Traceability issues in Length

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1. Introduction.

Before the development of laser frequency combs most national laboratories maintained primary wavelength standards as their national standard of length. Length measurements can now be made traceable to the SI second and these two approaches raise some issues, such as the most appropriate key comparison and who is responsible for CMCs for laser frequency calibration. Should the CCL/WGDM play a role?

In the past, the CCL was responsible for frequency measurements based on primary wavelength standards, but these are now being replaced by frequency measurements traceable to the SI second, and these are clearly the responsibility of the CCTF.

This discussion tries to clarify the issues and suggests an approach which would define the roles of the CCL and CCTF.

While many of us have become comfortable with seeing wavelength and frequency as different aspects of the same measurement, this is only true for non-relativistic cases and the *mise en pratique* restricts its application to these situations.

To help the discussion we have called the list of radiations provided in the *mise en pratique* under method (c), primary wavelength standards.

Our recommendations are:

1. That the CCL be responsible for:
(a). Validating combs for uncertainties > 10^{-11} using primary wavelength standards.
(b). CMCs for laser frequency calibrations traceable to primary wavelength standards.

2. The CCTF be responsible for;
(a). Validating combs for uncertainties < 10^{-11}.
(b). CMCs for laser frequency calibrations traceable to the SI second.

2. The three practical approaches for realising the metre which are listed in the *mise en pratique* are (put very briefly):

(a): time how long light takes to travel the distance
(b): use the wavelength of a laser which has a calibrated frequency.
(c): use the wavelength of one of the lasers listed in the *mise en pratique*

The important distinction between the last two is that (b) requires you to measure the laser frequency, while (c) allows you to adopt the wavelength value (and uncertainty) published in the *mise en pratique*, provided the laser conforms with the conditions specified and accepted good practice is followed.

A wavelength standard that relies on a frequency calibration (method (b)) is a secondary standard as its value depends on another standard. Standards defined in method (c) can be primary national wavelength standards as their value is accepted without reference to another standard. This has been their role in the past and while they are no longer justified on a scientific basis (potentially less accurate than a laser frequency standard calibrated by a comb and traceable to the SI second), they continue to fill this role in many laboratories.

3. National standards need to be tested with key comparisons and there have been three key comparisons for laser wavelength standards:

1993 – 2000 BIPM.L-K10:
Restricted to 633nm lasers. Key comparison reference value was BIPM4.

2003 – 2007 BIPM.L-K11:
Open to a range of wavelength standards. Key comparison reference value was the frequency published in the *mise en pratique*.

2007 – on going CCL-K11:
Operates through 4 regional nodes. Key comparison reference value is the frequency published in the *mise en pratique*.

All of these key comparisons support primary wavelength standards and therefore method (c). Secondary standards are traceable to a primary standard, and in the case of method (b) this could be the SI second or a primary wavelength standard. They should be supported by a supplementary comparison.

One way of conduction K11 is for a national laboratory to take their nation wavelength standard to a node and obtain a frequency measurement. The value of this frequency should agree with the frequency value (and uncertainty) published in the *mise en pratique*. They can then quote a “degree of equivalence” with the value in the *mise en pratique* (and hence with all other participants).

Another way of conduction K11 is to compare two or a group of primary wavelength standards (method (c) lasers) and have at least one of these lasers traceable to a node in order to provide the key comparison reference value. The group comparison could be conducted like a K10 comparison, or single reference lines could be chosen, according to the technical protocol.

4. Accreditation of frequency calibration services based on combs

Time and frequency have one key comparison CCTF-K2001.UTC and treat frequency measurements as a dependent service. This does not validate comb measurements so there is a need to consider how this might be done and who is responsible. Circulating a stabilised laser would validate comb measurements at a moderate accuracy. The travelling laser BIPMP3 was compared with BIPM4 before and after travelling with a standard uncertainty of 3.6 kHz or 8×10^{-12}. If it were used to compare combs the uncertainty should be reduced as the uncertainty of BIPM4 would be absent. Lasers at 532 nm are significantly better and could also be used. As the absolute frequency measurement should not add any uncertainty at this level of accuracy, it should be a relatively simple process to validate a comb frequency calibration service to 10^{-11}. This could be a particular class of frequency CMC that is assigned to the CCL.

Comb frequency measurements with lower uncertainty are more difficult to validate with existing travelling frequency standards. Combs can be subject to phase noise from frequency synthesisers at uncertainty levels below 10^{-12} (for a 1s period), so the technical aspects of the comb become important. A CMC with an uncertainty that is less than 10^{-11} probably needs a comb comparison and should be managed by the CCT.