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THE STUDY OF THE BEHAVIOR IN TIME OF THE STANDARD, USED FOR CALIBRATING A DIGITAL MULTIMETER, TO IMPROVE THE EXPANDED MEASUREMENT UNCERTAINTY

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Abstract **– Uncertainty of measurement comprises many components. Some of these components can be estimated from the statistical distribution of results of measurements and strings can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated based on experience or based on other information from field measurements, by accepting certain probability distribution. The paper refers to the influence that has a standard accuracy of the extended measurement uncertainty. It is a study of the behavior over time of standard used in a chain of calibration, to obtain a history of its behavior over time, to improve the measurement uncertainty associated with the quantity generated by the standard and thus to improve the uncertainty extended measuremen,t that contributes to the expression of measurement result.**

Keywords: *accuracy, measurement uncertainty, traceability.*

1. INTRODUCTION

In the special publications, metrology is defined as a field of knowledge relating to measurement, covering all aspects, both as theoretical and practical measurements of whatever level of accuracy, the quantity measured, manner and purpose for which the measurement is made , science or technology involved.

In a modern industrialized society, Metrology is of great importance in many areas of our daily lives.

Metrology is mandated to carry out the scientific basis of measurement, to ensure uniformity in measurement and to ensure the correct use of measures, measuring equipment and measurement methods.

Accurate measurements are a prerequisite for high quality industrial production.

They also serve to promote and ensure our living conditions (eg medical, safety, the environment, etc.) and contribute to the expansion of scientific knowledge. Measurements ensure safety, protect consumers and remove barriers to trade.

Particularly, Metrology seeks ways of achieving uniformity measurements, the accuracy and compatibility of measurements, the correlation of measurements with reference to accepted standards.

Following the activities of society, measurements have been improved, with an important role in the great discoveries of physics and the great progress in knowledge of micro and macro universe.

2. DIGITAL MULTIMETERS, ACCURACY, TRACEABILITY AND UNCERTAINTY OF MEASUREMENT

Digital multimeters are electric measuring instruments, which provide the measurement information in digital form, the result of the measurement being supplied as a numerical value on a display. These meters, which currently are register a rapid and spectacular development, can measure different inputs as follows:
- direct and alternating current intensity;
- direct and alternating voltage;
- frequency;
- capacity etc. this being the reason for which are known as digital multimeters.

Working principle of a digital measuring device is to transform the quantity to be measured, continuously variable in time, into discrete signals, which, after a specific processing, allowing the display quantity to be measured in numerical form. The main technical and metrological characteristics of a digital multimeter are: accuracy, resolution, fidelity, speed measurement, smoothness, noise rejection.

The accuracy of a measuring instrument is its property to provide answers close to a true value.

Definition of accuracy, in accordance with ISO / IEC 99/2007, is: closeness of agreement between a measured quantity value and a true quantity value of a measurand.

The concept "uncertainty" means "doubt" and thus in a broader sense, "measurement uncertainty" means doubt about the validity of a measurement result.

Formal definition of the term "measurement uncertainty", in accordance with ISO / IEC 99/2007 – *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*, is the following: non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

Measurement uncertainty includes components arising from systematic effects, such as components associated with correction and the assigned quantity values of measurement standards, as well as definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of quantity values from series of measurements and can be characterized by standard deviation. The other components, which may de evaluated by Type B evaluation of measurement uncertainty, can also be characterised by standard deviation, evaluated from probability density functions based on experience or other information.

Quality products and services depends increasingly more accurate measurements. One of the mandatory requirements to obtain correct values, after the measurements are made, is that standards used are traceable to national or international standards.

The concept of “traceability” has been relatively recently adopted in the metrological vocabulary from Romania. In 1996 the international standard 13251/1993 – *International vocabulary of basic and general terms in metrology (VIM)*, edited by the most important organizations of metrology in the world, (BIMP, IEC, ISO, OIML), was adopted as Romanian standard.

Currently it is being adopted as standard Romanian, Publication ISO / IEC 900/2007 – *International vocabulary of metrology – Basic and general concepts and associated terms (VIM).*

Traceability represents the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

In accordance with EN ISO/IEC 17025/2005 – *General requirements for the competence of testing and calibration laboratories,* a calibration/testing laboratory establishes traceability of its own standards and measuring instruments to SI by an unbroken chain of calibrations or comparisons which linking them to relevant primary standards. The link to SI may be achieved by reference to national standards.

The laboratories of metrology have to achieve all requirements of this standard in order to demonstrate that they apply the system of management quality, they are competent and that they can provide valid technical results. The measuring results should be compatible with results that are obtained following measurements everywhere in the country or in the world.

This target can be accomplished if the reference standard, used in a given place, is introduced into an unbroken chain of comparisons with higher rank standards, up to primary standard. Thus the traceability to national and international standards is achieve.

In the Fig. 1 is presented the traceability chain for AC voltage unit.

For each of this comparisons the uncertainty of the standard should be signicantly less than the estimated measurement uncertainty for calibrtated object.

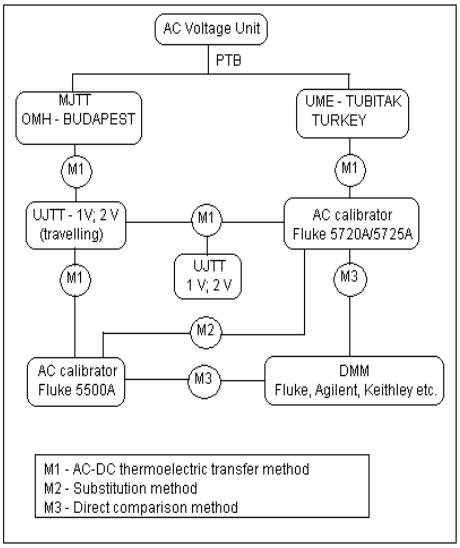


Figure 1: Traceability chain of dissemination of AC voltage

The error of indication, e_x , of the DMM to be calibrated, is obtained from the relationship

$$E_x = \overline{V_X} + \delta V_{XT} + \delta V_X - V_S - \delta V_{SD} - \delta V_{ST} \quad (1)$$

where:

$\overline{V_X}$ – average value for *n* independent observations, which we read on the display of the meter to be calibrated;

δV_{XT} – correction applied to the value displayed by the digital multimeter due to changes in ambient temperature compared with the reference temperature;

δV_X – correction applied to the value displayed by the digital multimeter, following the resolution and the instability of short-term;

V_S – voltage or current value generated by the standard (calibration certificate is used);

δV_{SD} – correction applied following the standard drift over time;

δV_{ST} – correction applied to the value displayed by the standard due to changes in ambient temperature compared with the reference temperature;

Each element of the formula (1) has a value and an associated uncertainty:

a) The average value for n independent observations, which we read on the display of the meter to be calibrated, $\overline{V_X}$ is calculated according to the formula:

$$\overline{V_X} = \frac{\sum_{i=1}^{n} V_{X_i}}{n} \quad (2)$$

Uncertainty of element V_X is calculated :

$$u\left(\overline{V_X}\right) = \sqrt{\frac{\sum_{i=1}^{n}\left(V_{X_i} - \overline{V_X}\right)^2}{n(n-1)}} \quad (3)$$

b) Correction applied to the value displayed by the digital multimeter due to changes in ambient temperature compared with the reference temperature, δV_{XT} , is applied only when measurement are performed at a temperature different from the reference temperature and there are temperature correction coefficients, c_{XT} , in the technical book.

Uncertainty of element, δV_{XT} , is applicable only in case the measurement temperature differs from the reference temperature. In such case, we measure temperature T to which we have noticed a variation a_1.

$$u(\delta V_{XT}) = \frac{a_1 \times c_{XT}}{\sqrt{3}} \quad (4)$$

c) Correction applied to the value displayed by the digital multimeter, following the resolution and the instability of short-term, δV_X..

Generally, do not apply this correction, therefore $\delta V_X = 0$.

Uncertainty of element δV_X .

We estimate, by the quantity $\pm a_2$, the modification of the digital multimeters indication due to its own instability of short-term (depends on device resolution).

DMM resolution is modified, with a unit, of the least significant digit of the indication multimeter.

It is expressed in measuring units like in the case of the measurand (e.g. microvolts, microamperes, etc).

Each DMM reading has a correction due to the finite resolution of the display which is estimated to be 0 V with limits of ± 0,05 V (one half of the magnitude of the least significant digit).

The uncertainty is estimated:

$$u(\delta V_X) = \frac{a_2}{2\sqrt{3}} \quad (5)$$

d) The output value (voltage or current) by the standard, V_S (in the calibration certificate of the standard Fluke 5720A).

Uncertainty of element V_S

The value of measurement uncertainty, $U(V_S)$, stated in the calibration certificate of the standard Fluke 5720A , for $k = 2$, is used.

e) Correction due to drift-time of standard, δV_{SD} , is considered according to data provided by historical standard used.

Uncertainty of element δV_{SD}.

The value of the measurement uncertainty $U(\delta V_{SD})$, stated in the technical book of the standard Fluke 5720A, for $k = 2$, is used, or, if there is a standard history , the drift-time of the values of the standard will be estimated.

$$u(\delta V_{SD}) = \frac{a_3}{2\sqrt{3}} \quad (6)$$

f) Correction applied to the value displayed by the standard due to changes in ambient temperature, δV_{ST} , is applied only when measurements are performed at a temperature diffrent from the reference temperature T_o = 23 ^{0}C and the technical book provides temperature correction coefficients c_{ST}.

Uncertainty of element δV_{ST} is applicable only in case the measurement temperature differs from the reference temperature. In such case, we measure temperature T to which we have noticed a variation a_4.

$$u(\delta V_{ST}) = \frac{a_4 \times c_{ST}}{\sqrt{3}} \quad (7)$$

The composed standard uncertainty is calculated according to the formula:

$$u_c(E_X) = \sqrt{\sum u^2(V_i)} \quad (8)$$

The expanded standard uncertainty (for $k = 2$) associated to the value of measurand is:

$$U = k \times u_c(E_X) \quad (9)$$

In Fig. 2 is given an example of how to draw up a budget of uncertainty when calibrate a digital multimeter. As illustrated in the graph in Fig. 2, the variance due to drift in time of values generated by the standard used, is a percentage of 76 % of the variance combined prepared according to budget uncertainty. Given these results it can be concluded that a decrease of measurement uncertainty can be achieved by reducing the component $u(\delta V_{SD})$.

Uncertainty Budget for 1 V ; f = 1 kHz - DIRECT COMPARISON METHOD

1.T=23ºC ± 5ºC

Quantity	Estimate	Standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	variance combined	variance combined
X_i	x_i	$u(x_i)$		c_i	$u_i(y)$	$u^2_i(y)$	$u^2_i(y)$
Vxmed	0.999730	3.16E-07	Normal	1	3.1623E-07	1.00E-13	$u^2(Vxmed)$
δV_X	0	5.774E-07	Rectangular	1	5.7735E-07	3.33E-13	$u^2(\delta V_X)$
V_S	1.000003	0.000015	Normal	-1	0.000015	2.25E-10	$u^2(V_S)$
δVs_D	0	0.000027	Normal	-1	0.000027	7.02E-10	$u^2(\delta Vs_D)$
E	**-0.00027 V**				**0.0000305 V**		

Standard Uncertainty : *uc(E)*= 0.0305 mV

Expanded Uncertainty : *U* = *k* x *uc(E)* = 2 x 0,0305 mV = 0.0610 mV

E=-0,27 mV *U*= ± 0,06 mV

2.T=32ºC (T ≠To; To=23ºC ± 5ºC)

Quantity	Estimate	Standard uncertainty	Probability distribution	Sensitivity coefficient	Uncertainty contribution	variance combined	variance combined
X_i	x_i	$u(x_i)$		c_i	$u_i(y)$	$u^2_i(y)$	$u^2_i(y)$
Vxmed	0.999730	3.16E-07	Normal	1	3.1623E-07	1.00E-13	$u^2(Vxmed)$
δV_X	0	5.774E-07	Rectangular	1	5.7735E-07	3.33E-13	$u^2(\delta V_X)$
V_S	1.000003	0.000015	Normal	-1	0.000015	2.25E-10	$u^2(V_S)$
δVs_D	0	0.000027	Normal	-1	0.000027	7.02E-10	$u^2(\delta Vs_D)$
$\delta Vs(T)$	0	0.000003	Rectangular	-1	0.000003	1.20E-11	$u^2(\delta Vs(T))$
E	**-0.00027 V**				**0.0000307 V**		

Standard Uncertainty : *uc(E)*=0.0307 mV

Expanded Uncertainty : *U* = *k x uc(E)* = 2 x 0,0307 mV = 0.0613 mV

E=-0,27 mV *U*= ± 0,06 mV

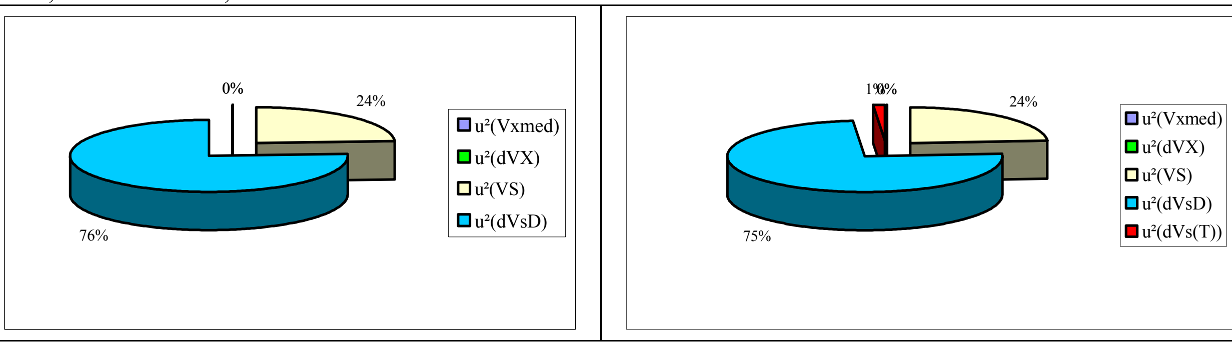
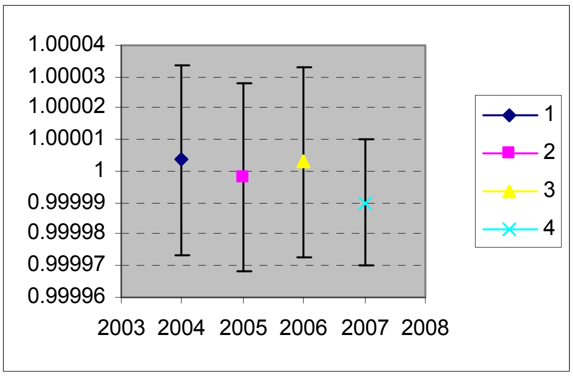


Fig. 2 – Uncertainty budget

Reducing this component, $u(\delta V_{SD})$, can be achieved by studying the behavior in time of the standard used to establish a history of it.

Estimated component, $u(\delta V_{SD})$, is a result of the calculations to determine the appropriate size range a_5, where can be any conventional true value, which can be attributed to measurand generated by the standard used, considering a rectangular distribution.

Year	Applied Value	Frequency	Measured value (V_S)	Uncertainty of measurement $U(V_S)$ P=95 % (k=2)
	V	kHz	V	µV/V
2004	1.000000	1	1.000003	30
2005	1.000000	1	0.999998	30
2006	1.000000	1	1.000003	30
2007	1.000000	1	0.999990	20



Following the calculations, we found that component of combined standard uncertainty, (δV_{SD}), is reduced by 28%. When we consider the history of the standard used to calibrate a digital multimeter, find that, after quadratic composition of all components of uncertainty estimates, the measurement result is affected by an expanded measurement uncertainty of less than 16.7%.

3. CONCLUSIONS

Taking into consideration the observations made and presented graphic examples, consider that for high accuracy measurements, which is to achieve results with a measurement uncertainty as small, will take into account both the working conditions of specific procedures, as well as the specifications, which makes measuring device manufacturer in the technical book. In order to obtain the best performance measurement, using a measuring device will meet the specifications relating to environmental conditions (temperature, humidity, pressure) as well as in technical terms, which refers to the measuring device settings in to obtain the highest measurement accuracy. Study of behavior in time of the standard used in calibrating a measuring device, leading to lower values for expanded measurement uncertainty and hence lead to better performance measurement results.

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