National Institute of Standards and Technology
Time and Frequency Division
Atomic Frequency Standards Group, M/S 847.5
325 Broadway
Boulder, CO, 80305 USA

FAX MESSAGE

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To: Dr. Felicitas Arias
Time Section, BIPM
FAX: 33 1 45 07 70 59
Phone: 33 1 45 07 70 76

From: Dr. Thomas E. Parker
FAX: 1 303 497 6461
Phone: 1 303 497 7881

Dear Dr. Arias,

Attached is the report of our most recent formal evaluation of NIST-F1, a cesium fountain frequency standard. The report period is for the 40 day interval from MJD 53359 to 53399, whereas the fountain was operated in a near continuous fashion over a shorter evaluation interval from MJD 53366.8 to 53391. Details of the standard's design, construction, and performance are presented in references 1 - 5 listed on page 7. A new paper updating the fountain operation and uncertainties is nearing completion and is expected to be submitted for publication shortly. A detailed summary of the present evaluation is included in this report. The evaluation results using the BIPM format are given on pages 2 and 7.

The only significant change to the fountain for this evaluation was the replacement of the microwave synthesizer with new equipment that has lower noise and is more reliable. This has resulted in a lower statistical uncertainty than in our previous evaluation, even though this was a shorter run. Again we have included the uncertainty due to the determination of the spin exchange shift as part of the type A uncertainty.

Thomas E. Parker

SUMMARY

December 2004/January 2005 Evaluation of NIST-F1

The most recent evaluation of NIST-F1 is reported. The number

$$Y_{(NISTF1\text{-}maser)} = -291.88\text{x}10^{-15}$$

is the average fractional frequency difference between NIST-F1 and the hydrogen maser ST0005, (clock # 40205) over the 40 day report period MJD 53359 to 53399. ***(Note: this is a different maser than we had been previously using.)*** The type A uncertainty of the fountain for this evaluation (statistical confidence on the frequency measurement including a component due to spin exchange, but not including dead time) is $0.41\text{x}10^{-15}$ (1σ). The type B uncertainty from known biases (not including spin exchange) is $0.34\text{x}10^{-15}$ (1σ). The combined uncertainty (type A and type B) is $0.53\text{x}10^{-15}$ (1σ). The uncertainty becomes $0.61\text{x}10^{-15}$ (1σ) when the contribution from dead time, $u_{link/lab}$, is included. A detailed description of the various biases and uncertainties is given in the following sections of this report.

RESULTS IN BIPM FORMAT

Report period		MJD 53359 to 53399
Maser frequency (ST0005), clock # 40205)		$Y_{(NISTF1\text{ - }maser)} = -291.88\text{x}10^{-15}$
Statistical	u_A	$0.41\text{x}10^{-15}$
Systematic	u_B	$0.34\text{x}10^{-15}$
Link to clock	$u_{link/lab}$ (40 days)	$0.30\text{x}10^{-15}$
Link to TAI	$u_{link/TAI}$ (40 days)	$0.75\text{x}10^{-15}$
Combined	u	$0.97\text{x}10^{-15}$

1. DETAILS OF EVALUATION

An accuracy evaluation of NIST-F1 has been completed in which the frequency of a hydrogen maser was determined with respect to the primary frequency standard. The report period is 40 days, but the fountain was operated only over the 24.2 day evaluation interval of MJD 53366.8 to 53391. Of the 24.2 days intended for the measurement of the maser frequency, only 20.5 days of data were collected (85% run time). The lost run time was from a combination of intentional and unintentional interruptions to the fountain operation. The outside temperature was particularly variable during this evaluation which resulted in a variable laboratory temperature. This resulted in more than a normal amount of dead time. A time line of the entire 40 day report period is shown in Table 1 below. Ideally the medium density run would have been carried out closer to the middle of the evaluation interval but it was located at the end in order to accommodate a comparison with our optical frequency standards.

Table 1: Time Line

MJD	Event
53359	Start report period
53366.8	Start fountain run, low density
53376	End low density, start high density
53379	End high density, start low density
53389	End low density, start medium density
53391	End medium density
53399	End report period

A factor of about 7 in atom densities was covered in this evaluation and the frequency for zero density was obtained by a weighted linear least-mean-square fit. Other corrections are also made to the raw frequency data in order to compensate for known biases which are described below. Units for all biases are fractional frequency x10^{-15} and all uncertainties are 1 sigma.

A. Quadratic Zeeman Bias

The quadratic Zeeman bias was determined by measuring the linear Zeeman splitting of the microwave spectrum. The resulting bias and uncertainty are shown below.

Bias	Type B Uncertainty
+36.53	<0.1

B. Spin Exchange Bias

Measurements were made over a range of atom densities. A factor of 7 in atom density was covered and the frequency for zero density was obtained from the zero density intercept of a weighted linear least-mean-square fit. Using this approach there is no fixed spin exchange bias, however the shift in fractional frequency from the lowest measured density to zero density was -0.42×10^{-15} with an uncertainty of 0.10×10^{-15}. These values are shown below for information purposes only. They are not included in the type B biases and uncertainties since they are already incorporated into the intercept and its uncertainty (type A uncertainty). Note that 81% of the fountain run time was at the lowest atom density.

Bias	Type B Uncertainty
(-0.42)	(0.10)

C. Blackbody Bias

The blackbody bias is calculated from the temperature of the drift region. The resulting bias and its uncertainty are shown below.

Bias	Type B Uncertainty
-21.21	0.26

D. Combined variable and fixed biases

There are additional biases that do not change under normal circumstances, for example the gravitational red shift correction. The complete list of all biases (fixed and run dependent) and their corresponding uncertainties are shown in Table 2.

Table 2: Known Frequency Biases and Their Type B Uncertainty.
(Units are fractional frequency x10^{-15})

Physical Effect	Bias	Type B Uncertainty
Second-order Zeeman	+36.53	< 0.1
Second-order Doppler	< 0.1	< 0.1
Cavity pulling	< 0.1	< 0.1
Rabi pulling	< 0.01	< 0.1
AC Zeeman (heaters)	< 0.1	<0.1
Cavity phase (distributed)	< 0.1	< 0.1
Fluorescence light shift	< 0.1	<0.1
Adjacent atomic transitions	< 0.1	< 0.1
Spin exchange	(-0.42)*	(0.10)*
Blackbody	-21.21	0.26
Gravitation	+180.54	0.10
Electronics		
RF spectral purity	0	< 0.1
Integrator offset	0	< 0.1
AM on microwaves	0	< 0.1
Microwave leakage	0	0.2
	Total Type B Standard Uncertainty	0.34

*For information purposes only. Not used in total, see section 1-B for details

2. EVALUATION INTERVAL RESULTS (MJD 53366.8 to 53391)

When corrections for the biases of Table 2 are applied, the following result for the measurement of $Y_{(NISTF1\text{-}maser)}$ is obtained. Because the type A uncertainty now includes the spin-exchange bias uncertainty, we include (in parentheses in the table below) the combined statistical uncertainty of all the data collected in this evaluation (as if there were no linear fit). This is included only for its informational value. Units are fractional frequency $x10^{-15}$.

Corrected Frequency	Type A Uncertainty (includes spin exchange)	Total Type B Uncertainty (does not include spin exchange)	Combined Uncertainty
-291.88	0.41 (0.25)	0.34	0.53

3. INFLUENCE OF DEAD TIME

NIST-F1 was operated for a total of only 20.5 days during this 40 day report period so the dead time has an impact on the overall uncertainty. However, NIST has a well characterized ensemble of hydrogen masers so this impact can be accurately quantified. The frequency stability and drift of the reference maser are well known. No drift correction was required because the frequency drift on this maser is very small and the run time was well centered. However, the dead time contributes an additional type A uncertainty of $0.30x10^{-15}$. See references 6 - 8.

4. FINAL REPORT PERIOD RESULTS (without time transfer uncertainty)

Applying the correction resulting from dead time to the evaluation interval results yields the following 40 day final report period results.

Report period	MJD 53359 to 53399
Maser frequency (ST0005, clock # 40205)	$Y_{(NISTF1\text{ - }maser)} = -291.88x10^{-15}$
Type A uncertainty (not including dead time)	$0.41x10^{-15}$ (1σ)
Type B uncertainty	$0.34x10^{-15}$ (1σ)
Combined uncertainty (fountain only)	$0.53x10^{-15}$ (1σ).
Type A uncertainty from dead time	$0.30x10^{-15}$ (1σ)
Combined uncertainty with dead time	$0.61x10^{-15}$ (1σ).

5. FINAL RESULTS USING BIPM FORMAT (includes time transfer uncertainty)

Report period		MJD 53359 to 53399
Maser frequency (ST0005), clock # 40205)		$Y_{(NISTF1 - maser)} = -291.88\text{x}10^{-15}$
Statistical	u_A	$0.41\text{x}10^{-15}$
Systematic	u_B	$0.34\text{x}10^{-15}$
Link to clock	$u_{link/lab}$ (40 days)	$0.30\text{x}10^{-15}$
Link to TAI	$u_{link/TAI}$ (40 days)	$0.75\text{x}10^{-15}$
Combined	u	$0.97\text{x}10^{-15}$

6. REFERENCES

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