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PUBLICATION OF BIPM TWSTFT REPORTS AND INTRODUCTION OF TWSTFT INTO THE CONSTRUCTION OF TAI

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Introduction

The TWSTFT technique is currently operational in seven European, three North American and five Pacific Rim time laboratories. Some other laboratories have reached pre-operational status.

Analysis of the performance of TWSTFT, which is now in use for several TAI links, shows that clocks located on different continents can be compared by this technique at five-day intervals at their full level of performance, without being affected by time-transfer measurement noise. Thus, if TWSTFT were used for all TAI links, the stability of TAI would be improved for periods of up to 20 days.

The introduction of TWSTFT into TAI has brought about another important change for the better; TAI is no longer reliant on a single technique, because TWSTFT links are backed up by GPS links and vice versa. Also, for the first time, two transatlantic links are used in its construction, and each of these links is performed by two independent techniques. This very new situation increases the robustness of the construction of TAI.

BIPM TWSTFT Reports

Following a recommendation of the 14 April 1999 meeting of TWSTFT Participating Stations, in May 1999 the BIPM Time Section started publishing regular BIPM TWSTFT Reports in which selected TWSTFT links through INTELSAT 307° E are computed and compared with the corresponding GPS links. Eighteen reports have been published to date. Extracts from the 18th Report, which covers the data for eight selected TWSTFT links from January to February 2001, are provided in Appendix I for example.

Modified Allan variance analysis of TWSTFT and GPS links shows that the TWSTFT technique performs better for all analysed links for averaging times less than 10 days. This is particularly striking for the USNO/NPL link, where TWSTFT reveals the behaviour of the clocks with an averaging time as short as 5 days (see Figure 2 of Section II of Appendix I). Using a GPS link we have to wait 20 days to smooth out the white-phase noise of the time transfer.

The BIPM TWSTFT Reports are distributed be e-mail to interested laboratories and are also available by ftp (62.161.69.5, see the directory /Publication/), and via the BIPM web site (www.bipm.org, see Scientific Work of the Time Section). Computer-readable data for all the TWSTFT links published in the Reports are available from the same address.

Introduction of TWSTFT links into TAI

Following a decision of 14th CCTF in April 1999, several TWSTFT links were introduced into TAI. Three TWSTFT links are currently used in the construction of TAI: USNO/NPL, VSL/PTB and NPL/PTB. For these the corresponding GPS C/A-code common-view links are also computed and stored as back-up data. The TWSTFT links used for TAI are calibrated by GPS common-view. An ongoing calibration of the TWSTFT links is being carried out between the USNO and various European laboratories using a US X-band geostationary satellite.

The TUG/PTB TWSTFT link was used in the computation of TAI from July 1999 to June 2000, when the TUG time laboratory ceased regular operations. This TWSTFT link was calibrated differentially by transportation of a portable TWSTFT station in May-June 1998.

In March 2001 the TWSTFT link between the NIST and the PTB was temporarily suspended as primary link due to changes of the INTELSAT 307° E transponders. For the time being GPS data are being used for the computation of TAI, and the corresponding TWSTFT data are being stored as back-up.

Several other TWSTFT links in Europe and the Pacific Rim are being prepared for introduction into the construction of TAI. A summary of all the TAI time links is provided in Appendix II.

Appendix I

Extracts from the 18th BIPM TWSTFT Report

Table of Contents

Section I

Comparison of TWSTFT and GPS CV links computed at the BIPM

Results of the computation for eight time links are given in Tables 1 to 8. Plots showing the differences between the TWSTFT results and the GPS results are given in Figures 1 to 8. In order to compare easily the various plots, the same scale has been used for all, i.e. *y*-axis with an amplitude of 30 ns and *x*-axis spanning Modified Julian Dates 51500–52000.

- TWSTFT links

  Because the TWSTFT data are unevenly spaced by intervals of 2 or 3 days, they are linearly interpolated to give the data for the TAI standard dates at intervals of 5 days.

  When TWSTFT sessions are missing and data are interpolated between TWSTFT sessions more than 5 days apart, results are printed in bold characters. The upper limit for interpolation is 10 days.

- GPS C/A-code common-view links

  GPS C/A-code common-view links are computed using IGS precise ephemerides and IGS ionosphere maps.

Table 1. NIST/PTB link

Introduction of NPL/PTB TWSTFT link into TAI

Date 2001 (MJD)	[*UTC(NIST) – UTC(PTB)*] /ns		TWSTFT – GPS
	TWSTFT	GPS (*Circular T*)	
5 January (51914)	2	4	–2
10 January (51919)	–3	–4	1
15 January (51924)	–3	–4	1
20 January (51929)	–4	–7	3
25 January (51934)	–11	–8	–3
30 January (51939)	–18	–16	–2
4 February (51944)	–23	–21	–2
9 February (51949)	–25	–25	0
14 February (51954)	–25	–20	–5
19 February (51959)	–15	–12	–3
24 February (51964)	**–14**	–11	–3

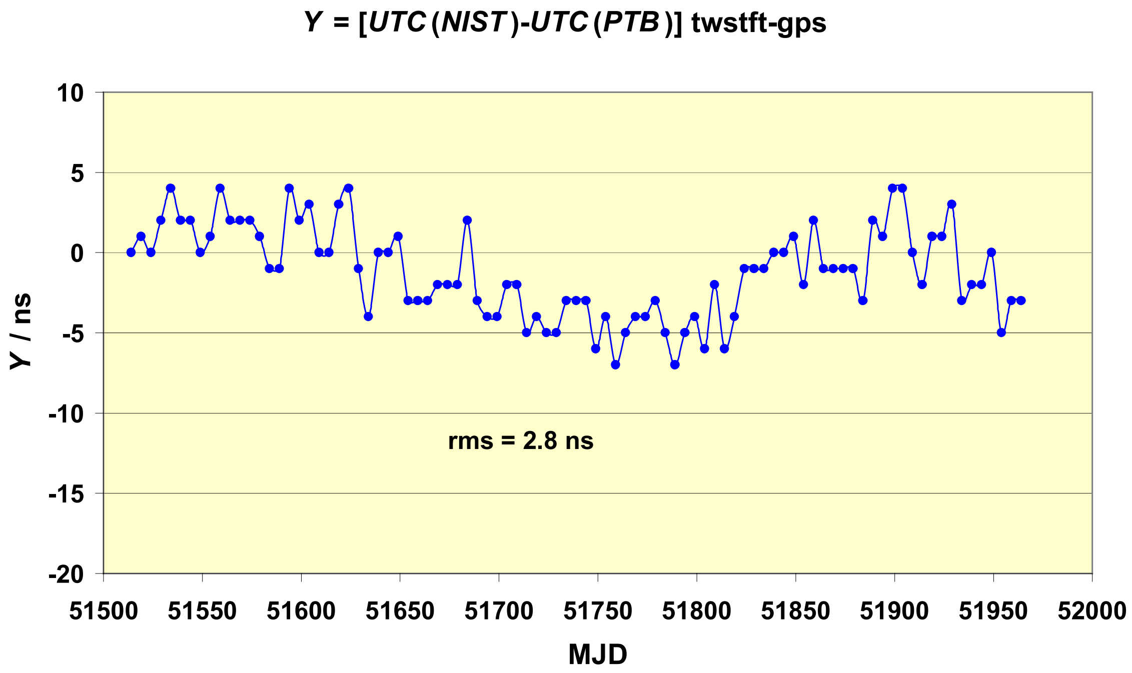

Figure 1. Differences between TWSTFT and GPS C/A-code common-view for NIST/PTB link.

Notes: A new calibration of the NIST/PTB TWSTFT link derived from *Circular T* after July 1999 was applied starting from 29 November 1999 (MJD = 51511).

For the NIST/PTB link, the GPS data were used for the computation of TAI, and the corresponding TWSTFT data were stored as back-up. Since 4 January 2001 (MJD = 51914) the TWSTFT data are used for the computation of TAI and the corresponding GPS data are computed in parallel and kept as back-up.

Table 2a. USNO/NPL link with NPL TWSTFT Station 01

Date 2001 (MJD)	[*UTC(USNO) – UTC(NPL)*] /ns		TWSTFT– GPS
	TWSTFT (*Circular T*)	GPS	
5 January (51914)	23	35	–12
10 January (51919)	24	35	–11
15 January (51924)	25	36	–11
20 January (51929)	23	36	–13
25 January (51934)	18	34	–16
30 January (51939)	17	30	–13
4 February (51944)	15	26	–11
9 February (51949)	11	25	–14
14 February (51954)	9	25	–16
19 February (51959)	7	21	–14
24 February (51964)	**5**	21	–16

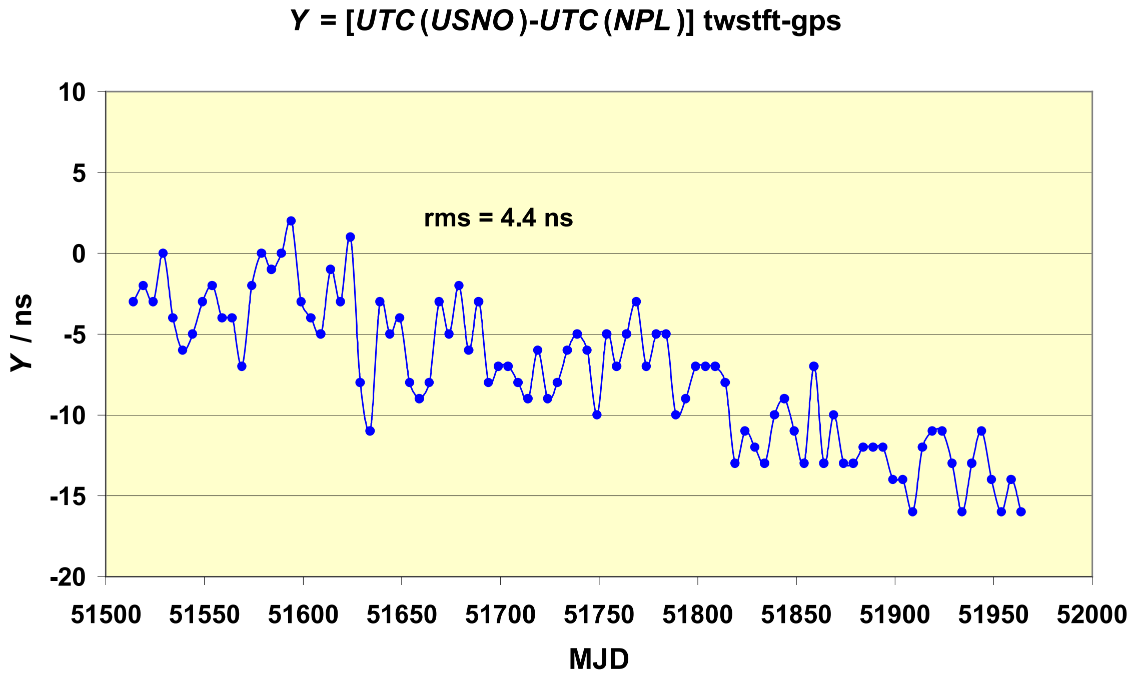

Figure 2a. Differences between TWSTFT (NPL station 01) and GPS C/A-code common-view for USNO/NPL link.

Notes: A new calibration of the USNO/NPL TWSTFT link derived from *Circular T* after June 1999 was applied starting from 29 November 1999 (MJD = 51511).

The USNO/NPL TWSTFT link with NPL TWSTFT Station 01 has been included in the computation of TAI since 1 January 2000 (MJD = 51544).

Table 2b. USNO/NPL link with NPL TWSTFT Station 02

Date 2001 (MJD)	[*UTC(USNO) – UTC(NPL)*] /ns		TWSTFT– GPS
	TWSTFT (*Circular T*)	GPS	
5 January (51914)	23	35	–12
10 January (51919)	24	35	–11
15 January (51924)	25	36	–11
20 January (51929)	23	36	–13
25 January (51934)	18	34	–16
30 January (51939)	17	30	–13
4 February (51944)	14	26	–12
9 February (51949)	10	25	–15
14 February (51954)	7	25	–18
19 February (51959)	3	21	–18

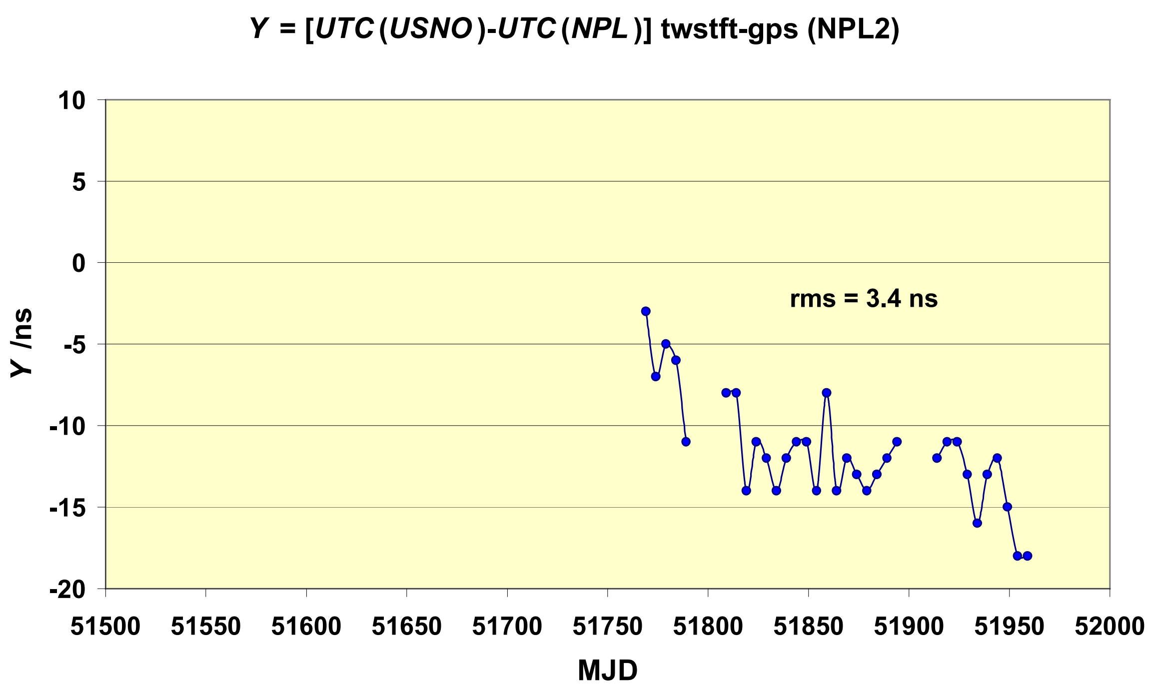

Figure 2b. Differences between TWSTFT (NPL station 02) and GPS C/A-code common-view for USNO/NPL link.

Table 3. USNO/PTB link

Date 2001 (MJD)	[*UTC(USNO) – UTC(PTB)*] /ns		TWSTFT – GPS
	TWSTFT	GPS	
5 January (51914)	–2	12	–14
10 January (51919)	–5	6	–11
15 January (51924)	–3	10	–13
20 January (51929)	–2	8	–10
25 January (51934)	–7	9	–16
30 January (51939)	–11	2	–13
4 February (51944)	–17	–4	–13
9 February (51949)	–22	–7	–15
14 February (51954)	–25	–8	–17
19 February (51959)	–17	–1	–16
24 February (51964)	**–18**	0	–18

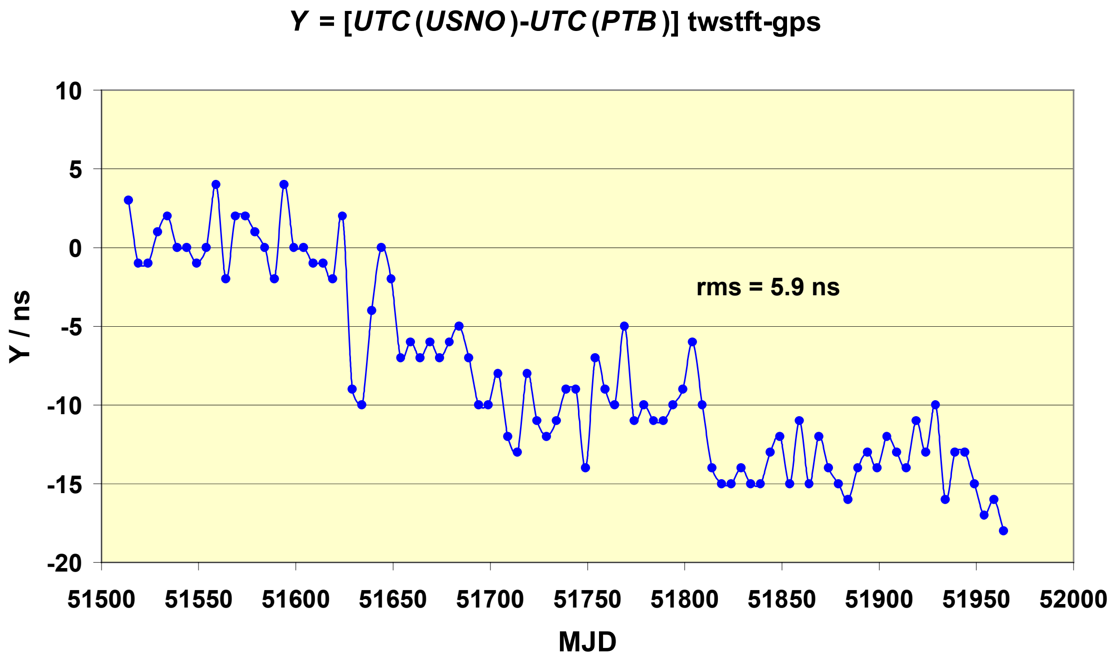

Table 3. Differences between TWSTFT and GPS C/A-code common-view for USNO/PTB link

Note: A calibration of the USNO/PTB TWSTFT link derived from *Circular T* values from July 1999 was applied starting from 29 November 1999 (MJD = 51511).

Table 4. VSL/PTB link

Date 2001 (MJD)	[*UTC(VSL)* – *UTC(PTB)*] /ns		TWSTFT – GPS
	TWSTFT (*Circular T*)	GPS	
5 January (51914)	–33	–36	3
10 January (51919)	–21	–29	8
15 January (51924)	–12	–14	2
20 January (51929)	–16	–24	8
25 January (51934)	–12	–17	5
30 January (51939)	–9	–11	2
4 February (51944)	–14	–22	8
9 February (51949)	–19	–22	3
14 February (51954)	–23	–27	4
19 February (51959)	–15	–19	4
24 February (51964)	–24	–30	6

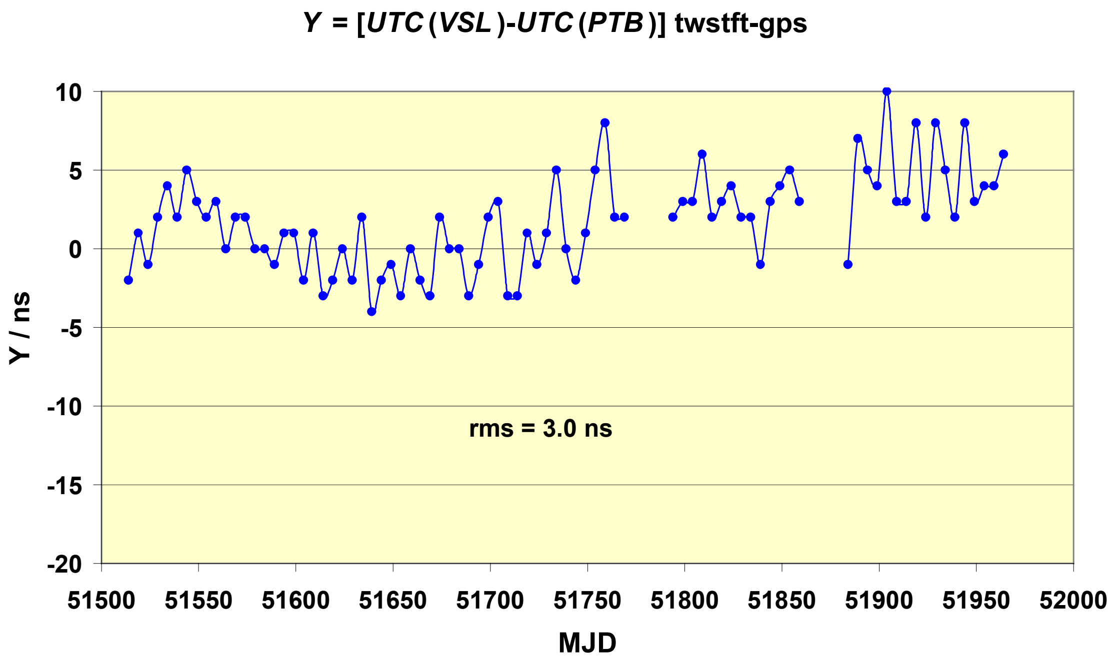

Figure 4. Differences between TWSTFT and GPS C/A-code common-view for VSL/PTB link

Notes: The VSL/PTB TWSTFT link was calibrated by *Circular T*.

The VSL/PTB TWSTFT link has been included in the computation of TAI since 1 January 2000 (MJD = 51544).

Table 5. NPL/NIST link

Date 2001 (MJD)	[*UTC(NPL) – UTC(NIST)*] /ns		TWSTFT – GPS
	TWSTFT	GPS	
5 January (51914)	–28	–27	–1
10 January (51919)	–27	–25	–2
15 January (51924)	–25	–22	–3
20 January (51929)	–21	–21	0
25 January (51934)	–16	–18	2
30 January (51939)	–13	–12	–1
4 February (51944)	–10	–9	–1
9 February (51949)	–9	–6	–3
14 February (51954)	–9	–13	4
19 February (51959)	–9	–10	1
24 February (51964)	**–9**	–10	1

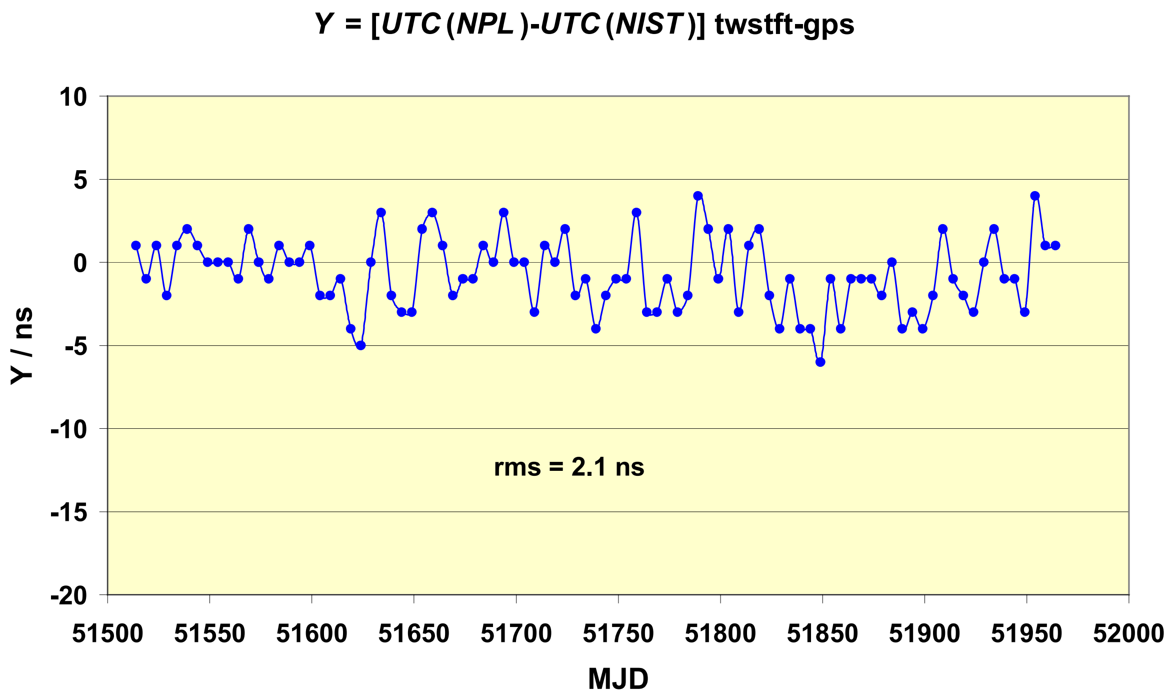

Figure 5. Differences between TWSTFT and GPS C/A-code common-view for NPL/NIST link

Note: The NPL/NIST TWSTFT link was calibrated using *Circular T* values dating from July 1999, and the calibration value was applied at the beginning of September 1999 (MJD = 51429).

Table 6. NPL/PTB link

Date 2001 (MJD)	[*UTC(NPL) – UTC(PTB)*] /ns		TWSTFT – GPS
	TWSTFT (*Circular T*)	GPS	
5 January (51914)	–25	–23	–2
10 January (51919)	–27	–30	3
15 January (51924)	–28	–28	0
20 January (51929)	–25	–27	2
25 January (51934)	–26	–26	0
30 January (51939)	–29	–28	–1
4 February (51944)	–32	–31	–1
9 February (51949)	–32	–31	–1
14 February (51954)	–33	–32	–1
19 February (51959)	–23	–21	–2
24 February (51964)	–22	–21	–1

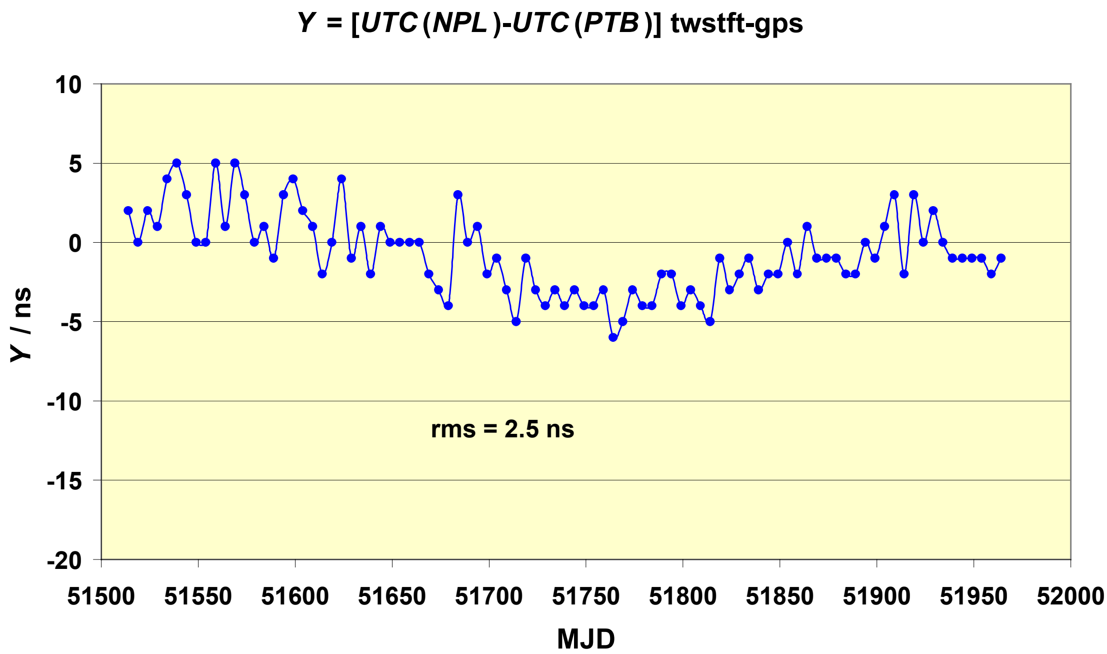

Figure 6. Differences between TWSTFT and GPS C/A-code common-view for NPL/PTB link.

Notes: A new calibration of the NPL/PTB TWSTFT link using *Circular T* was applied on 29 November 1999 (MJD = 51511).

The NPL/PTB TWSTFT link has been included in the computation of TAI since 4 July 2000 (MJD = 51729).

Table 7. NPL/VSL link

Date 2001 (MJD)	[*UTC(NPL) – UTC(VSL)*] /ns		TWSTFT – GPS
	TWSTFT	GPS	
5 January (51914)	6	14	–8
10 January (51919)	–9	–3	–6
15 January (51924)	–15	–7	–8
20 January (51929)	–8	–3	–5
25 January (51934)	–14	–9	–5
30 January (51939)	–20	–17	–3
4 February (51944)	–18	–9	–9
9 February (51949)	–13	–8	–5
14 February (51954)	–11	–4	–7
19 February (51959)	–4	–2	–2
24 February (51964)	4	9	–5

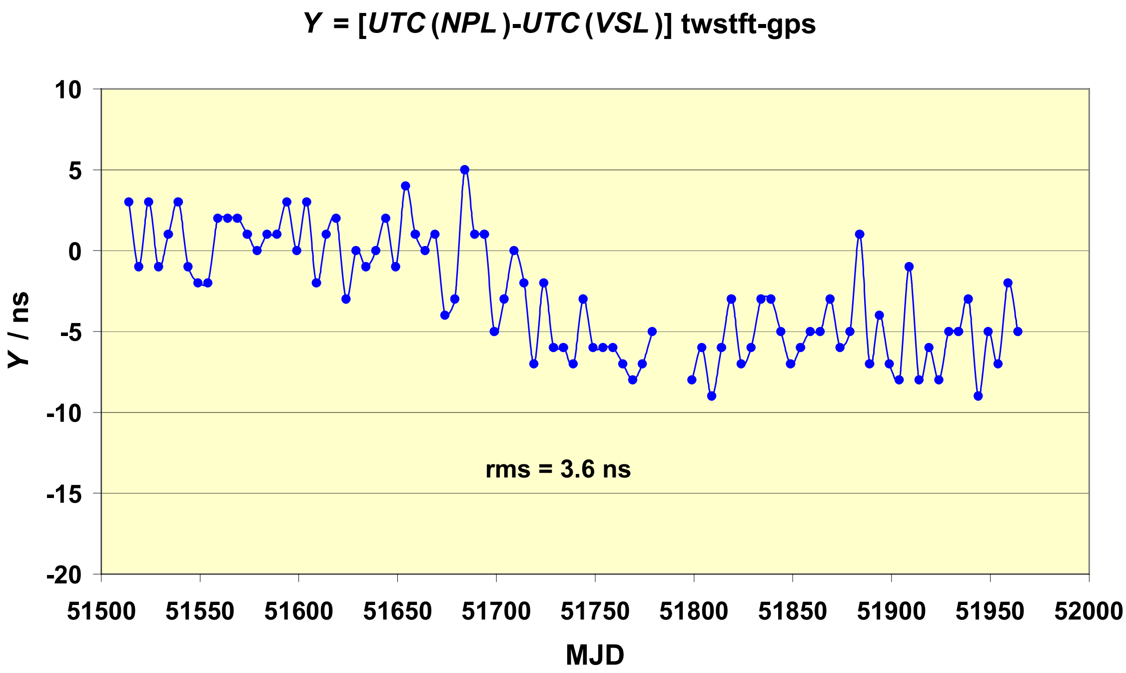

Figure 7. Differences between TWSTFT and GPS C/A-code common-view for NPL/VSL link

Note: A new calibration of the NPL/VSL TWSTFT link using *Circular T* was applied on 29 November 1999 (MJD = 51511).

Table 8. PTB/OCA link

Date 2000/2001 (MJD)	[*UTC(PTB) – OCA clock*] /ns		TWSTFT – GPS
	TWSTFT	GPS	
26 December (51904)	–	3642	–
31 December (51909)	–	3766	–
5 January (51914)	–	3891	–
10 January (51919)	–	4016	–
15 January (51924)	–	4138	–
20 January (51929)	4465	4262	203
25 January (51934)	4593	4396	197
30 January (51939)	4723	4524	199

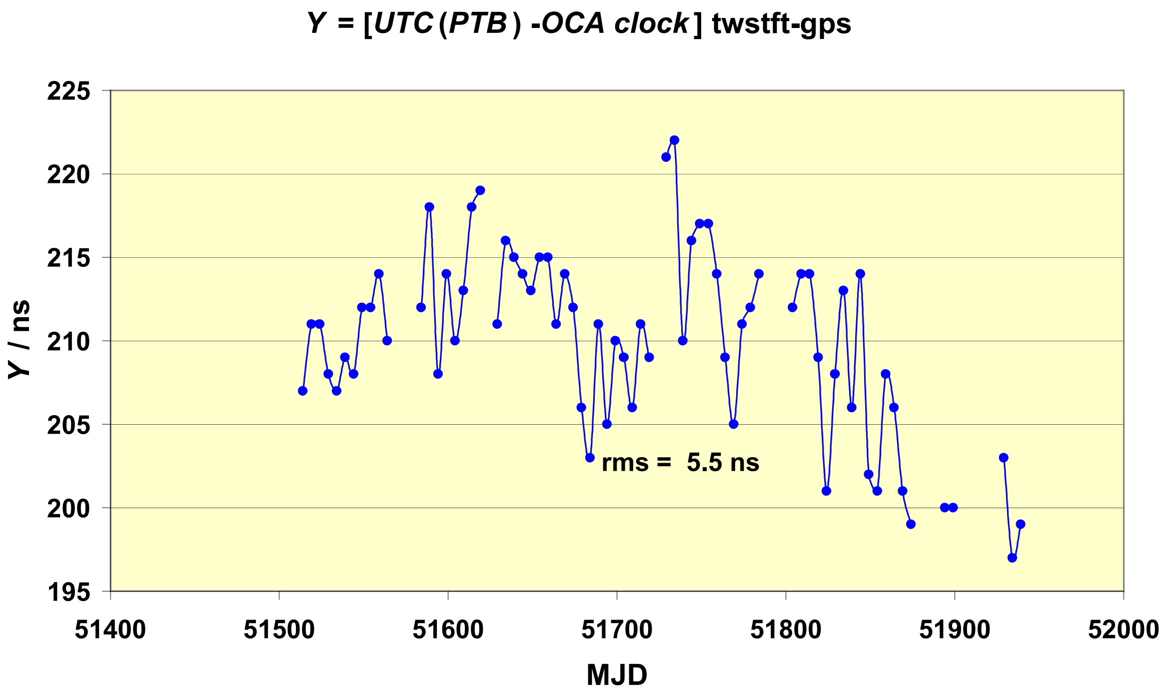

Figure 8. Differences between TWSTFT and GPS C/A-code common-view for PTB/OCA link

Section II

Frequency stability of the TWSTFT and GPS CV links
reported in Section I

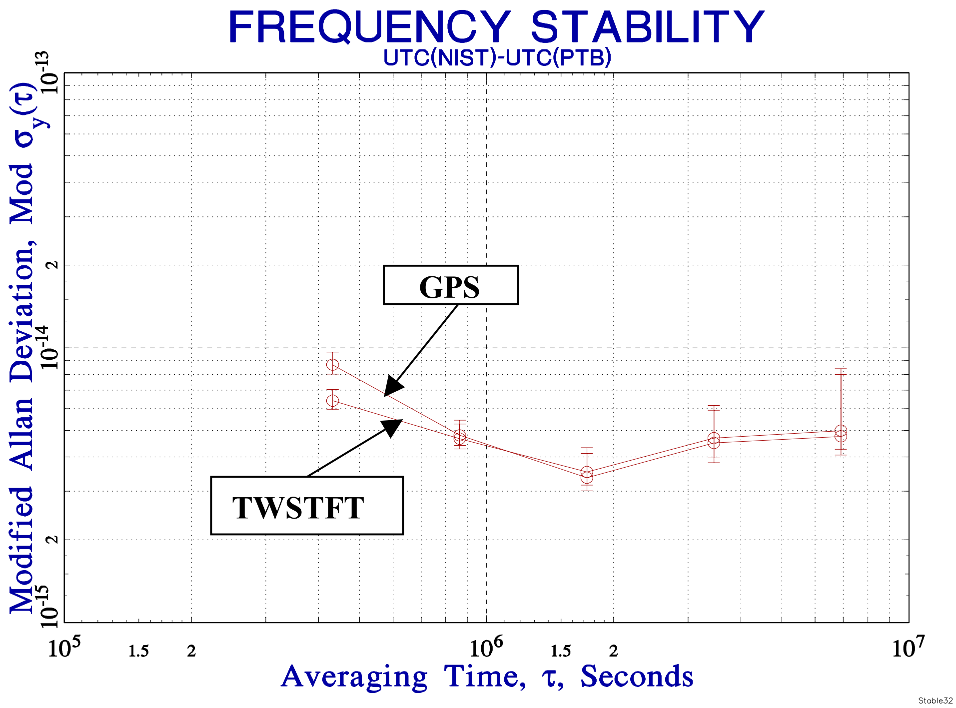

Figure 1. Frequency stability of [*UTC(NIST) – UTC(PTB)*] by GPS CV and by TWSTFT.

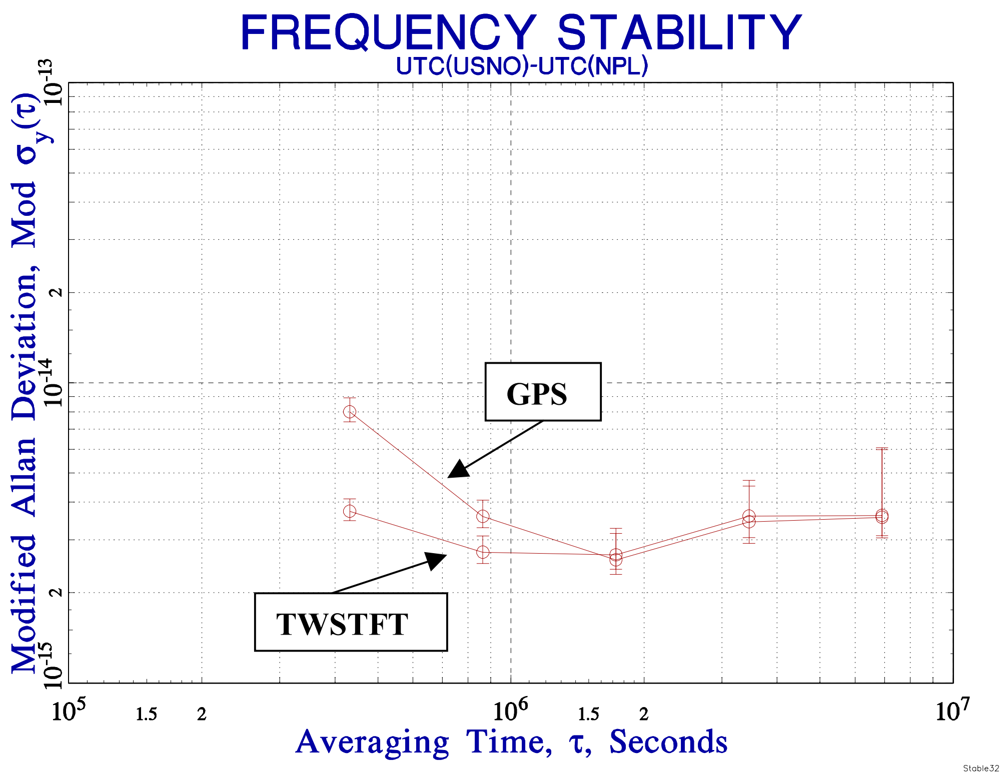

Figure 2. Frequency stability of [*UTC(USNO) – UTC(NPL)*] by GPS CV and by TWSTFT.

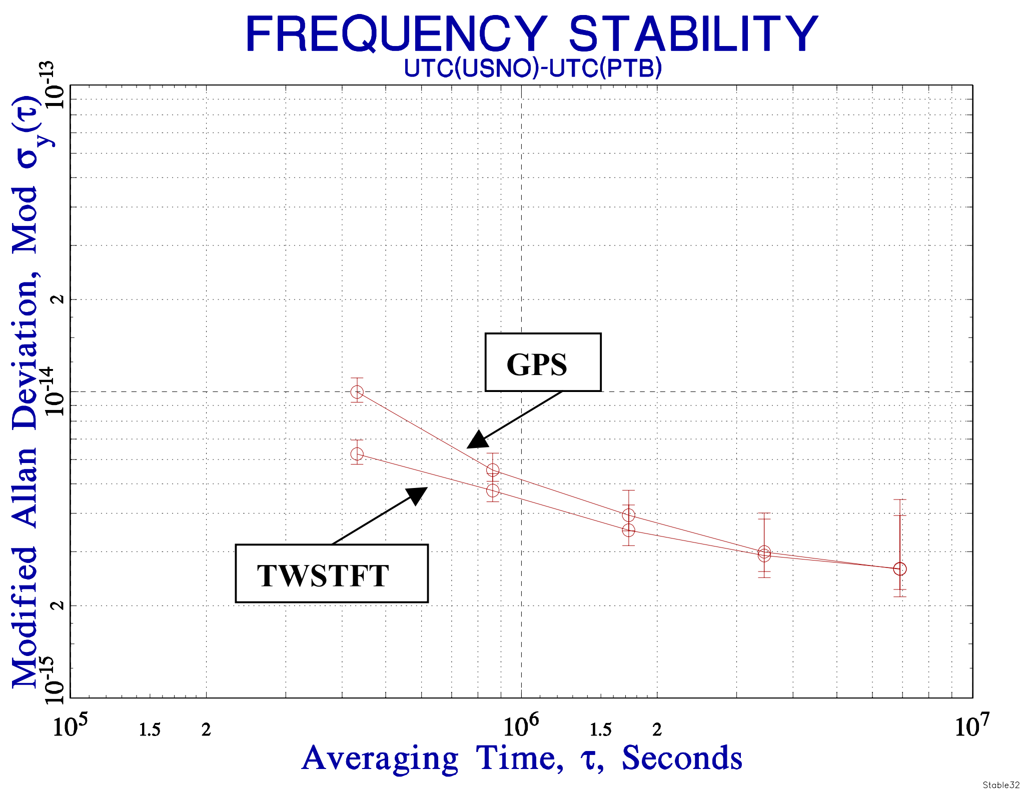

Figure 3. Frequency stability of [*UTC(USNO) – UTC(PTB)*] by GPS CV and by TWSTFT.

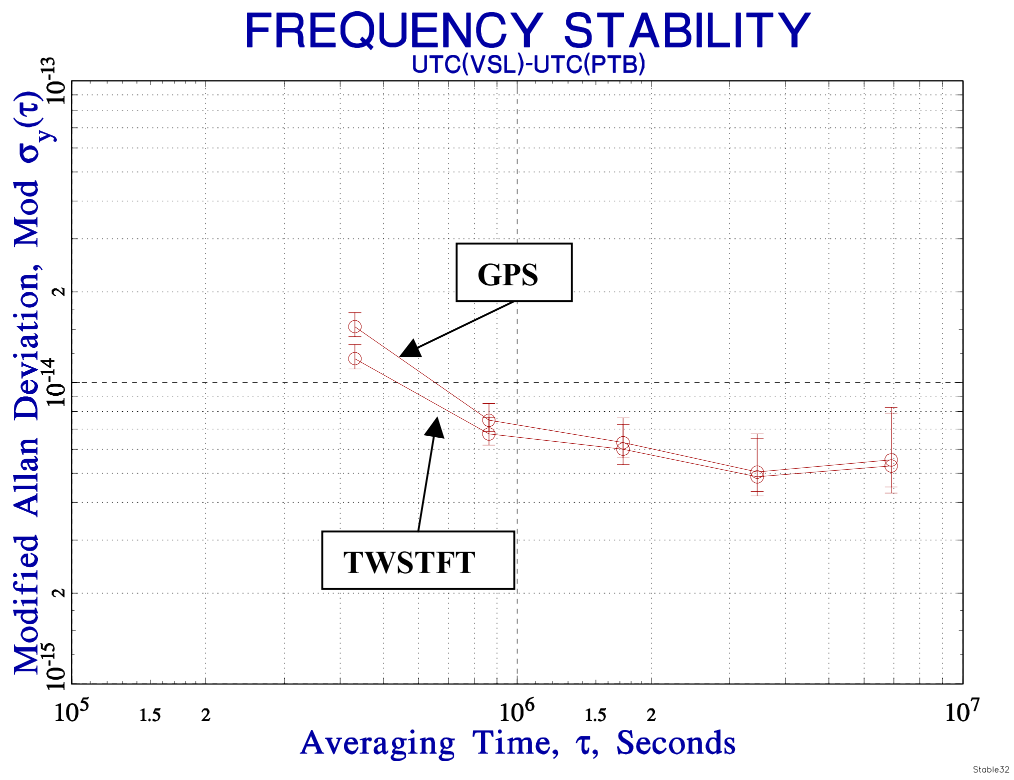

Figure 4. Frequency stability of [*UTC(VSL) – UTC(PTB)*] by GPS CV and by TWSTFT.

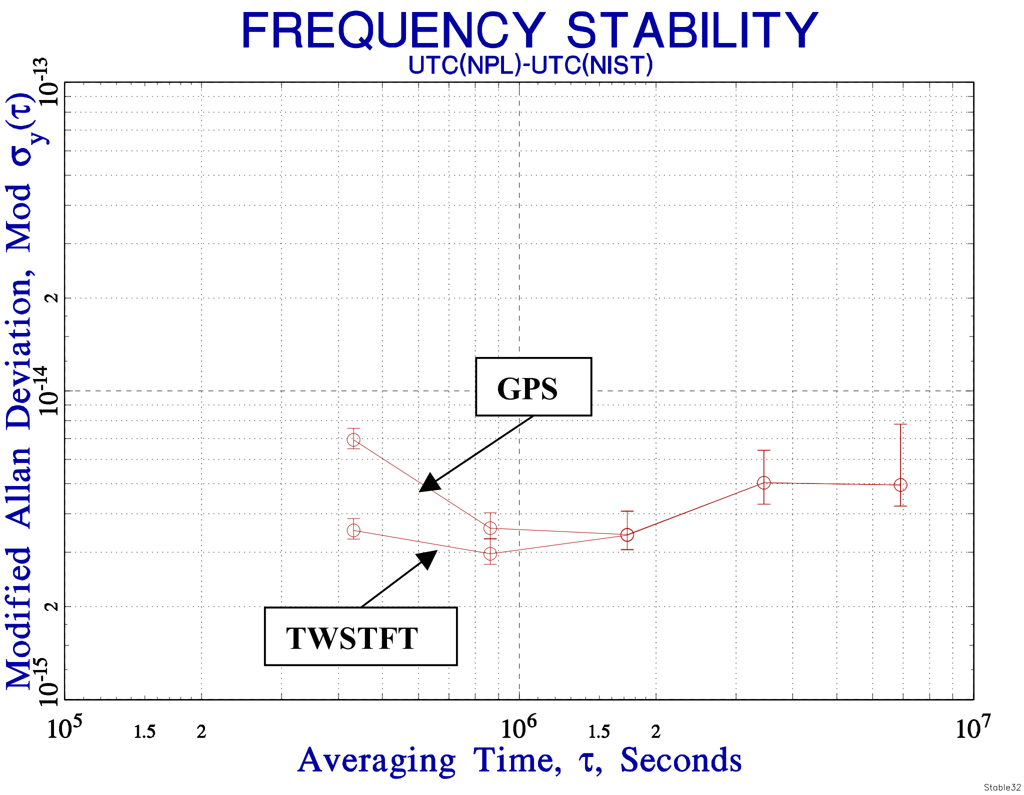

Figure 5. Frequency stability of [*UTC(NPL) – UTC(NIST)*] by GPS CV and by TWSTFT.

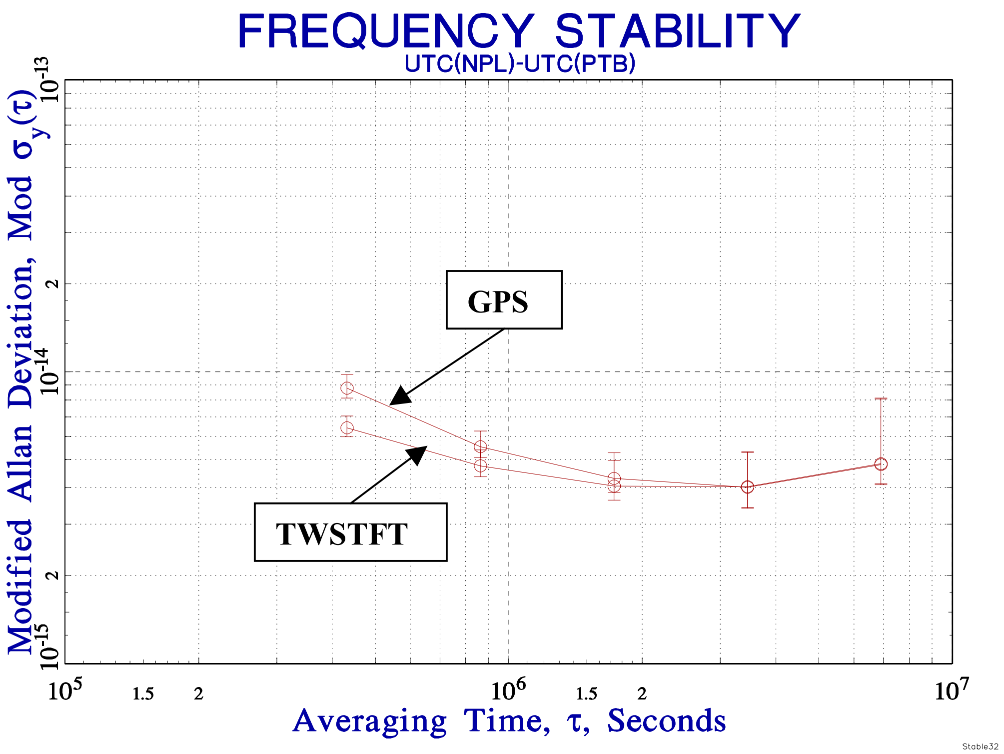

Figure 6. Frequency stability of [*UTC(NPL) – UTC(PTB)*] by GPS CV and by TWSTFT.

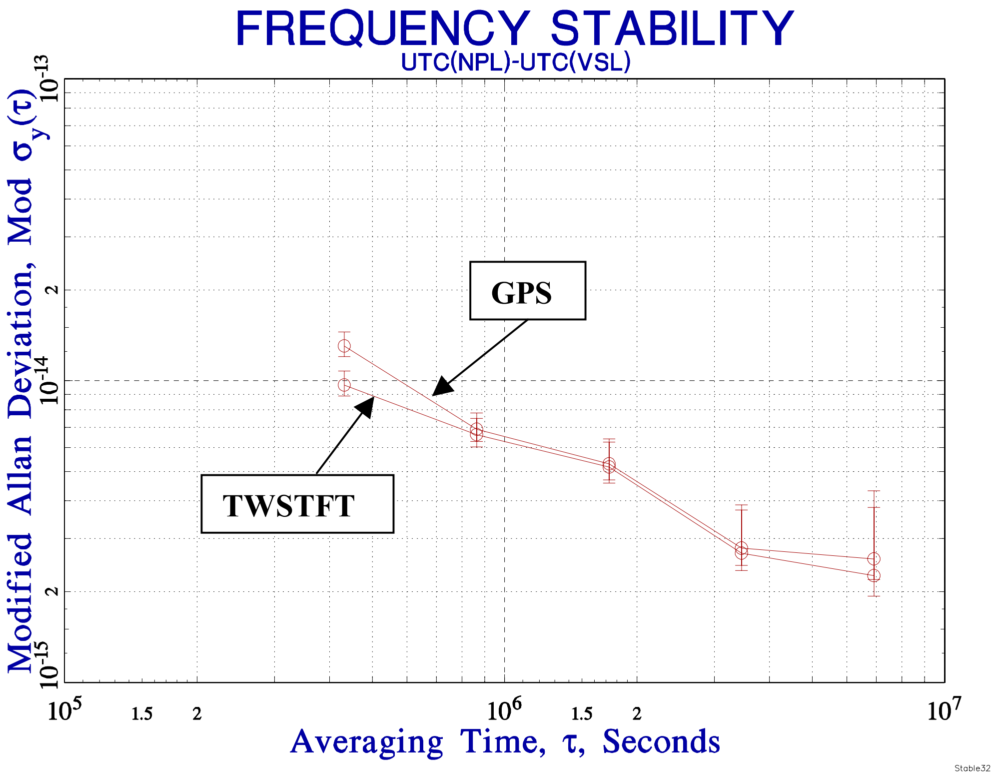

Figure 7. Frequency stability of [*UTC(NPL) – UTC(VSL)*] by GPS CV and by TWSTFT.

Section III: Description of equipment providing data for this report.

Lab.	GPS CV	TWSTFT (through INTELSAT 307° E)
NIST	Receiver type: NBS/TTR5 Receiver serial no: 010 Internal delay: 53.0 ns Reference name: UTC(NIST) Reference type: ensemble of 4 Cs + 5 H-masers	Modem type: University of Stuttgart/MITREX 2500 Modem serial no: Antenna: 3.7 m – steerable Degree of automation: 85 % Reference name: UTC(NIST) Reference type: ensemble of 4 Cs + 5 H-masers
OCA	Receiver type: AOA/TTR5 Receiver serial No: Internal delay: Reference name: OCA clock Reference type: 1 Cs	Modem type: University of Stuttgart/MITREX 2500 Modem serial no: Antenna: 1.8 m – VSAT Andrew Degree of automation: Reference name: OCA clock Reference type: 1 Cs
NPL *	Receiver type: AOA/TTR5A Receiver serial No: 276 Internal delay: 68.5 ns Reference name: UTC(NPL) Reference type: 1 H-maser	Modem type: TimeTech/SATRE (carrier-phase option) Modem serial no: 038 Antenna: 2.4 m – VSAT Degree of automation: Reference name: UTC(NPL) Reference type: 1 H-maser
PTB	Receiver type: Rockwell Collins/TTR5 Receiver serial No: Internal delay: 77 ns Reference name: UTC(PTB) Reference type: 1 Lab. Cs	Modem type: TimeTech/SATRE (carrier-phase option) Modem serial no: 037 Antenna: 1.8 m – VSAT Degree of automation: Reference name: UTC(PTB) Reference type: 1 Lab. Cs
TUG *	Receiver type: NBS/TTR5 Receiver serial No: 012 Internal delay: 55.6 ns Reference name: UTC(TUG) Reference type: 1 Cs	Modem type: TimeTech/SATRE Modem serial no: 043 Antenna: 1.8 m – VSAT-1 Degree of automation: full Reference name : UTC(TUG) Reference type: 1 Cs
USNO *	Receiver type: AOA/TTR6 Receiver serial no: 440 Internal delay: Reference name: UTC(USNO MC) Reference type: 1 H-maser + freq. syntent.	Modem type: University of Stuttgart/MITREX 2500 Modem serial no: 85006 Antenna: 4.6 m – steerable Degree of automation: Reference name: UTC(USNO MC) Reference type: 1 H-maser + freq. syntent.
VSL	Receiver type: VSL/TTR5 Receiver serial no: VSL01 Internal delay: 63.9 ns Reference name: UTC(VSL) Reference type: 1 Cs + micro-phase-stepper	Modem type: Univerity of Stuttgart/MITREX 2500 Modem serial no: 85008 Antenna: 3 m – steerable Degree of automation: Reference name: UTC(VSL) Reference type: 1 Cs + micro-phase-stepper

Notes

* The NPL, TUG and USNO are also equipped with TWSTFT back-up stations.
The TUG back-up station is portable and fully automated.

Appendix II: A summary of all the TAI time links.