NIST AND OP GPS RECEIVER CALIBRATIONS SPANNING TWENTY YEARS: 1983 - 2003*

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Abstract

We present results from two calibrations performed in 2003 between the Global Positioning System (GPS) common-view receivers located at the National Institute of Standards and Technology (NIST) and at the Bureau National de Métrologie – Systèmes de Référence Temps Espace (BNM-SYRTE) of the Observatoire de Paris (OP) in the context of calibrations performed over 20 years, 1983-2003. We also present several years of continuous comparisons between receivers located at each of the two labs: NIST and OP. These results show that the best GPS receivers in use have delay variations with peak differences of under 5 ns over a year. This contributes to defining the current practical limits of GPS common-view time transfer. Since GPS common-view time transfer is still used for the majority of links between laboratories contributing to International Atomic Time (TAI), the noise and uncertainties in common-view affect the short-term performance of TAI, for averaging times from 5 to 30 days.

1. Introduction

One of the goals of this paper is to present the long-term stability of the best common-view GPS receivers. We do this by giving long-term comparisons of such receivers, both among co-located receivers, and among receivers calibrated by means of a travelling receiver.

GPS common-view time transfer is still the dominant mode for establishing the links between laboratories contributing to TAI. The instability of the receiver delays is probably the largest contributor to the instability in TAI in short-term, from 5 days out to about 30 days.

We can see this in Figure 1: the modified Allan deviation (MDEV) [8] of TAI against the NIST scale AT1e. AT1e is a post-processed time scale dominated by five Hydrogen Masers (H-Masers), all in environmental chambers controlling temperature and humidity. The stability of AT1e is below 3 part in 10^{16} at 10 day, about 10^6 seconds [5]. This is well below the apparent flicker phase modulation (PM) noise dominated deviation in Figure 1, from 5 days out to almost 40 days.

The data in Figure 1 are consistent with a flicker PM noise model for the first three points, because the slope on the log-log plot is –1. The first three points are for averaging times of 5, 10, and 20 days. At 40 days, there seems to be some flattening as the clock noise begins to contribute. Flicker PM at the levels in Figure 1 from 5 to under 40 days is typical of GPS common-view time transfer [2,4,6]. The long term stability between AT1e and TAI in Figure 1 is dominated probably by either random-walk frequency modulation , giving a slope of +½, or linear frequency drift, giving a slope of +1.

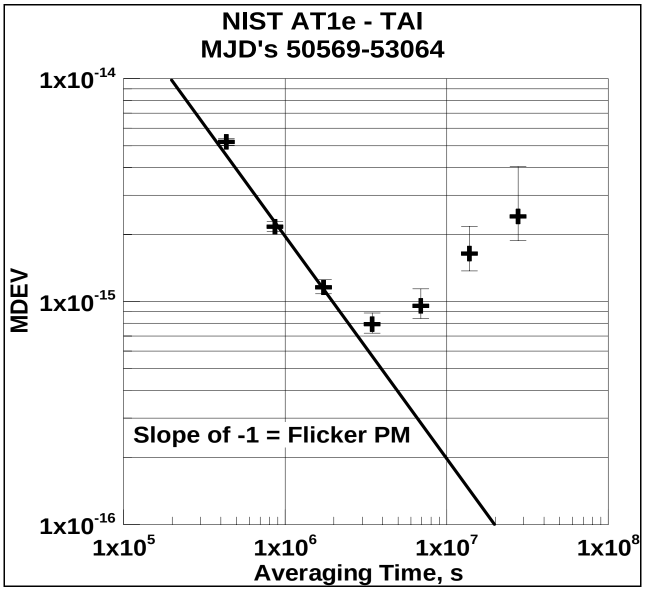

Figure 1: Modified Allan Deviation of NIST AT1e, the NIST post-processed H-Maser scale, against TAI. The data cover almost seven years, from May 1, 1997 to February 29, 2004.

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The data in Figure 1 cover almost seven years. Since the clocks contributing to TAI improve continuously, the stability of TAI should improve also with time. Figure 2 gives MDEV of NIST AT1e against TAI for about the last 2 years. The long term stability is markedly improved over Figure 1. The short term, from 5 to 20 d, is somewhat improved but still dominated by flicker PM, hence by transfer noise. The improvement in transfer is probably due to the increased use of Two-Way Satellite Time and Frequency (TWSTFT) [1] among a few of the labs, since common-view GPS time transfer has not improved significantly in the last few years. Unfortunately, TWSTFT is expensive both in equipment costs and staff time. It is unlikely that this method will be used by most links contributing to TAI.

Many receiver systems have temperature dependant delays in the receivers, the antenna cables, and the antennas[3,7]. The impedance matching in the antenna cable can produce slowly changing instabilities of the order of tens of nanoseconds [9]. Hence, it is important to routinely calibrate receiver delays against each other, by doing common-clock experiments with a travelling receiver.

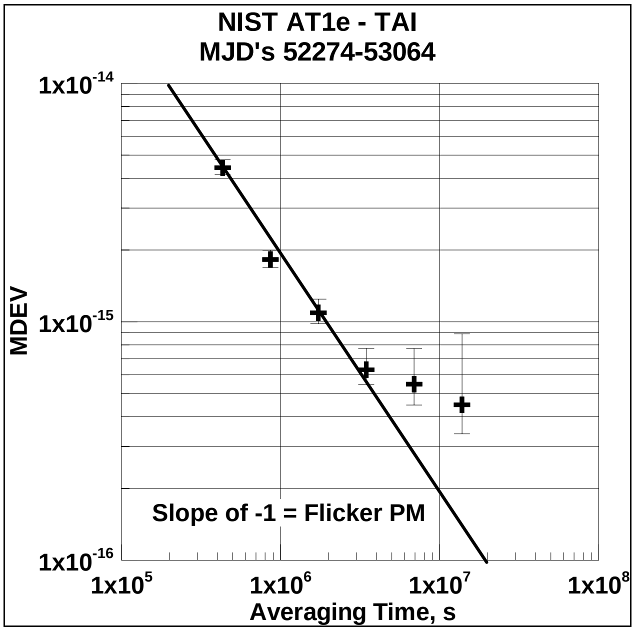

Figure 2: Modified Allan Deviation of NIST AT1e, the NIST post-processed H-Maser scale, against TAI. The data cover over 2 years, from December 31, 2001 to February 29, 2004.

2. OP – NIST Calibrations

One of the longest histories of such calibrations is that between NIST, Boulder, Colorado, USA, and OP, Paris, France. The primary receivers at the two institutions have remained the same over that time: NBS10 at NIST, and NBS51 at OP. Since these receivers have been used to link the respective labs UTC offsets, changes in delays correspond to corrections that need to be added to the difference in the UTC values.

We present the results of these calibrations in both Table 1 and Figure 3, in the form of the correction needing to be added to UTC(NIST) – UTC(OP). We give the corrections from calibrations along with their uncertainties since the original NBS-type receiver was first placed at OP in July, 1983.

We see that the variation in delays is 6.3 ns over 20 years. We also see there may be changes up to 4.4 ns in periods of several months, January to April 1988, though the uncertainties on those calibrations overlap. Also note that the two calibrations of 2003 have a good agreement. There seems to be a consistency in the differential delay over the last few years.

Date	*d*/ns	*u(d)*/ns
July 1983	0.0	2.0
September 1986	0.7	2.0
October 1986	–1.4	2.0
January 1988	–3.8	3.0
April 1988	0.6	3.0
March 1995	–3.7	1.0
May 1996	–0.7	1.5
May 2002	–5.0	3.0
July 2003	–5.6	1.9
December 2003	-5	3

Table 1. Some past calibrations between NIST and OP: *d* are differential time corrections to be added to [*UTC*(NIST)-*UTC*(OP)], and *u(d)* are estimated uncertainties for the periods of comparisons.

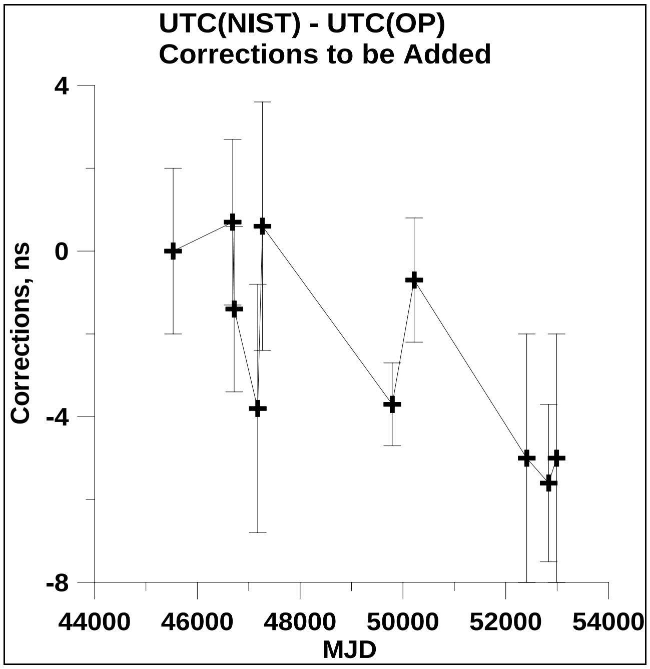

Figure 3: A plot of the data in Table 1.

3. Local Common-Clock Comparisons

There have been many GPS receivers at both NIST and BNM-SYRTE of OP. We show here the deviations between some of them in each lab. Figure 4 gives the variations of several receivers at BNM-SYRTE against the long-term primary receiver, NBS51. Each point in the figure is computed every day from a linear fit of the common-views between the receivers, which follow the BIPM International Tracking Schedule. These are all NBS-type receivers, although produced by various manufacturers.

As indicated in the figure, receiver data have been offset to separate the time series. We see that over many years receiver delays generally changed by only a few nanoseconds, with some exceptions. There was a step in the data of VSL15 against NBS51 that lasted over a year. There were some large deviations at the end of the A400 data against NBS51, which exhibit the end of life of A400. Annual terms of amplitude 5 ns appear in the A263 data against NBS51 and at the end of the TTR01 data against NBS51, of amplitude 2.5 ns. This might partly come from the common NBS51 reference receiver, since the phase is similar. Such an annual variation can be detected only from long-term studies as this one.

Figure 5 shows data for receivers at NIST against NBS10, the primary receiver. We see a significant difference in stability among receivers. Some of the multi-channel receivers (labelled M1, M2, and M3) vary significantly over the year 2003. The NIST M3 receiver, however, appears to be as stable as the NBS-type in long term. The M3 receiver needs to be calibrated, however. Again we see that the best receivers vary under 5 ns over a year. This is consistent with previously published data. Local common-clock data at NIST were previously published spanning the years 1991 – 1997 [10]. That paper reported typical variations of about 5 ns over a year, often with an annual signature. There were, of course, larger deviations at times.

4. Conclusions

The delays of the most stable GPS common-view time transfer receivers vary typically by a few nanoseconds over years, generally by less than 5 ns peak-to-peak. Some changes in the receiver delays, such as annual terms, can be detected only from such long-term studies. Receiver calibrations are essential to maintain accuracy and long-term stability in TAI. However, TAI is currently dominated by common-view time transfer instabilities from 5 to 30 d. We need a significantly more stable time-transfer system than the current GPS common-view system, if we are to compare the clocks contributing to TAI at shorter averaging times. TWSTFT is significantly more stable, but requires more resources as well.

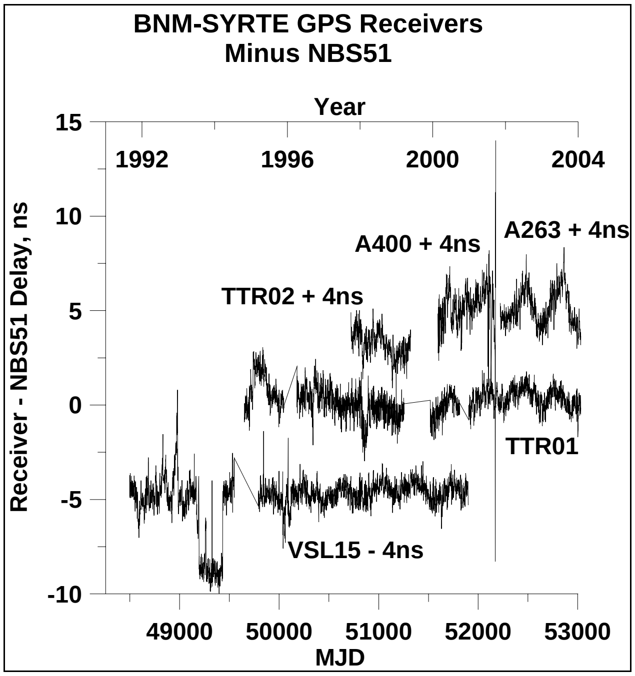

Figure 4: Delays of receivers at BNM-SYRTE minus the delay of NBS51, the primary receiver. The data have offsets added to them as indicated. Note that the vertical spike after MJD 52000 is solely from the data of the A400 receiver against NBS51.

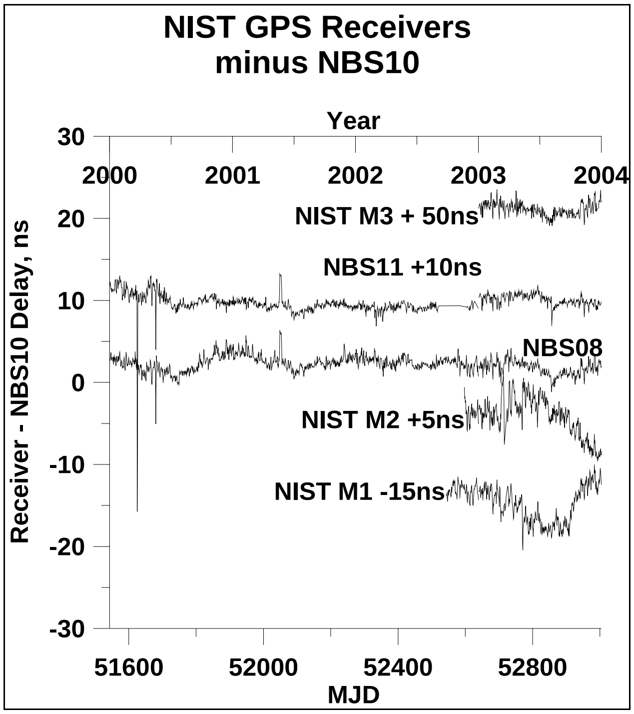

Figure 5: Delays of receivers at NIST minus the delay of NBS10, the primary receiver. NBS08 has no offset added to it, though other receivers have offsets as indicated.

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