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IMPLEMENTATION AND VALIDATION OF CALIBRATION METHODS IN THE AREA OF HIGH FREQUENCIES

M. Cundeva-Blajer[1]/Presenter, Gj. Dimitrovski[1], K. Demerdziev[1]

[1] Ss. Cyril and Methodius University in Skopje, Faculty of Electrical Engineering and Information Technologies-Skopje, Republic of North Macedonia, mcundeva@feit.ukim.edu.mk

Abstract:
The paper presents a methodology for calibration of high-frequency instruments, such as oscilloscopes, counters and function generators operating above 1 MHz up to GHz level. The methods were developed at the Laboratory for Electrical Measurements at Ss. Cyril and Methodius University in Skopje, following the Calibration Guide EURAMET cg-7. The paper also discusses the challenges of setting up measurement traceability chain and uncertainty evaluation. These methods are important for the region of Southeast Europe, where the metrology facilities for calibration/testing of high frequency electronic devices are not sufficiently developed to meet the needs of the fast-growing automotive supply chain sector.

Keywords: high frequencies calibration, EURAMET cg-7, oscilloscope, electronic components testing

1. INTRODUCTION

The expansion of production facilities in the automotive supply chain in recent years in the region of Southeast Europe has increased the need for the development of testing and calibration facilities for advanced electronic components. However, the conformity assessment bodies in the field of electronic devices are insufficient in the region of Southeast Europe, [1]. This implies the necessity of upgrading the capacities of testing and calibration infrastructure in the area of testing electronic components. One of the most demanding fields is the calibration of high frequency testing devices, such as oscilloscopes, counters and function generators. In this paper, novel calibration methods for instruments for high frequencies over 1 MHz up to GHz level, in compliance with the Calibration Guide EURAMET cg-7 Version 1.0 (06/2011), [2], developed at the Laboratory for Electrical Measurements (LEM) at Ss. Cyril and Methodius University in Skopje (UKIM), will be presented. The establishment of an unbroken measurement traceability chain at high frequencies is an international metrological challenge, [3]. The evaluation of uncertainty due to significant and with unknown properties contributing influential factors, represents a computationally intensive modeling task. As a result of the lack of appropriate metrological facilities, the validation of the developed calibration methods poses further implementation obstacles. In this contribution, the methodology for overcoming these issues and the obtained metrology outputs in the Laboratory of Electrical Measurements at Ss. Cyril and Methodius University in Skopje, are elaborated and discussed.

2. NEEDS ANALYSIS IN THE FIELD OF HIGH FREQUENCY METROLOGY

The field of high frequencies has less developed calibration infrastructure in comparison to other electrical quantities, [5], [8-13]. Furthermore, most of the National Metrology Institutes and accredited calibration laboratories in their published calibration & measurement capabilities (CMCs) demonstrate restricted scopes in the field of high frequencies (mostly up to 1 MHz), [6].

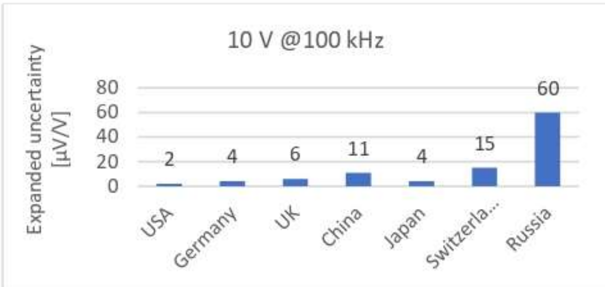

Figure 1. Expanded measurement uncertainties of 10 V voltage @100 kHz at the international NMIs

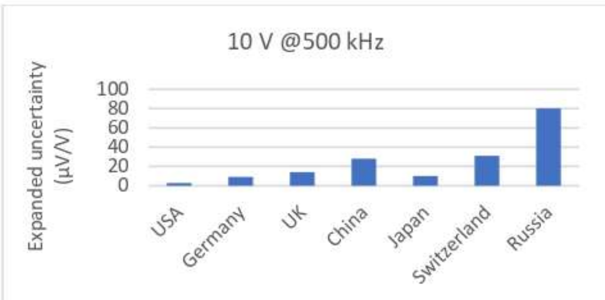

Figure 2. Expanded measurement uncertainties of 10 V voltage @500 kHz at the international NMIs

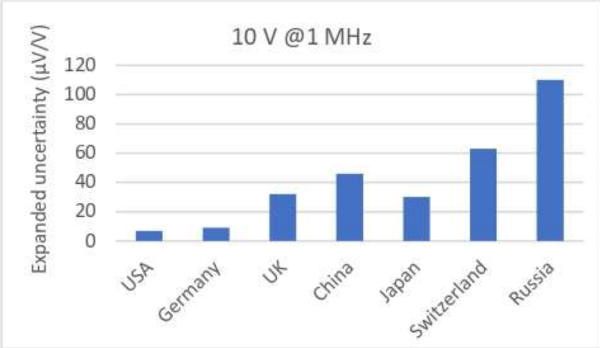

Figure 3. Expanded measurement uncertainties of 10 V voltage @1 MHz at the international NMIs

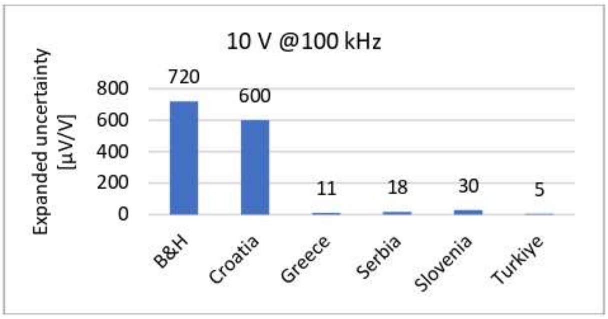

Figure 4. Expanded measurement uncertainties of 10 V voltage @100 kHz at labs in Southeast Europe

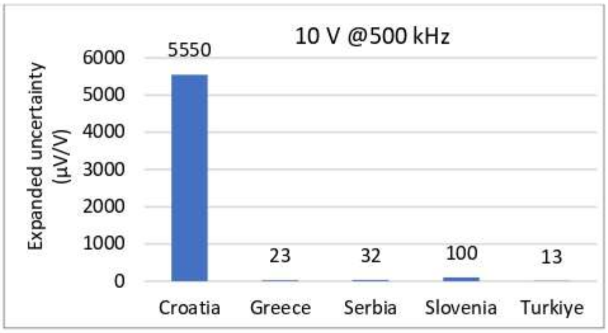

Figure 5. Expanded measurement uncertainties of 10 V voltage @500 kHz at labs in Southeast Europe

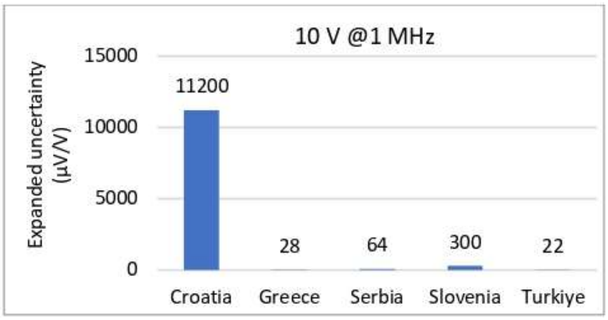

Figure 6. Expanded measurement uncertainties of 10 V voltage @1 MHz at labs in Southeast Europe

The current state-of-the-art in the field of high frequency metrology is presented bellow through the comparison of the best CMCs at international and at regional level of Southeast Europe, where the LEM laboratory is located. In Figures 1-3, a comparison of the best CMCs at international level and in Figure 4-6 at regional level of Southeast Europe for frequencies of 100 kHz, 500 kHz and 1 MHz, are presented, based on the available data in the KCDB database of BIPM, [6]. High frequencies above 1 MHz introduce challenges in the process of calibration and the number of National Metrology Institutes (NMIs) and accredited calibration laboratories which perform these calibrations is restricted, [6], [8-13].

Figure 7. LEM reference standard multifunctional calibrator Transmille 4015 with oscilloscope calibration option SPC600

LEM has been an accredited calibration laboratory for electrical quantities instruments according to ISO 17025:2017 since 2015, [4]. Its personnel is developing a new calibration method for calibration of high frequency instruments (oscilloscopes, counters and function generators), [3] in compliance to the Calibration Guide EURAMET cg-7 Version 1.0 (06/2011), [2].

Table 1. Technical specification of the reference standard for electrical inductance of LEM

Multifunctional Calibrator Transmille 4015	
Supplement to the multifunctional calibrator for calibration of oscilloscopes with frequency range up to 600 MHz Transmille SPC600	
Range	Resolution
2 mV/Div to 10 mV/Div	10 nV
20 mV/Div to 100 mV/Div	100 nV
200 mV/Div to 2 V/Div	1 µV
5 V/Div to 20 V/Div	10 µV
50 V/Div	100 µV
Range:	Best annual accuracy:
DC Voltage 2mV to 50V/Div	0.01 %
AC Voltage 2mV to 50V/Div	0.1 %
Time Base 2ns/Div. to 5s/Div.	5 ppm
Frequency (reference frequency 50 kHz)	30 ppm
Rise time/fall	1 ns
Wave forms	Combined at least up to 100 ns

LEM has recently acquired a reference standard for calibration of oscilloscopes, the Transmille 4015 Multifunctional Calibrator with the option SPC600 for calibration of high frequency instruments i.e., oscilloscopes and counters with frequency range up to 630 MHz illustrated in Figure 7, with technical specification as presented in [7] and in Table 1. It is calibrated in the oscilloscope measurement range at the producer's accredited calibration laboratory with established measurement traceability to national (NPL) and international primary reference standards (BIPM), with an accompanying calibration certificate. The SPC600 option is a built-in black box option of the Transmille 4015 Multifunctional Calibrator and there is no publicly available information on the physical system of the realisation of the reference standard [7].

3. CALIBRATION PROCEDURE FOR HIGH FREQUENCY INSTRUMENTS DEVELOPED IN LEM

The national metrology institutes and the calibration laboratories in the field of electrical quantities develop diverse calibration methods for high frequency instruments i.e. oscilloscopes, counters or function generators, [8-13]. According to the Calibration Guide EURAMET cg-7 Version 1.0 (06/2011), [2] the calibration procedure of oscilloscopes obligatory includes two main stages:

- calibration of the vertical deflection (measurement of the voltage amplitude along the vertical axis),
- frequency bandwidth calibration (frequency measurement along the horizontal axis).

The two stages are independent of each other, but both are necessary to perform a complete oscilloscope calibration procedure. Each set value, generated by the reference standard, is measured repeatedly 12 times according to [2].

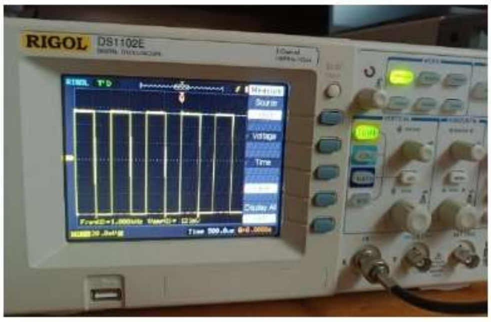

Figure 8. UUT 100 MHz RIGOL DS1102E Oscilloscope calibrated with the Transmille 4015 Multifunctional Calibrator

In this case study, the Laboratory for Electrical Measurements (LEM), validates the developed calibration procedure through real case calibration of a 100 MHz digital oscilloscope RIGOL DS1102E, with technical specification in [14] and presented in Figure 8.

The uncertainty budget, for the both calibration stages (calibration of the vertical deflection and of the frequency bandwidth), is derived by combing data from a component of type A and components of type B, as in GUM, [5] and [15]. The uncertainty of type A, u_A, is calculated from the experimental data subjected to statistical processing, i.e. the mean value, X_{mean}, and the standard deviation of the measurement, s_A, as in:

$$s_A = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_{icor} - X_{mean})^2} \quad (1)$$

where

$$X_{mean} = \frac{1}{n}\sum_{i}^{n} X_{icor} \quad (2)$$

$$X_{icor} = X_i - X_{ref} \quad (3)$$

X_i is the measured value in the particular point and X_{ref} is the reference value from the calibrator. The following uncertainty components are fused in the uncertainty budget of type B, u_B:

u_{res_instr} – from calibrated instrument resolution,
u_{res_refst} – from reference standard resolution
u_{d_refst} – from reference standard drift
u_{c_refst} – from the reference standard calibration

The combined uncertainty of type B equals:

$$u_B = \sqrt{u^2_{res_{instr}} + u^2_{res\_refst} + u^2_{d\_refst} + u^2_{c\_refst}} \quad (4)$$

The total combined uncertainty is:

$$u_c = \sqrt{u_A^2 + u_B^2} \quad (5)$$

The expanded uncertainty deployed in the particular rules for conformity of statement is:

$$U = 2 \cdot u_c \quad (6)$$

The delivery of the combined uncertainty is shown in the Ishikawa diagram in Figure 8.

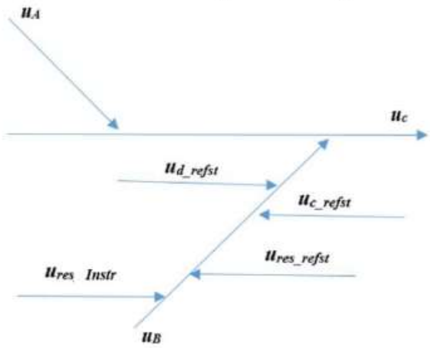

Figure 9. Ishikawa fishbone diagram of the factors in the combined uncertainty budget in calibration of high frequency instrument (valid for the two main oscilloscope parameters - the vertical deviation and the frequency band)

Table 2. Inputs of combined uncertainty budget for calibration of the digital oscilloscope RIGOL DS1102E at 12 V, @1 kHz

U_{ref} [V]	U_{mean} [V]	u_A [V]	u_{res_instr} [V]	u_{d_refst} [V]	u_{c_refst} [V]
12.000	11.97	0.0225	0.00289	0.00842	0.000005

The results of the calculation by using the data fusion concept, [5] at the measurement point of 12 V at frequency of 1 kHz are given in Table 2, with values expressed in V. The derived combined uncertainty is:

$$u_c = 0.024 \text{ V} \quad (7)$$

and the expanded uncertainty is:

$$u = 0.048 \text{ V} \quad (8)$$

Similar methodology for uncertainty calculation in the calibration of the frequency bandwidth at 100 kHz, 500 kHz, 1 MHz and 50 MHz (results above the maximal frequency range of the publicly available CMC) at 1 V voltage, is applied. The results the concrete measurement setting are presented in Table 3.

Table 3. Inputs of combined uncertainty budget for calibration of the frequency bandwidth at different measurement points

f_{ref}	f_{mean}	u_A	u_{res_instr}	u_{d_refst}	u_{c_refst}
100 [kHz]	99.88333 [kHz]	0.50779 [kHz]	0.00289 [kHz]	0.0006 [kHz]	0.00005 [kHz]
500 [kHz]	498.5833 [kHz]	1.0037 [kHz]	0.00289 [kHz]	0.003 [kHz]	0.00005 [kHz]
1 [MHz]	0.998667 [MHz]	0.00604 [MHz]	0.00029 [MHz]	0.000006 [MHz]	0.0000005 [MHz]
50 [MHz]	50.06333 [MHz]	0.04560 [MHz]	0.00289 [MHz]	0.0003 [MHz]	0.000005 [MHz]

The derived combined and expanded uncertainties are provided in Table 4.

Table 4. Combined and expanded uncertainty for calibration of the frequency bandwidth at different measurement points

f_{ref}	u_c	U
100 [kHz]	0.51 [kHz]	1.02 [kHz]
500 [kHz]	1.004 [kHz]	2.008 [kHz]
1 [MHz]	0.006 [MHz]	0.012 [MHz]
50 [MHz]	0.046 [MHz]	0.091 [MHz]

4. SUMMARY AND CONCLUSIONS

The paper provides an analysis of the state-of-the-art CMCs available at international NMIs and laboratories in Southeast Europe for calibration of high frequency instruments. The restrictions of the publicly available CMC at high frequencies level i.e. over 1 MHz, are evident and the metrology gap is clearly identified.

The Laboratory of Electrical Measurements in Skopje has acquired and installed high accuracy class reference standard for high frequency instruments calibration (oscilloscopes or counters), and suitable calibration methods, with experimental validation presented in this contribution, has been developed. The extension of the accreditation scope of LEM over 1 MHz up to 630 MHz, will significantly improve the available high frequency calibration infrastructure. This will contribute to increased quality of the electronic components test facilities in the region, supporting and impacting the specific industries, like the automotive supply chain and wider.

5. ACKNOWLEDGEMENT

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