Global Navigation Satellite Systems for Positioning and Time Transfer

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Observation Equations

- **Code observation (on one or two carrier frequencies)**

$$p_i^j = \rho_i^j - c\,\Delta t^j + c\,\Delta t_i + \Delta\rho^j_{i_{\text{ion}}} + \Delta\rho^j_{i_{\text{trop}}} + \epsilon^j_{i_{\text{cod}}}$$

- **Simplified time transfer**

$$\Delta t_1 - \Delta t_2 = \frac{1}{c}\left[p_1^j - p_2^j - \left(\rho_1^j - \rho_2^j\right)\right]$$

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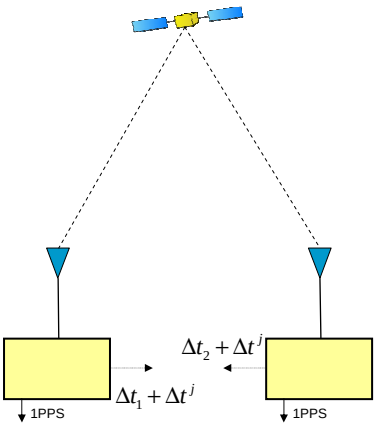
Common View Time Transfer



- "traditional method"
- quasi-simultaneous observations of one satellite by two receivers (simultaneous in s/c time scale)
- broadcast ephemeris
- dual frequency → ionosphere correction
- receiver *i* computes its clock offset using satellite *j*

$$\Delta t_i + \Delta t^j = \frac{1}{c}\left(p_i^j - \rho_i^j\right)$$

- 1PPS output/input synchronized to receiver clock
- off-line processing of measurements at CERN/LNGS

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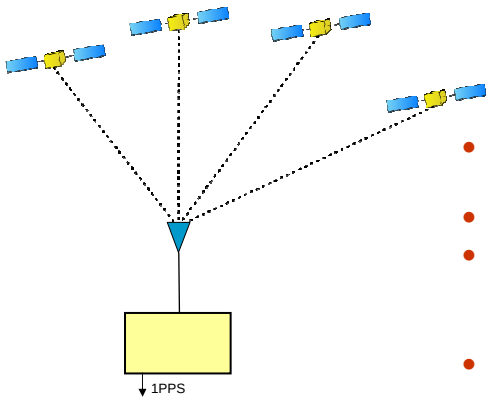
All in View Timing Receivers



- "standalone mode"
- Receiver computes its clock offset from GPS time using all satellites in view → receiver internal clock synchronized to GPS time
- 1PPS output synchronized to receiver clock
- broadcast ephemeris
- dual frequency → ionosphere correction
- (on-line) mode of PolaRx receivers at CERN and LNGS

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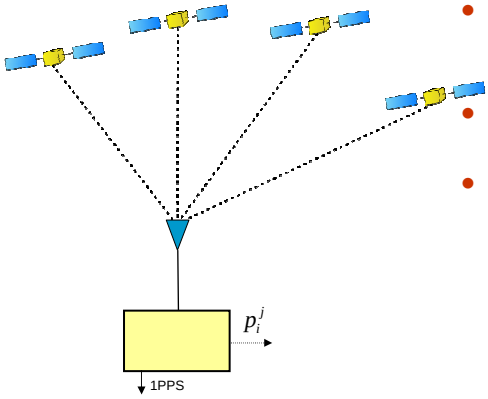
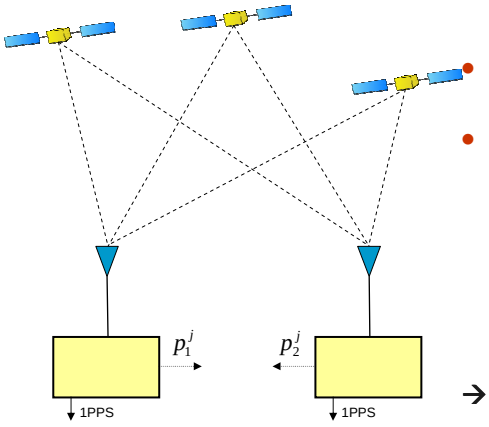
All in View PPP



- "Precise Point Positioning" (off-line processing)
- receiver stores "pseudorange" and "phase" observations
- 1PPS output synchronized to receiver clock
- Off-line computation of receiver clock offset (and station coordinates) using
  - high-precision IGS satellite orbits and satellite clock corrections
  - scientific processing software

→ Δt_i

Geodetic Time Transfer

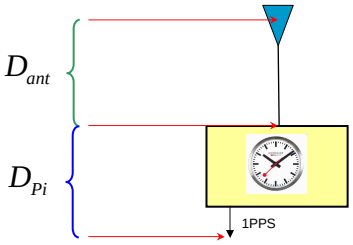


- receivers store "pseudorange" and "phase" observations
- 1PPS outputs synchronized to receiver clocks
- Off-line computation of receiver clock offsets (and station coordinates) using
  - high-precision IGS satellite orbits and satellite clock corrections
  - scientific processing software

→ $\Delta t_2 - \Delta t_1$

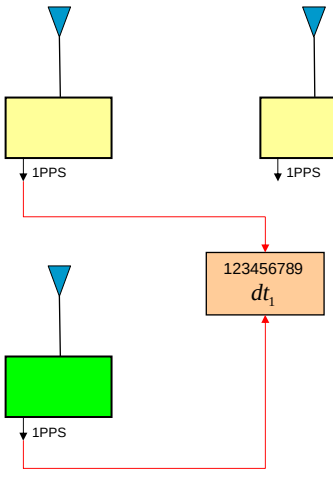
Receiver-Internal Delays

- D_{ant} antenna cable delay (frequency independent)
- D_{Pi} "internal" delay (frequency dependent



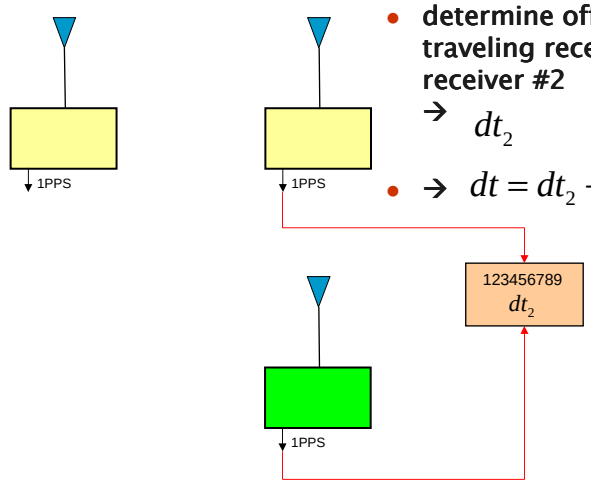
- "receiver" clock determined from processing is referenced to antenna phase center
- both delays take into account by timing receivers
- only relevant for absolute timing!
- delays calibrated by METAS for CERN and LNGS receivers

Calibration with Traveling Receiver



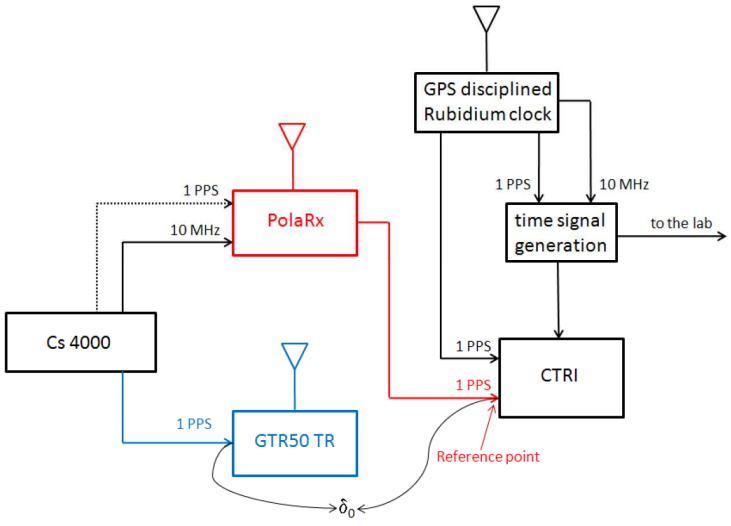
- determine offset between traveling receiver and receiver #1
  → dt_1

Calibration with Traveling Receiver

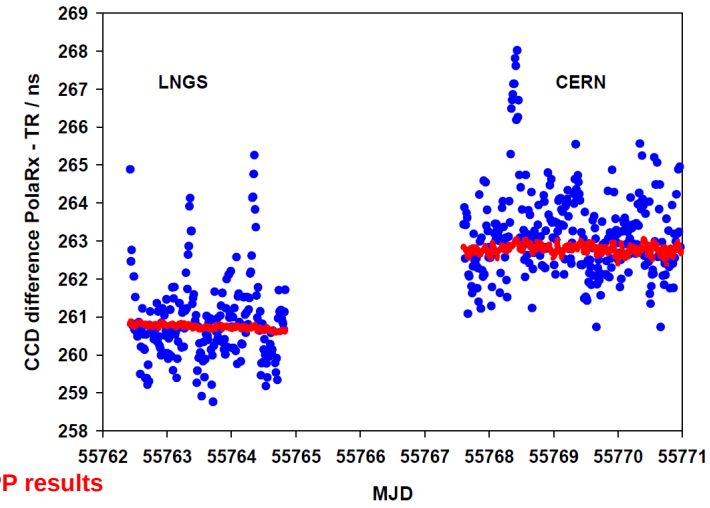


- determine offset between traveling receiver and receiver #2
  → dt_2
- → $dt = dt_2 - dt_1$

Setup at CERN and LNGS



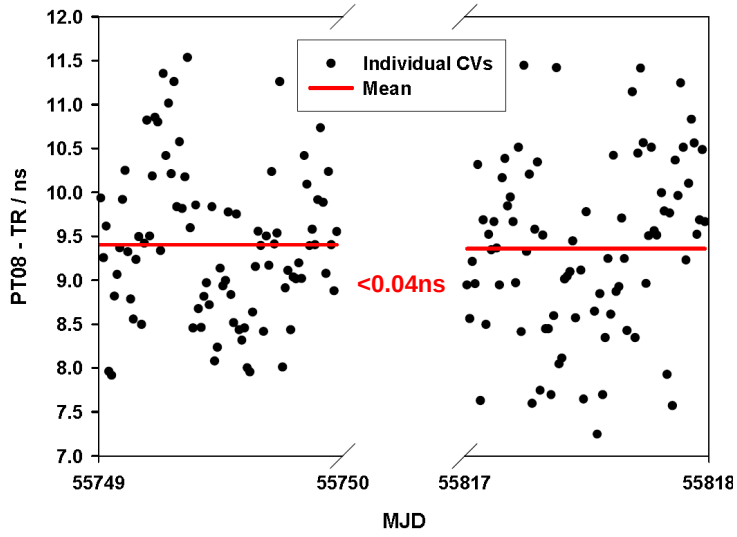
PTB Calibration Results



PPP results

P_3 results (common view)

Traveling Receiver Closure



<0.04ns

PTB Calibration Results

Lab	Type of data evaluation	Total duration of data taking	# of averaged data	CCD / ns	SD / ns
LNGS	P3	2.4 days	2	260.74	0.79
	PPP	2.4 days	4	260.74	0.34
CERN	P3	3.4 days	16	263.05	0.06
	PPP	3.4 days	2	262.78	0.11

$C_{GPS,P3}$ = -2.31 ns ± 0.90 ns
$C_{GPS,PPP}$ = -2.04 ns ± 0.62 ns

Summary

- PTB performed a state of the art relative time transfer calibration between CERN and LNGS.
- A mobile time transfer receiver and two different data processing methods were used (P_3 CV and PPP).
- $C_{LNGS} - C_{CERN}$ = 2.31 ± 0.90 ns
- Remember: this refers to the 1PPS reference points NOT to the actual measurement points in the labs!
- An independent "geodetic time transfer" should be performed (requires receiver RINEX data files); in this case the internal delays must be taken from the METAS calibration.
  → monitoring (a posteriori) of $dt(t)$