Calibration of geodetic-type GPS receivers

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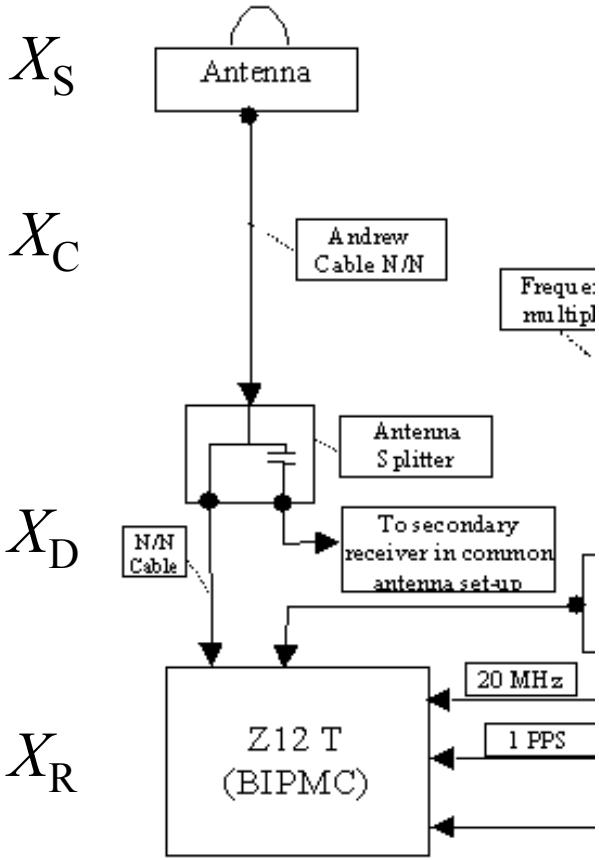
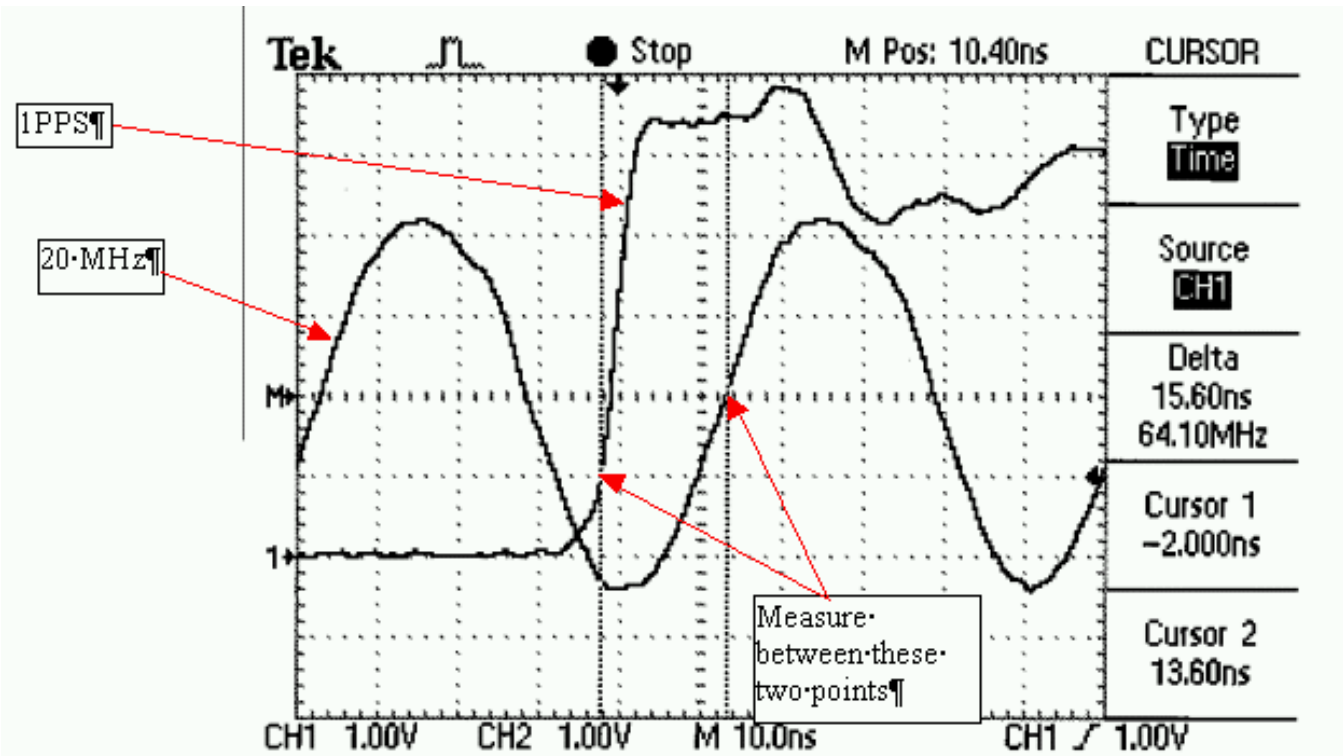
Some definitions

- X_R = receiver internal delay (from the "internal reference")
- [X_D = short cable + splitter delay]
  (not present in normal operation)
- X_C = antenna cable delay
- X_S = antenna delay
  and also (not shown here)
- X_O = Offset from "internal reference" to 1PPS-in (to be measured)
- X_P = Offset from 1PPS-in to laboratory reference (to be measured)



Measurement of X_O (1PPS - 20 MHz in)

- Internal reference defined as suggested by Ashtech initial specs: 20-MHz in inverted and delayed by 15.8 ns.
- Other choices possible (and may be desirable) e.g. direct 20-MHz in.
- Oscilloscope measurement necessary, because all other references are 1PPS.



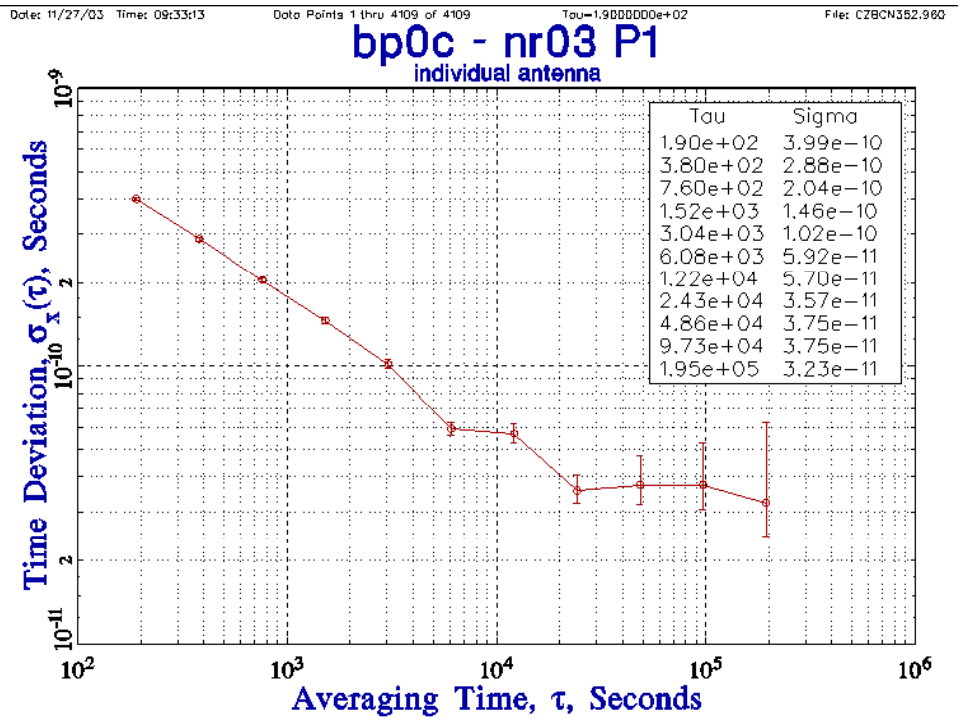
Procedure for differential calibration

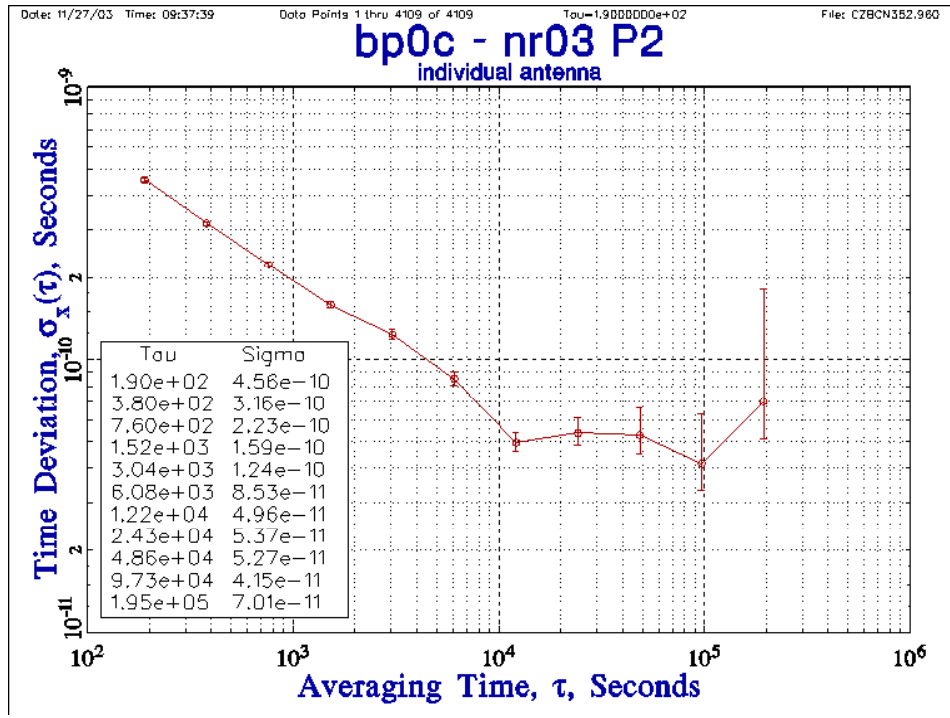
- Install two systems in short baseline (different antennas, same reference)
  - Measure offset between 1PPS in and 20 MHz in (X_O)
  - Measure X_P and X_C ($+ X_D$) (cables)
  - Take some days of measurements X_{sb}
  - one obtains $\Delta [X_R + X_S] = X_{sb} + \Delta [X_P + X_O - X_C (- X_D)]$

- Optional: To get the receiver delay only: Install two systems in zero baseline (same antenna, same reference)
  - Take some days of measurements X_{zb}
  - one obtains $\Delta [X_R] = X_{zb} + \Delta [X_P + X_O - X_D - X_C]$
  - But may be better not to disturb the set-up

Short-term stability of differential calibration

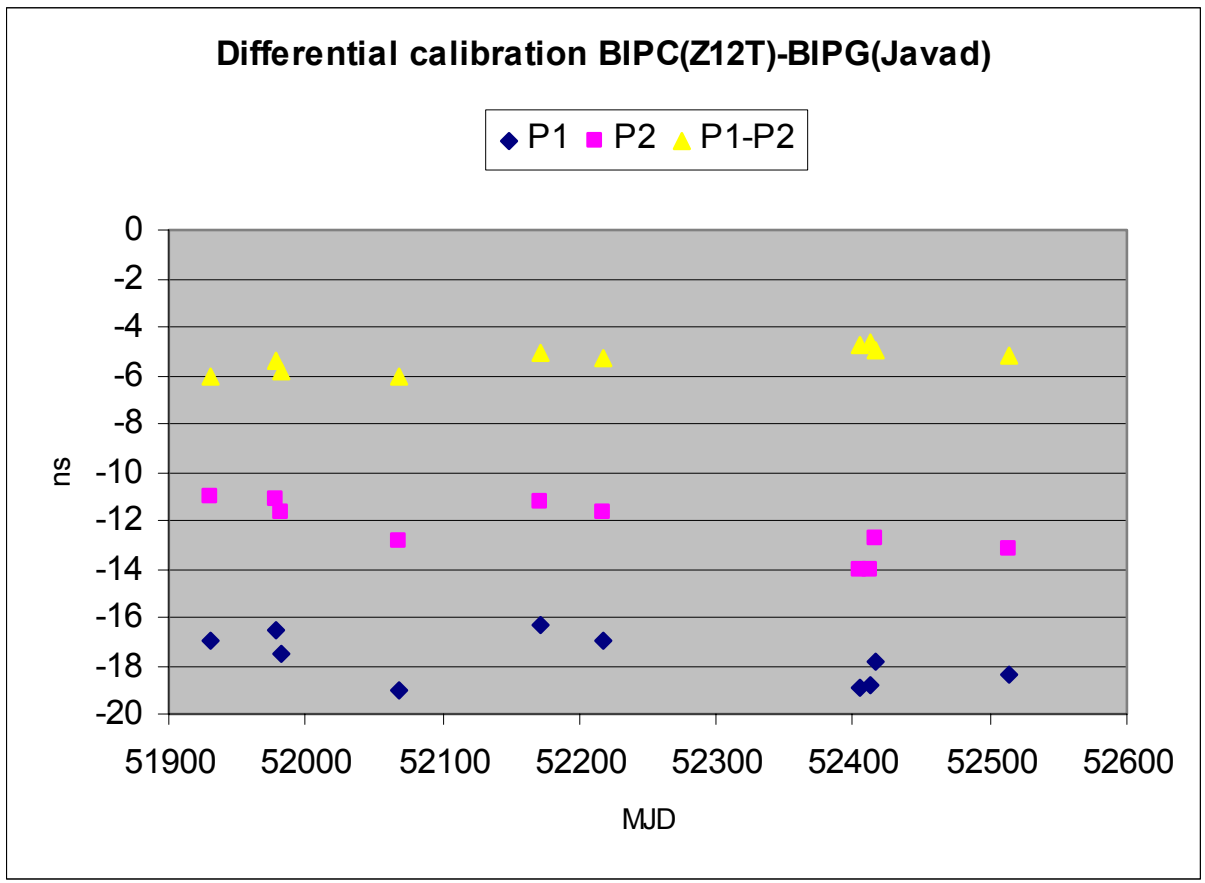
- Statistical uncertainty of differential measurements well below 0.1 ns for an averaging time below one day at each frequency.





Long-term stability of differential calibration

- Regular comparisons with Javad receiver kept at the BIPM: 10 measurements in 2001-2002, each lasting several days (or 1-2 days with different set-up)
  - ΔP1 dispersion of results: 2.7 ns p/p (1.0 ns RMS)
  - ΔP2 dispersion of results: 3.1 ns p/p (1.2 ns RMS)
  - Δ(P1-P2) dispersion of results: 1.4 ns p/p (0.5 ns RMS)



Uncertainties for differential calibration

	L1/2	L1-L2
• X_R (reference receiver)	0.6 ns	0.3 ns
• $X_R + X_S$ (reference receiver)	2.1 ns	2.0 ns
• X_C (both systems)	0.3 ns	0.0 ns
• X_O (both systems)	0.5 ns	0.0 ns
• X_P (both systems)	0.3 ns	0.0 ns
• $X_C - X_O - X_P$ (both systems)	0.7 ns	0.0 ns
• Measurement (code)	0.1 ns	0.1 ns
• X_R (receiver under study)	1.2 ns	0.3 ns
• $X_R + X_S$ (receiver under study)	2.3 ns	2.0 ns

Use of calibration results

- P3 = 2.54 P1 - 1.54 P2 or P3 = P1 + 1.54 (P1-P2)
- Uncertainty of a calibration result

	P1	**P2**	P1-P2
Total system	**2.5 ns**	**2.5 ns**	2.0 ns

⇒ Estimated accuracy of P3 measurement (total uncertainty for one receiver): **4 ns**

- Stability of P3 measurement (link comparisons): **1 ns**
- Stability of repeated P3 calibrations: **2 ns**

⇒ Most of the uncertainty is from the calibration reference.

⇒ Estimated accuracy of a differentially calibrated P3 link (variable part of the uncertainty for two receivers): **3 ns**

But: Potential variations in (P1-P2) delay with change of set-up

⇒ Conservative estimate for a P3 link: **5 ns**

BIPM Z12-T's calibration trips

- METAS (Switzerland): February 2001
- BNM-SYRTE (France): March 2001, February 2003
- USNO and NRL (USA): April-May 2001 + November 2002
- NPL (UK): June 2001
- ORB (Belgium): July 2001, July 2003 (2 receivers)
- CNES (France): August 2001
- IEN (Italy): October 2001
- TL (Taiwan): January 2002 (2 receivers)
- CRL (Japan): March 2002, October 2003
- NMIJ (Japan): April 2002
- IFAG (Germany): June 2002, June 2003
- PTB (Germany): July 2002, June 2003
- NIST -Ucolorado (USA): October 2002
- USNO (USA): December 2002
- DLR (Germany): April 2003
- NRC (Canada): December 2003
- Regular differential measurements at the BIPM vs. Javad, now 2nd Z12-T

Differential calibration results (TAIP3 receivers)

Rec./Lab. ID	Date of calib.	**XR1+XS1**		**XR2+XS2**
BIPC (Z12-T)	May 2000 Absolute	**305.6 ns**		**321.9 ns**
WAB1 (GeTT)	Feb. 2001	**Ref +1.5 ns**		**Ref +0.3 ns**
LPTF (Z12-T)	Feb. 2003	**Ref +10.9 ns**		**Ref +6.2 ns**
BRUS (Z12-T)	July 2003	**Ref -2.1 ns**		**Ref -9.1 ns**
IEN (Z12-T)	Oct. 2001	**Ref +2.1ns**		**Ref -4.5 ns**
TWTF (Z12-T)	Dec.01-Jan.2002	**Ref +1.9 ns**		**Ref -4.2 ns**
CRL (Z12-T)	Oct. 2003	**Ref +2.9 ns**	**(TBC)**	**Ref -4.9 ns**
NMIJ (Z12-T)	Apr. 2002	**Ref +4.6 ns**		**Ref +0.1 ns**
BKG (Z12-T)	June 2003	**Ref -12.8 ns**		**Ref -14.7 ns**
PTBB (Z12-T)	July 2002	**Ref -0.6 ns**		**Ref -2.6 ns**
USN1 (Z12-T)	Dec. 2002	**Ref -305.7 ns**		**Ref -318.9 ns**
DLR (Z12-T)	Apr. 2003	**Ref +307.5 ns**		**Ref +301.9 ns**
NRC (Z12-T)	Dec. 2003	**Ref +5.9 ns**		**Ref +2.5 ns**

P3 link accuracy: comparisons with other techniques

- Standard uncertainty of differential calibration of a P3 link is of order 3 ns
- TAI publications: u_B = 5 ns is used.

Link	Date of P3 calibration	Type and date of other calibration	P3-other	Comments
OP-PTB	02/03-06/03	C/A 06/03, 08/03	0-4 ns	several ns variations (1)
USNO-PTB	12/02-06/03	TW 06/02, 01/03	7 ns	1-ns stability
CRL-PTB	10/03-06/03	C/A 11/03	-19 ns	Uncertain P3 set-up (2)
CH-PTB	02/01-06/03	OP-CH C/A 12/03	4-8 ns	several ns variations (3)

(1) OP-PTB: Results of most two recent C/A calibrations differ by 4-5 ns.

(2) CRL-PTB: CRL Z12-T has different hardware set-up.

(3) CH-PTB: C/A receivers calibrated in two different calibration trips.

Conclusions

- Geodetic-type GPS receivers are used for time comparisons
- Calibration of these systems is under way

- Long term stability of hardware delays seems at the level of 1 ns.
- Accuracy of P3 link of order 3 ns, conservatively extended to 5 ns.
- Comparison with other techniques about consistent with combined uncertainties.

- Need to keep the set-up as stable as possible.
- Monitor hardware delays through IGS.