Bundesamt für Eich- und Vermessungswesen

Bundesamt für Eich- und
Vermessungswesen (BEV)
Vienna, Austria

Report on on-going CCL Key Comparison for the period 2018 to 2020

Comparison of optical frequency and wavelength standards

CCL-K11

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Vienna, Austria, December 2021

Contents

1 Document control

Version Draft B	Issued on 04. August 2021
Version Draft B.2	Issued on 03. September 2021 (misspelling for NMISA laser corrected)
Version Final	Issued on 10. December 2021

2 Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

At its meeting in September 2007, the CCL decided upon a key comparison of optical frequency and wavelength standards, named CCL-K11, with BEV as the pilot laboratory. The comparison was registered in 2008 and it is supposed as an on-going comparison.

The scheme outlined in this document covers the technical procedure to be followed during the measurements. The goal of the CCL key comparisons is to demonstrate the equivalence of routine calibration services offered by NMIs to clients, as listed in Appendix C of the Mutual Recognition Agreement (MRA). To this end, participants in this comparison agree to use the same apparatus and methods as routinely applied to calibrations of client artefacts.

By their declared intention to participate in this key comparison, laboratories accept the general instructions and to strictly follow the technical protocol of this document.

This document constitutes the tenth final report for the ongoing key comparison CCL-K11.

2.1 Technical protocol version

As an on-going comparison the technical protocol of CCL-K11 was updated to account for unforeseeable events. Additionally it was desirable to clarify the calculations of the KCRV and to streamline the reporting needs.

The campaign reported here spanned a period of three years. During this time the technical protocol was updated incrementally but in essence the individual comparisons were in line with the current approved version 3.0. The measurement reports (Draft A reports) in Appendix A have been reformatted somewhat for a standardized look.

3 Organization

3.1 Participants

Table 1. List of participant (and node) laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
BEV (pilot, node)	Michael Matus Bundesamt für Eich- und Vermessungswesen (BEV) Arltgasse 35, 1160 Wien Austria	Tel. +43 1 21110 826540 E-mail: michael.matus@bev.gv.at
MIRS	Lucija Črepinšek Lipuš University of Maribor, Faculty of Mechanical Engineering Smetanova 17, 2000 Maribor Slovenia	Tel. +386 2 220 7762 E-Mail: lucija.lipus@um.si
NMISA	Faith Hungwe National Metrology Institute of South Africa (NMISA) Building 5 CSIR Campus, Brummeria, Pretoria 0184 South Africa	Tel. +27 12 841 4936 E-mail: fhungwe@nmisa.org
EIM	Christos Bantis Hellenic Institute of Metrology (EIM) Industrial Area of Thessaloniki, Block 45 57022 Sindos, Thessaloniki Greece	Tel. +30 2310 569 952 E-mail: bandis@eim.gr
BFKH	Gábor Szikszai Government Office of the Capital City Budapest (BFKH) 37-39 Németvölgyi road, Budapest 1124 Hungary	Tel. +36 1 458 5854 E-mail: szikszai.gabor@bfkh.gov.hu

3.2 Schedule

Table 2 lists the measurements in chronological order, specifying the participants, the places and the dates. It is a characteristic of this comparison to receive the data immediately after completing the measurements which are performed in the respective node or host laboratories. For the period 2018 to 2020 four participants took part in the comparison.

Table 2. Schedule of the comparison.

RMO	Laboratory (country code)	Date of measurement	Node laboratory (place of measurements)	Comments
EURAMET	MIRS (SI)	November 2018	BEV	2nd participation
AFRIMETS	NMISA (ZA)	November 2018	BEV	2nd participation
EURAMET	EIM (GR)	January 2019	BEV	–
EURAMET	BFKH (HU)	February 2020	BEV	2nd participation (then MKEH)

4 Artefacts

4.1 Description of artefacts

The artefacts in this campaign are iodine stabilized HeNe-lasers at λ ≈ 633 nm, stabilized on the f component of the $^{127}I_2$ R(127) 11-5 transition. The designation of the artefacts, as chosen by the owner, is given in table 3.

Table 3. Artefacts participating**.**

Laboratory (country code)	Designation of standard	Description
MIRS (SI)	MIRS1	MeP, Lasertex Ltd., Wroclaw, Poland LJSC-3-11, 1/2008
NMISA (ZA)	NMISA-MUFASA	MeP, Winters Electro Optics, W100, SN: 294
EIM (GR)	EIM-1	MeP, NPL type, SN: LL0401/R16
BFKH (HU)	BFKH-1	MeP, Winters Electro Optics, W100, SN: 237

5 Measuring instructions

5.1 Measurands

All measurements reported here were performed according to the so-called method m1 as discussed in Appendix E of the technical protocol (Absolute frequency measurement traceable to the realisation of the SI second). The setup of the node laboratory is outlined in the Appendix A of this report.

In advance of to the actual measurements each participating laboratory had to state:

- The expected frequency of the standard, f_e. This should normally be the frequency used in their calibration service. It is either the recommended value or a value determined by some other means.
- The standard uncertainty u_e of the expected value. This should be a value compatible with the uncertainty given in the CMC for this service (if applicable).
- The operational parameters used to obtain the two values mentioned above (if applicable).
- Sensitivity coefficients with uncertainties for parameters appearing in the uncertainty budget for the standard (if applicable).

The stated frequency f_e is the actual measurand in this type of key comparison. It is compared on a per lab basis with the measured frequency f_m possibly corrected to the reference operational parameters as given below. One has to note, that the comparison is blind; the participant are not told the result of the measurement before stating their value for f_e.

The standard uncertainty of the determined frequency is composed of two parts, one from the frequency measurement, u_0, and one from the uncertainty in the settings of the working (and other) parameters, u_p. The latter, the uncertainties related to the standard itself are to be estimated by each operator in accordance with their quality system. The uncertainty stemming from the measurements, u_0, is estimated by the operator of the experiment alone, or together with personnel involved in the comparison, again in accordance with a quality procedure. These uncertainties are reported in appendix C.2 and C.3 of the Technical Protocol and are given as standard uncertainties following GUM practice.

The combined uncertainty of u_0 and u_p , u_m, reported in C.4 of the technical protocol is given as the root sum squares of u_0 and u_p.

Table 4 gives the values used for the most important reference working parameters for the respective laser. Additional information can be found in the appendix.

Table 4. Reference working parameter values for the standards as given in B.3 of the measurement report included in the appendix.

Standard	Power in µW	Modulation width (peak to peak) in MHz	I_2 cold-finger temperature in °C	Cell wall temperature in °C
MIRS1	60	6.0	15.0	25
NMISA-MUFASA	70	6.0	15.0	25
EIM-1	86	6.0	15.0	25
BFKH-1	90	6.0	15.0	25

6 Results

6.1 Results and standard uncertainties as reported by participants

The stated frequencies f_e, the measured frequencies f_0 (see section 7) and f_m are given in table 5. The allocated standard uncertainties u_e, u_0 and u_m, respectively, are included in parenthesis.

NMISA and EIM estimate f_e and u_e from the values as published in the MEP 2003 when the standards are operated at the working conditions as laid out in table 4.

MIRS and BFKH make use of a long history of comparisons and absolute laser frequency calibrations to estimate the respective values.

The data from table 5 are used to calculate the final results according to equations (5-7). The results are given in table 6 and figure 1, respectively.

Table 5. Expected frequency f_e, measured (uncorrected) frequency f_0, and measured frequency, corrected for influence of operational parameters f_m , together with the respective standard uncertainties of the values.

Standard	All frequencies given are offset by 473 612 353 MHz		
	f_e (u_e) / kHz	f_0 (u_0) / kHz	f_m (u_m) / kHz
MIRS1	600.0 (12.0)	603.383 (0.118)	604.655 (2.835)
NMISA-MUFASA	604.0 (10.0)	602.068 (0.064)	598.520 (2.091)
EIM-1	604.0 (10.0)	607.133 (0.205)	607.802 (2.814)
BFKH-1	607.2 (12.0)	608.565 (0.116)	607.072 (3.534)

Table 6. Degree of equivalence and E_n value for the standard.

Standard	Δf_r	$U_r = 2u_r$	$E_n = \Delta f_r / U_r$
MIRS1	$-9.8 \cdot 10^{-12}$	$52.1 \cdot 10^{-12}$	−0.19
NMISA-MUFASA	$+11.6 \cdot 10^{-12}$	$43.1 \cdot 10^{-12}$	+0.27
EIM-1	$-8.0 \cdot 10^{-12}$	$43.9 \cdot 10^{-12}$	−0.18
BFKH-1	$+0.3 \cdot 10^{-12}$	$52.8 \cdot 10^{-12}$	+0.01

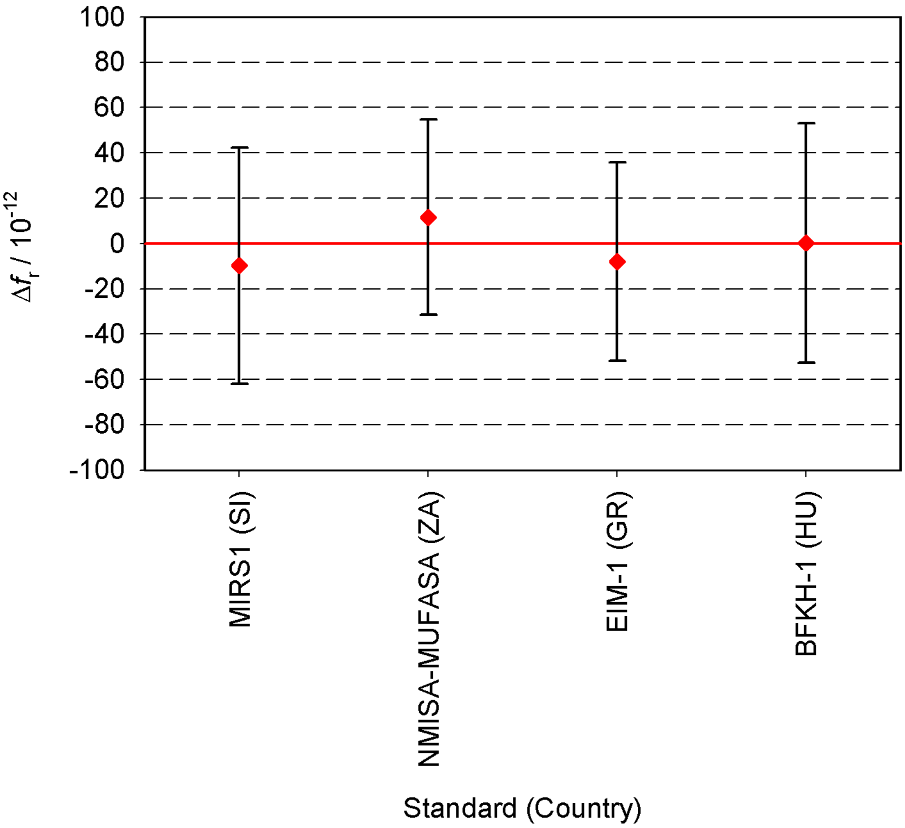

Figure 1. Relative degree of equivalence for the standards. Error bars represent the relative expanded uncertainties $U_r(i)$ for $k = 2$.

7 Analysis

7.1 Calculation of the key comparison reference value (KCRV)

It is a distinctive feature of this key comparison, that the KCRV is determined on a per participant basis. Thus each participant has its own KCRV which is used to test consistency.

Denote the measured (uncorrected) frequency f_0 with standard uncertainty u_0, and the measured frequency, corrected for influence of operational parameters f_m with standard uncertainty u_m.

$$f_m = f_0 + f_p \tag{1}$$

The symbol f_p denotes the condensed information about the influence of the actual working parameters and other quantities on the laser frequency. It is defined here as a correction so it must be added to the raw value. A linear model is usually sufficient:

$$f_\mathrm{p} = \sum_i s_i \cdot \Delta x_i \tag{2}$$

Where the s_i denotes the sensitivity coefficients and Δx_i the deviations of the respective working parameters from the reference values (care must be taken choosing the correct signs for both quantities). The uncertainties are thus derived in a straightforward way as:

$$u_\mathrm{p} = \sqrt{\sum_i \left(u(s_i)\cdot \Delta x_i\right)^2 + \sum_i \left(s_i \cdot u(\Delta x_i)\right)^2} \tag{3}$$

and

$$u_\mathrm{m} = \sqrt{u_\mathrm{p}^2 + u_0^2} \tag{4}$$

In the case that no correction due to working parameters is requested by the participant, one can formally set f_p and u_p equal to zero.

Denote the expected frequency f_e with standard uncertainty u_e, and the measured frequency, corrected for influence of operational parameters f_m with standard uncertainty u_m. In the nomenclature of the CIPM-MRA f_m (together with its standard uncertainty u_m) denotes the KCRV and f_e (together with its standard uncertainty u_e) denotes the measurand.

For a particular standard, i, construct the dimensionless quantities

$$\Delta f_\mathrm{r}(i) = \frac{f_\mathrm{e}(i) - f_\mathrm{m}(i)}{f_\mathrm{m}(i)} \tag{5}$$

$$u_\mathrm{r}(i) = \frac{\sqrt{u_\mathrm{e}^2(i) + u_\mathrm{m}^2(i)}}{f_\mathrm{m}(i)} \tag{6}$$

It must be noted that f_e and f_m should be transferred to the same (usually nominal) working parameters for the standard, which would be expected to coincide with those for which f_e is valid if no other instructions are given by the participating laboratory.

7.2 Calculation of Degrees of Equivalence

To test consistency between the measured values and the expected ones, hypothesis testing at a confidence level of 95 % is to be performed. The result will serve as a basis for the review of the CMC and indicate the compatibility with the claimed capabilities. In this framework the "degree of equivalence" (DoE) can be obtained in the usual way. Thus the (relative) DoE is Δf_r (equ. 5) with its standard uncertainty u_r (equ. 6). The consistency can thus be checked by the following condition:

$$-1 \le E_\mathrm{n} = \frac{\Delta f_\mathrm{r}(i)}{U_\mathrm{r}(i)} \le 1 \quad \text{with} \quad U_\mathrm{r}(i) = 2 \cdot u_\mathrm{r}(i) \tag{7}$$

As discussed at the 14th CCL meeting, June 2009, it is neither necessary nor useful to determine a pair-wise degree of equivalence. For all results reported the expanded uncertainty to a 95 % confidence level can be obtained by multiplying the standard uncertainties with k = 2.

7.3 Discussion of results

Frequency measurements have been carried out on four national wavelength standards. A good agreement between the stated and the measured frequency values was found.

All participants have respective CMC for this kind of service. The entry for NMISA is apparently erroneous (maybe caused by the transformation to KCDB 2.0). The uncertainties stated in this comparison are equal to or smaller than the claimed CMC uncertainty. Since the actual entries in the KCDB allow for some flexibility, the values summarized in table 7 are somewhat homogenized.

Table 7. CMCs and claimed uncertainties in the comparison (expanded uncertainties for k = 2)

Laboratory (country code)	$U_e = 2u_e$		U_{CMC}	KCDB entry
MIRS1 (SI)	24 kHz	≤	24 kHz	2.4E1 kHz @ 474 THz
NMISA (ZA)	20 kHz	<	2.4 MHz	2.4E0 MHz @ 474 THz[1]
EIM (GR)	20 kHz	<	24 kHz	4.0E-2 fm @ 633 nm
BFKH (HU)	24 kHz	≤	24 kHz	2.4E1 kHz @ 474 THz

7.4 Linking of result to other comparisons

Plotting the DoE of all participants in the same graph links the results of this on-going key comparison as shown in Figure 2. This is possible even for different nominal frequencies since the DoE are defined as relative quantities.

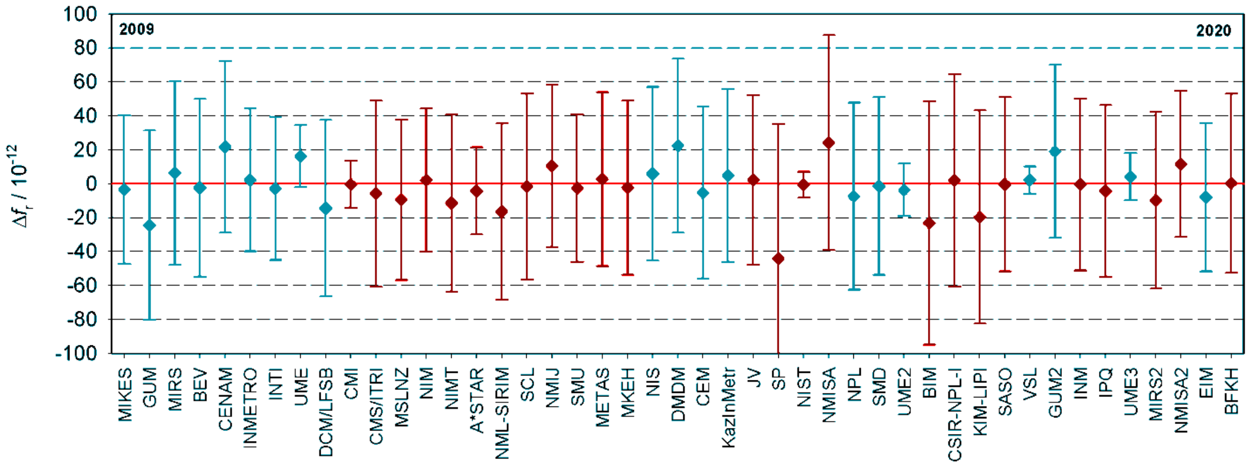

Figure 2. Relative degree of equivalence for all standards taking part in CCL-K11 since the start of this comparison. Error bars represent the relative expanded (for k = 2) uncertainties $U_r(i)$.

Appendix A Equipment and measuring processes of the participants

Details on the individual equipment and standards can be found in the following measurement reports These files are electronic copies; the respective node laboratories keep the signed originals.

[1] At the time of writing the entry in the KCDB 2.0 was 10 %. This is obviously a changeover mistake. The value stated here is taken from the current accreditation scope which is in line with the "old" KCDB value.

Participant data

Details of the participant must be provided in advance to the actual measurements by sending the completed Table A to the pilot lab's contact (michael.matus@bev.gv.at). An agreement with the node laboratory is a matter of course. The actual date of measurement might be updated in the final report at a later stage.

A.1 Participant data	
Laboratory (Country code)	MIRS (SI) Metrology Institute of republic Slovenia, Laboratory for Production Measurements
RMO	EURAMET
Contact person, Operator	Lucija Črepinšek Lipuš
Address	University of Maribor, Faculty of Mechanical Engineering Smetanova 17, 2000 Maribor Slovenia
Phone, Fax, Email	Tel. +386 2 220 7762 E-Mail: lucija.lipus@um.si
Artefact's designation	MIRS1
CMC	24 kHz
Date of measurements	23.11.2018

A.2 Host/node data	
Laboratory (Country code)	BEV (AT)
Contact person, Operator	Michael Matus
Address	Bundesamt für Eich- und Vermessungswesen Arltgasse 35, 1160 Wien Austria
Phone, Fax, Email	Tel. +43 1 21110 826540 Fax +43 1 21110 996000 E-Mail: michael.matus@bev.gv.at

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Description of artefact

Details of the standard relevant to the comparison are collated in the following tables. The participant had to decide in advance of the actual measurements to what extent they wish to correct for deviations of working parameters. The parenthesis notation for stating standard uncertainties is used in table B.3.

B.1 Description of artefact (mandatory)	
Designation	MIRS1
Manufacturer Model / Type Serial Number	Lasertex Ltd., Wroclaw, Poland LJSC-3-11 1/2008
Wavelength (approx.)	633 nm
Operation principle	MEP 2003
Last compared	2009 during CCL-K11
Comments	Laser tube changed and calibrated at GUM (PL)

B.2 Detail information of artefact (mutable)	
Laser type	Iodine stabilised HeNe Laser
Stabilisation technique	Saturation spectroscopy on iodine vapour, 3*f* frequency modulation
Dither frequency	1.6 kHz
Modulation width	6.0 MHz
Iodine cell	Lasertex, 6 cm, double Brewster
Laser cavity length	33 cm
Cavity mirrors (curvature, transmission, location)	M1: 0.6 %, cell side, output mirror M2: 0.3 %, tube side

B.3 Reference conditions and sensitivity coefficients of artefact (optional)

Parameter	**Nominal value**	**Sensitivity coefficient (standard uncertainty)**	**Comment**
Output power	60 μW	−0.15 (0.03) kHz/μW	measured
Modulation width	6.0 MHz	−15.7 (1.8) kHz/MHz	measured
Iodine cell cold finger temperature	15.0 °C	−17.0 (1.9) kHz/°C	measured
Cell wall temperature	25 °C	+0.16 (0.12) kHz/°C	estimated

Participant Results Report Form

The measurement result (C.1) of the comparison has to be determined by the participant in advance, before measurements are performed by the node/host lab. The remainder of the table has to be filled by the node laboratory. The parenthesis notation for stating standard uncertainties is used here.

C.1 "Measurement result" of participant (stated before C.2!)	
Expected frequency f_e	473 612 353 600.0 (12.0) kHz

C.2 Frequency measurement of host laboratory (to be performed after C.1!)	
Measured frequency f_0 (uncorrected)	473 612 353 603.383 (0.118) kHz

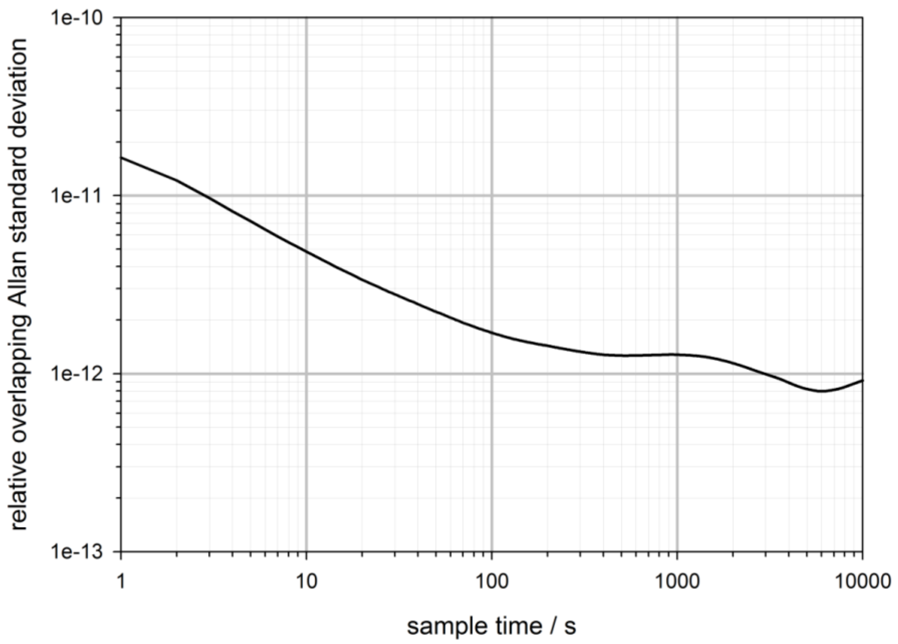
C.3 Correction due to working parameters (optional)		
Parameter	**Measured value**	**Frequency correction**
Output power	97 (5) µW	+5.550 (1.340) kHz
Modulation width	5.66 (0.10) MHz	−5.338 (1.685) kHz
Iodine cell cold finger temperature	15.1 (0.1) °C	+1.700 (1.711) kHz
Cell wall temperature	29.0 (3.0) °C	−0.640 (0.679) kHz
Overall frequency correction f_p	+1.272(2.832) kHz	

C.4 Measurement of host laboratory (KCRV)	
Measured frequency $f_m = (f_0 + f_p)$	473 612 353 604.655 (2.835) kHz

C.5 Comparison Result	
Frequency difference $\Delta f = f_e - f_m$	−4.655 (12.330) kHz
Fractional frequency difference $\Delta f / f_e$	−9.8 (26.0) · 10^{-12}
Degree of equivalence stated as E_n value	−0.19

Description of Measurements

- Method: A femtosecond fibre laser comb generator (BEV) is used to measure the absolute frequency of the 633 nm standard. The output beam of the standard is transferred to the comb via free space, avoiding optical feedback using a double stage Faraday isolator. All counters and synthesizers are referenced to an active hydrogen maser. This maser is part of the BEV clock assemble which takes part in the CCTF-K001.UTC key comparison thus providing a link to the SI.
- Conditions: The measurements are made in accordance with the BEV quality system (respective working document A_0118). After some test runs, mainly to use the warm up period, one 6 000 s long measurement was made with a sample time of 1 s (raw data filename mirs_04_K11.dat). This measurement started 24 h after switching on the standard, as determined by the participant. Possible cycle slips and outliers are automatically detected and removed using a schema described in the references of the technical protocol and the working document A_0118.
- Special observation: The laser shows a significant frequency drift, the frequency stated and measured is valid 24 h after switching on and for a averaging time of 6 000 s.
- Allan variance stability: A long run absolute frequency measurement of the laser was used to determine the relative overlapping Allan standard deviation (raw data filename mirs_05.dat, 252 000 s).



Participant data

Details of the participant must be provided in advance to the actual measurements by sending the completed Table A to the pilot lab's contact (michael.matus@bev.gv.at). An agreement with the node laboratory is a matter of course. The actual date of measurement might be updated in the final report at a later stage.

A.1 Participant data	
Laboratory (Country code)	NMISA (ZA)
RMO	AFRIMETS
Contact person, Operator	Faith Hungwe
Address	Building 5 CSIR Campus, Brummeria, Pretoria 0184 South Africa
Phone, Fax, Email	Tel. +27 12 841 4936 E-mail: fhungwe@nmisa.org
Artefact's designation	NMISA-MUFASA
CMC	U = 2.4 MHz @ 474 THz
Date of measurements	15.11.2018 – 20.11.2018

A.2 Host/node data	
Laboratory (Country code)	BEV (AT)
Contact person, Operator	Michael Matus
Address	Bundesamt für Eich- und Vermessungswesen Arltgasse 35, 1160 Wien Austria
Phone, Fax, Email	Tel. +43 1 21110 826540 Fax +43 1 21110 996000 E-Mail: michael.matus@bev.gv.at

Description of artefact

Details of the standard relevant to the comparison are collated in the following tables. The participant had to decide in advance of the actual measurements to what extent they wish to correct for deviations of working parameters. The parenthesis notation for stating standard uncertainties is used in table B.3.

B.1 Description of artefact (mandatory)	
Designation	NMISA-MUFASA
Manufacturer Model / Type Serial Number	Winters Electro Optics, USA W100 294
Wavelength (approx.)	633 nm
Operation principle	MEP 2003
Last compared	Never
Comments	New laser

B.2 Detail information of artefact (mutable)	
Laser type	Iodine stabilised HeNe Laser
Stabilisation technique	Saturation spectroscopy on iodine vapour, 3*f* frequency modulation
Dither frequency	8.33334 kHz
Modulation width	6.0 MHz
Iodine cell	BIPM 1114, 10 cm, Brewster windows
Laser cavity length	26.5 cm
Cavity mirrors (curvature, transmission, location)	M1: 30 cm, 0.7 % , front, output mirror M2: ∞, 0.25 %, rear

B.3 Reference conditions and sensitivity coefficients of artefact (optional)			
Parameter	**Nominal value**	**Sensitivity coefficient (standard uncertainty)**	**Comment**
Output power	70 µW	+0.007 (0.01) kHz/µW	From literature
Modulation width	6.0 MHz	−10.0 (1.0) kHz/MHz	From literature
Iodine cell cold finger temperature	15.0 °C	−15.0 (0.2) kHz/°C	From literature
Cell wall temperature	25 °C	+0.5 (0.5) kHz/°C	From literature

Participant Results Report Form

The measurement result (C.1) of the comparison has to be determined by the participant in advance, before measurements are performed by the node/host lab. The remainder of the table has to be filled by the node laboratory. The parenthesis notation for stating standard uncertainties is used here.

C.1 "Measurement result" of participant (stated before C.2!)	
Expected frequency f_e	473 612 353 604.0 (10.0) kHz

C.2 Frequency measurement of host laboratory (to be performed after C.1!)	
Measured frequency f_0 (uncorrected)	473 612 353 602.068 (0.064) kHz

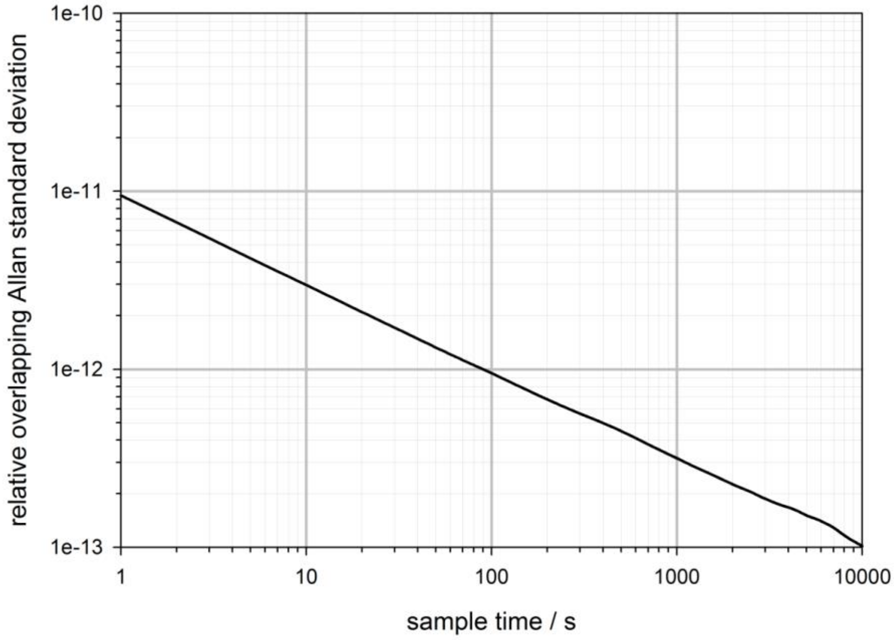
C.3 Correction due to working parameters (optional)		
Parameter	**Measured value**	**Frequency correction**
Output power	88.8 (5) µW	−0.132 (0.191) kHz
Modulation width	5.725 (0.100) MHz	−2.740 (1.037) kHz
Iodine cell cold finger temperature	14.955 (0.050) °C	−0.600 (1.503) kHz
Cell wall temperature	25 (3) °C	+0.000 (1.000) kHz
Overall frequency correction f_p	−3.557 (2.091) kHz	

C.4 Measurement of host laboratory (KCRV)	
Measured frequency $f_m = (f_0 + f_p)$	473 612 353 598.520 (2.091) kHz

C.5 Comparison Result	
Frequency difference $\Delta f = f_e - f_m$	+5.480 (10.216) kHz
Fractional frequency difference $\Delta f / f_e$	+11.6 (21.6) · 10^{-12}
Degree of equivalence stated as E_n value	+0.27

Description of Measurements

- Method: A femtosecond fibre laser comb generator (BEV) is used to measure the absolute frequency of the 633 nm standard. The output beam of the standard is transferred to the comb via free space, avoiding optical feedback using a double stage Faraday isolator. All counters and synthesizers are referenced to an active hydrogen maser. This maser is part of the BEV clock assemble which takes part in the CCTF-K001.UTC key comparison thus providing a link to the SI.
- Conditions: The measurements are made in accordance with the BEV quality system (respective working document A_0118). After some test runs, mainly to use the warm up period, one 420 000 s long measurement was made with a sample time of 1 s (raw data filename NMISA_03.dat). Possible cycle slips and outliers are automatically detected and removed using a schema described in the references of the technical protocol and the working document A_0118.
- Special observation: —
- Allan variance stability: A long run absolute frequency measurement of the laser was used to determine the relative overlapping Allan standard deviation (raw data filename NMISA_03.dat, 420 000 s).



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Participant data

Details of the participant must be provided in advance to the actual measurements by sending the completed Table A to the pilot lab's contact (michael.matus@bev.gv.at). An agreement with the node laboratory is a matter of course. The actual date of measurement might be updated in the final report at a later stage.

A.1 Participant data	
Laboratory (Country code)	EIM (GR)
RMO	EURAMET
Contact person, Operator	Christos Bantis
Address	Hellenic Institute of Metrology (EIM) Industrial Area of Thessaloniki, Block 45 57022 Sindos, Thessaloniki Greece
Phone, Fax, Email	Tel. +30 2310 569 952 E-mail: bandis@eim.gr
Artefact's designation	EIM-1
CMC	24 kHz (KCDB: 4.0E-2 fm @ 633 nm)
Date of measurements	28.01.2019 – 31.01.2019

A.2 Host/node data	
Laboratory (Country code)	BEV (AT)
Contact person, Operator	Michael Matus
Address	Bundesamt für Eich- und Vermessungswesen Arltgasse 35, 1160 Wien Austria
Phone, Fax, Email	Tel. +43 1 21110 826540 Fax +43 1 21110 996000 E-Mail: michael.matus@bev.gv.at

Description of artefact

Details of the standard relevant to the comparison are collated in the following tables. The participant had to decide in advance of the actual measurements to what extent they wish to correct for deviations of working parameters. The parenthesis notation for stating standard uncertainties is used in table B.3.

B.1 Description of artefact (mandatory)	
Designation	EIM-1
Manufacturer Model / Type Serial Number	NPL — SN: LL0401/R16
Wavelength (approx.)	633 nm
Operation principle	MEP 2003
Last compared	2005 (BIPM.L-K11)
Comments	—

B.2 Detail information of artefact (mutable)	
Laser type	Iodine stabilised HeNe Laser
Stabilisation technique	Saturation spectroscopy on iodine vapour, $3f$ frequency modulation
Dither frequency	586 Hz
Modulation width	6 MHz
Iodine cell	SN: 6p-7/96, active length 85mm, Brewster window
Laser cavity length	353 mm
Cavity mirrors (curvature, transmission, location)	M1: ∞, 0.86 %, front - output mirror M2: 100 cm concave, rear - iodine cell end

B.3 Reference conditions and sensitivity coefficients of artefact (optional)

Parameter	**Nominal value**	**Sensitivity coefficient (standard uncertainty)**	**Comment**
Output power	86 µW	−0.06 (0.03) kHz/µW	Measured at BIPM.L-K11
Modulation width	6.0 MHz	−7.6 (1.0) kHz/MHz	Measured at BIPM.L-K11
Iodine cell cold finger temperature	15.0 °C	−12.9 (0.6) kHz/°C	Measured at BIPM.L-K11
Cell wall temperature	25 °C	+0.2 (0.6) kHz/°C	Estimated like in BIPM.L-K11

Participant Results Report Form

The measurement result (C.1) of the comparison has to be determined by the participant in advance, before measurements are performed by the node/host lab. The remainder of the table has to be filled by the node laboratory. The parenthesis notation for stating standard uncertainties is used here.

C.1 "Measurement result" of participant (stated before C.2!)	
Expected frequency f_e	473 612 353 604 (10.0) kHz

C.2 Frequency measurement of host laboratory (to be performed after C.1!)	
Measured frequency f_0 (uncorrected)	473 612 353 607.133 (0.205) kHz

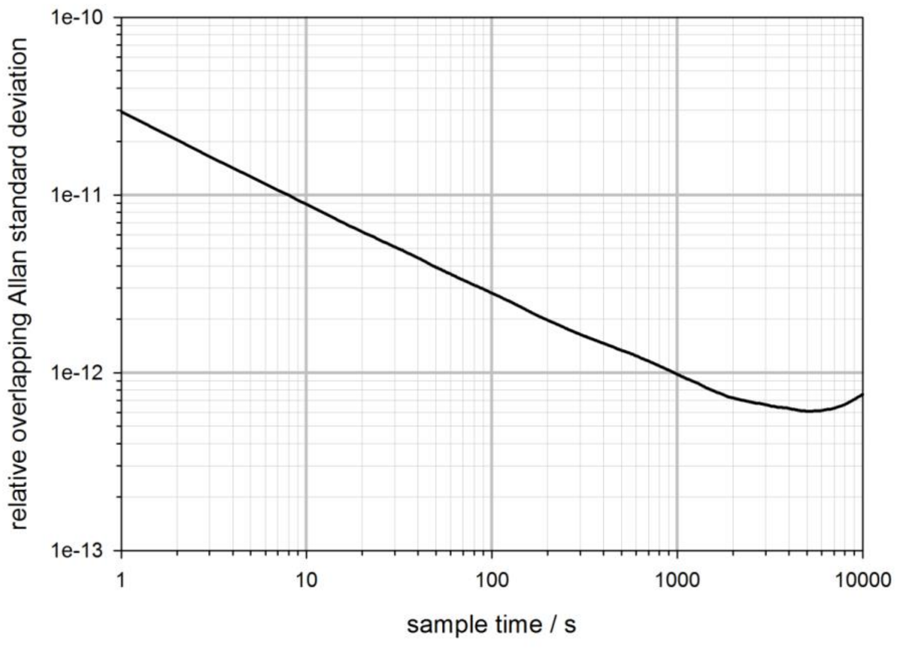
C.3 Correction due to working parameters (optional)		
Parameter	**Measured value**	**Frequency correction**
Output power	103 (5) µW	+1.020 (0.592) kHz
Modulation width	5.938 (0.100) MHz	−0.471 (0.763) kHz
Iodine cell cold finger temperature	15.0 (0.2) °C	+0.000 (2.580) kHz
Cell wall temperature	24.4 (2.0) °C	+0.120 (0.538) kHz
Overall frequency correction f_p	+0.669 (2.807) kHz	

C.4 Measurement of host laboratory (KCRV)	
Measured frequency $f_m = (f_0 + f_p)$	473 612 353 607.802 (2.814) kHz

C.5 Comparison Result	
Frequency difference $\Delta f = f_e - f_m$	−3.802 (10.388) kHz
Fractional frequency difference $\Delta f / f_e$	−8.0 (21.9) · 10^{-12}
Degree of equivalence stated as E_n value	−0.18

Description of Measurements

- Method: A femtosecond fibre laser comb generator (BEV) is used to measure the absolute frequency of the 633 nm standard. The output beam of the standard is transferred to the comb via free space, avoiding optical feedback using a double stage Faraday isolator. All counters and synthesizers are referenced to an active hydrogen maser. This maser is part of the BEV clock assemble which takes part in the CCTF-K001.UTC key comparison thus providing a link to the SI.
- Conditions: The measurements are made in accordance with the BEV quality system (respective working document A_0118). After some test runs, mainly to use the warm up period, one 10 000 s long measurement was made with a sample time of 1 s (raw data filename EIM_003.dat). Possible cycle slips and outliers are automatically detected and removed using a schema described in the references of the technical protocol and the working document A_0118.
- Special observation: The laser shows a frequency drift which correlates with the drift of the optical output power. The frequency stated and measured is corrected for by using the corresponding coefficient in Table B.3.
- Allan variance stability: A long run absolute frequency measurement of the laser was used to determine the relative overlapping Allan standard deviation (raw data filename EIM_004.dat, 64 000 s).



Participant data

Details of the participant must be provided in advance to the actual measurements by sending the completed Table A to the pilot lab's contact (michael.matus@bev.gv.at). An agreement with the node laboratory is a matter of course. The actual date of measurement might be updated in the final report at a later stage.

A.1 Participant data	
Laboratory (Country code)	BFKH (HU)
RMO	EURAMET
Contact person, Operator	Gábor Szikszai
Address	37-39 Németvölgyi road, Budapest 1124 Hungary
Phone, Fax, Email	Tel. +36 1 458 5854 E-mail: szikszai.gabor@bfkh.gov.hu
Artefact's designation	BFKH-1
CMC	U = 24 kHz @ 633 nm (iodine stabilized He-Ne laser)
Date of measurements	13.02.2020 – 14.02.2020

A.2 Host/node data	
Laboratory (Country code)	BEV (AT)
Contact person, Operator	Michael Matus
Address	Bundesamt für Eich- und Vermessungswesen Arltgasse 35, 1160 Wien Austria
Phone, Fax, Email	Tel. +43 1 21110 826540 Fax +43 1 21110 996000 E-Mail: michael.matus@bev.gv.at

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Description of artefact

Details of the standard relevant to the comparison are collated in the following tables. The participant had to decide in advance of the actual measurements to what extent they wish to correct for deviations of working parameters. The parenthesis notation for stating standard uncertainties is used in table B.3.

B.1 Description of artefact (mandatory)	
Designation	BFKH-1
Manufacturer Model / Type Serial Number	Winters Electro Optics Model 100 237
Wavelength (approx.)	633 nm
Operation principle	MEP 2003
Last compared	2010 CCL-K11
Comments	Laser tube replaced since last participation

B.2 Detail information of artefact (mutable)	
Laser type	Iodine stabilised HeNe Laser
Stabilisation technique	Saturation spectroscopy on iodine vapour, 3*f* frequency modulation
Dither frequency	8.333 kHz
Modulation width	6.0 MHz
Iodine cell	BIPM 543, 10 cm, Brewster windows
Laser cavity length	26.5 cm
Cavity mirrors (curvature, transmission, location)	M1: 30 cm, 0.7 % , front, output mirror M2: ∞, 0.25 %, rear

B.3 Reference conditions and sensitivity coefficients of artefact (optional)			
Parameter	**Nominal value**	**Sensitivity coefficient (standard uncertainty)**	**Comment**
Output power	90 µW	−0.048 (0.050) kHz/µW	As in 2010 participation
Modulation width	6.0 MHz	−9.0 (2.0) kHz/MHz	As in 2010 participation
Iodine cell cold finger temperature	15.0 °C	−14.0 (1.0) kHz/°C	As in 2010 participation
Cell wall temperature	25 °C	+0.0 (0.5) kHz/°C	As in 2010 participation

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Participant Results Report Form

The measurement result (C.1) of the comparison has to be determined by the participant in advance, before measurements are performed by the node/host lab. The remainder of the table has to be filled by the node laboratory. The parenthesis notation for stating standard uncertainties is used here.

C.1 "Measurement result" of participant (stated before C.2!)	
Expected frequency f_e	473 612 353 607.2 (12.0) kHz

C.2 Frequency measurement of host laboratory (to be performed after C.1!)	
Measured frequency f_0 (uncorrected)	473 612 353 608.565 (0.116) kHz

C.3 Correction due to working parameters (optional)		
Parameter	**Measured value**	**Frequency correction**
Output power	127.1 (5.0) µW	+1.781 (1.870) kHz
Modulation width	5.714 (0.100) MHz	−2.574 (1.066) kHz
Iodine cell cold finger temperature	14.95 (0.20) °C	−0.700 (2.800) kHz
Cell wall temperature	25 (2) °C	+0.000 (0.000) kHz
Overall frequency correction f_p	−1.493 (3.532) kHz	

C.4 Measurement of host laboratory (KCRV)	
Measured frequency $f_m = (f_0 + f_p)$	473 612 353 607.072 (3.534) kHz

C.5 Comparison Result	
Frequency difference $\Delta f = f_e - f_m$	+0.128 (12.510) kHz
Fractional frequency difference $\Delta f / f_e$	+0.3 (26.4) · 10^{-12}
Degree of equivalence stated as E_n value	+0.01

Description of Measurements

Here a short summary of the actual measurement technique shall be given by the node lab.

- Method: A femtosecond fiber laser comb generator (BEV) is used to measure the absolute frequency of the 633 nm standard. The output beam of the standard is transferred to the comb via free space, avoiding optical feedback using a double stage Faraday isolator. All counters and synthesizers are referenced to an active hydrogen maser. This maser is part of the BEV clock assemble which takes part in the CCTF-K001.UTC key comparison thus providing a link to the SI.
- Conditions: The measurements are made in accordance with the BEV quality system (respective working document A_0118). After some test runs, mainly to use the warm up period, one 230 000 s long measurement was made with a sample time of 1 s (raw data filename BFKH_03.dat). Out of this data a 2200 s long section was used to determine the KCRV. Immediately before and after this section the working parameters have been determined. Possible cycle slips and outliers are automatically detected and removed using a schema described in the references of the technical protocol and the working document A_0118.
- Special observation: After power on the laser did not emit light. At some time overnight output appeared. The output power increased during the measurements monotonically. This is a well-known peculiarity of this brand of laser.
- Allan variance stability: A long run absolute frequency measurement of the laser was used to determine the relative overlapping Allan standard deviation (raw data filename BFKH_03.dat, 230 000 s).