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Calibration methods for high frequencies: Development and validation

Marija Cundeva-Blajer[1], Gjorgji Dimitrovski[1], Kiril Demerdziev[1], Venceslav Kafedziski[1], Goran Josifovski[1]

[1] *Ss. Cyril and Methodius University in Skopje (UKIM), Faculty of Electrical Engineering and Information Technologies (FEEIT), st. Rugjer Boskovik No. 18, 1000 Skopje, Republic of North Macedonia*

ABSTRACT
The paper presents an introduction of an advanced method for calibration of high-frequency instruments, such as oscilloscopes, frequency counters and function generators that operate at the frequencies between 1 MHz and GHz range. Based on conducted thorough survey of the needs for calibration of high-frequency measurement devices in the region of Southeast Europe, and the identified calibration and measurement capability gap in comparison to the international metrology offer, the Laboratory for Electrical Measurements at Ss. Cyril and Methodius University in Skopje developed new methods, following the general recommendations of the EURAMET cg-7 Calibration Guide. An original approach in the design of the experimental procedure, and a novel data fusion concept for the evaluation of the measurement uncertainty is deployed. The paper also investigates and resolves some challenges of setting up an unbroken measurement traceability chain, and uncertainty estimation for calibration in the domain of high frequencies. The established and accredited calibration capabilities are essential for the region of Southeast Europe, where the metrology facilities for the calibration/testing of high frequency electronic devices are inadequate to meet the conformity assessment needs of the quickly growing automotive supply chain sector, and the needs of other electrical and electronic industries.

Section: RESEARCH PAPER

Keywords: High frequency calibration; EURAMET cg-7; oscilloscope; electronic components testing

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Corresponding author: Marija Cundeva-Blajer, e-mail: mcundeva@feit.ukim.edu.mk

1. INTRODUCTION

The development of testing and calibration facilities for advanced electronic components is identified as an indispensable need, due to the growth of production facilities of electronic components in the automotive supply chain in Southeast Europe in recent years. However, the region has insufficient conformity assessment bodies in the field of electronic devices testing [1]. This implies the necessity for enhancing the testing and calibration infrastructure for electronic components. The calibration of high frequency testing devices, such as oscilloscopes, frequency counters and function generators, is one of the most challenging fields.

Another significant problem in calibration of instruments for high frequencies, is the establishment of an unbroken measurement traceability chain [2]. This is an international metrological issue, identified in published data with restricted traceable high frequency upper limits of the calibration and measurement capabilities (CMCs) of the National Metrology Institutes (NMIs) at the Key Comparison Database (KCDB) of the International Bureau of Weights and Measures (BIPM) [3].

Furthermore, the uncertainty evaluation of the calibration results at very high frequencies, poses a computationally intensive modeling task, due to the significant and unknown factors concerned [4]. The validation of the developed calibration methods is hindered by the lack of appropriate metrological facilities, i.e. restricted options for organization of proficiency testing schemes, inter-laboratory comparisons and other measures for quality assurance and confidentiality of the calibration results.

This paper describes the methodology for addressing these problems and the metrology outputs achieved at the Laboratory for Electrical Measurements at Ss. Cyril and Methodius University in Skopje. The development and adoption of advanced calibration methods for instruments operating from 1 MHz up to GHz frequency range, following the general recommendations of the EURAMET cg-7 Calibration Guide Version 1.0 (06/2011) [4], at the Laboratory for Electrical Measurements (LEM) at Ss. Cyril and Methodius University in Skopje (UKIM) is presented. The contribution illustrates how the metrology infrastructure is being enhanced in two ways by:

a) enabling the traceable measurements, i.e., calibrations of instruments of very high frequencies, that the regional labs cannot offer [2], [5], and
b) capacity building for innovative calibration and measurement uncertainty evaluation by the deploying the data fusion concept [6].

The main goal of this metrology research is the establishment of calibration facility for high frequency devices, complying with the accreditation requirements of ISO/IEC 17025 [7], with an expected outcome to bridge the existing quality infrastructure gap in high frequency testing, in the region of Southeast Europe.

2. NEEDS ANALYSIS IN HIGH FREQUENCY METROLOGY – GAP IDENTIFICATION BETWEEN SOUTHEAST EUROPE AND THE INTERNATIONAL METROLOGY OFFER

Compared to other electrical quantities, the calibration infrastructure for high frequencies is generally less developed [3], [8]-[15]. Moreover, the published CMCs of most of the NMIs in the KCDB database of BIPM and accredited calibration laboratories show limited scopes in the field of high frequencies (published CMCs are mainly with upper frequency limit of up to 1 MHz).

The comparison of the best CMCs of NMIs and accredited calibration labs, at international and regional level of Southeast Europe, where the LEM laboratory is located, illustrates the state-of-the-art in high frequency metrology. The best NMIs CMCs at international level at 100 mV AC voltage, and at 100 kHz, 500 kHz and 1 MHz frequencies, based on the data from the KCDB database of BIPM, are shown in Figure 1.

The best NMIs CMCs at international level at 10 V AC voltage, and at 100 kHz, 500 kHz and 1 MHz frequencies, based on the data from the KCDB database of BIPM, are shown in Figure 2.

The best NMIs CMCs at regional level of Southeast Europe at 100 mV AC voltage, and at 100 kHz, 500 kHz and 1 MHz frequencies, based on the data from the KCDB database of BIPM, are shown in Figure 3.

The best NMIs CMCs at regional level of Southeast Europe at 10 V AC voltage, at 100 kHz, 500 kHz and 1 MHz frequencies, based on the data from the KCDB database of BIPM, are presented in Figure 4.

From the derived data on the expanded uncertainty of AC voltage, at different voltage levels and at different high frequencies, the gap between the best CMCs of the NMIs at international level and the laboratory infrastructure in the region of Southeast Europe, it is evident that the discrepancy reaches more than 2 magnitude orders, while in some cases even measurement capabilities do not exist at all. Therefore, the

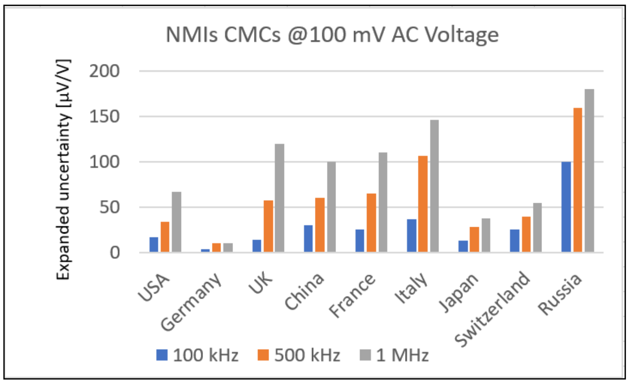

Figure 1. Expanded measurement uncertainties at 100 mV AC voltage and at three different high frequencies – NMIs CMCs at international level.

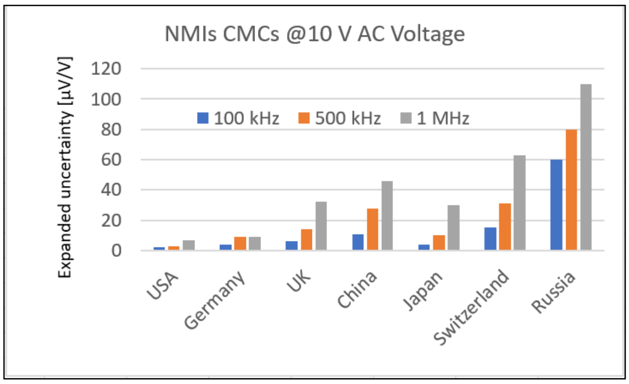

Figure 2. Expanded measurement uncertainties at 10 V AC voltage and at three different high frequencies – NMIs CMCs at international level.

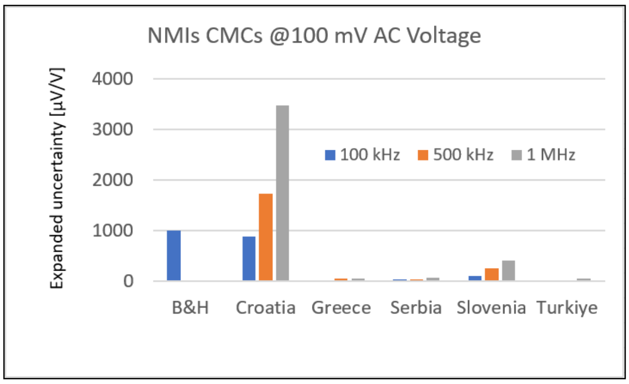

Figure 3. Expanded measurement uncertainties at 100 mV AC voltage and at three different high frequencies – NMIs CMCs at regional level in Southeast Europe.

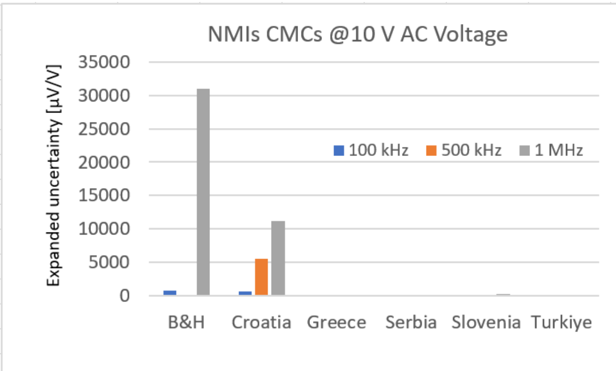

Figure 4. Expanded measurement uncertainties at 10 V AC voltage and at three different high frequencies – NMIs CMCs at regional level in Southeast Europe.

establishment and further accreditation of a calibration facility for high frequency instruments could significantly contribute to metrology infrastructure enhancement and provide profound laboratory capacity building in Southeast Europe.

Furthermore, from the conducted analysis of the international metrology offer, it is evident that high frequencies above 1 MHz pose significant calibration challenges, as the number of NMIs and accredited laboratories that perform these calibrations is limited [3], [8]-[15]. Based on these findings, the relevance of establishment and accreditation of a facility for calibration of measurement devices for frequencies from 1 MHz up to GHz range at the Laboratory for Electrical Measurements (LEM) at the Ss. Cyril and Methodius University in Skopje (UKIM), is fully justified.

3. INTRODUCTION OF CALIBRATION PROCEDURE FOR HIGH FREQUENCY INSTRUMENTS IN LEM

According to ISO 17025:2017, LEM has been an accredited calibration laboratory for instruments measuring electrical quantities since 2015 [5]. Recently, a new calibration method for high frequency instruments (oscilloscopes, frequency counters and function generators), in line with the EURAMET cg-7 Calibration Guide Version 1.0 (06/2011), has been developed. As his guide provides general guidelines for establishing the oscilloscope calibration procedure, some advanced and innovative approaches, such as the data fusion concept for the evaluation of the uncertainty of the calibration results [6], originally developed at LEM, are applied.

The reference standard for oscilloscope calibration at LEM is the Transmille 4015 Multifunctional Calibrator with the SPC600 option, used for calibration of high frequency instruments, such as oscilloscopes and frequency counters, with frequency range of up to 630 MHz. It is a recent acquisition of LEM, displayed in Figure 5, with technical specification as indicated in [16] and in Table 1. The manufacturer's accredited calibration laboratory, calibrated the instrument in the oscilloscope measurement range with measurement traceability to the UK NMI (National Physical Laboratory of United Kingdom - NPL) and international primary reference standards (BIPM), and supplied a calibration certificate. The SPC600 option is a built-in black box option of the Transmille 4015 Multifunctional Calibrator and the physical system realization of the reference standard is not publicly available [16].

4. CALIBRATION METHOD FOR HIGH FREQUENCY INSTRUMENTS: LEM INNOVATIVE DEVELOPMENT APPROACH

Various calibration methods for high frequency instruments, such as oscilloscopes, frequency counters or function generators, are developed by the NMIs and the calibration laboratories for electrical quantities [8]-[13]. The Calibration Guide EURAMET cg-7 states that the oscilloscope calibration procedure must include two main stages:

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

The two stages are independent from each other, but both are required to perform a full oscilloscope calibration procedure. According to the newly introduced calibration procedure at LEM, and in compliance with the Calibration Guide EURAMET cg-7, each set value, generated by the reference standard, is measured 12 times repeatedly, as in [4].

The validity of the developed calibration procedure is confirmed by applying it to two real case scenarios. The artefacts of calibration (units under test-UUT) are:

- UUT Nº 1 - 100 MHz digital oscilloscope RIGOL DS1102E, shown in Figure 6, with technical specification in [17], and
- UUT Nº 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope, owned by the Signal Processing for Communications Laboratory at FEIT, shown in Figure 7 and with technical specification in [18].

The two UUTs are digital oscilloscopes of different accuracy class and of different frequency bandwidth. The selection of the UUTs was made to cover a wide range of instruments to be potentially calibrated in the Laboratory for Electrical Measurements. The UUT Nº 1 - 100 MHz digital oscilloscope RIGOL DS1102E is of a lower accuracy class with a lower frequency range, representing a wider range of typical test equipment in the automotive supply chain sector of electronic components. The UUT Nº 2, the 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope is of a higher accuracy class with a very high frequency bandwidth, representing precise test equipment in the telecommunication sector. The developed calibration procedure is intended to be used with different measurement equipment, and, thus, its validation has to be conducted on different artefacts of calibration.

Figure 5. LEM reference standard - multifunctional calibrator Transmille 4015 with oscilloscope calibration option SPC600.

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 630 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 freq. 50 kHz)	30 ppm
Rise time/fall	1 ns
Wave forms	Combined at least up to 100 ns

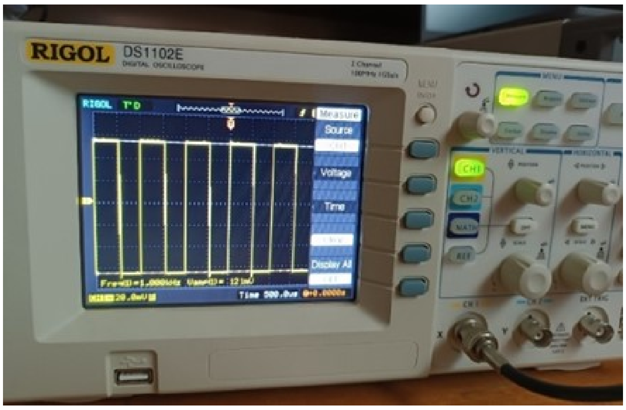

Figure 6. UUT Nº 1 - 100 MHz RIGOL DS1102E Oscilloscope calibrated with the Transmille 4015 Multifunctional Calibrator.

Figure 7. UUT Nº 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope calibrated with the Transmille 4015 Multifunctional Calibrator.

To obtain the uncertainty budget for the two calibration stages (calibration of the vertical deflection and of the frequency bandwidth), data from a component of type A and components of type B are fused, following the guidelines of GUM [19], by deploying the original LEM data fusion concept presented in [6], and by complying with the recommendations of the Euramet Guide [4].

The type A uncertainty u_{A} is derived from the statistical analysis of the experimental data, namely the mean value X_{mean} and the standard deviation of the measurement s_{A} as shown in:

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

where

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

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

X_i is the measured value in the particular measurement point and X_{ref} is the reference value from the calibrator. The following uncertainty components are fused as in [6], in the type B uncertainty budget u_{B}:

$u_{\mathrm{res\_instr}}$ – from the calibrated instrument resolution,
$u_{\mathrm{res\_refst}}$ – from the reference standard resolution,
$u_{\mathrm{d\_refst}}$ – from the reference standard drift,
$u_{\mathrm{c\_refst}}$ – from the reference standard calibration.

The combined uncertainty of type B equals:

$$u_{\mathrm{B}} = \sqrt{u^2_{\mathrm{res\_instr}} + u^2_{\mathrm{res\_refst}} + u^2_{\mathrm{d\_refst}} + u^2_{\mathrm{c\_refst}}}\,. \quad (4)$$

The total combined uncertainty is:

$$u_{\mathrm{c}} = \sqrt{u^2_{\mathrm{A}} + u^2_{\mathrm{B}}}\,. \quad (5)$$

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

$$u = 2 \cdot u_{\mathrm{c}}\,. \quad (6)$$

The Ishikawa diagram in Figure 8, illustrates how the combined uncertainty is obtained, using the LEM data fusion approach. The U_{mean} in Table 2 to Table 5 is the mean value calculated from the 12 numerically displayed values of the voltage when measuring the vertical deflection.

The analysis is conducted at two voltage levels:

- 120 mV, as in Table 2 for the UUT Nº 1 - 100 MHz RIGOL DS1102E Oscilloscope and Table 4 for the UUT Nº 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (results for Channel 1) and the following corresponding calculations, and

- 12 V as in Table 3 for UUT Nº 1 and in Table 5 for UUT Nº 2, each at a frequency of 1 kHz square wave without DC component.

Table 2 provides the absolute values in mV of uncertainty components used in the data fusion concept, at the measurement point of 120 mV and frequency 1 kHz, in the process of calibration of the UUT Nº - 1 digital oscilloscope RIGOL DS1102E.

The combined uncertainty is derived as follows:

$$u_{\mathrm{c}} = 0.18\ \mathrm{mV} \quad (7)$$

and the expanded uncertainty is:

$$U = 0.37\ \mathrm{mV}\,. \quad (8)$$

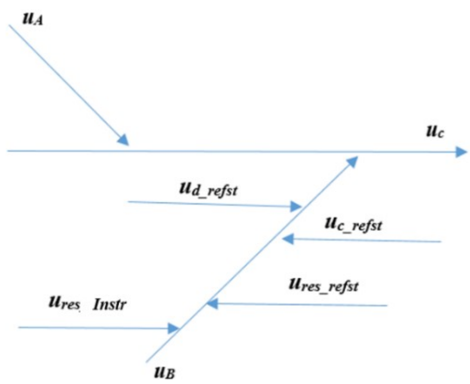

Figure 8. Ishikawa fishbone diagram of the influential factors fused in the combined uncertainty budget in calibration of high frequency instrument (valid for the two main oscilloscope parameters - the vertical deviation and the frequency band).

Table 2. Inputs of combined uncertainty budget for calibration of the UUT Nº 1 - digital oscilloscope RIGOL DS1102E at 120 mV, @1 kHz.

U_{ref} in mV	U_{mean} in mV	u_{A} in mV	$u_{\mathrm{res\_instr}}$ in mV	$u_{\mathrm{d\_refst}}$ in mV	$u_{\mathrm{c\_refst}}$ in mV
120.00	120.50	0.1508	0.00289	0.1040	0.00065

Table 3 shows the absolute values in V of uncertainty components used in the data fusion concept, at the measurement point of 12 V and frequency 1 kHz, in the process of calibration of the UUT N° 1 - digital oscilloscope RIGOL DS1102E. The combined uncertainty is derived as follows:

$$u_{\mathrm{c}} = 0.024\ \mathrm{mV} \tag{9}$$

and the expanded uncertainty is:

$$U = 0.048\ \mathrm{mV}\,. \tag{10}$$

Table 4 provides the absolute values in mV of uncertainty components used in the data fusion concept, at the measurement point of 120 mV and frequency 1 kHz, in the process of calibration of the UUT N° 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1). The combined uncertainty is derived as follows:

$$u_{\mathrm{c}} = 0.12\ \mathrm{mV} \tag{11}$$

and the expanded uncertainty is:

$$U = 0.23\ \mathrm{mV}\,. \tag{12}$$

Table 5 shows the absolute values in V of uncertainty components used in the data fusion concept, at the measurement point of 12 V and frequency 1 kHz, in the process of calibration of the UUT No 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1). The combined uncertainty is derived as follows:

$$u_{\mathrm{c}} = 0.0096\ \mathrm{mV} \tag{13}$$

and the expanded uncertainty is:

$$U = 0.019\ \mathrm{mV}\,. \tag{14}$$

The similar data fusion approach [6], for calculating the uncertainty in the calibration of the frequency bandwidth at 100 kHz, 500 kHz, 1 MHz and 50 MHz (the 50 MHz results are beyond the maximum frequency range of the NMIs' CMCs that are publicly accessible in the KCDB of BIPM) at 1 V voltage, is applied. The f_{mean} in Table 6 and Table 8 is the mean value calculated from the 12 numerically displayed values of the frequency when measuring the frequency bandwidth.

Table 6 provides the uncertainty components and Table 7 shows the obtained combined and expanded uncertainty at 100 kHz, 500 kHz, 1 MHz and 50 MHz (the 50 MHz results are beyond the maximum frequency range of the NMIs' CMCs that are publicly accessible in the KCDB of BIPM) in the calibration process of the frequency bandwidth of the UUT N° 1 - digital oscilloscope RIGOL DS1102E at 1 V voltage.

Table 8 provides the uncertainty components and Table 9 shows the obtained combined and expanded uncertainty at 5 MHz, 50 MHz and 500 MHz (all these results far beyond the maximum frequency range of the NMIs' CMCs that are publicly available in the KCDB of BIPM), in the calibration process of the frequency bandwidth of the UUT N° 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1) at 1 V voltage.

5. DISCUSSION AND CONCLUSIONS

The current metrology offer for calibration of high frequency instruments is thoroughly analyzed, through a survey of the CMCs published in the KCDB of BIPM by NMIs and laboratories at international level and in the region of Southeast Europe. The limitations of the publicly accessible CMCs at high

Table 3. Inputs of combined uncertainty budget for calibration of the UUT N° 1 digital oscilloscope RIGOL DS1102E at 12 V, @1 kHz.

U_{ref} in V	U_{mean} in V	u_{A} in V	$u_{\mathrm{res\_instr}}$ in V	$u_{\mathrm{d\_refst}}$ in V	$u_{\mathrm{c\_refst}}$ in V
12.000	11.97	0.0225	0.00289	0.00842	0.000005

Table 4. Inputs of combined uncertainty budget for calibration of the UUT N° 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1) at 120 mV, @1 kHz.

U_{ref} in mV	U_{mean} in mV	u_{A} in mV	$u_{\mathrm{res\_instr}}$ in mV	$u_{\mathrm{d\_refst}}$ in mV	$u_{\mathrm{c\_refst}}$ in mV
120.00	118.87	0.05091	0.00289	0.1040	0.00065

Table 5. Inputs of combined uncertainty budget for calibration of the UUT N° 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1) at 12 V, @1 kHz.

U_{ref} in V	U_{mean} in V	u_{A} in V	$u_{\mathrm{res\_instr}}$ in V	$u_{\mathrm{d\_refst}}$ in V	$u_{\mathrm{c\_refst}}$ in V
12.000	11.90	0.0045	0.00029	0.00842	0.000005

Table 6. Inputs of combined uncertainty budget for calibration of the frequency bandwidth of the UUT N° 1 - digital oscilloscope RIGOL DS1102E at 1 V voltage.

f_{ref}	f_{mean}	u_{A}	$u_{\mathrm{res\_instr}}$	$u_{\mathrm{d\_refst}}$	$u_{\mathrm{c\_refst}}$
in kHz	in kHz	in kHz	in kHz	in kHz	in kHz
100	99.88333	0.50779	0.00289	0.0006	0.00005
500	498.5833	1.0037	0.00289	0.003	0.00005
in MHz	in MHz	in MHz	in MHz	in MHz	in MHz
1	0.998667	0.00604	0.00029	0.000006	0.0000005
50	50.06333	0.04560	0.00289	0.0003	0.000005

Table 7. Combined and expanded uncertainty for calibration of the frequency bandwidth of the UUT N° 1 - digital oscilloscope RIGOL DS1102E at 1 V voltage.

f_{ref}	u_{c}	U
in kHz	in kHz	in kHz
100	0.51	1.02
500	1.004	2.008
in MHz	in MHz	in MHz
1	0.006	0.012
50	0.046	0.091

Table 8. Inputs of combined uncertainty budget for calibration of the frequency bandwidth of the UUT N° 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1) at 1 V voltage.

f_{ref}	f_{mean}	u_{A}	$u_{\mathrm{res\_instr}}$	$u_{\mathrm{d\_refst}}$	$u_{\mathrm{c\_refst}}$
in MHz	in MHz	in MHz	in MHz	in MHz	in MHz
5	5.0137	0.0035	0.000029	0.007	0.00001
50	50.005	0.0156	0.00029	0.07	0.0003
500	499.97	0.34	0.0029	0.7	0.0006

Table 9. Combined and expanded uncertainty for calibration of the frequency bandwidth of the UUT N° 2 - 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope (Channel 1) at 1 V voltage.

f_{ref}	u_{c}	U
in MHz	in MHz	in MHz
5	0.0078	0.016
50	0.072	0.14
500	0.78	1.56

frequencies i.e. above 1 MHz, are evident and the metrology gap is well identified, and, especially, the discrepancy of the metrology infrastructure in the region of Southeast Europe and the international metrology current state-of-the-art. It can be concluded that the international chain of measurement traceability above 1 MHz is not completely established, which imposes the necessity of further development of the metrology of high frequencies.

The Laboratory for Electrical Measurements in Skopje has obtained and set up a high accuracy class reference standard for calibrating high frequency instruments (oscilloscopes, function generators or frequency counters), and developed suitable calibration methods, with experimental validation presented in this paper. The original LEM data fusion concept for the evaluation of the uncertainty of the measurement results was used in the methods development. The methods are validated through two real artefacts calibration i.e., digital oscilloscopes of different accuracy and different frequency bandwidth. The developed procedures are proven to be adequate for the purpose of calibration, even for oscilloscopes of extremely high frequency bandwidth, such as the 3 GHz Rohde & Schwarz RTO2034 4-channel Oscilloscope. This was also confirmed through a successful peer assessment procedure for extension of the accreditation scope of LEM, which was accomplished by the Institute of Accreditation of Republic of North Macedonia on 22.09.2023 [20].

The proposed data fusion concept is universal and can be used in the development of other calibration/testing methods for extension of the laboratory's CMC and accreditation scope.

The extension of the LEM accreditation scope in the frequency range between 1 MHz and 630 MHz, is going to enhance the available high frequency calibration infrastructure, and this refers especially to the region of Southeast Europe. The establishment of this calibration facility also facilitates the further implementation of proficiency testing schemes and inter-laboratory comparisons in calibration of high frequency instruments as well as insuring unbroken traceability chain of the high frequency measurements, which have previously not been possible in this European region. This will improve the quality of the electronic component testing facilities in the region of Southeast Europe, as well as other high frequency measurements, supporting and influencing specific industries, such as the automotive supply chain, the production of electronic components and the telecommunications sector.

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REFERENCES

[1] SeeNext EOOD, Automotive Industry in Southeast Europe, Report, 2003 Edition. Online [Accessed 11 August 2024] https://seenext.org/reports/automotive-industry-in-southeast-europe-2023-edition/

[2] M. Čundeva-Blajer, Gj. Dimitrovski, V. Sapundžiovski, V. Dimčev, K. Demerdžiev, Infrastructure Development For Extreme Electrical Metrology, Jour. Elect. Eng. and Inf. Tech., Vol. 7, No. 2, 2022, pp. 101–109. DOI: 10.51466/JEEIT2272201101chb

[3] BIPM, Website. Online [Accessed 28 June 2023] https://www.bipm.org

[4] EURAMET, Calibration Guide cg-7: Calibration of Measuring Devices for Electrical Quantities Calibration of Oscilloscopes, Version 1.0 (06/2011). https://www.euramet.org/Media/docs/Publications/calguides/EURAMET_cg-7__v_1.0_Calibration_of_Oscilloscopes.pdf

[5] K. Demerdziev, M. Cundeva-Blajer, V. Dimcev, M. Srbinovska, Z. Kokolanski, Improvement of the FEIT Laboratory of Electrical Measurements Best CMC Through Internationally Traceable Calibrations and Inter-Laboratory Comparisons, Int. Conf. ETAI 2018, Struga, R. Macedonia, 20-22 September 2018 (ETAI 6-4)

[6] M. Cundeva-Blajer, Data Fusion for Uncertainty Evaluation in Extreme Electrical Metrology, Proc. Int. Con. Measurement, Quality and Data Science MQDS 2023, Bordeaux, France, 5-7 June 2023.

[7] ISO, ISO/IEC 17025: 2017 General requirements for the competence of testing and calibration laboratories

[8] Y. Kuojun, P. Zhixiang, S. Jiali, Y. Peng, A fast baseline and trigger level calibration method in digital oscilloscope, 2019 IEEE I²MTC, Auckland, New Zealand, 2019, pp. 1-6. DOI: 10.1109/I2MTC.2019.8827158

[9] C. Cho, J.-G. Lee, P. Hale, J. A. Jargon (+ another 3 authors), Calibration of channel mismatch in time-interleaved real-time digital oscilloscopes, 85th Microwave Measurement Conf. (ARFTG), Phoenix, AZ, USA, 22 May 2015, pp. 1-5. DOI: 10.1109/ARFTG.2015.7162896

[10] W. Weifeng, Z. Yijiu, Y. Zhonghao, H. Hui, Z. Shanshan, Design of automatic calibration in digital oscilloscope, 2019 14th IEEE Int. Conf. on Electronic Measurement & Instruments (ICEMI), Changsha, China, 2019, pp. 79-85. DOI: 10.1109/ICEMI46757.2019.9101611

[11] M. Bieler, S. Seitz, M. Spitzer (+ another 6 authors), Rise-Time Calibration of 50-GHz Sampling Oscilloscopes: Intercomparison Between PTB and NPL, IEEE Trans. on Instrumentation and Measurement, vol. 56, no. 2, April 2007, pp. 266-270. DOI: 10.1109/TIM.2007.890609

[12] C. Cho, J. -G. Lee, T.-W. Kang, N.-W. Kang, Calibration of sample-time error in a sampling oscilloscope and uncertainty analysis, CPEM 2016, Ottawa, Canada, pp. 1-2. DOI: 10.1109/CPEM.2016.7540669

[13] K. Dongju, L. Joo-Gwang, L. Dong-Joon, C. Chihyun, Traceable calibration for a digital real-time oscilloscope with time interleaving architecture, 2018 Meas. Sci. Tech. 29, 2018, 015003. DOI: 10.1088/1361-6501/aa892c

[14] Gj. Dimitrovski, M. Cundeva-Blajer, K. Demerdziev, Contribution to Improved Measurement and Calibration Capabilities in the Field of Measuring Instruments for High-Frequencies, Journal of Electrical Engineering and Information Technologies 2022, Volume 8, No. 2, pp. 101-107. DOI: 10.51466/JEEIT2382211111d

[15] M. Cundeva-Blajer, Gj. Dimitrovski, K. Demerdziev Implementation and Validation of Calibration Methods in the Area of High Frequencies, Proceedings of the IMEKO TC8&TC11&TC24 Joint International Conference, Funchal-Madeira Islands, Portugal, 11-13 October 2023, DOI: 10.21014/tc11-2023.05

[16] Transmille, Transmille 4015 Adavnced Multiproduct Calibrator. Extended Specifications, Transmille, UK 2022. Online [Accessed 11 August 2024] https://www.transmille.com/download/4015-extended-specifications-v1-2/#

[17] Rigol, User's Guide, DS1000E, DS1000D Series, Digital Oscilloscopes, Sept.2010.

[18] Rhode & Schwarz, RTO2000 Oscilloscope, Product Brochure Version 20.00, April 2021
[19] BIPM, Evaluation of measurement data-Guide to the expression of uncertainty in measurement, JCGM 100:2008 GUM. Online [Accessed 11 August 2024] https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf
[20] Institute of Accreditation of the Republic of North Macedonia, Website. Onliune [Accessed 4March 2024] https://iarm.gov.mk/en/homepage/