

Guidelines on the Calibration of Digital Multimeters

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Calibration Guide

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GUIDELINES ON THE CALIBRATION OF DIGITAL MULTIMETERS

Purpose

This document has been produced to enhance the equivalence and mutual recognition of calibration results obtained by laboratories performing calibrations of digital multimeters.

Authorship and Imprint

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EURAMET e.V.
Bundesallee 100
D-38116 Braunschweig
Germany

e-mail: secretariat@euramet.org
phone: +49 531 592 1960

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Guidance Publications

This document gives guidance on measurement practices in the specified fields of measurements. By applying the recommendations presented in this document laboratories can produce calibration results that can be recognized and accepted throughout Europe. The approaches taken are not mandatory and are for the guidance of calibration laboratories. The document has been produced as a means of promoting a consistent approach to good measurement practice leading to and supporting laboratory accreditation.

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Guidelines on the Calibration of Digital Multimeters

1. INTRODUCTION

- 1.1. The aim of this document is to provide guidelines on the Calibration of Digital Multimeters (DMMs) for calibration laboratories (CLs), accredited or not. It does not claim to be an exhaustive compilation of all the metrological details of DMMs, not even of those relevant for their calibration, but it can supplement the manufacturer's recommendations for calibration, that have to be always followed. The pertinent standards and documents have been taken into account (see references).

Even though these guidelines are not intended to cover the question of judging compliance of a DMM to specification, they suggest a suitable calibration method on which a statement of compliance can be based. For assessment and reporting of compliance, readers may refer to ILAC Guideline G8 [1].

- 1.2. The category of apparatus referred to is that of multifunctional measuring instruments with digital reading for the measurement of the quantities: DC voltage, AC voltage (low frequency), DC current, AC current (low frequency), resistance. This category does not include instruments which, although they also measure one or more of these quantities, are primarily intended for measuring quantities of a different type such as power, energy and AC impedance or for measurements at frequencies higher than 1 MHz. The guidelines given can also be applied to digital instruments that are able to measure only some of the quantities mentioned above (e.g. digital voltmeters), but not for panel instruments or instruments developed for specialised applications.

2. TERMINOLOGY

- 2.1 **Calibration.** Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication (VIM 2.39 [2]).
- 2.2 **Adjustment (of a measuring system).** Set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured (VIM 3.11). Depending on the instrument, the adjustment can be performed by physical adjustment (of internal components) or via the instrument's firmware.

- 2.3 **Zero adjustment.** Adjustment of a measuring system so that it provides a null indication corresponding to a zero value of a quantity to be measured (VIM 3.12).
- 2.4 **Measurement error (error).** Measured quantity value minus a reference quantity value (VIM 2.16).
- 2.5 **Metrological confirmation.** Set of operations required to ensure that measuring equipment conforms to the requirements for its intended use (ISO 10012 3.5 [3]).
- 2.6 **Resolution (of a displaying device).** Smallest difference between displayed indications that can be meaningfully distinguished (VIM 4.15). For digital instruments, the resolution feature is often expressed by the number of digits displayed by the instrument.
- 2.7 **Indication interval.** Set of quantity values bounded by extreme possible indications (VIM 4.3).
- 2.8 **Full scale.** Absolute maximum indication of an instrument in a specified range.
- 2.9 **Functional test/ verification.** A test/verification performed on an instrument in order to verify if its functions are working properly.
- 2.10 **Self-calibration / auto-calibration.** Internal calibration process of an instrument, with the aim of improving its accuracy.
- 2.11 **Crest factor.** Ratio between the peak value of an AC signal and its rms value.

3. PROCEDURE

3.1 General Considerations

- 3.1.1 The procedure must ensure that the instrument under calibration gives to the user traceable measurements results. The user should be able to use the measurement results reported in the calibration certificate during metrological confirmation of the instrument.
- 3.1.2 The procedure should also provide that the instrument can be calibrated along with accessories.

3.2 Preliminary Operations

- 3.2.1 The first operation which must be done is the verify the state, safety, and functioning of the DMM, this is necessary for checking of possible faults of the instruments, and it is usually partially performed by its firmware at the power-on.
- 3.2.2 If the functionality check is positive, the stabilization times specified by the manufacturer shall be observed.
- 3.2.3 Another operation is the setting of reference and use conditions can consist, if the instrument allows, in a self-calibration (ACAL, SELFCAL, etc.), and offset compensations for dc functions.

3.3 Sequence of Operations

- 3.3.1 Depending upon the “as received” calibration state of the DMM and the customer's requirements, three different sequences of operation can be performed:
- | | | | | | |
|----|-------------------------------|----|---------------|----|---------------|
| a) | - Pre-adjustment calibration | b) | - Adjustment | c) | - Calibration |
| | - Adjustment | | - Calibration | | |
| | - Post-adjustment calibration | | | | |

- 3.3.2 Sequence a) is the standard sequence for DMMs which have the adjustment function. Pre-adjustment calibration (calibration before the adjustment) provides information on the behaviour of the instrument in the period that has elapsed since the previous calibration. Adjustment brings the readings of the instrument within the limits of manufacturer's specifications. The post-adjustment calibration (calibration after the adjustment) documents the state of the instrument after the adjustment has been performed.
- 3.3.3 The sequence b) can be followed when the calibration state of the instrument, when it arrives at the CL, is not relevant to the customer, and it is so possible to omit the preliminary calibration. This may be the case if the instrument has never been submitted to periodical calibration, or if operations have been carried out, for example repairs, that have significantly altered its metrological characteristics. This sequence may only be chosen at the explicit request of the customer or if the repair has been carried out, immediately before calibration, by the CL or by a laboratory directly related to it.
- 3.3.4 If the instrument has not the adjustment function or it turns out to have maintained its accuracy in a highly satisfactory manner, it is possible not to perform adjustment and to follow sequence c). The limits which must not be exceeded by the calibration results, in order for this to be possible, must be selected in such a way that the instrument remains presumably within specification during the following period of use.
- For example, for non high-accuracy instruments with manual type adjustment, which usually have low drift with respect to specification, the limits to the deviation between the applied quantity and the reading can be set at 70 % of the annual specification, declared by the manufacturer, at all the measurement points, and 50 % if the point corresponds to a value for which the instrument was adjusted. For other more accurate instruments, the limit can be set at 50 % of the specification for all measurement points.
- The sequence c) can be implemented, on customer request, even when an instrument is outside specifications, because the customers uses correction factors, deductible by the calibration results, and relies on the history of the instrument instead on manufacturers specifications.
- 3.3.5 Adjustment must be performed according to the method prescribed by the manufacturer. All the operations listed in the instruction manual of the instrument must be carried out, except for those of an exceptional nature.
- 3.3.6 Usually calibration procedures must be performed configuring the instrument in such a way as to be able to obtain the best measurement accuracy, and standards and devices required for calibration shall be appropriate for use. For high-accuracy DMMs, to reduce the calibration time, a less demanding configuration can be used if the increase in uncertainty is negligible with respect to specification.
- 3.3.7 If in the normal measurement configuration of a specific quantity or scale the DMM employs any accessory or fixture, the calibration shall be performed in the same configuration.

3.4 Measurement Operations

3.4.1 Definition of Measurement Points

- 3.4.1.1 The definition of a minimum and appropriate set of measurement points for the calibration of a generic DMM should be flexible enough to allow the application to different models of instruments, to consider the working principles of the instrument, including all the measurement points requested by the manufacturer, and to take into account customer requirements.
- 3.4.1.2 Moreover, due to the wide variety of types of instruments, in order to grade the number of calibration points and the uncertainty level according to the accuracy and use of the

Table 1 – DMM resolution $\leq 4 \frac{3}{4}$ digits (39 999 counts)

Function	Measurement points ^(a)	
DC voltage	Zero ^(b) /+ 10 %, ± 90 %	in all ranges
	± 10 %, + 50 %, ± 90 % ^(c)	in a selected intermediate range
DC current	Zero ^(b) , + 90 %	in all ranges
	+ 10 %, 50 % ^(d) , ± 90 %	in a selected intermediate range
DC resistance	Zero ^(b) /+ 10 %, + 90 %	in all ranges
AC voltage AC+ DC voltage	10 %	50 Hz/ 1 kHz ^(e) in the smallest range
	10 %, 50 %, 90 %	20 Hz ^(f) , 50 Hz, 1 kHz in a selected intermediate range
	90 %	20 Hz ^(f) , 50 Hz, 1 kHz, 20 kHz, 50 kHz, 100 kHz ^(g) in all ranges ^(h)
AC current	10 %	50 Hz/ 1 kHz ^(e) in the smallest range
	90 %	20 Hz, 50 Hz, 1 kHz, 5 kHz ^(g) in all ranges ^(h)
Others ⁽ⁱ⁾	Zero ^(b) /10 %, 90 %	in all ranges

(a) Expressed as % of full scale value.

(b) Zero in smallest measuring range.

(c) At least five evenly distributed measuring points.

(d) For range > 1A.

(e) Only 1 frequency value.

(f) If requested.

(g) At least 3 frequency values.

(h) Including the smallest.

(i) Other function as e. g. Capacitance, Frequency.

Table 2 – DMM resolution > 4 $\frac{3}{4}$ digits (39 999 counts)

Function	Measurement points ^(a)	
DC voltage	Zero ^(b) /+ 10 %, + 50 % ^(c) , ± 90 %	in all ranges
	± 10 %, + 30 %, ± 50 %, + 70 %, ± 90 % ^(d)	in a selected intermediate range
DC current	Zero ^(b) /+ 10 %, + 90 %	in all ranges
	+ 10 %, 50 % ^(e) , ± 90 %	in a selected intermediate range
DC resistance	Zero ^(b) /+ 10 %, + 90 %	in all ranges
AC voltage AC+ DC voltage	10 %	1 kHz in the smallest range
	10 %, 50 %, 90 %	20 Hz ^(f) , 40 ≤ f ≤ 60 Hz ^(g) , 1 kHz in a selected intermediate range
	90 %	20 Hz ^(f) , 40 ≤ f ≤ 60 Hz ^(g) , 1 kHz, 20 kHz, 50 kHz, 100 kHz ^(h) in all ranges ⁽ⁱ⁾
AC current	10 %	40 ≤ f ≤ 60 Hz ^(g) / 1 kHz ^(j) in the smallest range
	90 %	20 Hz ^(f) , 40 ≤ f ≤ 60 Hz ^(f) , 1 kHz, 5 kHz ^(h) in all ranges ⁽ⁱ⁾
Others ⁽ⁱ⁾	Zero ^(b) /10 %, 90 %	in all ranges

(a) Expressed as % of full scale value.

(b) Zero in smallest measuring range.

(c) For DMM of resolution $\geq 7 \frac{1}{2}$ digit (19 999 999 counts).

(d) At least five evenly distributed measuring points.

(e) For range > 1A.

(f) If requested.

(g) Only 1 frequency value in the interval.

(h) At least 3 frequency values.

(i) Including the smallest.

(j) Other function as e. g. Capacitance, Frequency.

instrument, the DMMs can be divided in two main categories based on the instrumental resolution; if this number varies from one function of the instrument to another, reference is made to the maximum number.

The first category includes low-accuracy working instruments, with a resolution of no more than 4 $\frac{3}{4}$ digits (resolution counts $\leq 39\,999$). The second one includes instruments with a resolution from more than 4 $\frac{3}{4}$ up to 8 $\frac{1}{2}$ digits ($39\,999 < \text{resolution counts} \leq 19\,999\,999$).

3.4.1.3 Referring to the two categories above, the Tables 1 and 2 give indications for compiling the minimum set of measurement points, expressed as a percentage of the instrument range.

3.4.1.4 Remarks to be considered for a correct interpretation of Tables 1 and 2 are given in the following.

3.4.2 Measurement Corrections

3.4.2.1 **Zero error and correction.** There are two kind of correction operations concerning the offset compensations, one related to the instrument and the other one concernig the measurement circuit.

Instrumental zero correction: for DC measurements on voltage, current and resistance, it is intended that a preliminary zero operation be performed on each range, when this function is available. For DC voltage a low thermal-emf short circuit will be used to null the input. For DC current the input circuit will be left open. For both 2-wire and 4-wire DC resistance the input terminals will be shorted together.

Circuitual zero correction: for DC resistance calibration by means resistance standards, in case of 2-wire measurement, compensation for lead resistance will be obtained shorting the leads on the side of the resistor under measurement. In case of 4-wire measurement, offset compensation is usually obtained by shorting the current terminals and measuring the voltage.

Special zero procedures reported in the instruction manual of the instrument should be followed. In case the instrument can not compensate for the offset, a zero measurement will be included in the list of measurement points.

3.4.2.2 **Error of measurement.** For each measurement range, one measurand value shall be calibrated, applying a pole reversal, if required; this measured value shall preferably be at the full scale or 90 % of the full scale. For AC measurements the error of measurement shall be determined at various frequencies, if required.

3.4.2.3 **Linearity of the indication.** It shall be determined at least in one measurement range for one DC and one AC measurement value, using an appropriate number of calibrating points (not less than 5) at fixed frequency (usually 1 kHz).

3.4.2.4 The figure 10% indicates a beginning of scale value; measurement values between zero and 10% of full scale are not recommended, since they are measured with more accuracy in the next lower range, but if they are required their associated uncertainty must be adequate. The figure 90 % indicates a full-scale value; the actual value may vary from 50 % to 99 % of the full scale for all functions except for resistance, where it can vary from 30 % to 99 %.

3.4.2.5 The value 50 Hz denotes a measurement point that is intended to calibrate the instrument at power frequency; the actual value may vary from 40 Hz to 60 Hz or, at most, to 100 Hz. It should be noted that for high accuracy instruments powered by the mains, it is better to avoid performing measurements at mains frequency (50 or 60 Hz) because of possible beating between the frequency of the applied signal and that of the mains.

3.4.2.6 The frequency of 1 kHz denotes the central frequency value given in the specifications, at which, usually, the instrument is adjusted; the actual value may vary from 200 Hz to 1

kHz depending on the instrument model. Frequency values higher than 1 kHz are indicative, but their number is binding. The actual values should be determined so as to verify the various frequency bands defined in the specifications of the instrument.

- 3.4.2.7 For AC voltage measurements, care must be taken that the values given in Tables 1 and 2 do not reach the limits of the instrument in peak-voltage and in voltage-frequency product.

4. MEASUREMENT UNCERTAINTY

- 4.1 The measurement uncertainty should be evaluated for each measurement result according to the international guidelines on uncertainty evaluation [4, 5].
- 4.2 Subsequent to calibration and under normal conditions of use, the uncertainty associated by the customer with the readings of the DMM will depend on type of its specifications, that can include the reference standard uncertainties (total or absolute specifications) or not (relative specifications), the calibration sequence (with or without instrument adjustment) and the reference standard uncertainty used in the DMM calibration.

For example, if it is performed the calibration sequence c) (see 3.3.1), the DMM reading uncertainty will be the combination of the calibration uncertainty and the DMM specifications, chosen consistently with the calibration interval of the DMM.

When the calibration sequences a) and b) are implemented, if the DMM specifications are expressed as relative and absolute (or total) and the reference standards used for DMM adjustment have uncertainties lower or equal than the manufacturer requirements, then the DMM reading uncertainty will coincide with the absolute specifications, still for the chosen calibration interval of the DMM. Instead if the reference standards uncertainties are greater than the manufacturer requirements, then the DMM reading uncertainty will be the combination of the calibration uncertainty and the relative specifications.

- 4.3 In the absence of a specific different request by the customer, for a meaningful calibration of the DMM the uncertainties of the standards used in the adjustment and the measurement uncertainties should be low enough as to be possibly neglected in comparison with the manufacturer's accuracy specification. Reference should be made to the specification after one year, because this is in general referred to by the customer during the period of validity of the calibration.
- 4.4 As an example, a ratio between specification and calibration uncertainties of 4:1 is usually sufficient. It may not be possible to meet this requirement for low resolution DMMs where the resolution of the DMM reading dominates both the accuracy specification and the calibration uncertainty. Also in the case of more accurate DMMs, it is not always possible to achieve a 4:1 ratio for all functions and ranges. The CLs should strive for limiting the number of calibration points where a ratio lower than 4:1 is used.

5. CONTENTS OF CALIBRATION CERTIFICATE

- 5.1 When compiling the calibration certificate the requirements specified in the ISO/IEC 17025 5.10 [6] will be met.
- 5.2 Besides the general information about the calibration certificate (such as the title, its univocal identifier, the number of page on each page with the total number of pages), the CL (name and address of the laboratory where the calibrations was carried out), the customer (name and address), the unambiguous identification of the DMM calibrated (such as its serial number), the date of its receipt and the date of performance of the calibration, the name, function and signature of person authorizing the calibration certificate, the following information is considered necessary in order to provide full knowledge of the operations performed on the DMM:

- 1) identification of the calibration method used (i. e. by the identifiers of calibration procedures used)
- 2) evidence that the measurements are traceable (i. e. citing the standards used in the calibration)
- 3) the conditions (i. e. environmental conditions as temperature and humidity) that have an influence on the calibration results
- 4) the calibration results with the units of measurement
- 5) the measurement uncertainty.

Examples of information that should be reported in certificates are shown in Appendix A.

5.2.1 Calibration method. Usually the calibration method should be described in detail in a well defined calibration procedures, containing the description of operations performed before and during the calibration process. Obviously the procedures can not contain the specific operations of which every kind of DMMs needs, so they have been described in the calibration certificate.

5.2.1.1 For example it should be described if functional test (self-test), self-calibration (e.g. zero settings or calibration with respect to internal standards or linearisation of the converters), initial calibration, adjustment, final calibration were performed. If any of the operations that are listed have not been carried out in a comprehensive manner, this fact should be indicated.

5.2.1.2 The reasons for the choice of operations and measurement points should be explained. Such reasons could be one or more of the following: customer's request, manufacturer's instructions contained in the user's manual of the DMM, EURAMET Calibration Guides.

5.2.1.3 The instrument settings during calibration of the various functions should be described. For example, if the instrument is able to measure resistance at two or four terminals, the pre-selected mode should be specified. Any zero settings performed on the instrument should also be indicated and, if there is more than one input, the one which has been used should be reported. This information may also be shown alongside the tables of results.

5.2.1.4 Information on the measurement circuit (e.g. connection of a terminal to ground), on the measurement method and on the course of operations should be reported, for allowing a correct evaluation of the results obtained.

5.2.1.5 If the DMM under test is sensitive to crest factor any appropriate information concerning the distortion of the AC calibration signals should be given.

5.2.1.6 Instrument's stabilisation times, concerning both the length of time the instrument remained in the laboratory environment and (if powered by the mains) the length of time it was powered on, before starting calibration.

5.2.2 Calibration results. The results are normally shown in tables in subsequent pages.

5.2.2.1 An example of a set of suitable column headings, in the tables, are "Applied Value" (or, for example, "Applied Voltage"), "Measurement Range" (if more than one is to be considered), "Instrument Reading", "Error of Indication" and the corresponding "Measurement Uncertainty". For AC input quantities, the "Applied Value" column will be subdivided to give separate columns for the level and frequency of the input. The column "Instrument Reading" may also be subdivided to allow the reporting of initial calibration and final calibration results when the instrument is adjusted.

5.2.2.2 In the event of one or more measurement results, reported in the tables, being obtained with instrument settings different from those indicated under 5.2.1, these results may be marked and the specific instrument settings given in a note below the table.

5.2.2.3 The unit of measurement should be indicated next to the relevant value or included in the column heading.

5.2.2.4 As regards the number of digits by which data should be reported on the certificate, the value of the quantity applied should have a resolution that is commensurate with its uncertainty. On the other side, for the multimeter reading the number of digits to be given is related to the resolution of the instrument. If the measurement result has a large number of digits, non-significant digits or those contained within the short-term instability of the reading should be discarded.

5.2.3 **Measurement Uncertainty.** The values of the uncertainty of measurement are reported alongside the corresponding measurement results. If the adjustment has been performed, also the uncertainties of the standards used should be reported in the certificate or qualified as negligible with respect to the instrument specifications where relevant.

5.2.3.1 Make the user aware that the given uncertainties take into account the resolution and the short term instability of the instrument being calibrated.

5.2.3.2 The uncertainty should be given with at most two significant digits. The excessive number of digits should be rounded (JCGM 100 7.2.6).

5.2.3.3 If the DMM under test is sensitive to crest factor, the effect of the distortion of the AC calibration signals should be taken into account when evaluating the calibration uncertainty.

5.2.3.4 Include a sentence such as:

“The measurement uncertainties stated in this document have been determined according to the ISO/IEC Guide 98. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k such that the coverage probability corresponds to approximately 95 %.” [7]

For accredited CLs could be necessary modify this expression according to the requirements of the specific accreditation body (for example adding the reference to EA 4/02 M:2013 guide).

NOTE on DMM resolution. In some cases, the combined standard uncertainty will be composed of two major contributions: a component from the finite resolution of the instrument (or from unstable reading), usually handled as a rectangular distributed component, and a component from other uncertainty contributions, which is usually assigned a normal distribution. To obtain an expanded uncertainty with about 95% coverage interval, the coverage factor will depend on the ratio between the rectangular and normal components and will vary from $k = 1.65$, when the rectangular component dominates, to $k = 2$ when the normal component dominates. However, it is not possible to write a closed-form formula for k , and there are no obvious, simple approximations for this relation. The deviation from $k = 2$ becomes significant (5 %) when the reading resolution is equal to or larger than 1.5 times the combination of the other uncertainty components. It is therefore the recommendation of this Guide, that the coverage factor k should be chosen from values of a t -distribution with effective degrees of freedom v_{eff} correspondingly to a coverage probability of approximately 95%.

5.2.4 **Additional information.** If necessary, and allowed, other information can be added to the content of the calibration certificate.

5.2.4.1 A statement concerning the validity of the calibration results reported in the certificate should be included. For example, a sentence such as:

“The results reported in this certificate refer to the condition of the instrument on the date of calibration and carry no implication regarding the long-term stability of the instrument”.

5.2.4.2 If statements of compliance with a specification is made, these should identify which clauses of the specification are met or not met.

5.2.4.3 Indicate any malfunctioning or anomaly detected.

5.2.4.4 If the calibration was not performed at the CLs premises, the location should be given under this heading.

6. LIST OF REFERENCES

- [1] ILAC G8:03/2009, Guidelines on the Reporting of Compliance with Specification.
- [2] VIM: - JCGM 200:2012, International Vocabulary of Metrology – Basic and General Concepts and Associated Terms, third edition, 2012 (JCGM 200:2008 with minor corrections).
- ISO/IEC Guide 99:2007, International vocabulary of metrology -- Basic and general concepts and associated terms (VIM).
- [3] ISO 10012:2003, Measurement Management Systems -- Requirements for Measurement Processes and Measuring Equipment.
- [4] JCGM series on Evaluation of measurement data, or ISO Guide 98 series, in particular GUM: - JCGM 100:2008, Evaluation of measurement data – Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM 1995 with minor corrections)
- ISO/IEC 98-3:2008, Guide to the expression of uncertainty in measurement (GUM:1995)
- [5] EA 4/02 M:2013, Expressions of the Uncertainty of Measurements in Calibration, September 2013 rev01.
- [6] ISO/IEC 17025:2005 General Requirements for the Competence of Testing and Calibration Laboratories.
- [7] ILAC-P14:01/2013 ILAC Policy for Uncertainty in Calibration.

APPENDIX A

Examples for the compilation of certificates for digital multimeters

Example 1 : calibration of a 3 ½ digits hand-held digital multimeter

CALIBRATION METHOD

The calibration of the digital multimeter was carried out at the points indicated by EURAMET Calibration Guide EURAMET cg-15, following the manufacturer's instructions given in the user's manual.

Before executing the measurements given in this certificate a self-test ("Test") procedure was successfully performed on the instrument.

As agreed with the customer, no adjustment of the multimeter was carried out.

The digital multimeter has been calibrated on the functions: DC voltage, AC voltage, DC current, AC current, resistance.

Identification of the procedures employed: A01VDC, A02VAC, A05IDC, A08IAC, A09RES.

Standards used for the calibration: multifunction calibrator ABCD mod.1001, id. STDMFC001.

Environmental condition:

Temperature: $(23 \pm 1) ^\circ\text{C}$

Relative Humidity: $(50 \pm 10) \% \text{ rh}$

CALIBRATION RESULTS

Examples of calibration results are shown in the tables on the following page.

The results reported in this certificate refer to the condition of the instrument on the date of calibration and carry no implication regarding the long-term stability of the instrument.

MEASUREMENT UNCERTAINTY

The uncertainty values reported in the tables of results have been obtained taking into account all contributing factors to uncertainty affecting the measurement, including those deriving from the resolution and from the short-term stability of the instrument being calibrated.

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor $k = 1.65$, which corresponds to a coverage probability of approximately 95 %. The standard uncertainty is a combination of a rectangular distributed component with width equal to 1 digit of resolution, and normally distributed components. The standard uncertainty of measurement has been determined in accordance with ISO/IEC Guide 98¹.

¹ If the CL is an accredited laboratory, the reference to EA 4/02 M:2013 guide could be added in the sentence.

Table 1. Function: DC voltage

Applied Voltage	Instrument		Measurement Result	
	Range	Reading	Error	Uncertainty
+ 20.00 mV	100 mV	+ 20.0 mV	0.00 mV	0.06 mV
+ 100.00 mV		+ 99.9 mV	-0.10 mV	0.06 mV
- 100.00 mV		-99.9 mV	0.10 mV	0.06 mV
+ 0.200 0 V	1 V	+ 0.200 V	0.0 mV	0.6 mV
+ 1.000 0 V		+ 0.999 V	-1.0 mV	0.6 mV
- 1.000 0 V		-0.999 V	1.0 mV	0.6 mV
+ 2.000 V	10 V	+ 2.00 V	0 mV	6 mV
- 2.000 V		-2.00 V	0 mV	6 mV
+ 10.000 V		+ 9.99 V	-10 mV	7 mV
+ 15.000 V		+ 14.98 V	-20 mV	8 mV
- 15.000 V		-14.97 V	30 mV	8 mV
+ 20.00 V	100 V	+ 20.0 V	0.00 V	0.06 V
+ 100.00 V		+ 99.8 V	-0.20 V	0.07 V
- 100.00 V		-99.7 V	0.30 V	0.07 V
+ 200.0 V	1000 V	+ 200 V	0.0 V	0.6 V
+ 1 000.0 V		+ 997 V	-3.0 V	0.7 V
- 1 000.0 V		-996 V	4.0 V	0.7 V

Table 2. Function: AC voltage

Applied Voltage		Instrument		Measurement Result	
Value	Frequency	Range	Reading	Error	Uncertainty
100.00 mV	50 Hz	100 mV	99.9 mV	-0.10 mV	0.10 mV
100.00 mV	1 kHz		99.7 mV	-0.30 mV	0.10 mV
1.000 0 V	50 Hz	1 V	0.998 V	-2.0 mV	1.0 mV
1.000 0 V	1 kHz		0.999 V	-1.0 mV	1.0 mV
2.000 V	1 kHz	10 V	2.02 V	20 mV	6 mV
10.000 V	50 Hz		10.03 V	30 mV	10 mV
10.000 V	1 kHz		10.01 V	10 mV	10 mV
10.000 V	20 kHz		9.91 V	-90 mV	10 mV
10.000 V	100 kHz		9.81 V	-190 mV	20 mV
15.000 V	1 kHz		14.98 V	-20 mV	13 mV
100.00 V	50 Hz	100 V	99.8 V	-0.20 V	0.10 V
100.00 V	1 kHz		99.5 V	-0.50 V	0.10 V
1 000.0 V	50 Hz	1000 V	995 V	-5.0 V	1.0 V
1 000.0 V	1 kHz		992 V	-8.0 V	1.0 V

(only results of voltage measurements are reported in this example)

Example 2: calibration of a DMM with resolution > 4 ¾ digits

CALIBRATION METHOD

The following operations were performed on the instrument in accordance with the customer's request and EURAMET Calibration Guide EURAMET cg-15.

Before executing any operation on the instrument a thermal stabilization was performed powering the instruments and placing it in the laboratory environment for the 24 hours preceding calibration.

The following preliminary operations were performed:

Functional self-verification procedure (FULL TEST): positive result.

Self-calibration procedure (AUTOCAL): no faults in the operating procedure.

The digital multimeter has been calibrated on the functions: DC voltage, AC voltage, DC current, AC current, resistance, according the following operating sequence:

1. Initial calibration.
2. Adjustment – all operations indicated in par. 4.1 of the instruction manual were carried out.
3. Final calibration.

Identification of the procedures employed: A01VDC, A01VAC, A05IDC, A07IAC, A09RES.

Standards used for the calibration:

DC voltage, current and resistance: multifunction calibrator ABCD mod.1001, id. STDMFC001.

AC voltage: AC/DC transfer standard ABCD mod. 2001, id. STDACDC001.

AC current: AC/DC transfer standard ABCD mod. 2001, id. STDACDC001, with set of standard AC shunts, id. STDACR010

Environmental condition:

Temperature: $(23 \pm 1) ^\circ\text{C}$

Relative Humidity: $(45 \pm 10) \% \text{ rh}$

The measurement points of calibration include the points recommended by the instruction manual and are in accordance with EURAMET Calibration Guide EURAMET cg-15.

Instrument settings during calibration are indicated alongside the tables of results.

DC voltage and resistance measurements were executed after short-circuiting the input and setting the instrument reading to zero (for each range used); a similar procedure was carried out for DC current, opening the current circuit.

CALIBRATION RESULTS

An example of the calibration results are shown in the table on the following page.

The results reported in this certificate refer to the condition of the instrument on the date of calibration and carry no implication regarding the long-term stability of the instrument.

MEASUREMENT UNCERTAINTY

The uncertainty values reported in the tables of results have been obtained taking into account all contributing factors to the uncertainty affecting the measurement, including those deriving from the resolution and from the short-term stability of the instrument being calibrated.

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by a coverage factor $k = 2$, corresponding to a coverage probability of

approximately 95 %². The standard uncertainty of measurement has been determined in accordance with ISO/IEC Guide 98³.

Table 1. Function: DC resistance

Instrument settings
 NDIG 8
 NPL 100
 OHMF for 10 Ω to 10 M Ω range
 OHM for 100 M Ω range
 OCOMP ON for $R \leq 100$ k Ω
 OCOMP OFF for $R > 100$ k Ω
 Input FRONT

Applied Value	Measurement Range	Instrument Reading		Measurement Result		
		Initial Calibration	Final Calibration	Initial Error	Final Error	Uncertainty
0.000 00 Ω	10 Ω	0.000 01 Ω	0.000 00 Ω	10 $\mu\Omega$	0 $\mu\Omega$	20 $\mu\Omega$
10.000 17 Ω		10.000 49 Ω	10.000 17 Ω	32 $\mu\Omega/\Omega$	0 $\mu\Omega/\Omega$	6 $\mu\Omega/\Omega$
10.000 17 Ω	100 Ω	10.000 17 Ω	10.000 14 Ω	0 $\mu\Omega/\Omega$	-3 $\mu\Omega/\Omega$	9 $\mu\Omega/\Omega$
100.001 24 Ω		100.001 11 Ω	100.001 32 Ω	-1.3 $\mu\Omega/\Omega$	0.8 $\mu\Omega/\Omega$	5.0 $\mu\Omega/\Omega$
0.100 001 2 k Ω	1 k Ω	0.100 001 1 k Ω	0.100 001 3 k Ω	-1.0 $\mu\Omega/\Omega$	1.0 $\mu\Omega/\Omega$	5.0 $\mu\Omega/\Omega$
0.999 991 0 k Ω		0.999 989 9 k Ω	0.999 992 1 k Ω	-1.1 $\mu\Omega/\Omega$	1.1 $\mu\Omega/\Omega$	5.0 $\mu\Omega/\Omega$
0.999 991 k Ω	10 k Ω	0.999 991 k Ω	0.999 992 k Ω	0 $\mu\Omega/\Omega$	1 $\mu\Omega/\Omega$	5 $\mu\Omega/\Omega$
9.999 883 k Ω		9.999 878 k Ω	9.999 894 k Ω	-0.5 $\mu\Omega/\Omega$	1.1 $\mu\Omega/\Omega$	5.0 $\mu\Omega/\Omega$
9.999 88 k Ω	100 k Ω	9.999 88 k Ω	9.999 90 k Ω	0 $\mu\Omega/\Omega$	2 $\mu\Omega/\Omega$	5 $\mu\Omega/\Omega$
99.997 17 k Ω		99.997 19 k Ω	99.997 37 k Ω	0.2 $\mu\Omega/\Omega$	2.0 $\mu\Omega/\Omega$	5.0 $\mu\Omega/\Omega$
0.099 997 2 M Ω	1 M Ω	0.099 997 4 M Ω	0.099 997 5 M Ω	2 $\mu\Omega/\Omega$	3 $\mu\Omega/\Omega$	8 $\mu\Omega/\Omega$
0.999 951 0 M Ω		0.999 951 0 M Ω	0.999 952 5 M Ω	0 $\mu\Omega/\Omega$	2 $\mu\Omega/\Omega$	10 $\mu\Omega/\Omega$
0.999 951 M Ω	10 M Ω	0.999 961 M Ω	0.999 954 M Ω	10 $\mu\Omega/\Omega$	3 $\mu\Omega/\Omega$	15 $\mu\Omega/\Omega$
9.998 720 M Ω		9.998 680 M Ω	9.998 696 M Ω	-4 $\mu\Omega/\Omega$	-2 $\mu\Omega/\Omega$	20 $\mu\Omega/\Omega$
9.998 72 M Ω	100 M Ω	9.999 14 M Ω	9.999 01 M Ω	42 $\mu\Omega/\Omega$	29 $\mu\Omega/\Omega$	50 $\mu\Omega/\Omega$
100.000 90 M Ω		100.015 00 M Ω	100.008 87 M Ω	141 $\mu\Omega/\Omega$	80 $\mu\Omega/\Omega$	60 $\mu\Omega/\Omega$

(only results of resistance measurements are reported in this example)

² Here a Gaussian probability distribution is assumed. Both the value of k and the coverage probability must be reported.

³ If the CL is an accredited laboratory, the reference to EA 4/02 M:2013 guide could be added in the sentence.