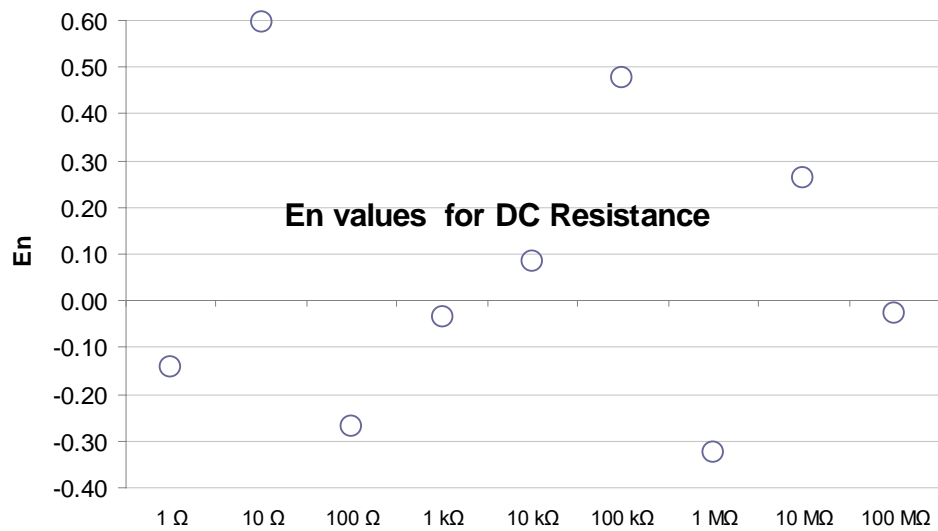


Fig. 7. *En* values for DC Resistance.

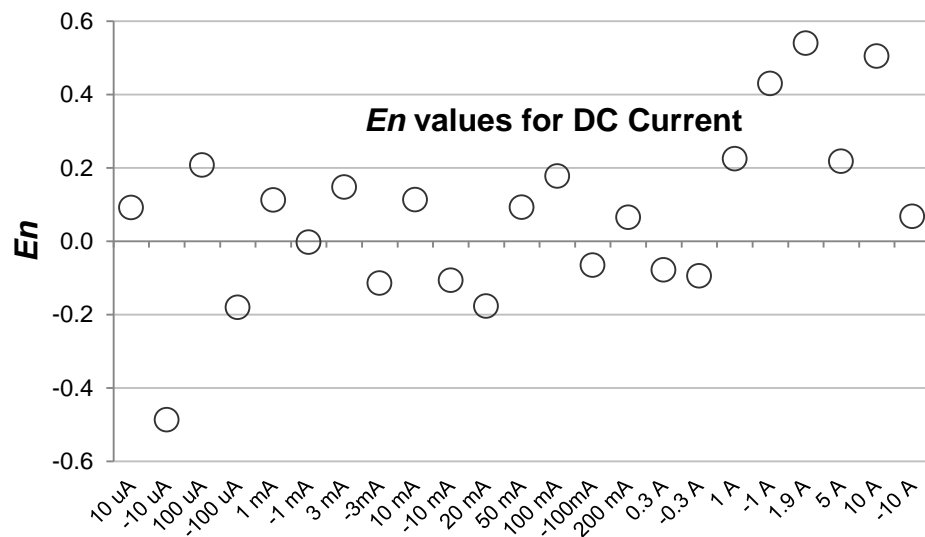


Fig. 8. *En* values for DC Current.

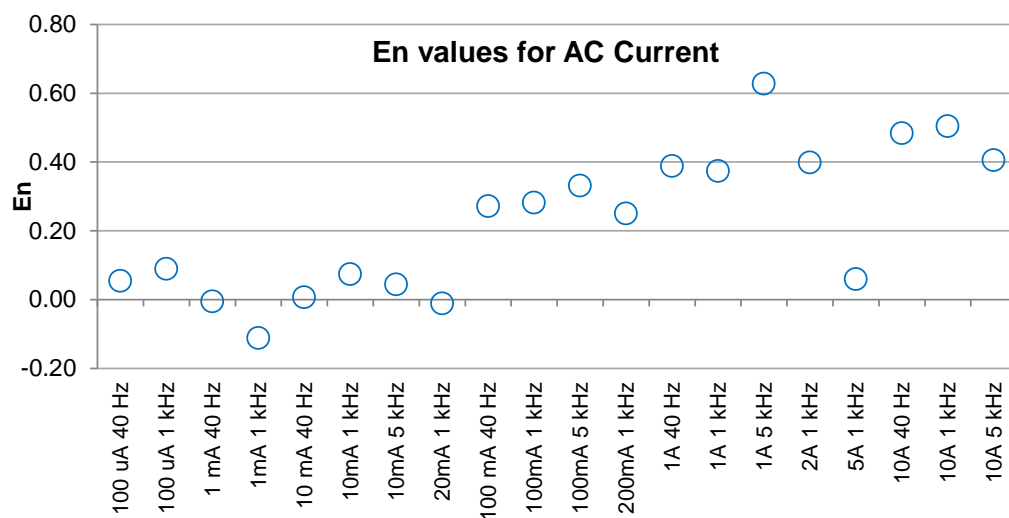


Fig. 9. *En* values for AC Current.

From these graphs it can be seen that $|En|$ was less than 1 for each measurement point of the ILC. The $|En|$ mean value was 0.3 for DC Voltage and DC Resistance while it was 0.2 for the other quantities.

5. CONCLUSIONS

The result of the ILC can be considered satisfactory as the Cal-Lab operates with very small uncertainties although it is a secondary laboratory. The criteria to evaluate the correlation coefficient between the measurements of the two laboratories could be more useful for ILCs in which the uncertainties of the correlated terms were higher than in this case. The Cal-Lab demonstrated to have adequate competence, instrumentation and calibration procedures to sustain its capabilities. This comparison exercise demonstrated that this kind of ILC allows to check adequately the measurement capabilities and techniques of high-level secondary laboratories. The used 8.5 digits MFC resulted eligible to employ in high accuracy ILCs for its wide measurement fields and its excellent definability. In addition, it showed high stability and insensibility to transport during the comparison to be involved also in multilateral ILCs that INRIM is actually carrying on with the best accredited secondary laboratories.

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