Technical protocol for the CCL-K11 key comparison of optical frequency/wavelength standards.

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I want to take part in CCL-K11 and agree on the procedures given in the present protocol.

I represent (Institute)…………………………………………………………

Name……………………………………………………………………………

Date and signature………………………………………………………………

BACKGROUND

The BIPM.L-K10 (K10) key comparison was initiated in 1993 to provide a basis for demonstrating equivalence of national realizations of wavelength-standards used for the realization of the definition of the SI-metre according to the method (c) in what was called the Mise en Pratique (MeP, refers to the document "Practical realization of the definition of the metre") [1]. Such a comparison seemed of particular importance since the whole field of dimensional metrology had to be traceable to such realizations of the metre. The K10 took only the 633 nm He-Ne standards into consideration. The measurand of the comparison was the difference of the *average* frequency of the hyperfine components d, e, f, and g in the R(127) 11-5 line as obtained by matrix measurements [2]. The frequency of the reference laser BIPM4 was used as the key comparison reference value and seen as representing the value recommended in the MeP.

During the last few years, the situation for realization of the SI-metre has changed due to the introduction of new techniques for absolute frequency measurements. This has opened up the alternative method (b) in the MeP to realize a frequency/wavelength standard traceable to the SI-second. The practical consequence of this development is that at least two ways are at the moment being used to realize the metre and that standards of different wavelengths, important for dimensional metrology applications, can now demonstrate traceability with relative ease. Considering these circumstances the 11th CCL meeting which was held in October 2003 at the BIPM decided to close the K10 comparison and initiate a new key comparison named BIPM.L-K11 (K11) [3]. First measurements in BIPM.L-K11 were made at the BIPM in May 2004. Results from BIPM.L-K10 and BIPM.L-K11 can be found at http://kcdb.bipm.org.

Subsequently, the CIPM has decided that the comb-related work used to provide external service should stop at the BIPM at the end of 2006. This decision had direct implications on the activity which supported the BIPM.L-K11 that consequently were closed down at the end of year 2006. A proposal for a new scheme for the comparison, based on a group of node-laboratories in the different RMOs and piloted by the Bundesamt für Eich- und Vermessungswesen (BEV, Austria) was therefore made. This proposal, which had been agreed by the President of the CCL, was given support by the CIPM at its 95th meeting last October and endorsed by the 13th meeting of CCL in September 2007. The present protocol details the procedures to follow in this new comparison, now transferred to the CCL, and named CCL-K11 and should be read by each participant before starting measurements.

SCOPE

The CCL-K11, being a key comparison, is designed to provide a technical basis for the review of CMC in the field of standard based optical frequency/wavelength calibrations, specifically those that are give under the entries 1.1.1 and 1.1.2 in the list of "Classifications of services in length", e.g.

1.1.1 Stabilized laser of the "mise en pratique":
1.1.2 Other stabilized lasers:

The K11 concerns in particular those wavelengths that are important for the field of dimensional metrology. However, only standards of highest metrological quality should be part of the comparison. Typical examples would be the 633 nm, 612 nm, 543 nm and 532 nm iodine stabilized standards but also other sources may become meaningful to include as reference standards. This is thus an extension compared to the K10, which as mentioned took only the 633 nm standards into consideration.

The CCL also proposed to include absolute frequency measurements, matrix measurements as well as direct frequency heterodyne measurements in which only the difference in frequency between two standards is measured. Besides being a key comparison, K11 will not only provide better estimates of the frequencies listed in the MeP but also extend the ways in which participants can claim traceability to the definition of the metre [4].

While the operation of the BIPM.L-K11 was piloted by the BIPM, and a clear majority of the measurements were carried out there, measurements in individual NMIs, absolute as well as heterodyne, were also possible and included in the scheme. These laboratories were named *host* laboratories (H). By including such regional heterodyne measurements the comparison could reach a larger number of laboratories in the RMOs.

In the new operation for CCL-K11 the BIPM is replaced by the BEV (P) as the pilot laboratory supported by 4 NMIs, here called *node* laboratories (N) e.g. MIKES, NMIJ-AIST, NPL and NRC.
Additional general information concerning key comparisons can be found in "Guidelines for key comparisons" at the WEB address http://kcdb.bipm.org/

PARTICIPANTS

Any NMI fulfilling the formal requirements[$] for participation in a key comparison and holding appropriate standards may participate in the comparison. Participating standards should already have demonstrated a performance at the highest level. It should be underlined that standards of lower stability, standards not operating optimally or standards that can be calibrated by similar standards in the home institute should not take part in K11.

MEASUREMENTS

The *measurand* of the comparison is the frequency of the reference component as defined in the list of recommended frequencies (LRF ,will replace the MeP but is still

[$] http://www.bipm.org/utils/en/pdf/guidelines.pdf under preparation by the CCL) for that particular wavelength, eg. the f-component of the 127(R) 11-5 transition in iodine with 633 nm He-Ne systems. The frequency value can be obtained by three different methods:

- m1 Absolute frequency measurement traceable to a realization of the SI-second as described in Appendix A
- m2 Heterodyne measurements by the “matrix method”. To extract the reference component frequencies a matrix inversion is needed as described in Appendix B.
- m3 Direct heterodyne measurements between the reference components for the two lasers by the introduction of an acousto-optic modulator (AOM), as described in Appendix C.

It is expected that measurements in the N and P will be of type m1. For measurements carried out in a Host laboratory to be included in K11 they need to follow the procedures defined in this protocol. They can be of m1, m2 and m3 type. In such regional comparisons at least one laser which recently has taken part in the K11 should be included if the measurements are of m2 or m3 type. If measurement of type m1 is used the traceability to the SI second should clearly reported as well as a documented validation process with a uncertainty budget for the comb measurement system which will serve as basis for the review process of the measurements in the Joint Working Group for Frequency Standards (JWGFS).
It is important to realize that the measurements are to be blind measurement. That is, the results of the measurements are to be communicated to the participant only after the measurements are completed.
The participating laboratory shall in advance to the measurements forward values of the expected frequency value of the standard and the for this frequency relevant operational parameters together with an uncertainty estimation and fill in those in table D4 in appendix D..

PROCEDURE

Contact

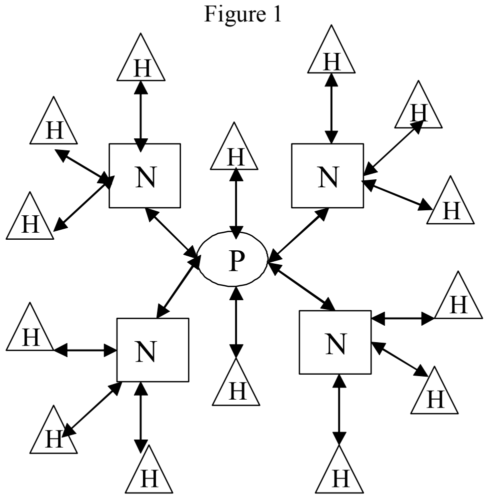
The initialization of a series of measurements to be included in K11 can be made on several ways, cf. figure 1.

- The N’s provide a call for the participation in a regional CCL-K11 comparison through, for instance, the yearly regional metrology meetings. Once a preliminary program is made up the N informs the P, which provides protocol and additional information. The KCDB office should be informed

- A local comparison is planned in an H and contact is made with P. (The KCDB office should be informed).

- An individual laboratory may contact the P directly to find out where and when the next measurement campaign will take place.

Figure 1



In the preparatory stage issues like, location, time schedule, methods to be used, linking to absolute measurements if needed, instrumentation etc are discussed. The P then forwards the present protocol and other relevant information.

Preparation

The participating laboratory should

- establish ATA carnets or other necessary documents a sufficiently long time in advance so that the transport of the scientific equipment is not delayed.
- communicate the dates for arrival for the scientific equipment and the participants to the host laboratory, and any needs for special administrative arrangements on the part of the host laboratory.
- arrange for their lodging.
- make preparations and arrangements for the return of the equipment.
- make home-based frequency comparisons of the standard if possible, both before and after the participation in the comparison, to reduce the possibility of undetected accidental frequency shifts in the transport of the standards.
- prepare a list of the relevant sensitivity coefficients and their uncertainties. These should be determined by measurements if possible and filled in table D6.

Conditions

- Neither the host laboratory, nor the participating laboratories have any liability in the case of an eventual failure of instrumentation and hence the inability to participate/continue to participate during the comparison.
- If an unforeseeable incident prevents a participant to take part in the comparison, the host laboratory should be informed without delay, to enable eventual modifications of the program in discussion with other participants when appropriate.
- The host laboratory is to provide appropriate calibrated (according to ISO/IEC 17025) equipment to measure laser power, beat frequency, modulation amplitude and temperature.
- It is desirable that the host laboratory makes available heavy equipment for general use (not as parts of the laser standard system), when this is possible, such as spectrum analysers, oscilloscopes and power supplies, and the auxiliary equipment needed for their use.
- The host laboratory should make arrangements so as to assure the safety of the equipment in their laboratories to avoid hazardous situations and theft of equipment during the comparison. However, the host laboratory takes no formal responsibility for the equipment and its use during the comparison.
- When undertaking a comparison including several laboratories, it is advisable to limit the number of participants sharing the same space in order to limit perturbations to acceptable levels.
- The laboratory in which the comparison takes place should offer an adequate metrological environment in respect to temperature, humidity, mechanical vibrations, acoustics etc.
- The set up and operation of the standard has to be made by the NMI operator according to the existing quality procedures of each individual participating NMI.
- Absolute frequency measurement should be made in accordance to the quality procedure of the host laboratory.
- The organisation and costs for the transport of the equipment and personnel is totally the responsibility of the participating laboratory.
- Normally, a comparison should not take more than one to two weeks. The date and duration for each laboratory should be agreed upon mutually.
- An important point to respect is the fact that the measurements should be made as “blind tests”. No frequency information is to be given to the participating laboratory before the end of the measurements unless it is evident that a critical malfunctioning is present. In any case, the sign of a large and unexpected deviation should not be communicated.

Measurements

Initial to the measurements the participating laboratory should give

- The expected frequency of the standard, f_e. This should normally be the frequency used in their calibration service. It could either be the recommended value or the value as determined by some other means.
- The standard uncertainty of the expected value, u_e. This should be a value compatible with the uncertainty given in the CMC for this service.
- The operational parameters for with the two above values are valid.
- Sensitivity coefficients with uncertainties for parameters to appear in the uncertainty budget for the standard taking part in CCL-K11. BIPM.L-K11 used an EXCEL sheet for this calculation which can be made available.

The operator of the standard prepare the standard for measurements and declare the standard ready for measurements when he consider the standard to be in proper working condition

Absolute frequency measurements are made and no intermediate results are to be made available before the measurements are completed. If possible a longer data series, >1000s, should be recorded to allow estimation of the short term Allan Variance for the standard.

RESULTS AND REPORT

The reporting is made in the following way,

– The N or H and the participating NMI fill out the measurement report (see Appendix D) for each individual laser to be included in a campaign report and forward this to the P.

– The P provides a yearly compilation of all measurements to the secretary of the CCL for distribution among the CCL members for review and subsequent inclusion in the BIPM KCDB.

– The P reports on the progress and intermediate conclusions of the comparison at each CCL.

The results of the successive comparisons will be evaluated and included in a database kept at the BIPM and accessible on the BIPM site, http://kcdb.bipm.org/

The measurand in each measurement should be the *frequency of the recommended radiation* as defined by the LRF for the wavelength under study. This frequency value will necessarily depend on a set of operating parameters. Typically for a 633 nm laser these would include:

- Modulation amplitude (for third harmonic system)
- Beam power
- Iodine cold finger temperature (iodine pressure)
- Iodine cell wall temperature
- …

For a specific laser and wavelength there could be more or other parameters of importance but should at least include those that are given in the LRF for that specific wavelength. The values for the operating parameters used in the actual measurements have to be reported [see section D7 in Appendix D]

If the measuring method m1 is used, it should be explicitly explained how the link to the SI second is made. If one of the measuring methods m2 or m3 is used, the link to absolute frequency measurements, being part of the K11, should be explained.

The corresponding sensitivity coefficients of the operational parameters need to be known to be able to estimate the uncertainty of the frequency of the standard. The *sensitivity coefficients, with their uncertainties*, should be measured or estimated and measurement results should be communicated to the host laboratory and included in the report [section D6]. These can be obtained either from direct measurements, estimation or from literature, give references to appropriate sources. The method to determine each parameter value should be indicated briefly.

The *standard uncertainty* of the determined frequency is composed of two parts, one from the frequency measurement, u_1, and one from the uncertainty in the settings of the working parameters, u_2. 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_1, are estimated from the operator of the experiment or together with personnel involved in the comparison, again in accordance with a quality procedure if such exist. These uncertainties are reported in sections D8 and D9 and should be given as standard uncertainty following GUM practice. The combined uncertainty of u_1 and u_2 , u_m, reported in D10 should be given as the root sum squares of u_1 and u_2.
After each measurement campaign in the node labs has been completed the measurement reports are forwarded to the P for the preparation of a measurement summary report. The results should be prepared according the following format.

Denote, the expected frequency f_e with standard uncertainty u_e and the measured frequency f_m with standard uncertainty u_m. For a particular standard, i, construct the quantities

$$\Delta f(i) = (f_e(i) - f_m(i)) / f_m(i)$$

$$u_c(i) = \left(\sqrt{u_e(i)^2 + u_m(i)^2}\right) / f_m(i)$$

u_m is obtained from u_1 and u_2 as defined above in the protocol. f_e and f_m should be transferred to the 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. To test consistency between the measured value and the expected one, hypothesis testing at a confidence level of 95% is to be made. The result will serve as a basis for the review of the CMC and indicate the compatibility with the claimed capabilities.

To arrive at a DoE between a standard i and a standard j we will rather use the difference

$$DoE(i,j) = \Delta f(i) - \Delta f(j)$$

with uncertainty

$$U(i,j)_{DoE} = k \cdot u(i,j)_{DoE} = k \cdot \sqrt{u_c(i)^2 + u_c(j)^2}$$

and $k = 2$ for a normally distributed probability density function and many degrees of freedom.

There might be correlations between the Δf values, especially, when several lasers are measured in a campaign using method "m2" or "m3", where the traceability comes through a reference laser, which uncertainty is of the same order as the uncertainty of the measured lasers. This correlation should be accounted for by adding a term

$$-2u_c(i)u_c(j) \cdot r(i,j)$$

to $U(i,j)_{DeO}$, where $r(i,j)$ is the correlation coefficient between the data of standards i and j [6, section 5.2.2].

The participating laboratory should, on receiving the results consider whether there are any implications for CMCs from that laboratory published in the KCDB. Any changes should be reviewed regionally and inter-regionally according to the established process for such reviews.

References

[1] Quinn T J 2001 *Metrologia* **40** 103-133 and Felder R 2003, *Metrologia* **42,** 323-325

[2] Bayer-Melms F., Chartier J.-M., Helmcke J., Wallard a. J., *PTB-Bericht*, 1977, **PTP-ME 17**, 139-146.

[3] Proceedings from the 11th CCL meeting. Available on the BIPM site www.BIPM.org

[4] International Organization of Standardization, ISO/IEC 17025, Geneva Switzerland.

[5] P. J. Mohr and B. N. Taylor, "CODATA recommended values of the fundamental physical constants: 1998," *J. Phys. Chem. Ref. Data*, Vol. 28, pp. 1713-1825,1999.

[6] Guide to the Expression of Uncertainty in Measurement, ISO/TAG 4. Published by ISO, 1993 (corrected and reprinted, 1995) in the name of the BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML. ISBN number is 92-67-10188-9, 1995.

[D1-D10] Appendix D.

Appendix A. Absolute frequency measurements [m1]

In addition to the results to report as mentioned in the previous section, details of the measurement system should be given. A brief description [section D5] of the measurement procedure is to be communicated including information such as :

- How traceability to the SI was obtained
- Beat scheme / measurement scheme
- Signal conditions (eg. 40 dB in a 300 kHz bandwidth)
- Criteria for disqualifying data points (phase slips)
- Allan variance to compare the stability of the measured beat to the expected stability of the standard measured
- References describing the measurement system, if there are any
- In particular should a description of a documented validation of the comb measurement system be included

Appendix B. Matrix measurements[m2].

Since the laser most used is the 633 nm He/Ne standard, and traditionally the heterodyne measurements were made as a matrix measurement, we will use this as an example. All possible combinations of the components d, e, f, and g are normally compared, excluding the diagonal elements in the resulting matrix. If one component of one of the lasers (For example f_2) has been absolutely measured it is possible to obtain the determination of the absolute value of all the other 7 components using the least square method. If no component is absolutely known it is still possible to obtain the f-f difference between the two lasers.

Procedure

1.1. The frequency measurement is obtained by mixing the two radiations on a photodiode, whose output signal is sent to a frequency counter that counts the number of cycles in a fixed gate time.

1.2. The heterodyne beat is then recorded for all combinations of the d, e, f, and g components for the two lasers, except for the diagonal elements giving 12 values.

1.3. With these data construct the vector

$\mathbf{Z}^T$ =

f_2	d_1-e_2	d_1-f_2	d_1-g_2	d_2-e_1	e_1-f_2	e_1-g_2	d_2-f_1	e_2-f_1	f_1-g_2	d_2-g_1	e_2-g_1	f_2-g_1

The frequencies are here represented by the component name d, f… and the index stands for laser 1 or 2. In order to apply the least square method we need one absolute frequency, in this example we choose f_2.

With the associated uncertainty matrix

$\mathbf{U_Z}$=

u_{f2}	0	0	0	...
0	$u_{d1\text{-}e2}$	0	0	...
0	0	$u_{d1\text{-}f2}$	0	...
0	0	0	$u_{d2\text{-}g2}$	...
...	...	...	...	...

Here u_{f2} is the standard uncertainty of the frequency of the component f_2 (of laser 2). The remaining principal diagonal elements are the frequency measurement uncertainties; they must not include components related to u_2 of [D9]. Here correlations are supposed to be null.

We are looking for the matrix $\mathbf{Q}^T$ =

d_1	e_1	f_1	g_1	d_2	e_2	f_2	g_2

which is related to matrix **Z** by the formula **A Q** = **Z**

The Q vector is thus obtained by a weighted least square method giving the estimate, $\mathbf{Q_e}$:

$$\mathbf{Q_e} = [\mathbf{A}^T (\mathbf{U_Z}^2)^{-1} \mathbf{A}]^{-1} \mathbf{A}^T (\mathbf{U_Z}^2)^{-1} \mathbf{Z}$$

$$\mathbf{U_Q}^2 = [\mathbf{A}^T (\mathbf{U_Z}^2)^{-1} \mathbf{A}]^{-1}$$

where $\mathbf{U_Q}$ is the associated uncertainty matrix and

A =

0	0	0	0	0	0	1	0
1	0	0	0	0	-1	0	0
1	0	0	0	0	0	-1	0
1	0	0	0	0	0	0	-1
0	-1	0	0	1	0	0	0
0	1	0	0	0	0	-1	0
0	1	0	0	0	0	0	-1
0	0	-1	0	1	0	0	0
0	0	-1	0	0	1	0	0
0	0	1	0	0	0	0	-1
0	0	0	-1	1	0	0	0
0	0	0	-1	0	1	0	0
0	0	0	-1	0	0	1	0

1.4. The vector $\mathbf{Q_e}$ contains the absolute frequency values of all the eight components, estimated from one absolute value (measured elsewhere with a comb) and 12 heterodyne frequency measurements.

1.5. The uncertainties obtained in the $\mathbf{U_Q}$ vector are the *a priori* uncertainties obtained from the statistical uncertainty in each matrix measurement. It should also be checked that the *posteriori* result is consistent by a reduced χ^2-test. This can reveal unexpected instabilities and possible problems when re-locking the standard. If the presence of such instabilities is detected the input uncertainties in the $\mathbf{U_z}$ matrix should be inflated so as to obtain a reduced χ^2 value of 1 (Birge ratio of 1, [5]). The BIPM can on request provide a software package for the inversion and χ^2-test of the data.

1.6. **Outline of consistency analysis**: To verify how well the estimated data $\mathbf{Q_e}$ and $\mathbf{U_Q}$ are consistent with the given data **Z,** consider $\mathbf{Z_e}$ obtained from the estimated data in $\mathbf{Q_e}$ as $\mathbf{Z_e}=\mathbf{AQ_e}$. From this data we calculate the chi-square: $\chi^2 = (\mathbf{Z}-\mathbf{Z_e})^T (\mathbf{U_Z}^2)^{-1} (\mathbf{Z}-\mathbf{Z_e})$ and the reduced chi-square $\chi_\nu = \chi/\nu$, where ν is the value of the degrees of freedom. In this case ν is equal to 5.

1.7. Values of χ_v significantly larger than 1 indicates that the uncertainty in measurement $\mathbf{U_Z}$ is smaller than the scatter of data represented in ($\mathbf{Z}$-$\mathbf{Z_e}$). This may indicate poor measurements or an unsuspected systematic effect. Conversely, values of χ_v smaller than 1 means that the uncertainty given in $\mathbf{U_z}$ is over estimated or correlations are present.
1.8. If χ_v is larger than one, it is possible to obtain the consistency, recalculating $\mathbf{Q_e}$ and $\mathbf{U_Q}$ considering larger uncertainty elements in $\mathbf{U_Z}$. This adjustment changes the value of $\mathbf{U_Q}$.
1.9. Results are given as defined in Appendix D.

1.10. In the case that no absolute measurement is available one can still estimate the frequency difference ($f_2 - f_1$) from the matrix $\mathbf{Q_e}$. Consider the linear equation:
1.11.

$$(f_2 - f_1) = \mathbf{TQ_e}$$

where $\mathbf{T}$ =

0	0	-1	0	0	0	1	0

and $\mathbf{Q_e}^{\mathbf{T}}$ =

d_1	e_1	f_1	g_1	d_2	e_2	f_2	g_2

The uncertainty associated to ($f_2 - f_1$) , $u_{ff}^2 = \mathbf{T}\, \mathbf{U}_Q^2\, \mathbf{T}^T$

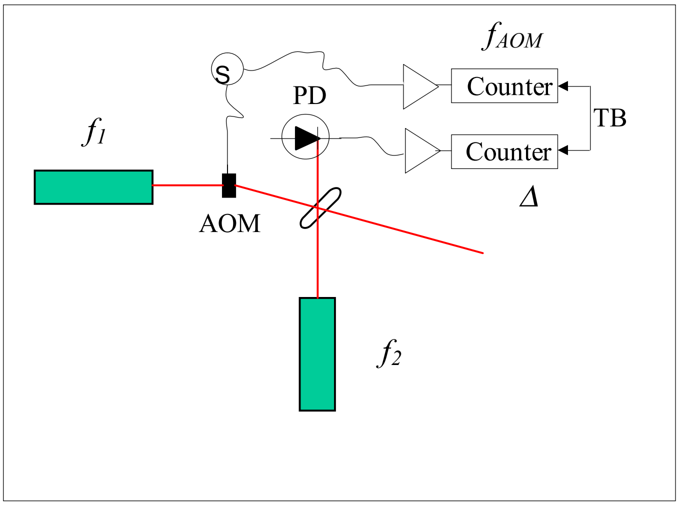
Note: Since f_2 is not known it is not possible to calculate $\mathbf{Q_e}$ directly by the way shown above. But by choosing an arbitrary value for f_2 in $\mathbf{Z}$ (e.g. 0 Hz) and a sufficiently small value for u_{f2} in $\mathbf{U_Z}$ (but $\neq$ 0!) one can obtain a "shifted" $\mathbf{Q_e}$, appropriate for this case.

This frequency difference together with its uncertainty can then be used to include the measurements in **K11** if a later absolute frequency value is obtained for one of the lasers shortly after.

If a series of measurements has been made using this technique to obtain the final value the individual data should be reported in appendix D table D5 to allow estimation of correlation in the DoE. The final frequency value should be reported in D10 in the same appendix.

Appendix C. Heterodyne measurements between the same components using an AOM
[m3].

The matrix method described in appendix B gives indirectly the difference in frequency between the f-component between the two lasers. Alternatively to the matrix method, an acousto-optic modulator can be used to shift the frequency of one of the lasers and the f-f difference can thus be directly measured.



The frequency difference between the lasers is then

$$f_1 - f_2 = \Delta \pm f_{AOM}$$

provided that the first order of the AOM us used and the sign of the AOM frequency shift is determined.

The counter needs either to be referenced to a time standard (TB) or calibrated but since both counters are measuring a frequency close to f_{AOM} the demands on the accuracy of the counters is relaxed as long as the counters are using the SAME time base. As an example, if we want to have a 10 Hz uncertainty from the counters and we have a 10 kHz frequency difference f_1 - f_2 of the lasers the relative accuracy of the counters only need to be 10^{-3} which is an extremely modest requirement for a modern counter.

If a series of measurements has been made using this technique to obtain the final value the individual data should be reported in appendix D table D5 to allow estimation off correlation in the DoE. The final frequency value should be reported in D10 in the same appendix..

Appendix D. Measurement report, CCL-K11.

After each series of comparison measurements a copy of this report is to be sent to Michael Matus at the BEV by e-mail for inclusion in the summary key comparison report. Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Node or host laboratory[1]

Lab. Name	
Contact person	
Address	
Tel.	
e-mail	

D2. Measurements[1]

Quantity compared	
Period	
Describe measurements	
References and/or other documentation	

[1] To be filled in by the host laboratory

Detailed description of standard[2]

Give description of the standard, one page for each participating standard (here examples are for a internal cell I_2 stabilized He-Ne laser 633 nm laser system)

D3. Laboratory

Lab. Name	
Operators	
Address	
Tel.	
e-mail	
	I have read the technical procedure and I agree to participate in CCL-K11 following this TP in particular and the MRA instructions for participation in key comparisons in general
Date/Signature	

D4. Standard

Designation of laser standard	
Standard last compared	
Modification on standard since	
Spectroscopy	
Modulation technique	
Modulation frequency /kHz	
Modulation width or index /	
Laser cavity length /cm	
Mirror curvature R1 (tube side) /cm	
Mirror curvature R2 (cell side) /cm	
Mirror transmission T1 (tube side) / %	
Mirror transmission T2 (cell side) / %	
Output mirror, 1 or 2.	
Designation of iodine cell	
Cell length /Brewster /flat windows/origin	

[2] To be filled in by the participating NMI.

Expected frequency given before measurement

Parameter	**value**	**Unit**	**Uncertainty**	**Comments**
Frequency	f_e=		u_e=	
Output power				*Measured with lasers stabilized to reference component*
Modulation width				
Iodine cell cold finger temperature				
Cell wall temperature				

D5. Description of measurements[1,2]

Give a brief description of the measurements made and the techniques used.

- Method:
- Conditions:
- Special observation:
- Allan variance stability

1) References to measuring system should be provided if there are any:.

D6. Sensitivity coefficients[2]

Parameter	**Sens. Coeff. Value**	**Uncertainty**	**Unit**	**Comments.**
Modulation width				
Iodine pressure				
Power (output)				
Cell wall temperature				

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[2]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	**value**	**Unit**	**Uncertainty**	**Comments**
Output power				*Measured with lasers stabilized to reference component*
Modulation width				
Iodine cell cold finger temperature				
Cell wall temperature				

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[1,2]

Source	Value	unit	comments
Frequency reference			
Stat. disp. of results			
Uncertainty in measurement method			
Total			

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[2]

Source	Value	unit	comments
Laser power			
Modulation width			
Iodine cold finger temperature			
Cell wall temp			
Electronic offset			
Cavity alignment			
Total			

D10. Results:

Name of standard	Lab.	Result	uncertainty	*Unit*	Comments
		$f_m=$	$u_m=$		

I agree on the results reported above

Date and signature (host lab)…………………………………………………………

Date and signature (participant)……………………………………………………