Specific Guidance for Calibration Laboratories in Electro -Technical

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1. Purpose

Specific guidance for Electro–Technical Calibration Laboratories is for laboratories seeking EAS accreditation in accordance with ISO/ IEC 17025: 2017.

This document does not cover all the requirements of ISO/IEC 17025: 2017 but normally those clauses which need explanations and are as additional requirements. These requirements should be read in conjunction with the relevant requirements of ISO/IEC 17025:2017.

2. Scope

This specific document will be useful for those who are involved with accreditation of calibration laboratories e.g. experts, assessors, officials engaged with day-to-day activities of accreditation.

3. Classification of Groups and Sub – groups:

The calibration of electro technical parameters for
(i). Permanent laboratory service
(ii). Onsite service
(iii). Mobile service is as follow:

Table 1: The calibration of electro technical parameter.

S. No.	Parameter	Permanent Laboratory Service	Onsite Service	Mobile Service
i	**ALTERNATING CURRENT** (<1 GHz) Attenuation, Capacitance, Current, Dielectric loss angle, Energy, Inductance, Impedance, FM Modulation, AM Modulation, Phase angle, Power, Power factor, Resistance, Reflection Coefficient, Voltage, High Voltage and others	√	√	√ *(except High Voltage)*
ii	**DIRECT CURRENT** Current, Power, Energy, Resistance, Voltage, Capacitance, High Voltage and others	√	√	√ *(except High Voltage)*
iii	**RF/Microwave (1 GHz and Above)** Attenuation, Impedance, Frequency	√	√ *(except VSWR,*	√

	Modulation, Amplitude Modulation, Power, VSWR, Phase Modulation and Others		*Power, Phase Modulation)*	
iv	**TIME & FREQUENCY** Frequency (LF and HF), Time interval, Time Period and others	√	√	√
v	**EMI/ EMC** Antenna Factor, Attenuation, Automotive Transient Generator, Coupling Factor/ Coupling Loss Directivity, Conducted RF, Combination Wave Surge, Damped Oscillatory Wave Generator, Decoupling of Common Mode Disturbance, Electrostatic Discharge, Electrical Fast Transients, EMI Test Receiver, Isolation, Impulse Voltage, Impulse/ Immunity Generator, Insertion Loss/ RF Attenuation, Impedance, Longitudinal conversion Loss, Preamplifier Gain, Phase angle, RF Power Amplifier, Ring Wave Generator, Telecom Surge Test System, Return loss (VSWR), Voltage Dips/ Interruptions, Voltage Division Factor and others	√	√ *(except Antenna factors)*	X
vi	**ELECTRICAL EQUIPMENT** Current Transformers, Voltage Transformers, Oscilloscopes, Bridges, CT-VT Comparator, Tr. Ratio Standard, Tan Delta (e.g. Dissipation factor), Gauss Meter and Others	√	√	√ *(Only oscilloscope and Bridges)*
vii	**TEMPERATURE SIMULATION**	√	√	√

Calibration involves both types of applications where precision measurement and precision sourcing are required.

These parameters may be sub group for calibration as a (i) Measure and (ii) Source

(i) **Measure:** A precision measurement device tests a sourcing instrument

(ii) **Source:** A precision source is used to test a measurement instrument

4. Reference Standards

a. Minimum capabilities a lab shall possess in terms of equipment's in order to get accreditation is as per the EAS decision based on the requirements of their industries/organizations.

b. List of equipment/ process for which accreditation shall not be granted, is as per the EAS decision based on the requirements of their industries/organizations.

The following suggestions may be followed:

a) Reference Multimeters having < 5 ½ Digit Display.
b) Clamp on meters/ Clamp Meter with DMM as Standard for measuring capability of high current.
c) Measuring (DC Volt/Current & Resistance) Capability of Temperature Process calibrator used for Temp. Simulation.
d)

Note: *If calibrated DMM is used as Null detector for calibrating Source by Comparison Method, same to be recommended in sourcing capability.*

d) Calibration of stopwatches using identical calibrated stopwatch (direct comparison method), the totalize method and the time-base method (see NIST special publication 960-22, "Stopwatch and Timer calibrations", 2009 . Counter meter Calibration.

c. Source calibration using Calibrated DMMs by comparison method to be recommended in
Measure Mode.

d. The calibration of all electrotechnical parameters can be done for (i) Permanent laboratory service (ii) Onsite service (iii) Mobile service **(exceptions are mentioned in Table 1).**

2. Environmental Conditions:

Wherever applicable, laboratory is required to maintain

- Appropriate environmental conditions related to Temperature, Humidity, Line regulation, Harmonic content in supply voltage, EMI/EMC, Stray magnetic fields, Vibration, Dust level, Acoustic noise level, Illumination level etc. and keep a record of the same.

- The environmental conditions maintained in the laboratory shall be such that it does not adversely affect the required uncertainty in measurement. Facilities should be provided for recording all applicable environmental parameters prevailing in the laboratory periodically during calibration. Laboratory shall define the periodicity of recording environmental conditions.

- The range of environmental conditions maintained in the laboratory should be reported in the calibration report/ certificate (e.g. 25±2ºC).

- Calibrations to be stopped when the environmental conditions are observed to be outside the specified limits.

- As far as possible, only the staff engaged in the calibration activity shall be permitted entry inside the calibration area. Access of other persons shall be controlled and defined**.**

Minimum 'Environmental Conditions' to be maintained in the (i) Permanent laboratory service (ii) Onsite service (iii) Mobile service is as follow:

Table 2: Environmental Conditions for electro-technical parameters

S. No.	Environmental Conditions	Permanent laboratory service	Onsite service	Mobile service
i	Temperature	25°C± 2°C	25°C± 5°C	25°C± 5°C
ii	Humidity (RH)*	30% to 75%	30% to 75%	30% to 75%
iii	Level of illumination	250-500 lux on the working table	250-500 lux on the working table	250-500 lux on the working table
iv	Acoustic noise	< 60dBA	< 60dBA	< 60dBA

v	Earth Resistance	< 1Ω (ICS 91.140.50)	< 1Ω (ICS 91.140.50)	< 1Ω (ICS 91.140.50)
vi	Neutral - Earth Voltage	< 1 V	< 1 V	< 1 V
vii	Total Harmonic Distortion	<5% (Ref. std IEC 66(SEC) 49,50, ICS 621; 313-13)	<5% (Ref. std: IEC 66(SEC) 49,50, ICS 621; 313-13)	<5% (Ref. std: IEC 66(SEC) 49,50, ICS 621; 313-13)
viii	Power Supply regulation	±2 to 5 % or better on Calibration Bench	±2 to 5 % or better on Calibration Bench	±2 to 5 % or better on Calibration Bench
ix	Frequency	50/60 Hz ±1 Hz	50/60 Hz ±1 Hz	50/60 Hz ±1 Hz

- The laboratory shall have regulated and uninterrupted power supply to provide backup to calibration bench.
- During calibration of Inductance parameter care shall be taken about the location of magnetic field sources like, transformers, looped wires, ferrous materials etc., in order to minimize magnetic interference in the measurements.
- Adequate screening of the laboratory against electromagnetic interference may be done if necessary. By-pass filters should also be provided to minimize conducted interference effect on the electronic equipment.
- Adequate protective measures, like use of transient suppressors etc., shall be taken by the laboratory to ward off high current spikes and transients emanating from switching on and off, of heavy machines, surges in power lines and other such reasons, from reaching the electronics equipment in general and computer-based systems involving data storage facilities in particular.
- For calibration of Inductance (Low Frequency) and DC Resistance, the temperature variation must be controlled such that the 'Measurement Uncertainty' due to temperature variation does not exceed 10% of the total 'Measurement Uncertainty'

For High Voltage Facility:

* For High Voltage (HV) Measurement the Humidity shall be < 60%

- The inductive voltage divider should be protected against the effects of AC magnetic fields. To ensure minimization of ground current and effects of mains hum interference, if required, isolation transformers and filters etc. may be employed.

- The calibration laboratory should have direct power supply from the substation as far as possible. Avoid not be on the same feeder line which is supplying power to workshops and other production areas which require operation of heavy-duty machines.
- Laboratory should have dedicated earth line from the earth pit in high voltage laboratory, to ensure earth resistance < 1 Ω.
- Relevant fire extinguishing equipment for possible fire hazards, shall be available in the corridors or convenient places in the laboratory. Adequate safety measures against electrical, chemical fire hazards must be available at the workplace. Laboratory rooms/ areas where highly inflammable materials are used/ stored shall be identified. Access to the relevant fire equipment shall be assured near these rooms/ areas.
- Specification SP 31- 1986, a special publication in the form of a wall chart, giving the method of treatment in case of electric shock, should be followed. The chart shall be placed near the power supply switchgear and at other prominent places as prescribed under Ethiopian Electricity Rules.

5. Metrological Traceability Requirement:

- To achieve traceability, laboratories shall follow EAS document “Policy on Calibration and Traceability of Measurements”.
- The traceability for Standards/ equipment used including range or no. of points covered in the range
- The reference standards used for calibration must be traceable to the SI system of units by way of unbroken chain of calibrations. Each step for the same with a declared measurement uncertainty.
- The reference standards used should be calibrated on their entire range and preferably at nine or more points equally divided over the range.
- The primary/secondary standard used for calibration of reference should have TUR ratio of 1:3 i.e. accuracy of primary/secondary standard used should be at least 3 times better than the required accuracy of the reference standard under calibration.
- Note: For high accuracy standards sometimes 3 times higher accurate primary/secondary standard may not be available, in such cases proper correction factors for all the uncertainty influences should be considered.

6. Calibration methods/Procedures:

- Laboratory may use standard methods as per national and International standards or as specified by reputed technical organization, or as per relevant scientific texts or journals or as specified by reputed manufacturer of the equipment.
- While performing calibration to achieve CMC, Test uncertainty Ratio (TUR) of preferably 3:1 must be followed. In exceptional cases coarser can be accepted with proper technical justification.

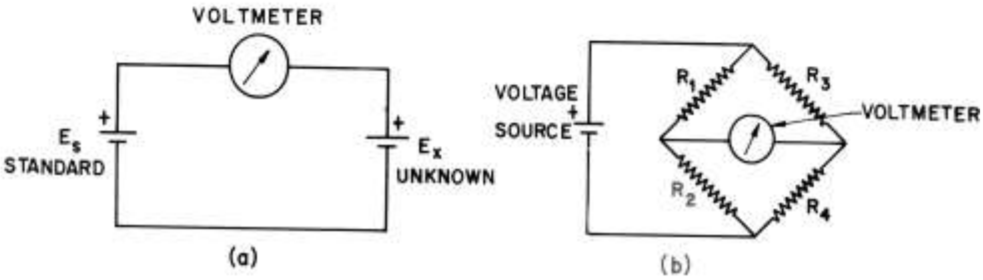
The following calibration methods are normally used for the electrotechnical parameters:

6.1 Comparison Technique

The simplest form of direct comparison technique is shown in **Figure 1(a,b)**

COMPARISON TECHNIQUES

(a) DIRECT COMPARISON (b) BRIDGE CIRCUIT



CASE I : (E_S-E_X) IS QUITE SMALL — METER TO BE SENSITIVE

CASE II : (E_S-E_X) IS LARGE — METER TO BE ACCURATE

CASE III : (E_S-E_X) IS QUITE LARGE — METER TO BE AS ACCURATE AS STANDARD

Figure 1(a, b) Comparison Techniques

Here E_s, is the standard and E_x is the unknown. They have been put in series opposition with a voltmeter indicating the difference between the two. If there is any difference, it is attributed to the unknown, the standard is assumed to be accurate and precise at the set value. Now, there can be three cases.

(i) (E_s - E_x) is quite small

This is the case where E_s and E_x are similar type of devices. Here, the meter accuracy is not very important because large uncertainty in the meter reading form only a small part of the total value of E_x as long as the difference between the two devices remains small. The meter needs only to be sensitive enough to measure this difference.

(ii) (E_s - E_x) is large

Here the meter must be accurate.

(iii) (E_s - E_x) is quite large

In this case the measurement becomes impractical as the meter must be as accurate as the standard itself.

Please note: Most of the precise voltage measurement falls in the first category.

The ideal situation would be to have some adjustable standard (for example DC calibrator/ differential voltmeter) with some output indicator. In this case, E_s and can be set precisely equal to E_x with voltmeter indicating the null and the value of the unknown could be read directly from the output dial of the standard. Also, at null no current is drawn from E_x so this combination of adjustable standard and voltmeter has got practically infinite resistance. Also, voltmeter just becomes a null detector and contributes almost no error to the measurement, it needs only to be sensitive.

But one word of caution - the adjustable standard is not as accurate at low output than at full output because it has non-linearities and this limits its resolution. If we can define or properly account for the uncertainties of the standard then the same can be used for the precise measurements.

Fig. 1 (b) depicts the 'Bridge circuits' which is another form of the comparison technique. In this case, in lieu of actual quantities one compares the ratios. For example, when $R_1/R_2 = R_3/R_4$ the bridge is at null and the voltmeter indicates null. Here again the accuracy of the voltmeter is not too important it needs to be sensitive only to indicate the null. As discussed earlier, the uncertainties are determined by the circuit elements and are only slightly dependent on the meter. By this method one can set two resistances equal within 1 ppm of their value by mounting the two alternately in the same arm and obtaining the null. This property is used in fabricating the precision resistive dividers.

6.2 Transfer Standard

In day to day measurements we often find primary standards to be;

- cumbersome and fragile
- isolated from working environment
- difficult to use

So, there must be some way of using the standard without disturbing it. This is usually done by referencing some precise instrument to the actual standard and then using it as a standard. The process is called 'Transfer of Standards'.

The transfer of value from the primary standard to another instrument is another example of comparison technique. Suppose that E_s is the standard E_x is to assume the value of the standard. If E_x is adjusted equal to standard value then it is a precise replica of the standard and may be used in its place. Sometimes E_s and E_x are not in the same place and it is difficult to bring them together. In such cases the transfer is made through an intermediate instrument called 'Transfer Standard'. The transfer standard is set equal to the actual standard and carried to the location of E_x and used as a standard.

A 'Transfer Standard' should be;

- stable
- immune to the environment
- easy to adjust and portable

6.3 Precise Ratio Technique

Precise ratio is usually defined by precise resistive dividers. A bridge comparison can be used to set a number of resistors equal to each other and then these can be arranged in variety of combination to get the desired ratios. For example, ten equal resistors can be arranged to form 10:1 divider or 9 can be arranged to form 9:1 or 9:8 or 9:7. Ratios generated in this fashion are extremely precise. The only significant sources of uncertainty come from the bridge components and not from the technique itself. If null detector is sensitive enough it can be practically eliminated as a source of error.

Significant uncertainties are due to;

i. Resistor instabilities
ii. Lead and terminal resistance
iii. Resolution of resistor adjustments

and these are usually quite small

Two resistors can be set equal within less than 1 ppm of their values and can be used to establish ratios within 1 ppm.

Now, let us discuss in the next section about the precision calibration system and how they are used for precision measurements in daily calibration work.

(i) Precision Calibration System

Instruments with an accuracy of 10-30 ppm are quite common now-a-days. They need a system with an accuracy of 2-6 ppm for their calibration i.e. at least five times better. Such a system can easily be assembled using

- an adjustable voltage source
- precision divider and
- 1 V transfer standard and null detector

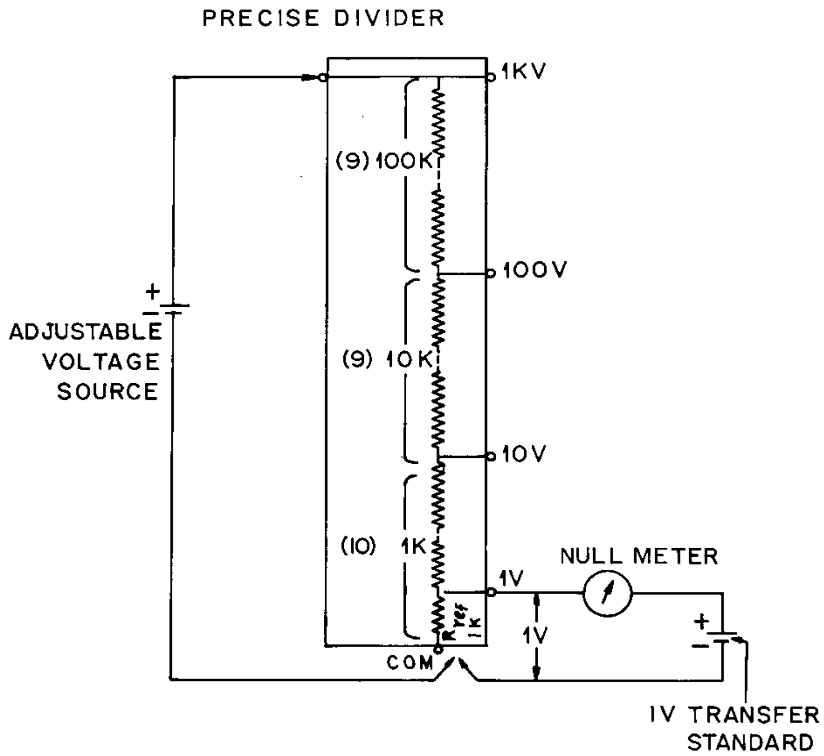
Let us discuss in brief about them.

(i) **Divider**

The 'Divider', which we are going to describe, is basically a 1 MΩ series divider with 27 outputs from 1V to 10V in 1V increment, from 10V to 100V in 10V increments. It consists of ten 1 kΩ resistors in series with nine 10 kΩ resistors and 100 kΩ resistors. All the ten 1kΩ resistors are first matched using bridge technique. Then all the nine 10 kΩ resistors are matched with a total of ten 1 kΩ resistors and finally all the nine 100 kΩ resistors are matched with a total of ten 1 kΩ resistors and finally all the nine 100 kΩ are matched with total of series combination of nine 10 kΩ resistors and ten 1 kΩ resistors. The contact between the resistors are mercury wetted and the whole divider is put in a clean oil bath maintained at constant temperature in order to avoid the contact potential and thermal emfs. The 'Bridge' maintained in this manner has a stability of the order of 1-2 ppm/month.

Fig. 1(c) shows the full calibration system. The adjustable voltage source adjusts the current through the divider such that the voltage across the bottom most resistance R_{ref} is exactly one volt. When all the resistances in the divider are exact multiple of the R_{ref} then the voltage drop across the individual resistances will also be exact multiple of 1V. Therefore, the voltage from any tap on the divider will also be exact multiple of 1 V i.e. voltage across R_{ref}. The absolute value of the resistors in the divider is not very important. The only important thing is that they must be an exact multiple of R_{ref}.

Such a calibration system is very precise and versatile. It can be used for the calibration of other voltage sources and voltmeter. The divider alone can be used for the calibration of precise voltage divider Kelvin Varley divider and ratiometers. The resistances in the divider can be re-arranged in variety of combinations to generate the requisite ratio. Again, the number of resistors in divider can be increased to increase the number of outputs.



CALIBRATION OF A PRECISION VOLTMETER

Figure 1 (c). Calibration system

We shall now describe the calibration of 'Precise Voltage Source' with the help of such a calibration system. Here the adjustable voltage source is replaced by a DC voltage source or a calibrator and it is connected to the voltage tap at which the calibration is desired. For example, it is connected to the 10 V tap. Therefore, the voltage across the R_{ref} will be exactly 1 V and the null meter will indicate a null. But when the output is not exactly 10 V, the null meter will indicate an error. The best way to read the error is to adjust the calibrator so that null meter indicates the null and the error can directly be read from the dials of the calibrator. The process is repeated for all the voltage levels within the range of the divider for null calibration with an uncertainty of 2-3 ppm.

6.4 Precision Current Calibration

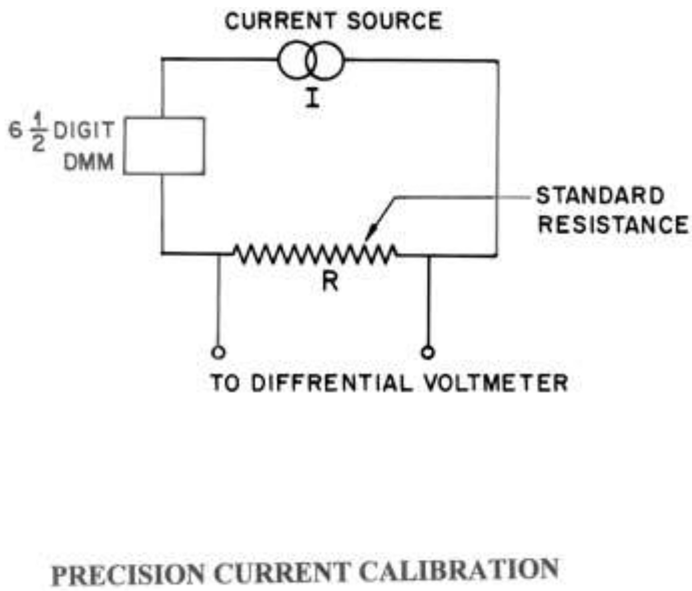


Figure 1(d) Precision Current calibration

A voltmeter with a standard resistor forms a very good high-resolution ammeter for the calibration of six and half digit DMM's. Constant current source is put in series with the standard resistor and DMM (Fig. 1 (d)). The current is adjusted equal to the value desired for calibration and the voltage drop is read with the help of the differential voltmeter. Since differential voltmeter has almost an infinite resistance at null, it does not load the standard resistor. The exact value of current is found out by dividing the voltage drop by the value of the resistance. If the resistors are in decade cardinal point like 100 Ω, 1 kΩ and 10 kΩ then the voltmeter will give the results directly in amperes. No calculation is necessary except to place the decimal point.

Notes:

(i) Methods like Difference Method, Null Method, Substitution Method, etc. can also be used for
Comparison.

(ii) Lab having only measurement capability (By Direct and Comparison Method) can calibrate source/ DMM.

6.5 Voltage/Current Method: Commonly known as V/I

Use for Measurement of Low Value Resistance (Mostly DC Resistance) for Precise Measurements.

6.6 Direct Method

Direct measurement with reference Equipment e.g. Multi-function calibrator or DMM

6.7 Automated Method

Any software used by laboratories for performing automated calibration shall be validated so that all parameters and ranges intended to be calibrated using the software are taken care of. Records for the same shall be available with the laboratory during assessment. Such software needs to be verified by the user laboratory periodically. Periodicity of these verifications may be decided by the user laboratory. Re-validation of software is required whenever there is a change in the version of the software used.

7. Parameters for CMC Calculation:

For permanent facility calibration

Calibration and Measurement Capability (CMC) is one the parameters that is used by EAS to define the scope of an accredited calibration laboratory, the others being parameter/quantity measured, standard/master used, calibration method used and measurement range.

The CMC is expressed as “the smallest uncertainty that a laboratory can achieve when calibrating the best existing device”. It is an expanded uncertainty estimated at a confidence level of approximately 95% corresponding to a coverage factor k=2.

Note: Refer EAS policy on “Calibration and Measurement Capability (CMC) and Uncertainty in Calibration”.

a. CMC value is not the same as expanded uncertainty reported in the calibration Certificate/Report (Issued by the laboratory). CMC values exclude the uncertainties which are attributed to the DUC (Device under Calibration).
b. For the purpose of CMC evaluation, the following components shall be considered however this is not limited; any other relevant component may be included.
    i. Repeatability (10 readings at least at minimum and maximum Points within the range, wherever applicable).
    ii. Uncertainty of master (Lab to verify whether error has been adjusted or not as mentioned in the calibration certificate).
    iii. Stability estimated by the laboratory.
    iv. Resolution of the readout unit.

For the purpose of CMC evaluation refer EAS “Policy on Calibration and Measurement Capability (CMC) and Uncertainty in Calibration”

7.1 Calibration Interval of Reference Standards:

The calibration intervals of the reference standards should be as per the respective standards/guidelines (e.g. ISO 10012 and ILAC G24 etc.).

7.2 Legal Aspects:

The calibration of Electrotechnical Parameters by any accredited laboratories is as per the requirement of the EAS, Regulatory bodies, law of the land etc. This should be clearly mentioned in the calibration certificate issued to the customer.

8. **Sample scope:**

S. No	Parameter / Quantity measured	Standards / Masters Used	Range(s)	Calibration & Measurement Capability			Remarks/ Method used
				Claimed by Laboratory (±)	Observed by Assessor (±)	Recommended by Assessor (±)	
1.	**Measure** DC Voltage	Fluke 8508A DMM	100µV to 10mV 10mV to 100mV	0.012 µV to 0.0042mV 0.0042mVto 0.0005mV	0.012 µV to 0.0042mV 0.0042mVto 0.0004mV	0.012 µV to 0.0042mV 0.0042mVto 0.0005mV	
	AC Voltage	Fluke 8508A DMM	**10Hz to 10kHz** 1mV to 100mV 100mV to 100V 100V to 1000V	0.002mV to 0.006mV 0.006mV to 0.017V 0.017V to 0.022V	0.004mV to 0.016mV 0.016mV to 0.013V 0.013V to 0.018V	0.004mV to 0.016mV 0.016mV to 0.017V 0.017V to 0.022V	
	Source AC Voltage	Wavetek 4808 Calibrator	**10kHz to 100kHz** 1mV to 100mV 100mV to 100V 100V to 1000V	0.0069mV to 0.03mV 0.03mV to 0.14V 0.14V to 0.91V	0.0069mV to 0.43mV 0.43mV to 0.1V 0.1V to 0.81V	0.0069mV to 0.43mV 0.43mV to 0.14V 0.14V to 0.91V	
		Wavetek 4808	100µA to 100mA	0.004µA to 0.005mA			

	DC Current	Calibrator	100mA to 1A 1A to 10 A	0.005mA to 0.00011A 0.00011A to 0.001A	0.014μA to 0.006mA 0.006mA to 0.00014A 0.00014A to 0.0029A	0.014μA to 0.006mA 0.006mA to 0.00014A 0.00014A to 0.0029A	
	DC Resistance	Wavetek 4808 Calibrator	1mΩ to 10Ω 10Ω to 100kΩ 100kΩ to 100MΩ	0.0004mΩ to 0.012Ω 0.012Ω to 0.0011kΩ 0.011kΩ to 0.019MΩ	0.0004mΩ to 0.042Ω 0.042Ω to 0.0021kΩ 0.021kΩ to 0.026MΩ	0.0004mΩ to 0.042Ω 0.042Ω to 0.0021kΩ 0.021kΩ to 0.026MΩ	

Signature of Lab Representative **Name:** **Date:**	**Signature of Assessor(s)** **Name:** **Date:**	**Signature of Team Lead** **Name:** **Date:**

9. Uncertainty calculation with example:

Measurement Uncertainty is evaluated as per ISO GUM :1995 document (their revised versions) and EAS uncertainty in measurement document

7.2 Repeatability to be evaluated using Type ‘A’ method
7.3 Required Type ‘B’ Components for Uncertainty Calculations

The following Type B components shall be necessarily considered as a minimum for estimation of uncertainty in measurement:
U1: Uncertainty reported in the calibration certificate of the standard(s) / master(s). (Lab to verify whether error has been adjusted or not as mentioned in the calibration certificate.) Also, Lab to mention the error separately if not adjusted in the calibration certificates issued to their customers.
U2: Uncertainty arising from Long Term Stability/ drift data of the measurement standard(s)/master(s) used for calibration (Detailed explanation for this component is provided below). If this data is not available accuracy/uncertainty provided by the manufacturer shall be used as per EAS policy.
U3: Uncertainty due to resolution of the Device/Unit under Calibration.
U4: Uncertainty due to other applicable influential factors such as temperature, power supply regulation, voltage co-efficient etc. affecting the measurements.

For the purpose of CMC evaluation refer **EAS** *“Policy on Calibration and Measurement Capability (CMC) and Uncertainty in Calibration”*

LONG TERM STABILITY: Long term stability data shall be generated by laboratories by preparation of control /trend charts based on successive calibration of their standard(s)/master(s) (preferably without adjustments) *. This shall be established by laboratories within two years based on minimum four calibrations from the date on which laboratories apply for EAS accreditation. For the accredited laboratories, this shall be established within a period of two years w.e.f. the date of issue.
The laboratories may need to get their standard(s)/master(s) calibrated more frequently to generate the stability data within the above stipulated time.

Till two years, the stability data provided by the manufacturer of the standard(s)/master(s) can be utilized for estimation of uncertainty. In case the stability data from the manufacturer is also not available, the accuracy specification as provided by the manufacturer can be used. However, manufacturer’s data will not be acceptable after the two-year period as mentioned above since the laboratories are expected to establish their own stability data by that period.

*In cases where the standard(s)/master(s) are adjusted during its calibration pre-adjustment data needs to be used for preparation of control/trend charts.

EXAMPLE OF UNCERTAINTY IN DC VOLTAGE MEASUREMENT – DIRECT METHOD

DIRECT METHOD

In this example:

The measurement involves the calibration of a cell in a standard cell enclosure by comparison to the laboratory's in-house reference standard (this has been calibrated against the primary standard).

The cell voltages have been determined from difference voltages using a calibrated digital voltmeter (8 ½ DMM).

Fig.1 Shows the electrical circuits used in the present measurements.

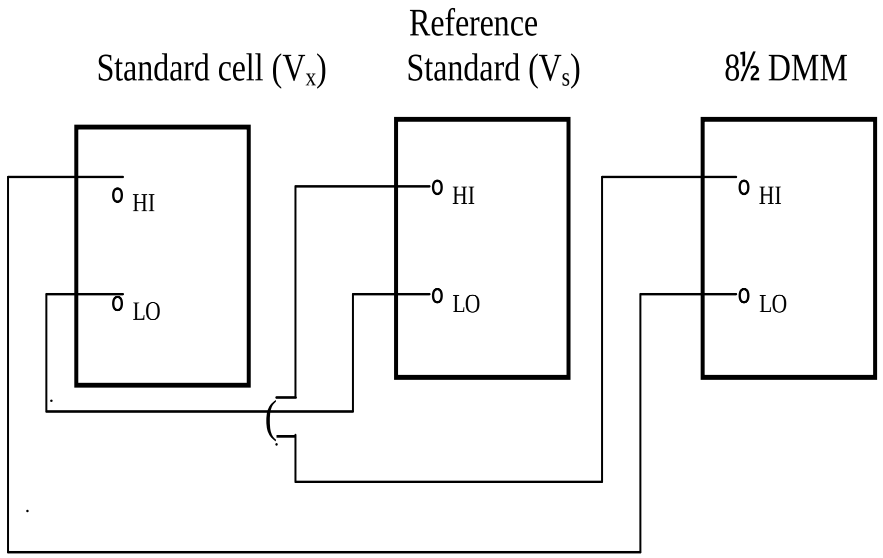


Fig. 1: The electrical circuit used for the calibration of the standard cell by the reference standard.

Some simplifying assumptions have been made:

i. Voltage changes due to steady secular drift of the controlled temperature have been included in the general drift term.

The mathematical model used for the evaluation:

The average voltage V_X of the unknown cell of standard cell enclosure has been obtained from the relationship.

$$V_X = V_S + \delta V_D + \delta V + c_S \delta t_S - c_x \delta t_x + \delta E \quad (1)$$

$$\text{and } \delta V = - \delta V_1 + \delta V_2 \quad (2)$$

where:

V_S : average voltage of the in-house reference standard

δVD : drift in value of the in-house reference standard (in this example it has decreasing trend)

δV1 : difference in voltage between the in-house reference standard and the unknown (in this example the cell has the value greater than the reference and as per Fig.1 the reference is connected to the positive potential thus the negative sign in the model),

δV2 : linearity deviation of the DMM

cS : temperature coefficient of cells of the in-house reference standard

δtS : temperature deviation of the in-house reference standard

cX : temperature coefficient of an unknown cell

δtX : temperature deviation of the unknown enclosure

δE : thermal emf in calibrating the unknown enclosure

The other inputs available to us are:

i. ***Reference standard***: The last calibration of the in-house reference standard against a primary or national standard calibrated at a national standards laboratory gave the voltage as **1.0179285 V** with an associated expanded uncertainty of ± **1.0 μV** (coverage factor **k = 2**).In the present case the uncertainty of a calibration result is obtained by a single **Type A** standard uncertainty evaluated from the pooled experimental standard deviation that characterizes the measurement. Degree of freedom is **90** (taking **10** sets of observations each having 10 numbers of observations).

ii. ***Drift of the reference standard***: The drift in the value of the in-house reference standard since its last calibration was estimated from the calibration history to be **-0. 6 μV** (decreasing trend) with deviations within ± **0.1 μV**.

iii. ***Temperature deviations***: Temperature deviations have been estimated to be within ± **2.0 mK** for the in-house reference and ± **1.0 mK** for unknown cell enclosure, it has been determined that the temperature coefficient of cell and reference standard are **0.104 μV/ mK** respectively.

iv. ***Thermal emf***: The thermal emf effects have been estimated to be within ± **0.1 μV**.

v. ***Voltage measurements***: Linearity deviations of the voltmeter (8 ½ DMM) used in the determination of voltage differences have been estimated to within ± **0.1μV**.

vi. ***Correlation***: None of the input quantities has been considered to be correlated to any significant extent.

vii. ***Measurements***: For the voltage difference between the unknown cell and the in -house reference standard, ten observations have been made as shown in Table 1.

Table 1. : Shows the calculation of the arithmetic mean and estimated standard deviation of the parameter $\delta V1$.

$\Sigma qi = -1906.32, \quad \Sigma (qi - \bar{q}) = 0, \quad \Sigma (qi - \bar{q})^2 = 0.109360$

$(\bar{q}) = \Sigma (q_i) / n = \delta \bar{V}_1 = -190.632\ \mu V$ **(3)**

$\{s (\delta V_1)\} = ([\{1/(n - 1) \} \Sigma (qi - \bar{q})^2] = 0 . 110\ \mu V$ **(4)**

Table 1.

n	q_i (μV)	($q_i - \bar{q}$) (μV)	($qi - \bar{q}$)^2 (μV)^2
1.	-190.33	+0.302	0.091204
2.	-190.73	-0.098	0.009604
3.	-190.69	-0.058	0.003364
4..	-190.65	-0.018	0.000324
5.	-190.69	-0.058	0.003364
6.	-190.63	+0.002	0.000004
7.	-190.65	-0.018	0.000324
8.	-190.64	-0.008	0.000064
9.	-190.66	-0.028	0.000784
10.	-190.65	-0.018	0.000324

i Mathematical model or Model of evaluation:

The measurement equation used are (1) and (2) and rewriting them

$V_X = V_S + \delta V_D + \delta V + c_S \delta t_S - c_x \delta t_x + \delta E$

And $\delta V = - \delta V_1 + \delta V_2$

Uncertainty equation:

For uncorrelated input quantities, the combined standard uncertainty

$$u_c^2(y) = \sum_{i=1}^{N} ([(f / (x_i)]^2 u^2(x_i)$$ **(5)**

$u_1(V_s)$ = Std. uncertainty in the average voltage of the in-house reference standard

$u_2(\delta V_D)$ = Std. uncertainty in the value of the drift of the reference standard

$u_3(\delta V_1)$ = Std. uncertainty in the value due to difference in voltage between the in-house reference standard and the unknown cell

$u4(\delta V2)$ = Std. uncertainty due to the linearity of the DMM

$u5(\delta ts)$ = Std. uncertainty due to temperature deviation of reference standard

$u6(\delta tx)$ = Std. uncertainty in the value due to temperature deviation of the unknown cell

$u7(\delta E)$ = Std. uncertainty in the value due to thermal emf

Then,

$$u_c^2(V_x) = (V_X / (Vs)^2 + u_1^2(V_S) + \{V_X / (\delta V_D)\}^2 + u_2^2(\delta V_D) + \{V_X / (\delta V_1)\}^2 u_3^2(\delta V_1) + \{V_X / (\delta V_2)\}^2 u_4^2(\delta V_2) + \{V_X / (\delta t_S)\}^2 u_5^2(\delta t_S) + \{V_X / (\delta t_x)\}^2 u_6(\delta t_x) + \{V_X / (\delta E)^2 u_7(\delta E)$$

$$= (c_1)^2 u_1^2(V_s) + (c_2)^2 u_2^2(\delta V_D) + (c_3)^2 u_3^2(\delta V_1) + (c_4)^2 u_4^2(\delta V_2) + (c_5)^2 u_5^2(\delta t_s) + (c_6)^2 u_6^2(\delta t_x) + (c_7)^2 u_7^2(\delta E) \quad (6)$$

Evaluation of sensitivity coefficient(c_i)

$c_1 \equiv \quad (V_S / Vs) = 1;$

$c_2 \equiv \quad \{\delta (V_D) / \delta (V_D)\} = 1;$

$c_3 \equiv \quad (\delta V_1) / (\delta V_1) = 1;$

$c_4 \equiv \quad \{ (\delta V_2) / (\delta V_2) = 1;$

$c_5 \equiv \quad \{ (c_S \delta t_S) / (\delta t_S) \} = 0.104;$

$c_6 \equiv \quad \{ (c_X \delta t_X) / (\delta t_X) \} = 0.104;$

$c_7 \equiv \quad \{ (\delta E) / (\delta E) = 1; \quad (7)$

Type A evaluation:

a. Given value of V_S (average voltage of the in-house reference standard):

The last calibration of the in-house reference standard against a primary or national standard calibrated at a national standards laboratory gave the voltage as **1.0179285 V** with an associated expanded uncertainty of ± **1.0 µV** (coverage factor **k = 2**).

In the present case the uncertainty of a calibration result is obtained by a single Type A standard uncertainty evaluated from the pooled experimental standard deviation that characterizes the measurement. Degree of freedom is 90 (taking 10 sets of observations each having 10 numbers of observations).

Thus, for present evaluation we take the value of V_S

V_S = 1. 0179285 V ± 0.5 µV (coverage factor k = 1) **(8)**

Standard uncertainty in the average voltage of the in-house reference standard:

u_1 (V_S) = 0.5 μV **(9)**

Degree of freedom (ν_1):

Given, ν_1 = 90 **(10)**

b. Difference in voltage between the in-house reference standard and the unknown cell (δV_1) :

Table 1 gives the 10 numbers of observations taken for this measurement, the calculation for the standard uncertainty gives,

$\Sigma qi = -1906.32$, $\Sigma (qi - \bar{q}) = 0$, $\Sigma (qi - \bar{q})2 = 0.109360$

arithmetic mean

$(\bar{q}) = \Sigma (q_i) / n = \delta \bar{V}_1 = -190.632\ \mu V$

estimated (experimental) standard deviation **{ s (δV_1)}**

$\{s (\delta V_1)\} = \sqrt{([\{1/(n - 1) \} \Sigma (qi - \bar{q})^2] }= 0 . 110\ \mu V$

Standard deviation of the mean:

$\{u (\delta V_1)\} = \{ s (\delta \bar{V}_1)\} / \sqrt{n} = 0.035\ \mu V$ **(11)**

Standard uncertainty in the value due difference in voltage between the in-house reference standard and the unknown cell:

$u_3 (\delta V_1) = 0.035\ \mu V$ **(12)**

Degree of freedom (ν_3):

(ν_3) = n -1 = 9 **(13)**

2. **Type B evaluation**:

a. Drift in the value of the in-house reference standard **(δV_D):**

The drift in the value of the in-house reference standard since its last calibration was estimated from the calibration history to be **-0. 6 μV** (decreasing trend) with deviations within $\pm$ **0.1 μV**.

Assumed rectangular distribution,

Standard uncertainty in the value of the drift of the reference standard:

$u_2 (\delta V_D) = (0.1) / \sqrt{3} = 0.058\ \mu V$ **(14)**

Degree of freedom (ν_2):

$\nu_2 = \infty$ **(15)**

b. Linearity deviation (δV_2) DMM:

Linearity deviations of the voltmeter (8 ½ DMM) used in the determination of voltage differences have been estimated to within ± **0.1 μV**.

Assumed rectangular distribution,

Standard uncertainty in the value of the linearity of the DMM:

$u_4(\delta V_2) = (0.1) / \sqrt{3} = 0.058\ \mu V$ **(16)**

Degree of freedom (ν_4):

$\nu_4 = \infty$ **(17)**

c. Temperature deviation (δt_S) of the in-house reference standard:

Temperature deviations have been estimated to be within ± **2.0 mK** for the in-house reference and it has been determined that the temperature coefficient of the reference standard is **+ 0.104 μV/ mK** respectively

Assumed rectangular distribution,

Standard uncertainty in the value due to temperature deviation of the reference standard:

$u_5(\delta t_S) = (2.0) / \sqrt{3} = 1.155\ mK$ **(18)**

Degree of freedom (ν_5):

$\nu_5 = \infty$ **(19)**

d. Temperature deviation (δt_X) of the unknown cell enclosure:

Temperature deviations have been estimated to be within ± **1.0 mK** for the unknown cell enclosure and it has been determined that the temperature coefficient of the unknown cell is **+ 0.104 μV/ mK** respectively.

Assumed rectangular distribution,

Standard uncertainty in the value due to temperature deviation of the unknown cell:

$u_6(\delta t_X) = (1.0) / \sqrt{3} = 0.577\ mK$ **(20)**

Degree of freedom (ν_6):

$\nu_6 = \infty$ **(21)**

e. Thermal emf (δE) in calibrating the unknown enclosure:

The thermal emf effects have been estimated to be within ± **0.1 μV**.

Assumed rectangular distribution,

Standard uncertainty in the value due to thermal emf effect:

$u_7(\delta E) = (0.1) / \sqrt{3} = 0.058\ \mu V$ **(22)**

Degree of freedom (ν_7):

$\nu_7 = \infty$ **(23)**

v. **Combined standard uncertainty $u_c^2(y)$:**

For uncorrelated input quantities:

$\mathbf{u_c^2(V_x) = (c_1)^2 u_1^2(V_s) + (c_2)^2 u_2^2(\delta V_D) + (c_3)^2 u_3^2(\delta V_1) + (c_4)^2 u_4^2(\delta V_2) + (c_5)^2 u_5^2(\delta t_s) + (c_6)^2 u_6^2(\delta t_x) + (c_7)^2 u_7^2(\delta E}$

(24)

Substituting the values and solving we get,

$\mathbf{u_c^2(V_x) = 0.286045}$ **(25)**

Hence,

$\mathbf{u_c(V_x) = \sqrt{0.286045} = 0.5348\ \mu V = 0.535\ \mu V}$ **(26)**

Effective Degree of Freedom ν_{eff}

Using Welch-Satterthwaite formula we estimate the effective degree of freedom of the standard uncertainty $\mathbf{u_c(y)}$ associated with the output estimate is as follows:

$$\nu_{eff} = \frac{\{u_c^4(y)\}}{\sum_{i=1}^{N} \{ u_i^4(y) \} / \nu_i} \qquad (27)$$

where the $\mathbf{u_i(y)}$ **[i = 1, 2, ---N]** is the contribution to the std. uncertainty associated with the output estimate y resulting from the std. uncertainty associated with the input estimate $\mathbf{x_i}$.

In present case,

$\mathbf{\nu_{eff} = \{u_c^4(V_X)\}[\{c_1)^4 u_1^4(V_S)/ \nu_1)\} + \{(c_2)^4 u_2^4(\delta V_D)/ \nu_2)\}- \{(c_3)^4 u_3^4(\delta V_1)/ \nu_3)\} + \{(c_4)^4 u_4^4(\delta V_2)/ \nu_4)\}+ \{(c_5)^5 u_5^4(\delta t_S)/ \nu_5)\}- \{(c_6)^4 u_6^4 (\delta t_X)/ \nu_6)\}+ \{(c_7)^4 u_7^4 (\delta E)/ \nu_7)\}]}$

(28)

$\mathbf{= \{0.535\}^4/[(0.5)^4/90\}+ \{(0.058)^4/\infty \}- \{(0.035)^4/9\}+ \{(0.058)^4/\infty\} + \{(0.120)^4/\infty\} - \{(0.060)^4/\infty\} + \{(0.058)^4/\infty\}}$

= 117.76 **(29)**

Since ν_{eff} is not an integer, truncate to lower complete integer, which is 117.

Expanded uncertainty U:

For degree of freedom, ν_{eff}**> 100, at 95.45%** level of confidence, the 't' factor from Student's 't' table is **3**.

[ν (degree of freedom)values may be taken from t-distribution table (G2) from the ISO GUM:1995 document (for reference purpose given here as table 3)].

Therefore, coverage factor k = 2 **(30)**

The expanded uncertainty U is:

$U = k\ u_c(y) = k\ u_c(V_X) = 2 \times 0.535 = 1.07\ \mu V$ (31)

Reported result:

The measured average voltage of the unknown cell is 1.0181185 V ±1.07 μV
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%

vii. **Uncertainty budget:**
Given in Table 2

Table 2. Uncertainty budget

Quantity X_i	Estimated value x_i	Limits $\pm\Delta(x_i)$	Uncertainty (μV)	Probability Distribution /Type A or B	Sensitivity Coefficient c_i	Degree of freedom ν_i	Uncertainty Contribution $u_i(y)$ [μV]	$\{u_i^2(y)\}$ $(\mu V)^2$
V_s	1.0179285 V	-	0.5 μV	normal type B	1	90	0.5	0.25
δV_D	-0.6 μV	0.1 μV	0.058 μV	rectangular type B	1	∞	0.058	33.64×10^{-4}
δV_1	-190.632 μV	-	0.035 μV	normal type A	1	9	0.035	12.25×10^{-4}
δV_2	-	0.1 μV	0.058 μV	rectangular type B	1	∞	0.058	33.64×10^{-4}
δt_s	-	2.0 mK	1.155 mK	rectangular type B	0.104 μV/mK	∞	0.120	1.44×10^{-2}
δt_x	-	1.0 mK	0.577 mK	rectangular type B	0.104 μV/mK	∞	0.060	3.6×10^{-3}
δE	-	0.1 μV	0.058 μV	rectangular type B	1	∞	0.058	33.64×10^{-4}
V_x	1.0181185 V							$\sum = 28.60\times10^{-2}$ $\sqrt{\sum} = 0.535$ (μV)

Table 3: Student t-distribution for degrees of freedom v

The t-distribution for v v defines an interval -t $_p$(v) to +t $_p$(v) that encompasses the fraction p of the distribution. For p = 68.27%, 95.45%, and 99.73%, k is 1, 2, and 3, respectively.

Degrees Freedom	**Fraction p in percent**					
(v)	**68.27**	**90**	**95**	**95.45**	**99**	**99.73**
1	1.84	6.31	12.71	13.97	63.66	235.80
2	1.32	2.92	4.30	4.53	9.92	19.21
3	1.20	2.35	3.18	3.31	5.84	9.22
4	1.14	2.13	2.78	2.87	4.60	6.62
5	1.11	2.02	2.57	2.65	4.03	5.51
6	1.09	1.94	2.45	2.52	3.71	4.90
7	1.08	1.89	2.36	2.43	3.50	4.53
8	1.07	1.86	2.31	2.37	3.36	4.28
9	1.06	1.83	2.26	2.32	3.25	4.09
10	1.05	1.81	2.23	2.28	3.17	3.96
11	1.05	1.80	2.20	2.25	3.11	3.85
12	1.04	1.78	2.18	2.23	3.05	3.76
13	1.04	1.77	2.16	2.21	3.01	3.69
14	1.04	1.76	2.14	2.20	2.98	3.64
15	1.03	1.75	2.13	2.18	2.95	3.59
16	1.03	1.75	2.12	2.17	2.92	3.54
17	1.03	1.74	2.11	2.16	2.90	3.51
18	1.03	1.73	2.10	2.15	2.88	3.48
19	1.03	1.73	2.09	2.14	2.86	3.45
20	1.03	1.72	2.09	2.13	2.85	3.42
25	1.02	1.71	2.06	2.11	2.79	3.33
30	1.02	1.70	2.04	2.09	2.75	3.27
31	1.000	1.645	1.960	2.000	2.576	3.000

9.1 National/ International Standards, References and Guidelines:

- National/ international standards, references and guidelines
- ISO/IEC Guide 98-3:2008 - Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM: 1995)
- Evaluation of measurement data - Guide to the expression of uncertainty in measurement, ‘JCGM 100:2008- (ISO/IEC 98-3)’.
- Euromet Guide CG-07 for Calibration of Oscilloscopes.
- NIST 960-12 Timer and Stop watch Calibrations
- Euromet Guide – CG-11 Calibration guide for Temperature simulation.
- ISO 10012 and ILAC G24

- ICS 91.140.50, IEC 66(SEC) 49,50, ICS 621; 313-13

Note: - Latest versions of relevant standard(s) should be followed for all the parameters.

Revision No.	Date approved	Revision History
1	2022-05-10	• The document is revised due to the name Ethiopian National Accreditation Office (ENAO) change to Ethiopian Accreditation Service (EAS) and new logo developed.