STEERING UTC (AOS) AND UTC (PL) BY TA (PL)

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Abstract

The independent Polish Atomic Time Scale TA (PL) is based on about 15 cesium atomic clocks, from seven laboratories in Poland and one in Lithuania. The clocks are compared using multi-channel TTS-2 and TTS-3 time receivers. In the past, data from physically distant clocks were collected weekly; more recently, they have been gathered daily. For this purpose, special software has been developed to allow automatic data collection, and an appropriate database has been created. TA (PL) was initially computed monthly as the weighted average of the participating clocks. The long-term stability of TA (PL) was approximately 3 parts in 10^{15}. In early 2006, experimental software for daily computations of TA (PL) was developed at the Astrogeodynamical Observatory in Borowiec (AOS) and the National Institute of Telecommunications (NIT). This software is now fully implemented, and allows daily steering of UTC (AOS) based on daily TA (PL). The purpose of this realization is to keep UTC (AOS) within ±10 ns of UTC, whereas previously it was kept within ±20 ns. Our paper describes the procedures being developed and gives most recent results.

1 INTRODUCTION

The Polish Atomic Time Scale TA (PL) was officially started on 1 June 2001. It is currently based on the readings of about 15 atomic clocks installed at several public and commercial institutions. The participating laboratories are referenced to the Central Office of Measures (GUM) using multi-channel GPS TTS-2 and TTS-3 receivers developed by the AOS (all acronyms and abbreviations are provided at the end of the paper) in cooperation with the BIPM **[1-3]**. The Time and Frequency Laboratory of GUM is connected to the TAI pivot point at the PTB in Braunschweig, Germany, using a TTS-2 receiver (see Figure 1). The Lithuanian Semiconductors Institute (LT) in Vilnius also participates in the realization of TA (PL) with two cesium standards. Until now TA (PL) has been realized as a weighted average of the participating clocks, using an algorithm similar to ALGOS **[4-8]**.

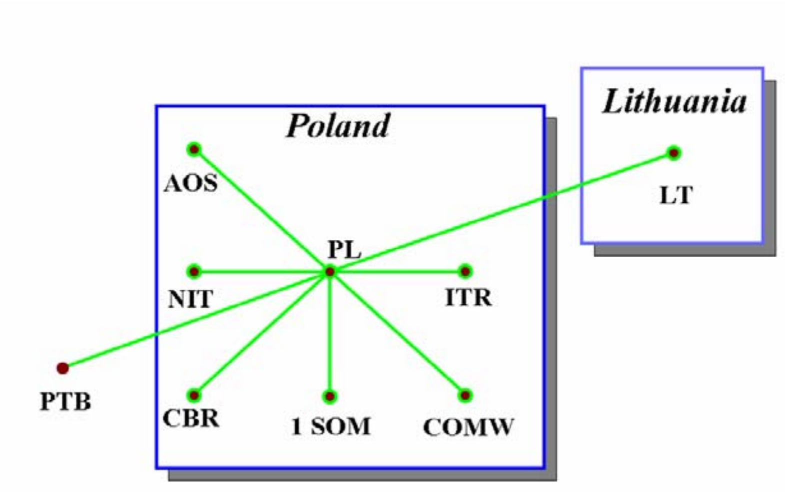

Figure 1. Organization of TA (PL) links.

The GUM and the NIT are responsible for organizing automatic data collection and all the computations are carried at the AOS in Borowiec. The organization of TA (PL) allows:

- the contribution of about 12 of the Polish atomic clocks to International Atomic Time (TAI);
- the connection of local atomic clocks to Polish Official Time;
- the realization of an independent atomic time scale with stability of the order 1 part in 10^{15} (see Figures 2).

Calibrations of the time transfer equipment used for the clock comparisons have been carried out by the AOS (see Table 1). Three of the participating laboratories: AOS, GUM, and LT provide their own realizations of UTC (k) and directly participate in TAI and UTC, and their equipment has been calibrated using the special BIPM "travelling" receiver (Table 1). The equipment delays were estimated by the BIPM.

Table 1. Clocks and time transfer receivers at laboratories participating in TA (PL).

Laboratory	Clock	Receiver	Receiver Serial Number	Year of calibration
AOS	1 Cs	TTS-2	P3	1996, 2000, 2002, 2003
CBR	2 Cs	TTS-2	12	-
GUM	3 Cs, 1 HM	TTS-2	23	1996, 2002
NIT	2 Cs	TTS-2	11	2003
ITR	1 Cs	TTS-2	22	-
SOM	1 HM	TTS-2	30	2003
COMW	1 Cs	TTS-2	34	2003
LT	2 Cs	TTS-2	20	2002
Upcoming clocks are:				
CBR	1 Cs (Datum)			
Toruń University	1 HM			
Polish Army	1 HP5071A			
LT	1 HP5071A			
AOS	2 HM			

From August 2004 to 2006, tests of UTC (AOS) based on TA (PL) were carried out in post-processing. Then TA (PL) started to be used in the prediction and forming of UTC (AOS). The accuracy of realization of UTC (AOS) with respect to UTC was roughly 20 ns.

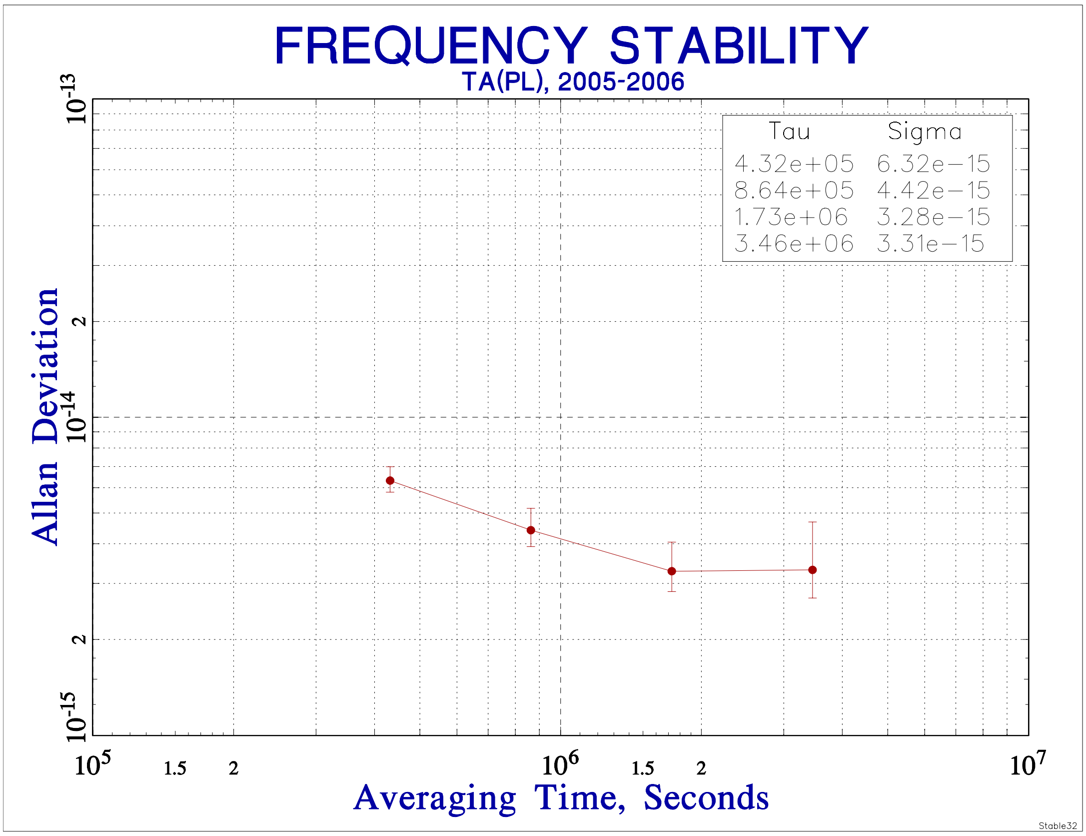

Figure 2. Frequency stability of [TAI – TA (PL)] in 2005-2006.

2 PROCEDURE OF UTC (AOS) STEERING

We give here an outline of the procedure currently being tested for steering of UTC (AOS) by TA (PL). There are five fundamental steps in this procedure:

1. 4-day linear prediction of TA (PL) based on [*TAI* – *TA* (PL)] in the previous period; see Figure 3.
2. Daily computation of rapid TA (PL)′ using AOS algorithm or NIST AT1; see Figure 4.
3. Corrections to be added to the AOS master clock to give UTC (AOS) are computed from [*TAI* – *TA* (PL)$_{predicted}$] and [*TA* (PL)′– AOS *master clock*] .
4. Frequency corrections for [*master clock* – *UTC* (AOS)] are estimated from differences between the current and the previous day.
5. These frequency corrections are applied through a micro-phasestepper to the 5 MHz frequency of the master clock, giving a hardware realization of steered UTC (AOS).

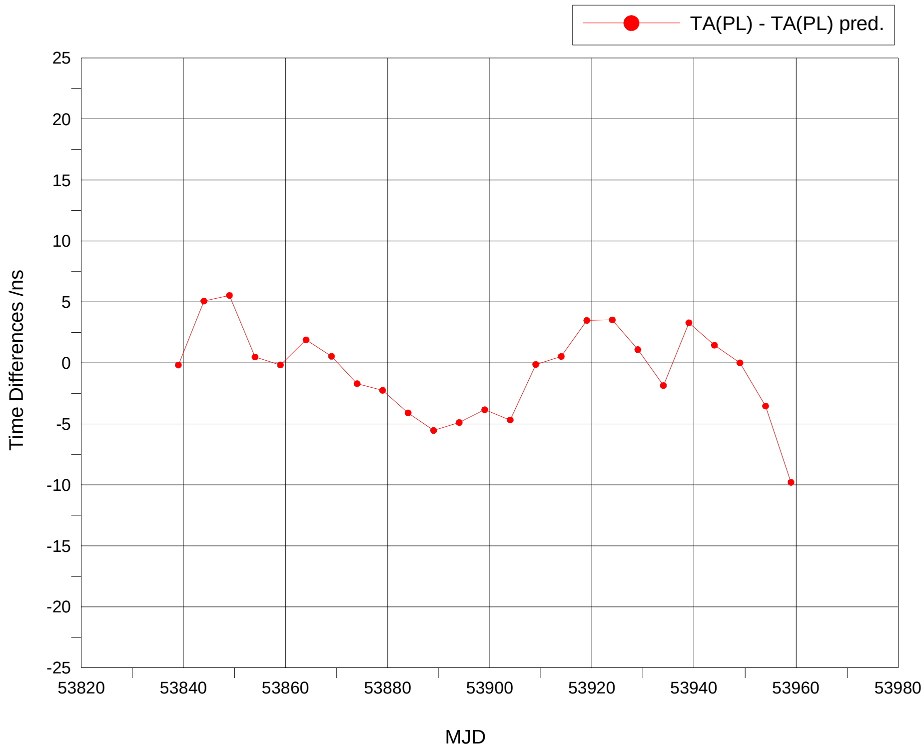

Figure 3. The differences [TA (PL) – TA $(PL)_{predicted}$], using a 45-day prediction for TA$(PL)_{predicted}$.

3 DAILY COMPUTATION OF TA (PL)′ AT AOS

The daily computation of TA (PL)′ is carried out at both the AOS and the NIT. The AOS has developed its own software and the NIT has adopted the NIST AT1 and AT2 algorithms; see Section 4. In addition, the GUM and NIT are developing an automated server gathering daily clock and time-link data from all laboratories contributing to TA (PL); see Section 5. This facility should be operational within a few months.

The AOS prototype algorithm for daily computation of TA (PL)′ is organized as follows:

- Clock data are collected every day at 6:00 UTC.
- TA (PL) is computed monthly from all TA (PL) clocks.
- TA (PL)′ is computed every day at 11:00 UTC, as a weighted average of the participating clocks.
- Initial drift for the first computation based on the average drift of clocks from the previous month is obtained from TA (PL).
- As a first approach, the clock weights of the clocks from the latest month of computation of TA (PL) are used.

The results obtained using the AOS and NIT algorithms can be compared; see Section 5. This comparison will be carried out automatically on the server gathering the data, located at GUM. Preliminary results of the AOS algorithm are provided in Figure 4.

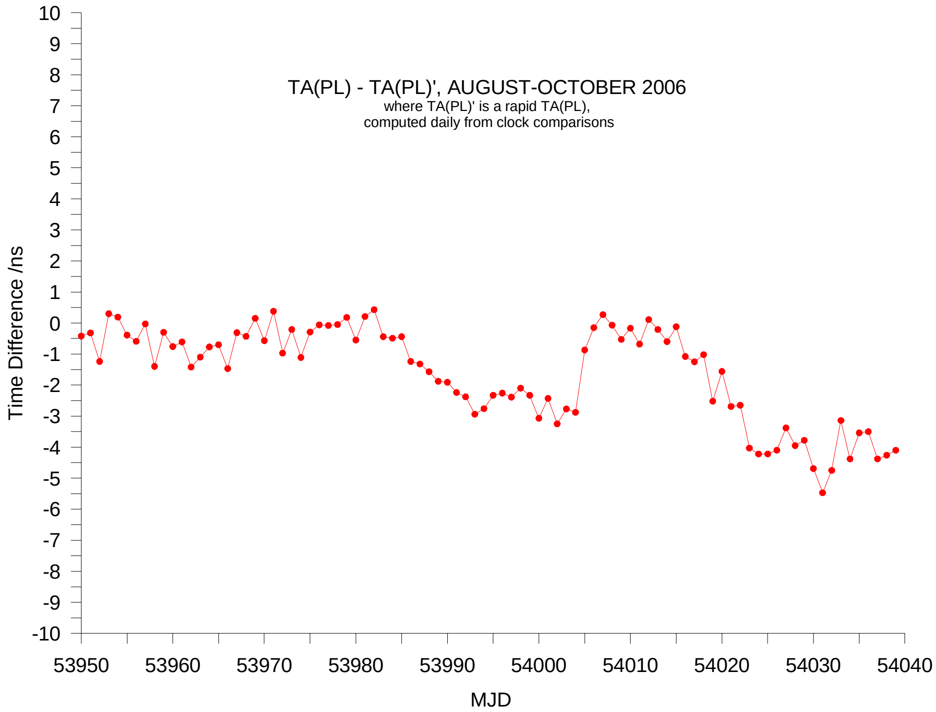

Figure 4. A comparison of definitive TA (PL), computed monthly, with rapid TA (PL)′, computed daily using the AOS algorithm.

Daily computation will allow daily steering of UTC (AOS) based on daily TA (PL)′ rapid, with the aim to keep UTC (AOS) within ±10 ns of UTC. Until recently UTC (AOS), based on the "old" TA (PL), was kept within ±20 ns. Some results are displayed on Figure 5. An indication of the improvement of achieved in UTC (AOS) is illustrated in Figure 6.

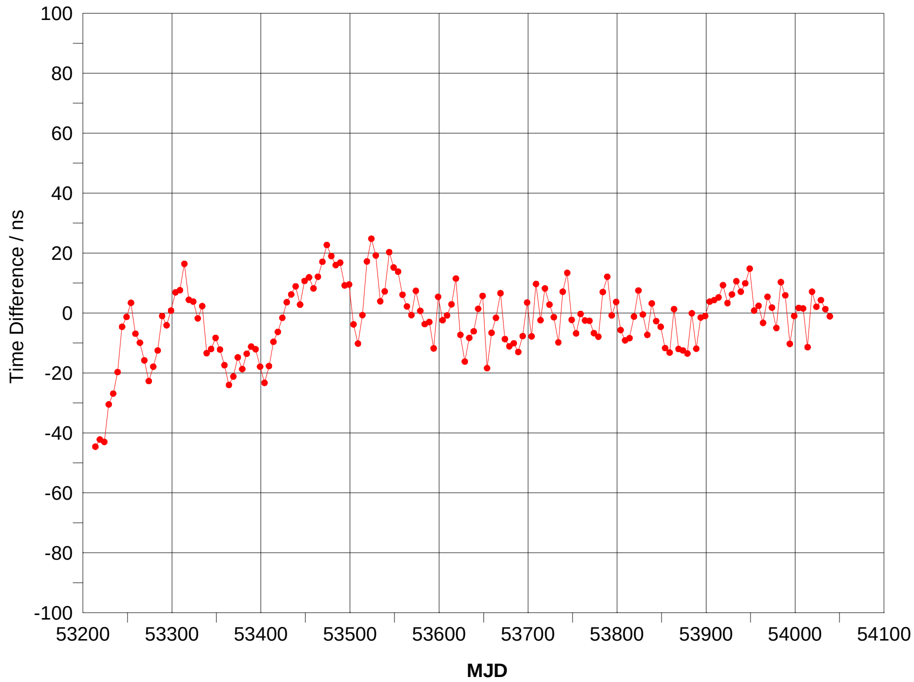

Figure 5. [UTC – UTC (AOS)].

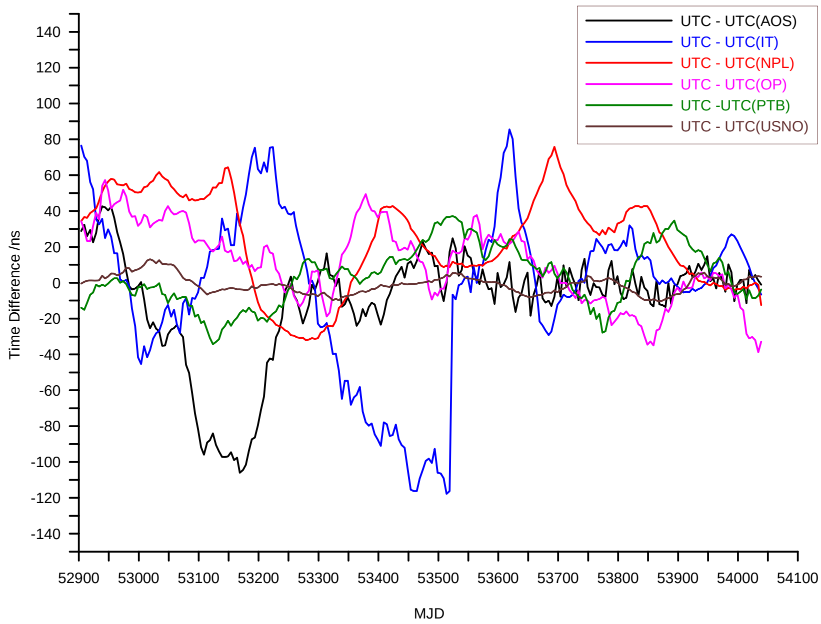

Figure 6. A comparison of some selected UTC timescales.

4 WORK ON NIST AT1 AND AT2 AT NIT

Work on the use of NIST AT1 and AT2 for the test time scale computation of TA (PL) has been under way at the NIT since 2005. First, an algorithm NIT AT1 based on AT1 was elaborated and tested, and then, in November 2006, tests started on a second algorithm NIT AT2 based on AT2 **[9,10]**. For the time being, these algorithms are used for the recomputation of existing data. The results of phase comparisons of NIT AT1 and NIT AT2 to TAI and their Time deviation and Allan deviation are presented in Figures 7 to 9.

The mean relative frequency shift over about 900 days is –0.31 ns/d for NIT AT1 and –0.15 ns/d for NIT AT2, compared to TAI. There are still several problems to be resolved, such as the detection of small frequency steps, precise fixing of initial parameters for NIT AT2, treatment of hydrogen masers, etc. When these problems are fixed, NIT AT1 and NIT AT2 will be used on the automatic server at GUM as alternative algorithms.

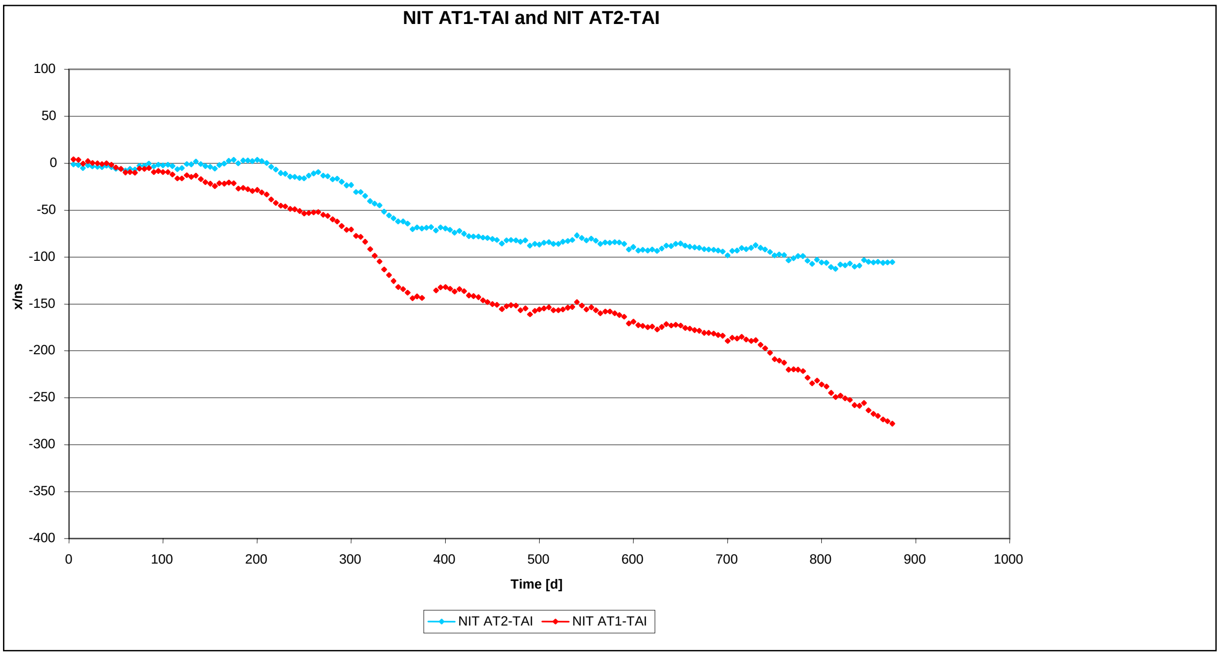

Figure 7. A comparison of NIT AT1 and NIT AT2 to TAI in 2004-2006.

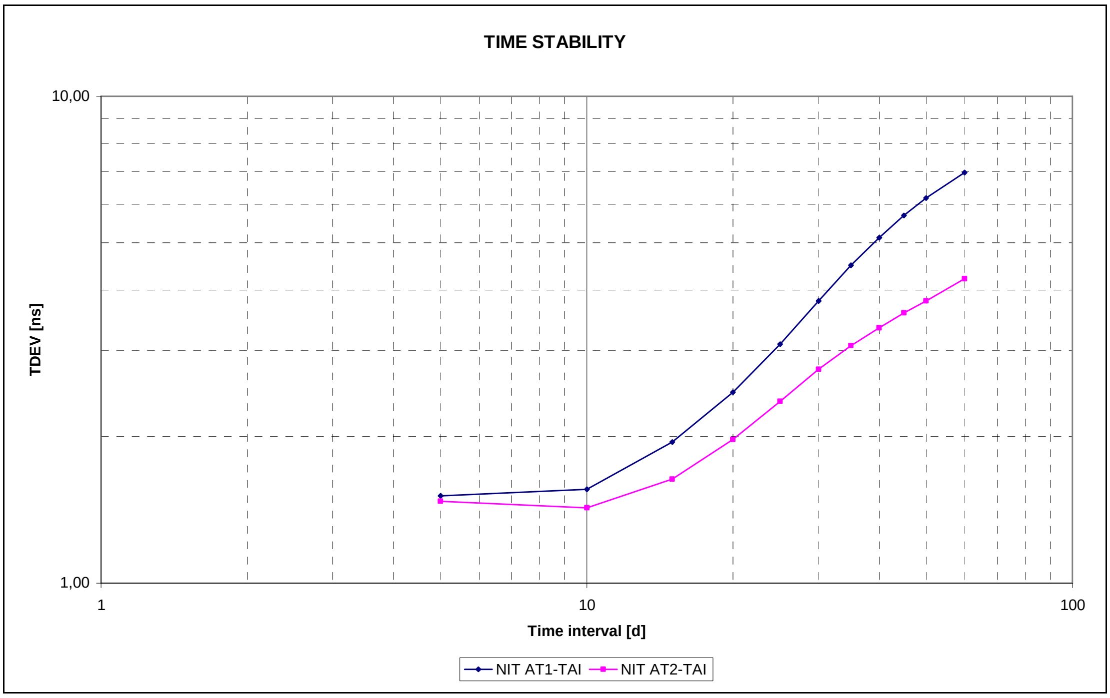

Figure 8. Time stability of [TAI – NIT AT1] and [TAI – NIT AT2] in 2004-2006.

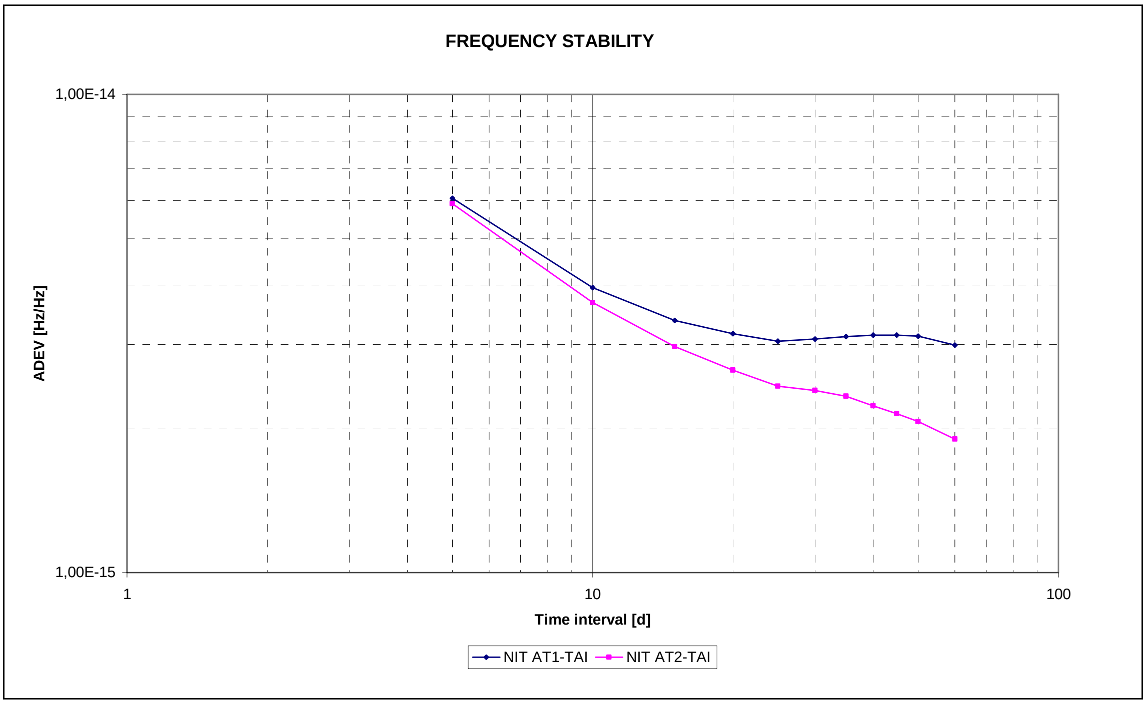

Figure 9. Frequency stability of [TAI – NIT AT1] and [TAI – NIT AT2] in 2004-2006.

5 AUTOMATED DATABASE FOR TA (PL)

In 2005, started work at NIT on an automated database for TA (PL). The goal of this work is to create a tool for data elaboration by the GUM. There are two main parts of the system:

- data acquisition – data flow (GPS time transfer and clock data) is realized through electronic mail from the laboratories contributing to TA (PL). All the information is filtered automatically from sender to measurements sent in attached text files of a predefined format.
- computation/presentation of results – measurement data are treated by implemented algorithms, and results are presented on the Internet as tables and figures.

During the data acquisition process, measurement results are transformed into [UTC (PL) – clock (i)]. Such data are used as input for the time scale algorithms. At present, two algorithms are being developed and tested at NIT:

- AOS algorithm based on BIPM ALGOS – used for basic TA (PL) computation;
- NIT AT1 based on NIST AT1 – used for an experimental mean-term optimized time scale.

6 FORTHCOMING DEVELOPMENTS

We foresee the following development in the coming months:

- The automated database at the GUM and NIT will be put into operation.
- Daily computation of TA (PL)′ using the AOS and NIT algorithms will be implemented on the automated server.
- Daily steering of UTC (AOS) and UTC (PL) will be applied to keep them within 10 ns of UTC.
- A second time-transfer technique (TWSTFT) will be introduced at AOS.

- AOS will soon be equipped with new two H-masers which will improve the realization of UTC (AOS).
- The NIT will develop a second application based on the NIST AT2 algorithm.

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8 ABBREVIATIONS AND ACRONYMS

ADEV – Allan deviation
AOS – Astrogeodynamical Observatory, Space Research Centre, Borowiec
BIPM – Bureau International des Poids et Mesures, Sèvres
CBR – Research Laboratory of Polish Telecom, Warsaw
COMW – Metrology Centre of Polish Army, Warsaw
GUM – Central Office of Measures, Warsaw
ITR – Institute of Tele- and Radio Electronics, Warsaw
NIST – National Institute of Standards and Technology, Boulder, Colorado

NIT – National Institute of Telecommunications, Warsaw
PL – stands here for the consortium of Polish time laboratories
PTB – Physikalisch-Technische Bundesanstalt, Braunschweig, Germany
SOM – Air Defence Centre of Metrology, Warsaw
LT – Lithuanian Semiconductors Institute, Vilnius, Lithuania
TA (*i*) – Atomic Time of laboratory *i*
TA (PL)′ – daily realization of TA (PL), rapid solution
TAI – International Atomic Time
TDEV – Time Deviation
TWSTFT – Two-Way Satellite Time and Frequency Transfer
UTC – Coordinated Universal Time
UTC (*i*) – Realization of UTC by laboratory *i*