# Report to the 17th Session of the CCTF

## Working Group on Primary Frequency Standards

Thomas E. Parker, Chair

Introduction

This is a new working group that was organized in 2005. The membership includes 20 individual from 13 metrology organizations, including the Time Section of the BIPM. The current Chairman is Tom Parker from the National Institute of Standards and Technology (NIST) in Boulder, USA. A list of members is included in Appendix A.

There are now six laboratories that are either regularly reporting, or have reported, the results of formal evaluations to the BIPM from seven different Cs fountain primary frequency standards (PFS). In addition there are three thermal beam standards that regularly report to the BIPM. The large number of new primary standards reflects a very healthy community, but also increases the need for coordination and communication among the labs in order to maintain accuracy in the stated uncertainties. This was the motivation for organizing this working group.

Terms of Reference

The terms of reference for the working group are given in Appendix B. The objectives of this working group as stated in the terms of reference are:

(1) Develop and propose standards for the documentation of frequency biases and uncertainties, operational details, and frequency transfer uncertainties for a PFS. Develop and propose standards for the reporting of the results of a PFS evaluation to the BIPM.

(2) Provide a forum to evaluate and discuss the consistency among primary frequency standards.

(3) Provide a forum to discuss and assess the overall knowledge of the accuracy of the SI second for use in establishing the frequencies of secondary standards (microwave and optical) and possibly an eventual redefinition of the second.

(4) Interact with the BIPM on issues related to PFS contributions to the accuracy of TAI, particularly in the process of integration of the first reports of a standard.

(4) Encourage and facilitate direct comparisons between primary frequency standards.

(5) Encourage and support laboratories with new standards under construction.

Meetings

The working group has held two meetings. The first was in August 2005 at the Joint meeting of the IEEE International Frequency Control Symposium (IFCS) and the Precise Time and Time Interval (PTTI) Systems & Applications Meeting in Vancouver, Canada, with 19 people attending. The second meeting was held in March 2006 at the European Frequency and Time Forum (EFTF) in Braunschweig, Germany, with 23 people in attendance. A number of topics were discussed and these included:

(1) What details should be included in a PFS report to the BIPM. It was reiterated that articles in peer reviewed should be the primary source(s) of information regarding the evaluation of frequency biases and uncertainties, and operational procedures. It was recommended that a peer review article should be submitted for publication before the first formal report of a PFS is sent to the BIPM. The reports sent to the BIPM with each PFS evaluation should contain all relevant information for that report interval, but there was no particular desire to have the reports include raw data. It was suggested that each evaluation report should contain a section that summarizes all of the accumulated changes in systematic bias uncertainties since the last peer reviewed paper.

(2) Timely reporting. The BIPM encourages timely reports for each PFS evaluation. The report must be at the BIPM by about the $7^{th}$ of the month (may vary) to be included in Circular T for the previous month. There are situations where the quantification of a bias may necessitate a delay in sending in the report by a few weeks, but delaying a report by several months is highly discouraged.

(3) Uncertainty of frequency transfer based on data published in Circular T. The uncertainties UTC - UTC(k) are now published in Circular T and, if they are used, they result in a significantly reduced frequency transfer uncertainty as compared to the expression that has been used up to the present. The reduced uncertainty has resulted from improved time/frequency transfer techniques. An extensive discussion resulted in a recommendation to the Time Section of the BIPM for a new expression that is included in Appendix C.

(4) Accuracy of stated uncertainties. The first few reported evaluations from a new standard are more likely to exhibit evidence that uncertainties have been underestimated (lack of self-consistency) than after some experience has been gained. Thus the question was brought up as to whether some procedure should be implemented that would limit the potential negative influence on TAI from a new standard. One such possible procedure would be a “provisional” status for all new standards such that for some specified number of reported evaluations over some specified period of time the results would be reported in Circular T, but not used in the determination of the rate of TAI. An extensive discussion was held and it became clear that the working group was about evenly divided as to whether any new procedures should be implemented, or the status quo should be maintained. However, it was agreed that recommendations should be made regarding the testing and documentation of new standards. Therefore, a document is being prepared that will contain a list of recommended procedure that should be followed in the commissioning of a new primary frequency standard.

A poster paper entitled "Comparing High Accuracy Frequency Standards via TAI", by G. Petit and P. Wolf was presented at the March 2006 EFTF. This paper addresses some of the consistency issues between Cs fountains.

(5) Workshop on primary frequency standards. A workshop on primary frequency standards is being planned. It most likely will be held in connection with the joint EFTF/IFCS in May 2007 in Geneva.

Future Meetings

Future meetings will be held as it is felt necessary. This should nominally be about once per year. Much of the business of the working group can be carried out via e-mail.

Appendix A

**Members of the Working Group on Primary Frequency Standards**

Chair: T. Parker (NIST)

| | |
|---|---|
| BIPM | G. Petit, P. Wolf |
| BNM-SYRTE | A. Clairon, S. Bize |
| INRIM | A. Godone, F. Levi |
| KRISS | Ho Seong Lee, Taeg Yong Kwon |
| METAS | Gregor Dudle |
| NICT | M. Hosokawa |
| NIM | Tianchu LI |
| NIST | S. Jefferts, T. O'Brian |
| NMIJ/AIST | T. Ikegami, Shinichi Ohshima |
| NPL | Krzysztof Szymaniec |
| NRC | Louis Marmet |
| PTB | A. Bauch |
| VNIIFTRI | Y. Domnin |

Appendix B

## Working Group on Primary Frequency Standards
## Terms of Reference

Members

The working group is made up of:

- representatives of all National Metrology Institutes (NMIs) that operate Primary Frequency Standards (PFSs) reporting to TAI,
- representatives of NMIs that are planning to operate at least one PFS reporting to TAI,
- representatives of the BIPM.

Chairperson

The chairperson is a member of the Working Group on Primary Frequency Standards representing an NMI operating a PFS appointed by the CCTF for the term of two consecutive CCTF meetings.

Objectives

(1) Develop and propose standards for the documentation of frequency biases and uncertainties, operational details, and frequency transfer uncertainties for a PFS. Develop and propose standards for the reporting of the results of a PFS evaluation to the BIPM.

(2) Provide a forum to evaluate and discuss the consistency among primary frequency standards.

(3) Provide a forum to discuss and assess the overall knowledge of the accuracy of the SI second for use in establishing the frequencies of secondary standards (microwave and optical) and possibly an eventual redefinition of the second.

(4) Interact with the BIPM on issues related to PFS contributions to the accuracy of TAI, particularly in the process of integration of the first reports of a standard.

(4) Encourage and facilitate direct comparisons between primary frequency standards.

(5) Encourage and support laboratories with new standards under construction.

Appendix C

## Frequency Transfer Uncertainty into TAI

Recommendation from the Working Group on Primary Frequency Standards regarding the uncertainty of a frequency transfer into TAI.

The current expression for the fractional frequency transfer uncertainty of a Primary Frequency Standard (PFS) reporting an evaluation into TAI is given in Eq. 1.

$$u_{l/TAI} = 3x10^{-14}/\tau \qquad (1)$$

Here $\tau$ is the interval of the report in days and the equation applies to all laboratories. This expression has been used for many years and is now out of date. Time transfer stabilities have improved significantly in the last few years, and the uncertainties for UTC - UTC(k) are now reported each month in Circular T for each laboratory. Therefore a new expression for $u_{l/TAI}$ is recommended and is shown in Eq. 2.

$$u_{l/TAI} = \left( \frac{\sqrt{u_A(k)_1^2 + u_A(k)_2^2}}{86400 \cdot \tau_0} \right) \Bigg/ \left( \frac{\tau}{\tau_o} \right)^x \qquad (2)$$

Here $u_A(k)_1$ and $u_A(k)_2$ are the uncertainties, in seconds, for UTC - UTC(k) at the beginning and end of the report interval respectively, for laboratory k as reported in Circular T. $\tau$ is the report interval in days. $\tau_0$ is the effective interval in days over which the $u_A(k)_i$ values are determined. The expression in the left hand parenthesis is therefore the fractional frequency uncertainty for time interval $\tau_0$. If time transfer noise were white PM over the period of interest (5 days to many tens of days) x would be 1. However, there is considerable evidence that time transfer noise over this interval is more likely to be flicker PM (probably caused by environmental perturbations) and therefore x should be in the range of 0.8 to 0.9. It should be noted that for most laboratories with a PFS the value of $u_{l/TAI}$ will be two to three times smaller with the new expression. The largest decrease in $u_{l/TAI}$ comes from the use of the $u_A(k)_i$ values, whereas the values of $\tau_0$ and x have a relatively minor impact.

Currently the recommended values for $\tau_0$, and x are given below.

$\tau_0$ = 5 days
x = 0.9

These values may change with more detailed knowledge of the time transfer noise processes, or may be tailored to individual laboratories. $\tau$ can be less than $\tau_0$ if $\tau_0$ is greater than 5 days.

It is recommended that the new equation be used starting as soon as practical in 2006