European cooperation for Accreditation of Laboratories

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Measurement and Generation of Small AC Voltages with Inductive Voltage Dividers

PURPOSE

This document has been produced by EAL to harmonise the measurement and generation of small AC voltages for calibration purposes. It provides guidance to national accreditation bodies in setting up minimum requirements for the calibration of AC voltmeters and AC voltage sources and gives advice to calibration laboratories to establish practical procedures.

Authorship

This document has been revised by EAL Committee 2 (Calibration and Testing Activities), based on the draft produced by the EAL Expert Group 'DC and LF Electrical Quantities'.

Official language

The text may be translated into other languages as required. The English language version remains the definitive version.

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Guidance Publications

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0 Introduction

0.1 Among other things, it is the task of the Experts Groups of the European cooperation for the Accreditation of Laboratories (EAL) to produce technical guidelines which may be used by accredited calibration laboratories. In this way, harmonisation of the technical work of calibration laboratories can be achieved and transparency of the calibration laboratories' work is increased.

0.2 The guidelines do not claim to fully cover all details of the measuring instruments in question. They are intended for specialists and lay down what is necessary within the scope of their objectives. They can serve as internal procedural instructions and thus become an integral part of quality manuals of the calibration laboratories.

0.3 This guideline deals with the generation and measurement of small AC voltages for calibration purposes by means of inductive voltage dividers. It describes methods for generating and measuring small AC voltages, which are capable of accreditation.

1 Scope

1.1 This guideline applies to the generation and measurement of small AC voltages from 1 mV to 1 V in the frequency range from 50 Hz to 100 kHz depending on the selected procedure and the measuring method used. The accreditation of the measurand AC voltage for voltages of more than 1 V is presupposed.

1.2 The measurement procedures applied and the measuring means employed by the accredited laboratory for carrying out the calibration shall be such that all parameters necessary for the calibration are traceable on the basis of the accreditation of the laboratory. Traceability to national standards and laboratory-specific measurement procedures shall be intelligibly documented.

2 Terms and abbreviations

D	nominal value of the divider ratio (value to be set)
IVD	inductive voltage divider
$\underline{K}$	complex correction of the divider ratio
K_B	imaginary component of the complex correction of the divider ratio
K_W	real component of the complex correction of the divider ratio
L_S	series inductance
PC	personal computer
R_S	series resistance

$\underline{U}_a$	complex output voltage
$\underline{U}_e$	complex input voltage
$\underline{Z}_a$	complex output impedance of the inductive divider
$\underline{Z}_2$	complex load impedance

3 Calibration equipment

3.1 Requirements to be met by calibration equipment

3.1.1 The calibration shall be carried out using measuring equipment traced back to national standards by direct or indirect comparison with a known associated uncertainty of measurement.

3.2 Reference conditions

3.2.1 The calibration of small AC voltages shall be carried out under the same reference conditions as those used in the calibration of the specific measuring set-up.

3.2.2 Prior to starting the measurements, it shall be ensured that warm-up times are complied with, that the measuring set-up is in thermal equilibrium and that interference fields — as far as they are of importance — are shielded.

4 Preparation for calibration

4.1 The measuring instrument or system shall be subjected to a visual inspection and a functional check. If these examinations reveal any defects, these shall be rectified. If this is not possible, the calibration shall be refused.

5 Description of the calibration procedure

5.1 Generation of small AC voltages for calibration purposes using an inductive voltage divider

5.1.1 Scope of the procedure

5.1.1.1 Subject to the conditions described, this calibration method for the generation of small AC voltages in a voltage and frequency range determined by the inductive divider (e.g. 1 mV to 1 V and 50 Hz to 1 kHz) is qualifiable for use in accredited laboratories.

5.1.2 Measurement procedure

5.1.2.1 Small AC voltages may be generated by division of a known higher voltage of 1 V, for example, using a calibrated inductive voltage divider. This voltage divider serves to trace voltage ratios back to turns ratios.

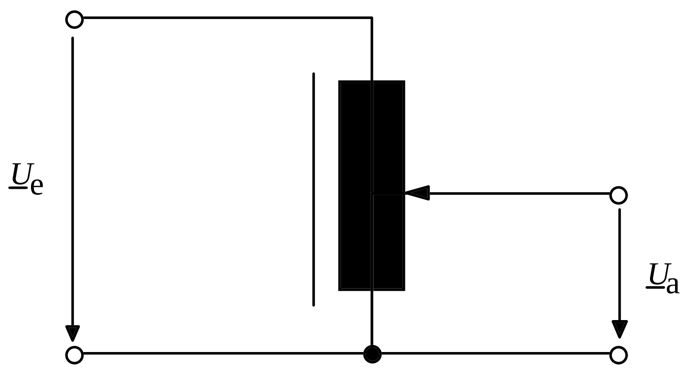

Fig. 1: Basic circuit of an unloaded inductive voltage divider

5.1.2.2 The complex ratio of the output voltage $\underline{U}_a$ of an unloaded inductive voltage divider to the input voltage $\underline{U}_e$ is obtained from the relation

$$\underline{U}_a/\underline{U}_e = D + \underline{K} = D + K_W + jK_B \qquad (1)$$

where D is the nominal value of the divider ratio, which is given by the switch setting. $\underline{K}$ is the complex correction of the divider ratio. It consists of the real component K_W and the imaginary component K_B. On the assumption that K_W and $K_B << D$, K_W represents the correction of the modulus of $\underline{U}_a/\underline{U}_e$, whereas the quotient K_B/D approximately describes the phase angle formed by $\underline{U}_a$ and $\underline{U}_e$, in radians.

5.1.2.3 According to this, the following is approximately valid for the modulus of the output voltage of the unloaded divider:

$$|U_a| \approx |U_e| \times [D + K_W] \qquad (2)$$

5.1.2.4 The output voltage of a divider loaded with the impedance $\underline{Z}_2$ can be calculated as follows:

$$\underline{U}_a \approx \underline{U}_e\,[D + K_W + jK_B - D\times\underline{Z}_a/\underline{Z}_2] \qquad (3)$$

where $\underline{Z}_a$ is the output impedance of the inductive voltage divider.

5.1.2.5 For the evaluation of a measurement result according to eq. (3), the following shall be taken into account:

- The input voltage $|U_e|$ shall be determined using the accredited method of AC voltage measurement.
- It is expedient to select for example 0,1; 0,01; 0,001 for the divider ratio D. With these divider ratios, the output impedance $\underline{Z}_a$ of inductive voltage dividers is small in most cases so that there is a slight dependence on the load only.
- At the frequencies 400 Hz and 1 kHz and the above-mentioned divider ratios, the complex correction $\underline{K}$ and their components K_W and K_B shall be traced back to national standards.
- The influence of the load $\underline{Z}_a/\underline{Z}_2$ shall be taken into account. For this purpose, the output impedance $\underline{Z}_a$ of the inductive voltage divider is assumed to consist of a resistance R_S and an inductance L_S in series connection. Their values shall be known in the frequency range referred to and for the divider ratios selected. If $\underline{Z}_a$ is not known, the influence of the load can be experimentally determined by doubling the load (halving $\underline{Z}_2$) and simultaneously measuring $\underline{U}_a$.

5.1.3 Influences on the measurement result

5.1.3.1 The measurement result obtained in an actual measuring set-up is subject to several influences that shall be taken into account. This section describes the various factors which may affect the measurement. It also suggests *corrective means* to be used to minimize the effects.

- Loading of the AC voltage source (calibrator) by the input impedance of the inductive voltage divider.

  The measurement of $|U_e|$ *is necessary if the internal source resistance is not negligible.*

  Note that an inductive load, such as an inductive voltage divider, can increase the output of some sources.

- Earth circuits.

  Apply defined guard technique.

- Radiation from external fields.

  Make measurements in shielded rooms, if necessary. Pay attention to radiation from data processing equipment (PCs, printers) and take electromagnetic compatibility rules into account.

- Noise voltage from the AC voltage source or the meter measuring $|U_e|$. This noise voltage will not be divided by the divider ratio in any case. Due to capacitive coupling, the noise voltage at the divider output can be of the same order as the input noise voltage.

  Use a filter to decrease the input noise voltage, if necessary.

- Take noise voltages generated by the measuring instrument and the source to be calibrated into consideration.
- Consider the influence of loading the divider, especially by longer test cables.

  Use short shielded (double-shielded) test cables.

- Compliance with the operating conditions of the inductive divider.
- Systematic influences by the instrument to be calibrated.
- Contact resistances of the divider (instability of the output voltage).

5.1.4 Uncertainty analysis

5.1.4.1 The uncertainty of measurement associated with the measured voltage $|\underline{U}_a|$ shall be determined in accordance with EAL-R2 [4] on the basis of the above eqs. (2) or (3).

5.1.4.2 Estimates should take into account all the influences mentioned in section 5.1.3. The drastic increase of the correction K_W and its uncertainty at small divider ratios shall be considered; it shall not be neglected.

5.1.5 Traceability

5.1.5.1 The voltage $|\underline{U}_e|$ shall have been traced back to national standards. The inductive voltage divider shall have been traced back to national standards in accordance with section 5.1.2. If frequencies other than the calibrated ones are used, the additional contributions to the uncertainty of measurement shall be estimated from the manufacturer’s statements.

5.2 Generation of small AC voltages for calibration purposes using the voltage ratio method

5.2.1 Scope of the procedure

5.2.1.1 This procedure for generating and measuring small AC voltages in the range from 1 mV to 1 V is qualifiable for use in accredited laboratories for a frequency range between 50 Hz and 100 kHz depending upon the inductive divider used, subject to the preconditions described. It is assumed that the laboratory is accredited for AC voltage measurements of magnitude 1 V and greater at these frequencies.

5.2.1.2 This method can be used for calibrating both indicating measuring instruments (see UUT in Fig. 2) and ac calibrators (see AC-CAL in Fig. 2).

5.2.2 Measurement procedure

5.2.2.1 Principle

(a) This procedure is based on the determination of the divider ratio of the inductive voltage divider using known AC voltages U_e and U_a in the range of some volts. It, therefore, basically consists of two steps:

1 determination of the divider ratio of the inductive divider used at higher voltages in the range of some volts

2 generation and measurement of small AC voltages using the calibrated divider.

5.2.2.2 Description of the procedure

(a) Determination of the ratio of the inductive voltage divider

The exact 1:10 ratio of the inductive divider is determined by AC voltage measurements at 1 V and 10 V. The calibration is carried out in the steps shown in Table 1 in the measuring set-up according to Fig. 2.

(A) Set the known voltage 10 V at frequency *f* on the AC calibrator (AC-CAL).

Set the divider ratio to 0,1 on the Inductive Voltage Divider (IVD).

Use the Low-Noise Preamplifier (AMP) for amplification to set the reference value — e.g. 1,000... V — on the AC voltmeter indicator (DMM).

(B) Set the known voltage 1 V at frequency *f* on the AC-CAL.

Adjust the divider ratio on the IVD so that the indicator DMM indicates the reference value 1,000... V. The amplification of the AMP shall not be altered. Record this ratio as *R*.

(b) Calibration of the voltages 100 mV, 10 mV, 1 mV

100 mV

(C) The voltage value 1 V and the frequency *f* set on the AC-CAL according to (B) are not altered.

The IVD divider ratio is set to 0,1.

Increase the AMP gain to reset the reference value on the indicator DMM.

(D) Set the AC-CAL to its 100 mV setting at frequency *f*.

Set the divider ratio to *R* as determined according to (B) on the IVD. Do not alter AMP amplification. Adjust AC-CAL such that the indicator DMM indicates the reference value 1,000...V. Hence the output voltage of the AC-CAL is equal to 100 mV to within the stated uncertainty of measurement.

10 mV

(E) Do not alter the 100 mV and the frequency *f* settings on the AC-CAL.

Set the IVD divider ratio to 0,1. Increase the AMP gain to reset the reference value on the indicator DMM.

(F) Set the AC-CAL to its 10 mV setting at frequency *f*.

Set the divider ratio to *R* as determined according to (B) on the IVD. Do not alter AMP amplification. Adjust AC-CAL such that the indicator DMM indicates the reference value 1,000...V. Hence the output voltage of the AC-CAL is equal to 10 mV to within the stated uncertainty of measurement.

1 mV

The calibration at 1 mV is carried out by analogy to the steps described in accordance with Table 1, items (g) and (h). Table 1 summarizes the procedure for determining the ratio of the inductive divider and the derivation of the calibrated voltage values for 100 mV, 10 mV, and 1 mV.

Table 1 : Steps for the calibration of 100 mV, 10 mV, and 1 mV, and sources of uncertainty

AC-CAL	IVD	AMP	DMM	Objective	Sources of uncertainty
a) apply 10 V b) apply 1 V	divider ratio 0,1 set reference value with divider ratio	reference value no change	e.g. 1,000... read 1,000...	*determination of divider ratio*	divider ratio 1:10 with AC/DC transfer standard, for further steps take correlation into account
c) keep 1 V applied d) apply 100 mV adjust AC-CAL to indicate 1,000... on DMM	divider ratio 0,1 divider ratio as under b)	set x10/ref. x10/ no change	e.g. 1,000... read 1,000...	*adjust 100 mV*	influence of the loading of the divider, eliminated by measure-ments a) and b) and procedure
e) keep 100 mV applied f) apply 10 mV adjust AC-CAL to indicate 1,000... on DMM	divider ratio 0,1 divider ratio as under b)	set x100/ref. x100/ no change	e.g. 1,000... read 1,000...	*adjust 10 mV*	temporal instabilities
g) keep 10 mV applied h) apply 1 mV adjust AC-CAL to indicate 1,000... on DMM	divider ratio 0,1 divider ratio as under b)	set x1000/ref. x1000/ no change	e.g. 1,000... read 1,000...	*adjust 1 mV*	noise, earth loops etc.

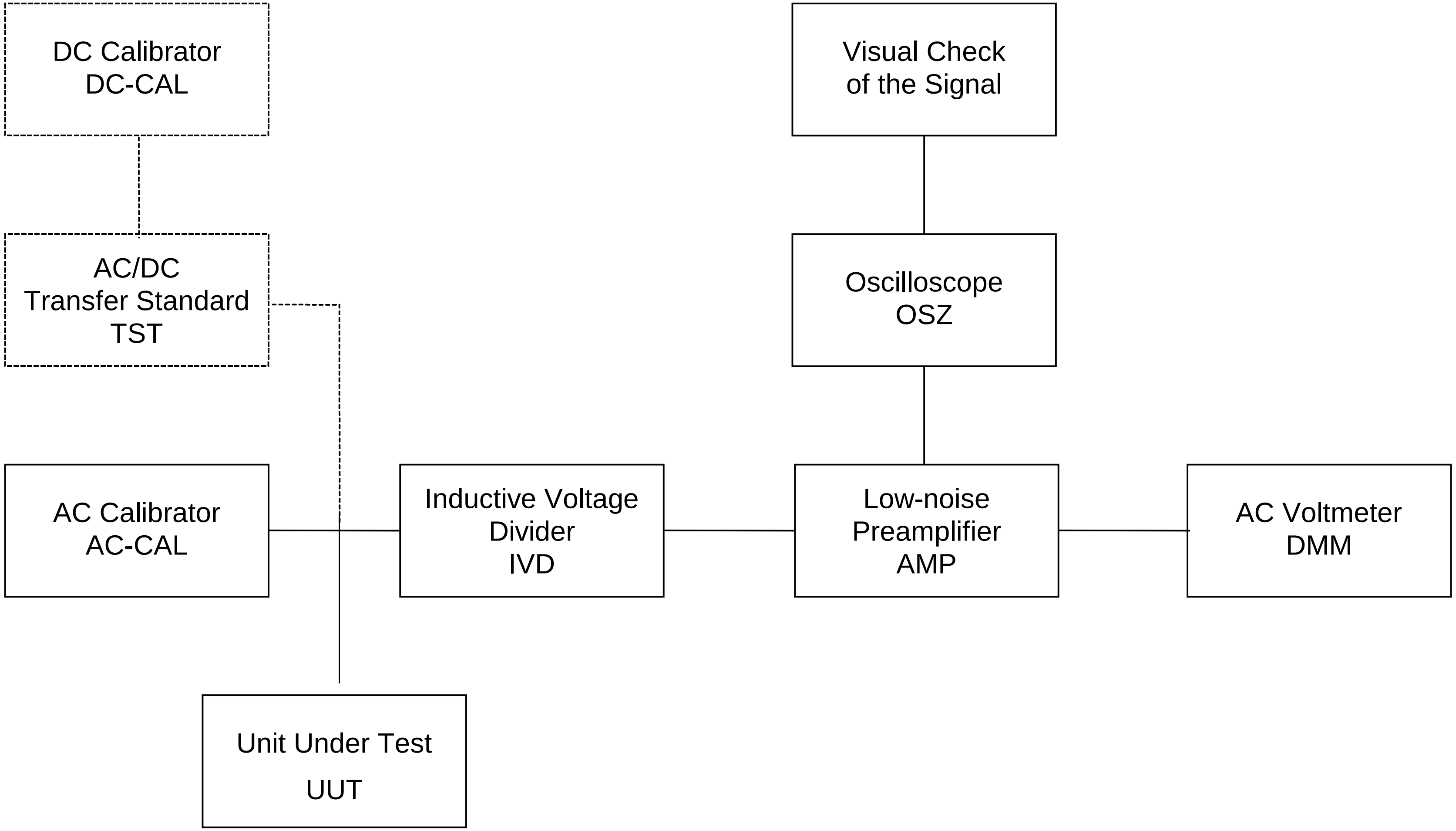

Fig. 2: Set-up for calibrating small AC voltages by the voltage ratio method

5.2.3 Uncertainty analysis

5.2.3.1 The uncertainty of measurement in the procedure has to be determined in accordance with EAL-R2. The uncertainties of measurement associated with the voltage levels of the individual 1:10 steps are correlated, as they are based on the determination of the ratio of the same inductive voltage divider. Therefore, the uncertainties of measurement have to be evaluated in each 1:10 step taking these correlations into account which predominantly result from the uncertainties of measurement associated with the 1 V and 10 V voltage levels of the AC calibrator (AC-CAL).

5.2.3.2 The loading of the divider output does not produce additional uncertainty contributions as it is calibrated within the scope of the procedure. This is valid as long as the input impedance of the low noise preamplifier (AMP) is not affected by its gain setting.

5.2.3.3 The stability of the comparison chain (IVD, AMP, and DMM) is a source of uncertainty which has to be taken into consideration. The short-term stability between two successive measurement steps is decisive in this respect. The significance of short-term preamplifier stability increases as a source of uncertainty with decreasing input voltage. The same applies to external influences exerted by earth loops, noise voltages, electromagnetic interferences etc.

5.2.3.4 The effect of the resolution of the measuring instruments AMP and DMM on the relative uncertainty of measurement associated with the input voltage of the IVD increases in significance with decreasing input voltage level. The same applies to external influences exerted by earth circuits, electromagnetic fields, noise voltages etc.

5.2.3.5 Other sources of uncertainty like noise or DC-offset of the AC calibrator (AC-CAL) can be eliminated by appropriate filtering.

5.2.4 Example of uncertainty analysis:

(Figures given are for illustrative purposes only.)

5.2.4.1 The determination of the uncertainty of measurement is divided into two steps: determining the uncertainty associated with the IVD ratio and determining the uncertainties associated with the results in the calibration at 100 mV, 10 mV, and 1 mV.

5.2.4.2 For the determination of the IVD ratio, it is assumed that the input voltage levels applied to the IVD are not measured directly during the procedure, but are derived from the calibrated AC-CAL. The ratio is determined following steps a) and b) in Table 1:

$$R = \frac{r_{0,1}}{r_{1,0}} = \frac{V_1}{V_{10}} v_{\mathrm{N}} v_{\mathrm{i}} \qquad (1)$$

where

$r_{0,1}$, $r_{1,0}$	transfer ratios of output and input voltages of the inductive voltage divider at its 0,1 and 1,0 settings;
$v_N = \dfrac{1+\dfrac{\delta V_{N1}}{V_{in}}}{1+\dfrac{\delta V_{N10}}{V_{in}}}$	correction ratio due to preamplifier instability and other interference effects;
$V_{in} = r_{1,0}V_1 = r_{0,1}V_{10}$	voltage at the preamplifier input in both settings;
$\delta V_{N1}, \delta V_{N10}$	corrections due to preamplifier instability and other interference effects;
$v_i = \dfrac{1+\dfrac{\delta V_{i10}}{V_i}}{1+\dfrac{\delta V_{i1}}{V_i}}$	ratio of voltages at the DMM in the 10 V and the 1 V setting of the calibrator (index i means indicated);
V_i	voltage indication (e.g. 1,000...V) of the DMM at both settings (index i means indicated);
$\delta V_{i1}, \delta V_{i10}$	corrections of the indicated voltage values due to the finite resolution of the DMM (index i means indicated).

5.2.4.3 The model function of equation (1) is a product of terms. The relative standard uncertainty of measurement associated with the calibration of the divider ratio R is the appropriate quantity to evaluate in this case. Its square is given by the sum of squares:

$$w^2(R) = w^2(V_1) + w^2(V_{10}) + w^2(v_N) + w^2(v_i) \quad (2)$$

5.2.4.4 **AC calibrator (**V_1, V_{10}**)**: For the frequency range 30 Hz to 100 kHz, the values of the ac voltage generated coincide with the respective voltage settings for the 1 V and the 10 V voltage level with an associated expanded relative uncertainty of measurement $W = 0{,}1\times10^{-3}$ (coverage factor $k = 2$). This value gives the associated relative uncertainty of measurement at the time of measurement. It includes the uncertainty contribution of the uncertainty of the values taken from the calibration certificate and an uncertainty contribution of the drift since the last calibration estimated from calibration history of the reference source. If an AC/DC transfer technique is available the relative uncertainty of measurement associated with the above mentioned voltage levels may be reduced by a calibration of these levels immediately before the determination of the IVD ratio (see 5.2.4.9). This case is included in Fig. 2.

5.2.4.5 **Preamplifier stability and other interference voltages (V_N):** Voltage variations due to short-term preamplifier stability and other interference effects at the amplifier input have been estimated from manufacturer's specifications and findings in previous measurements to be within

input voltage	limits	relative limits
1 V	2 µV	$\pm 2\times10^{-6}$
100 mV	±4 µV	$\pm 4\times10^{-5}$
10 mV	±7 µV	$\pm 7\times10^{-4}$
1 mV	±10 µV	$\pm 10\times10^{-3}$

The distribution resulting for the correction ratio ν_N is triangular with expectation 1,000... and limits (see EAL-R2-S1, example S3)

input voltage	limits
1 V	$\pm 4\times10^{-6}$
100 mV	$\pm 8\times10^{-5}$
10 mV	$\pm 14\times10^{-4}$
1 mV	$\pm 20\times10^{-3}$

5.2.4.6 **Voltmeter (ν_i):** The resolution of the 5½ digit voltmeter used in the 2 V range is 10 µV resulting in the limits ±5 µV for corrections due to the finite resolution of the instrument. The distribution of the voltage ratio ν_i at the DMM is triangular with expectation 1,000... and limits $\pm 10\times10^{-6}$. (Only uncorrelated contributions of the corrections have to be taken into account; see EAL-R2-S1, example S3).

5.2.4.7 **Uncertainty budget (inductive divider ratio *R*):**

quantity X_i	estimate x_i	rel. standard uncertainty $w(x_i)$	probability distribution	sensitivity coefficient c_i	rel. uncertainty contribution $w_i(y)$
V_1	1,000 00 V	50×10^{-6}	normal	1,0	50×10^{-6}
V_{10}	10,000 0 V	50×10^{-6}	normal	1,0	50×10^{-6}
ν_N	1,000 000	$1{,}63\times10^{-6}$	triangular	1,0	$1{,}63\times10^{-6}$
ν_i	1,000 000	$4{,}08\times10^{-6}$	triangular	1,0	$4{,}08\times10^{-6}$
R	0,100 000				$70{,}8\times10^{-6}$

5.2.4.8 **Relative expanded uncertainty:**

$$W = k \times w(R) = 2 \times 0{,}0708 \times10^{-3} = 0{,}14 \times 10^{-3}$$

5.2.4.9 **Note:** If the output voltages of the calibrator are calibrated by comparison with DC reference voltages, performing an AC/DC transfer (included in Fig. 2), the uncertainty of measurement of V_1 and V_{10} may be determined using the equations:

$$V_1 = V_{\mathrm{DC1}}(1 + \delta_1) \text{ and } V_{10} = V_{\mathrm{DC10}}(1 + \delta_{10}) \tag{3}$$

where

δ_1, δ_{10}	relative AC/DC voltage differences;
V_{DC1}, V_{DC10}	DC voltages.

This may lead to a reduction in the uncertainty of measurement associated with the IVD ratio R. The uncertainty budgets for this internal calibration are not included here.

5.2.4.10 The voltage levels 100 mV, 10 mV, and 1 mV are calibrated following a step-down procedure (see steps c) to h) in table 1) using the previously calibrated 1:10 ratio R of the IVD.

5.2.4.11 The value $V_{0,1}$ of the 100 mV level to be calibrated in terms of the value V_1 of the 1 V level of the calibrator is given by:

$$V_{0,1} = RV_1 v_{\mathrm{N}} v_{\mathrm{i}} \tag{4}$$

5.2.4.12 For the evaluation of the relative standard uncertainty of measurement associated with the value $V_{0,1}$, correlations between R and V_1 have to be taken into account resulting from the fact that V_1 has been used in the determination of R (see eq. (1)). This gives

$$w^2(V_{0,1}) = w^2(R) + 3w^2(V_1) + w^2(v_{\mathrm{N}}) + w^2(v_{\mathrm{i}}) \tag{5}$$

Factor 3 results from the correlations mentioned. Details of calculation are not given here.

5.2.4.13 **Uncertainty budget (100 mV level):**

quantity X_i	estimate x_i	rel. standard uncertainty $w(x_i)$	probability distribution	sensitivity coefficient c_i	rel. uncertainty contribution $w_i(y)$
R	0,100 000 V	$70{,}8\times10^{-6}$	normal	1,0	$70{,}8\times10^{-6}$
V_1	1,000 00 V	50×10^{-6}	normal	1,732	$86{,}6\times10^{-6}$
v_{N}	1,000 00	$32{,}7\times10^{-6}$	triangular	1,0	$32{,}7\times10^{-6}$
v_{i}	1,000 000	$4{,}08\times10^{-6}$	triangular	1,0	$4{,}08\times10^{-6}$
$V_{0,1}$	0,100 00 V				117×10^{-6}

5.2.4.14 **Relative expanded uncertainty:**

$W = k \times w(V_{0,1}) = 2 \times 0{,}117 \times 10^{-3} = 0{,}23 \times 10^{-3}$

5.2.4.15 The value $V_{0,01}$ of the 10 mV level to be calibrated in terms of the value $V_{0,1}$ of the 100 mV level of the calibrator is given by:

$$V_{0,01} = RV_{0,1}\nu_N\nu_i \qquad (6)$$

5.2.4.16 For the evaluation of the relative standard uncertainty of measurement associated with the value $V_{0,01}$ correlations between R, V_1 and $V_{0,1}$ have to be taken into account resulting from the fact that R has been used in the determination of $V_{0,1}$ (see eq. (4)) and R is correlated with V_1. This gives

$$w^2(V_{0,01}) = w^2(V_{0,1}) + 3w^2(R) + 2w^2(V_1) + w^2(\nu_N) + w^2(\nu_i) \qquad (7)$$

Factors 3 and 2 result from the correlations mentioned. Details of calculation are not given here.

5.2.4.17 **Uncertainty budget (10 mV level):**

quantity X_i	estimate x_i	rel. standard uncertainty $w(x_i)$	probability distribution	sensitivity coefficient c_i	rel. uncertainty contribution $w_i(y)$
R	0,100 000 V	$70{,}8\times10^{-6}$	normal	1,732	123×10^{-6}
$V_{0,1}$	0,100 00 V	117×10^{-6}	normal	1,0	117×10^{-6}
V_1	-	50×10^{-6}	normal	1,414	$70{,}7\times10^{-6}$
ν_N	1,000 0	572×10^{-6}	triangular	1,0	572×10^{-6}
ν_i	1,000 000	$4{,}08\times10^{-6}$	triangular	1,0	$4{,}08\times10^{-6}$
$V_{0,001}$	0,010 000 V				600×10^{-6}

5.2.4.18 **Relative expanded uncertainty:**

$W = k \times w(V_{0,01}) = 2 \times 0{,}600 \times 10^{-3} = 1{,}2 \times 10^{-3}$

5.2.4.19 The value $V_{0,001}$ of the 1 mV level to be calibrated in terms of the value $V_{0,01}$ of the 10 mV level of the calibrator is given by:

$$V_{0,001} = RV_{0,01}\nu_N\nu_i \qquad (8)$$

5.2.4.20 For the evaluation of the relative standard uncertainty of measurement associated with the value $V_{0,001}$ correlations between R, V_1 and $V_{0,01}$ have to be taken into account resulting from the fact that R has been used in the determination of $V_{0,01}$ (see eq. (6)) and R is correlated with V_1. This gives

$$w^2(V_{0,001}) = w^2(V_{0,01}) + 5w^2(R) + 2w^2(V_1) + w^2(\nu_N) + w^2(\nu_i) \qquad (9)$$

Factors 5 and 2 result from the correlations mentioned. Details of calculation are not given here.

5.2.4.21 **Uncertainty budget (1 mV level):**

quantity X_i	estimate x_i	rel. standard uncertainty $w(x_i)$	probability distribution	sensitivity coefficient c_i	rel. uncertainty contribution $w_i(y)$
R	0,100 000 V	$0{,}071\times10^{-3}$	normal	2,236	$0{,}159\times10^{-3}$
$V_{0,01}$	0,010 000 V	$0{,}606\times10^{-3}$	normal	1,0	$0{,}606\times10^{-3}$
V_1	-	50×10^{-6}	normal	1,414	$70{,}7\times10^{-6}$
v_N	1,000	$8{,}16\times10^{-3}$	triangular	1,0	$8{,}16\times10^{-3}$
v_i	1,000 000	$0{,}004\times10^{-3}$	triangular	1,0	$0{,}004\times10^{-3}$
$V_{0,001}$	0,001 000 V				$8{,}19\times10^{-3}$

5.2.4.22 **Relative expanded uncertainty:**

$$W = k \times w(V_{0,001}) = 2 \times 8{,}19 \times 10^{-3} \cong 16 \times 10^{-3}$$

5.2.4.23 The voltages generated by the calibrator are

setting	value
100 mV	$100{,}00\times(1 \pm 0{,}23\times10^{-3})$ mV
10 mV	$10{,}00\times(1 \pm 1{,}2\times10^{-3})$ mV
1 mV	$1{,}00\times(1 \pm 16\times10^{-3})$ mV

5.2.4.24 The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95%.

5.2.5 Traceability

5.2.5.1 Accreditation for the AC voltage values 10 V and 1 V in the frequency range concerned is essential for the traceability of results obtained in the procedure.

6 References

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