GNSS Receivers for Timing Applications

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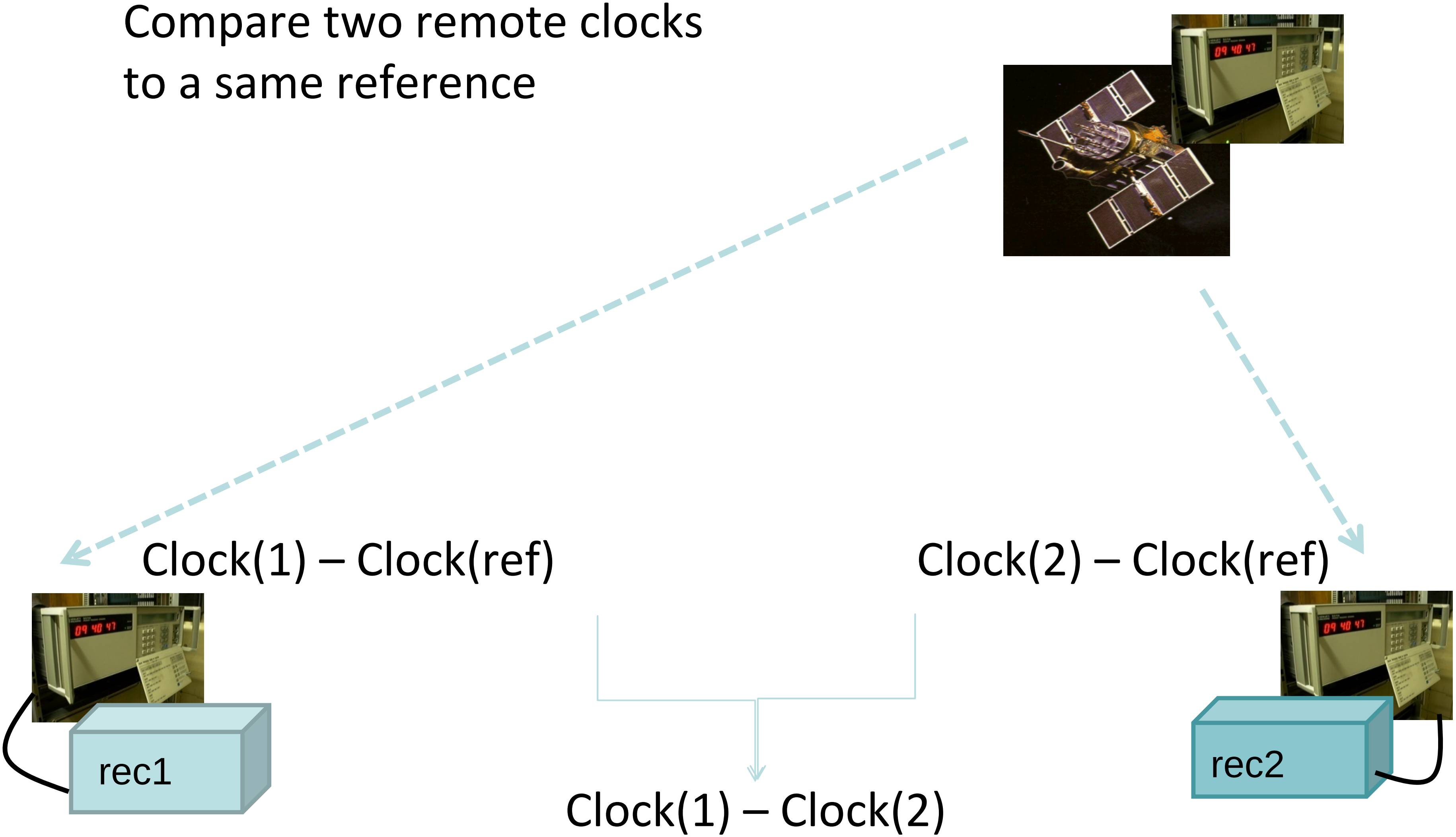
OUTLINE

- GPS time transfer: State of the art
- Receiver operation
- Calibration issues
- Output data and formats

GNSS Time and Frequency Transfer

Compare two remote clocks
to a same reference



State of the Art

- Frequency Transfer
- uncertainty < 100 ps / epoch
- Stability better than 1e^{-15} @ one day.

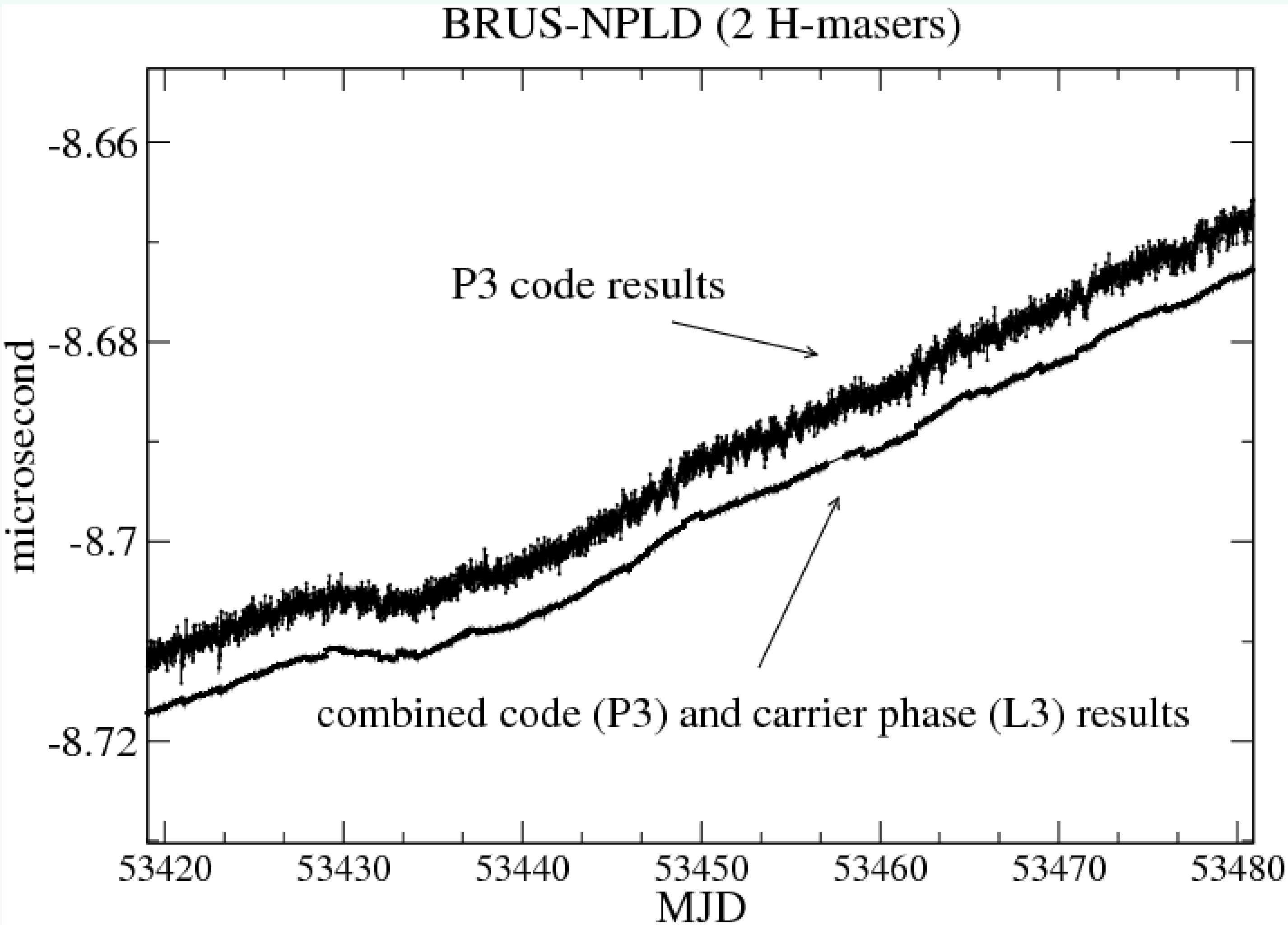
  thanks to carrier phase measurements

  BUT ambiguous→ not suitable for "time"

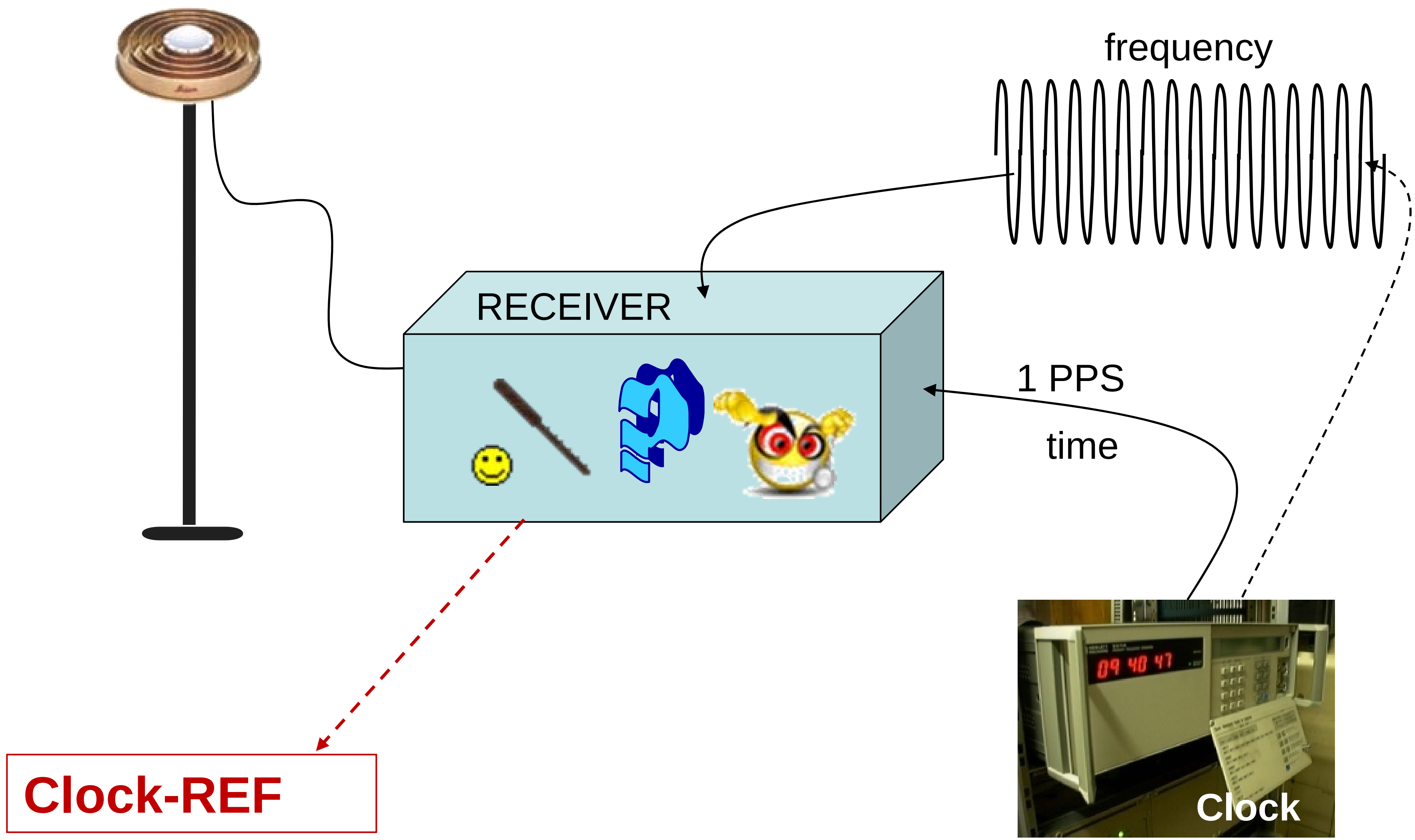
- Time transfer : pseudorange
- noise + calibration capabilities : a few nanoseconds

  uB uncertainty 5 ns in the BIPM circular T.

ionosphere-free
P code vs carrier phase



Basic setup



Usual denomination

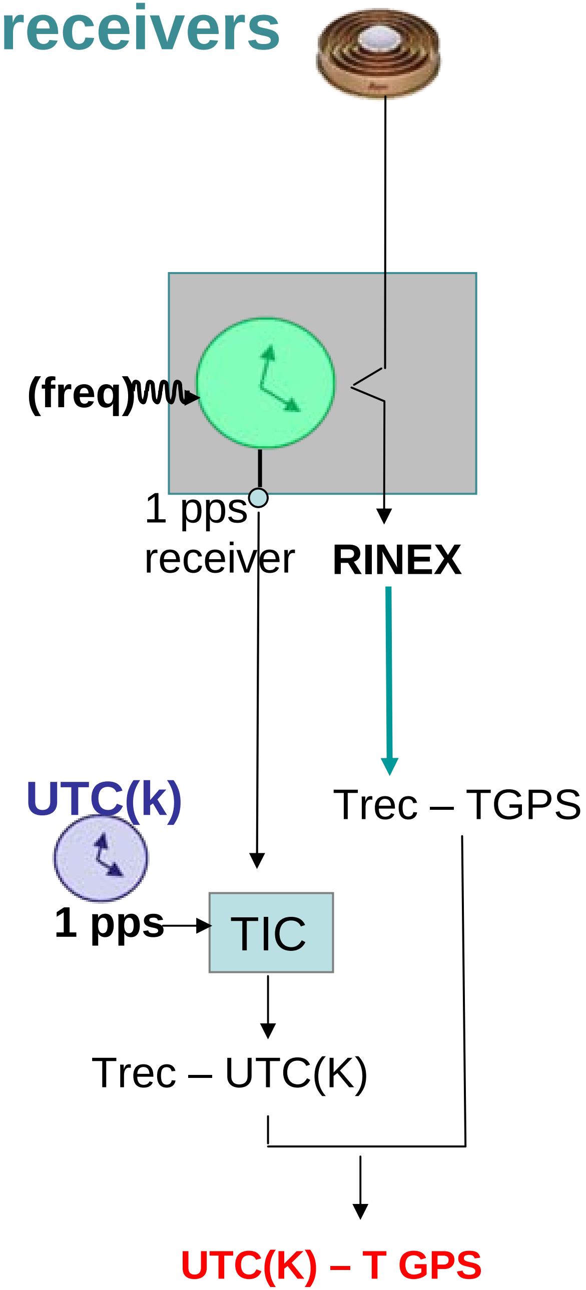
- **Geodetic receivers**: dual-frequency receiver providing both code and carrier phase measurements

- **Time receivers** : provides CGGTTS data

With different blends of these characteristics,

3 main types of receivers for timing applications exist presently

Classical Geodetic receivers



- Receiver clock synchronized with 1 µs of GPS Time

- Only valid if the connector "1PPS out" represents the internal clock Trec

- if freq comes from UTC(k): Very effective for frequency transfer, but the quality of the solution depends on the quality of the enslavement of the internal oscillator on the external frequency

- Very demanding for time transfer

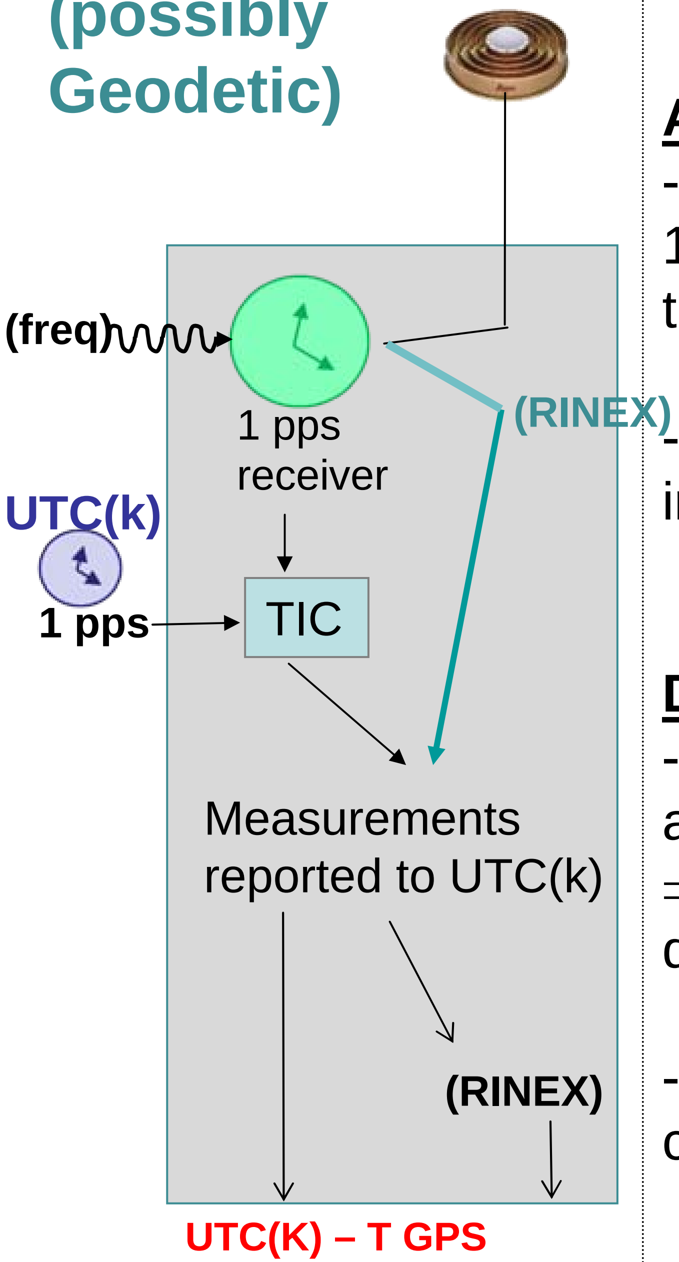
  (many delays to be determined)

Trec = receiver clock

TGSP = GPS time (or IGST)

UTC(k) = local realization of UTC within laboratory k, but can be any clock participating to time transfer applications

Time receivers (possibly Geodetic)



Advantage:
- calibration procedure is easy, as long as the 1PPS is the reference for calibrations and the trigger level of the receiver is known.

- Proper operation as a time receiver is simpler, in general.

Drawback:
- If RINEX data reported to UTC(k): may be affected by the TIC measurement
⇒phase noise is larger or even data affected more generally .

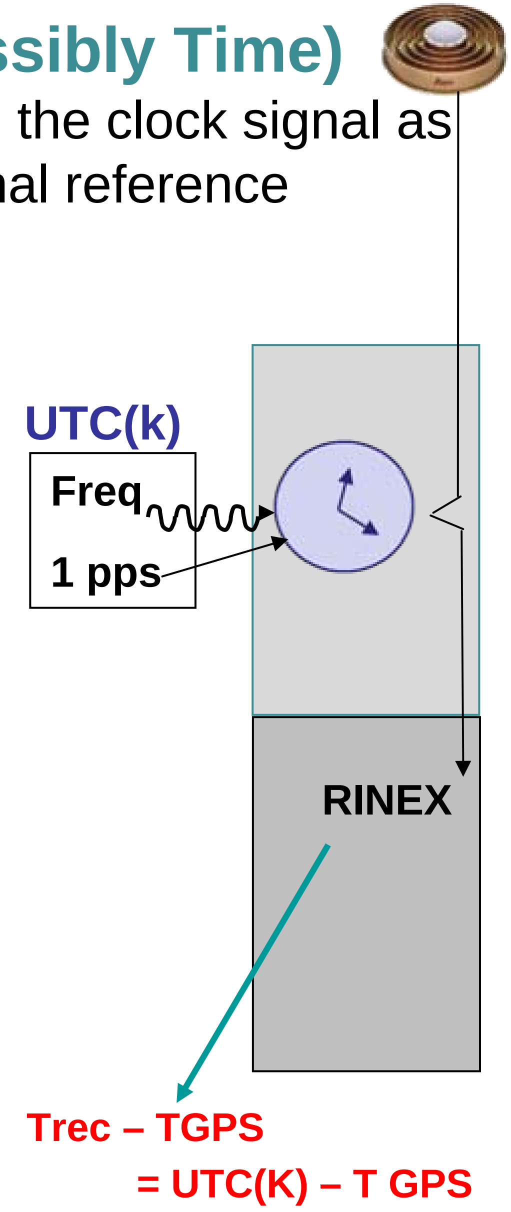
-If RINEX data reported to the internal reference: calibration procedure more complicate

Geodetic receivers (possibly Time)

using the clock signal as internal reference

Advantage :
No additional noise from a TIC

Drawback :
Calibration issue : need additional measurements to get UTC(k), following the definition of the internal reference from the combination of external 1 PPS and frequency.



Some considerations

- Input frequency : 5 or 10 Mhz

  i.e. standard frequency used in time labs

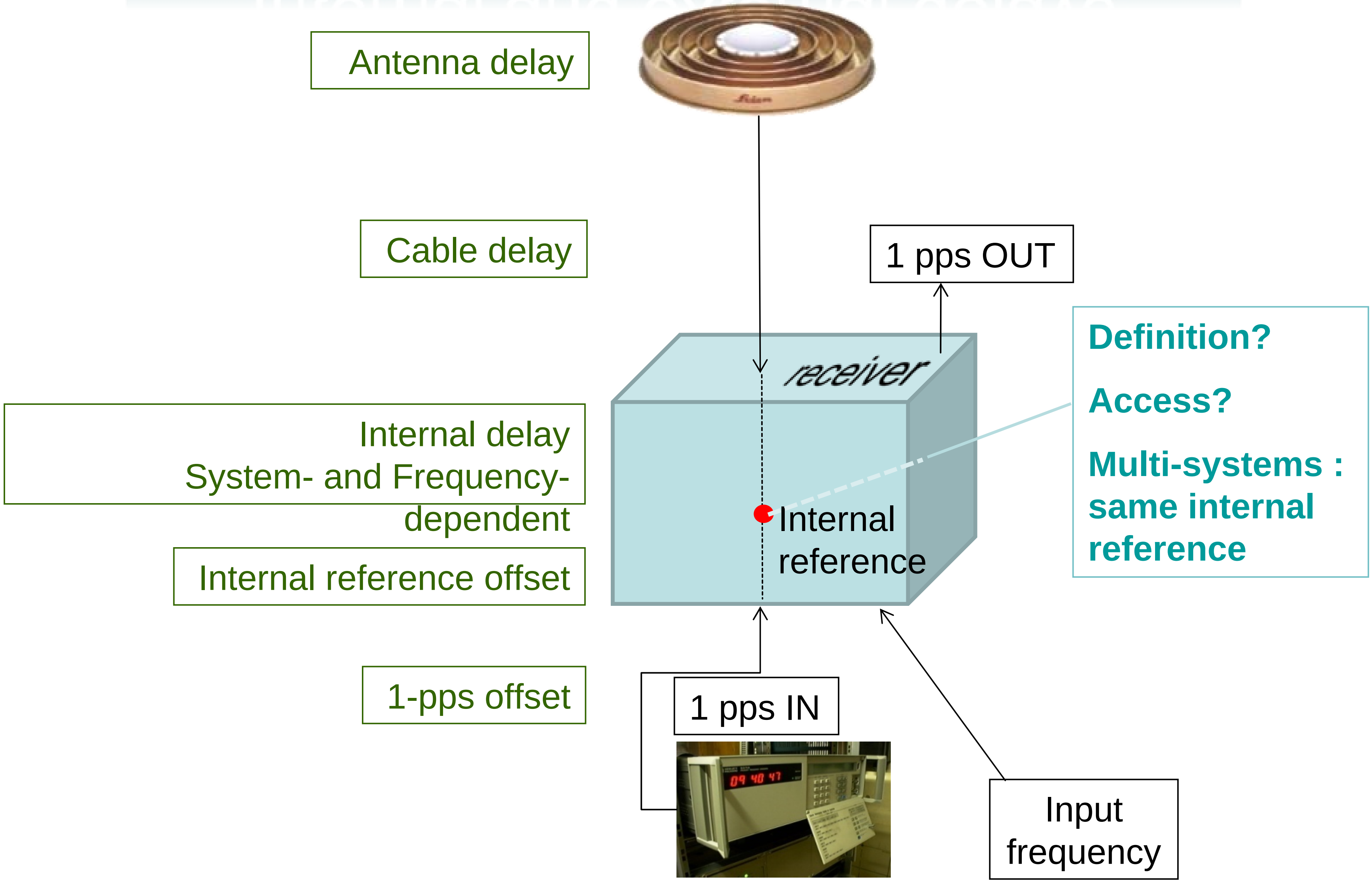
  + possibly 100 Mhz, from PFS
- If enslavement ： introduce no noise on the frequency
- The trigger level of the 1 PPS reference input should lie between 0. 5 V and 1 V (within the linear part of the rising edge) and its value should be known.
- The stability of the trigger circuit should be 100 ps or better

Calibration issues

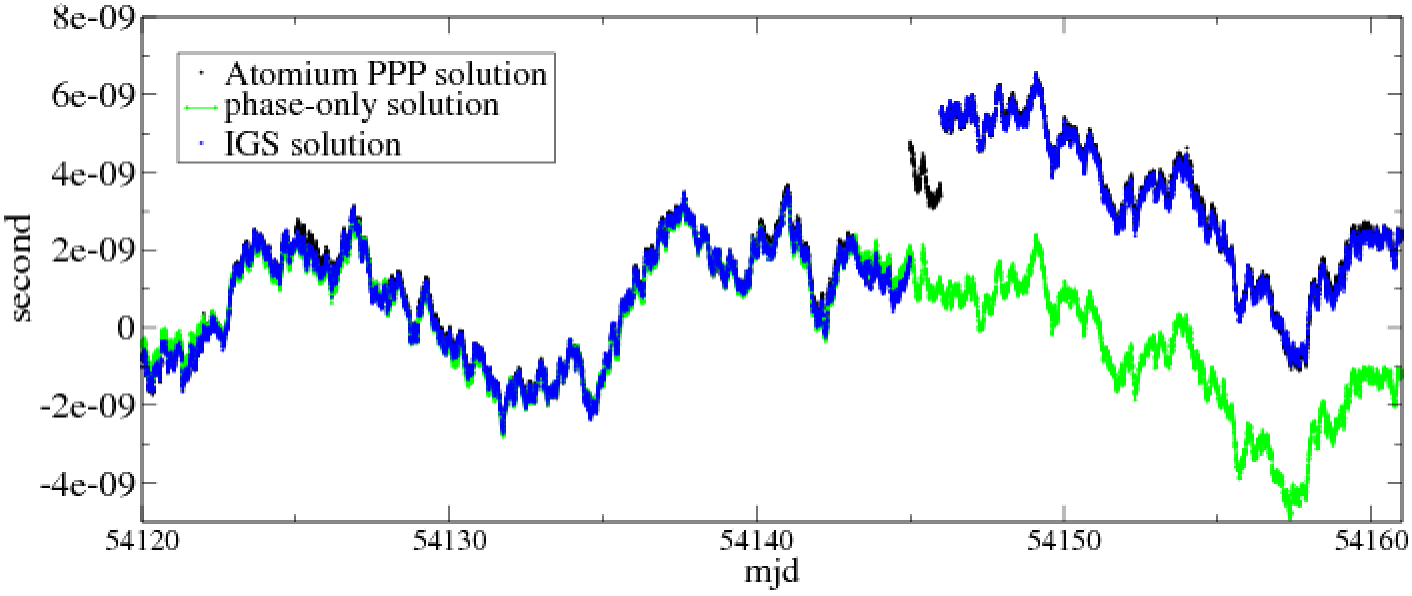
- hardware-induced timing biases must be known with a low uncertainty
- These delays must be constant

  → need for constant temperature
- Antennas and cables which minimize the impact of multipath reflections and similar effects

Internal and external delays

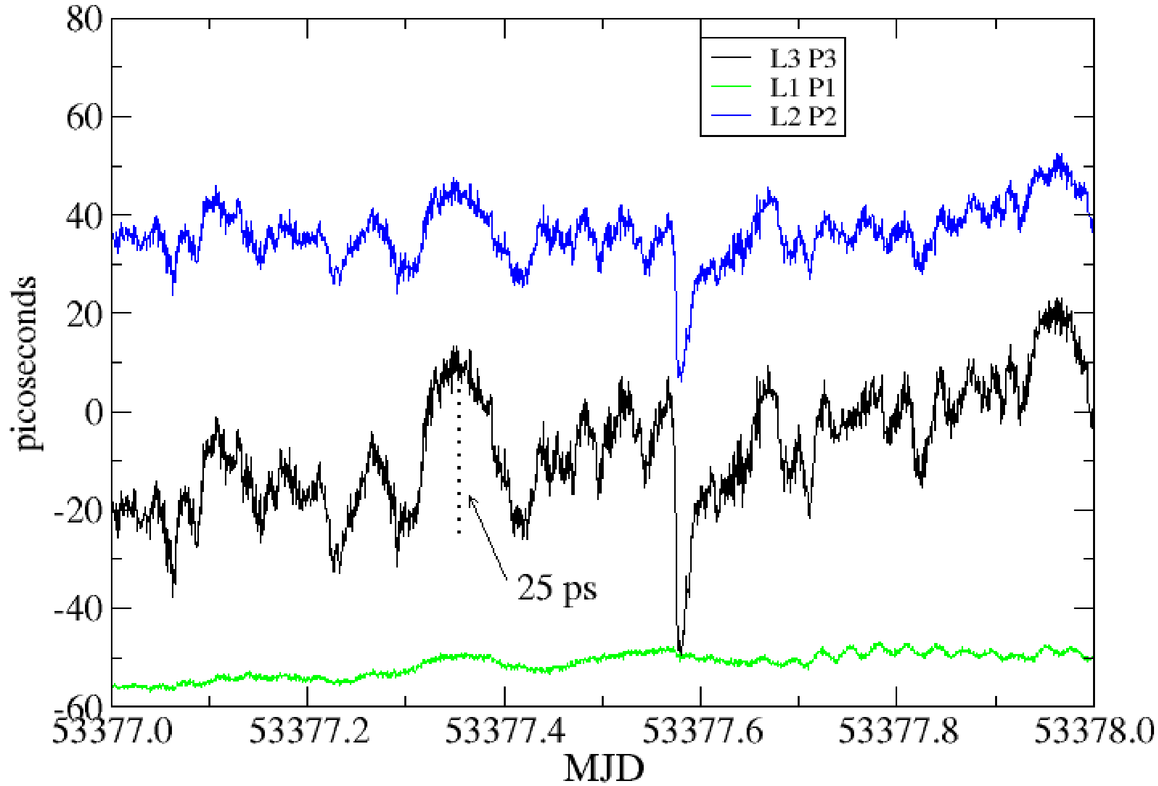


Jump in the pseudorange measurements, not in the Carrier phase measurements. Example



Temperature variations inside the receiver

Same clock connected to 2 receivers → should be ZERO



Low frequency variations: due to internal temperature variations;

Was due to variable processor activity, correlated with the number of busy channels

Output data and Formats

- 2 frequencies → remove 1st order ionosphere
- 3 frequencies

  → mitigate additional error sources

  → choice of the best combination
- Carrier-phase measurements, for short-term Frequency Transfer
- CGGTTS : will not be continued as it is, and can be deduced from raw data
- RINEX files : sandard as used by the geodetic community

Conclusions : Recommendations

Recommendations

- It is essential that the receiver functions are described in detail by the manufacturer:
  - physical point where the GNSS measurements are made or reported
  - relations between this point and the input/output signals,
  - relations between this point and the point to which the measurements are reported (if it is not the same).

- It is essential that the internal hardware delays be constant within the whole setup

…/…

Conclusions : Recommendations

Recommendations

- multi-system receivers:
  - same internal reference for the measurements of all the systems
  - possibility to determine inter-frequency, inter-system biases

    but can de determined within Time/Frequency transfer computations as already shown by GLONASS+GPS studies.

- Signals :
  - GPS : As long as possible : P1 and P2
  - GLONASS : P1-P2 → L1C and L2C
  - Galileo different possible combinations:TBD, !! E5(a+b)
  - COMPASS

  - for all systems : using 3 frequencies will allow better mitigation of measurement errors: TBS

Thank you!

CCTF : Consultative Committee for Time and Frequency

CCTF Recommendation S4(2001)

…continue the developments of absolute and differential **calibration** methods for all time transfer techniques with the aim of achieving 1 ns standard uncertainty…

CCTF Recommendation S 5 (2001)

the manufacturers of GNSS **receivers** used for timing implement the **technical guidelines** for receiver hardware compiled by the CCTF Group on GNSS Time Transfer Standards (CGGTTS)

→time transfer with an accuracy of 1 ns or better.

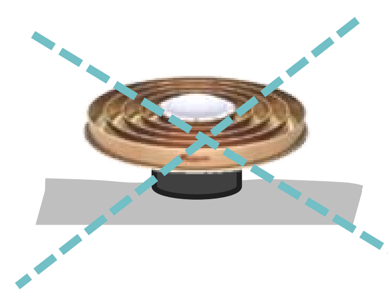
CCTF Recommendation 5(2006)

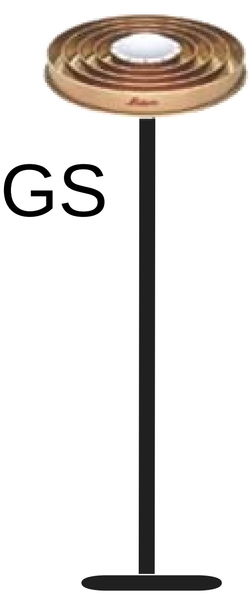
timing laboratories work to improve the **calibration** of time transfer equipment, and to reduce the source of the type-B uncertainties of the receiving equipment including:

- equipment that minimizes the impact of fluctuations in the ambient temperature and humidity,
- antennae and cables which minimize the impact of multipath reflections and similar effects.

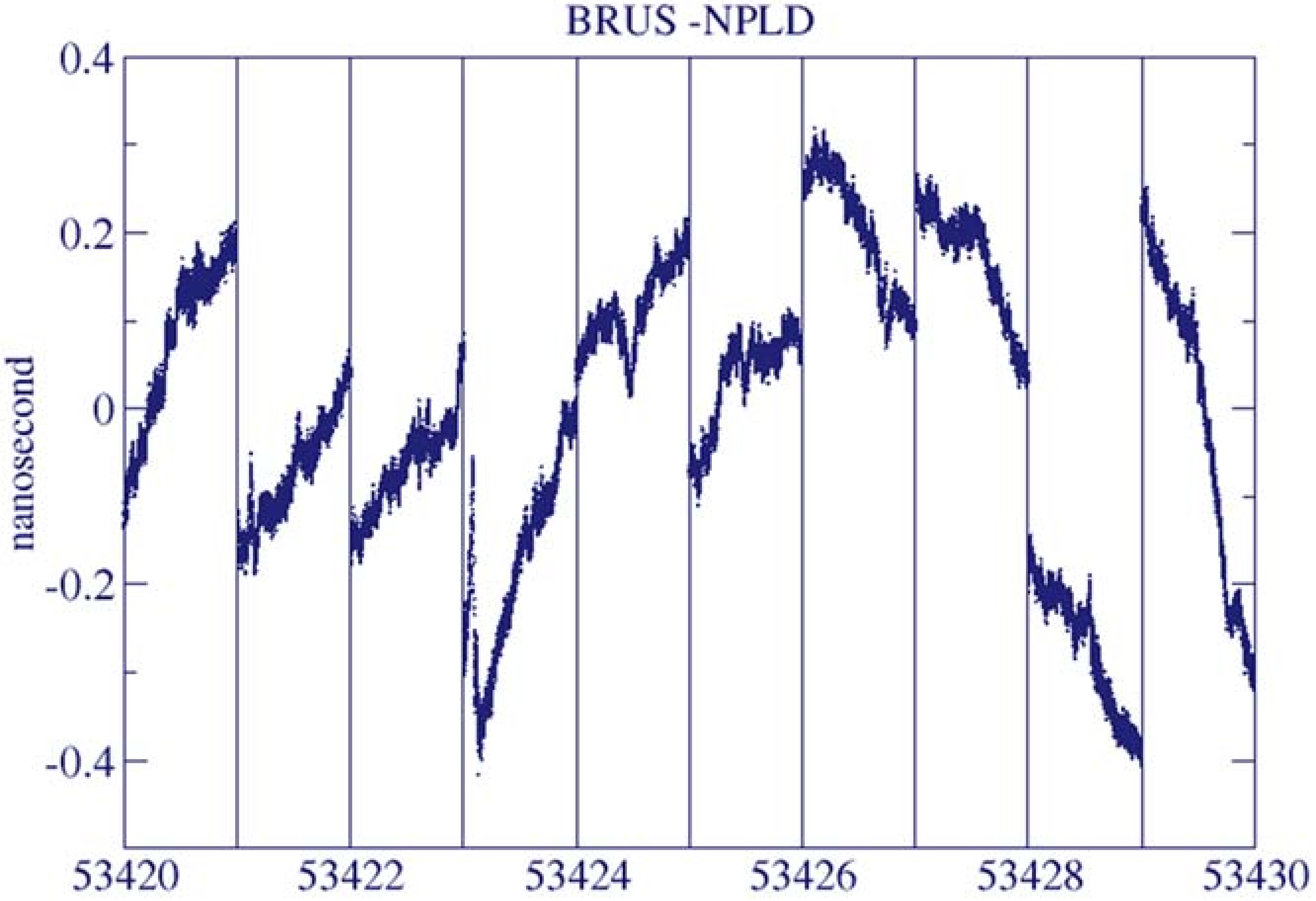
Cables and Antenna

- Both: stable with respect to environmental changes
- setup in a way that minimizes the reflections (multipath) and the near-field effects
- In particular, impedance matching
- Use the IGS phase center variations of the antenna → use antenna calibrated by the IGS

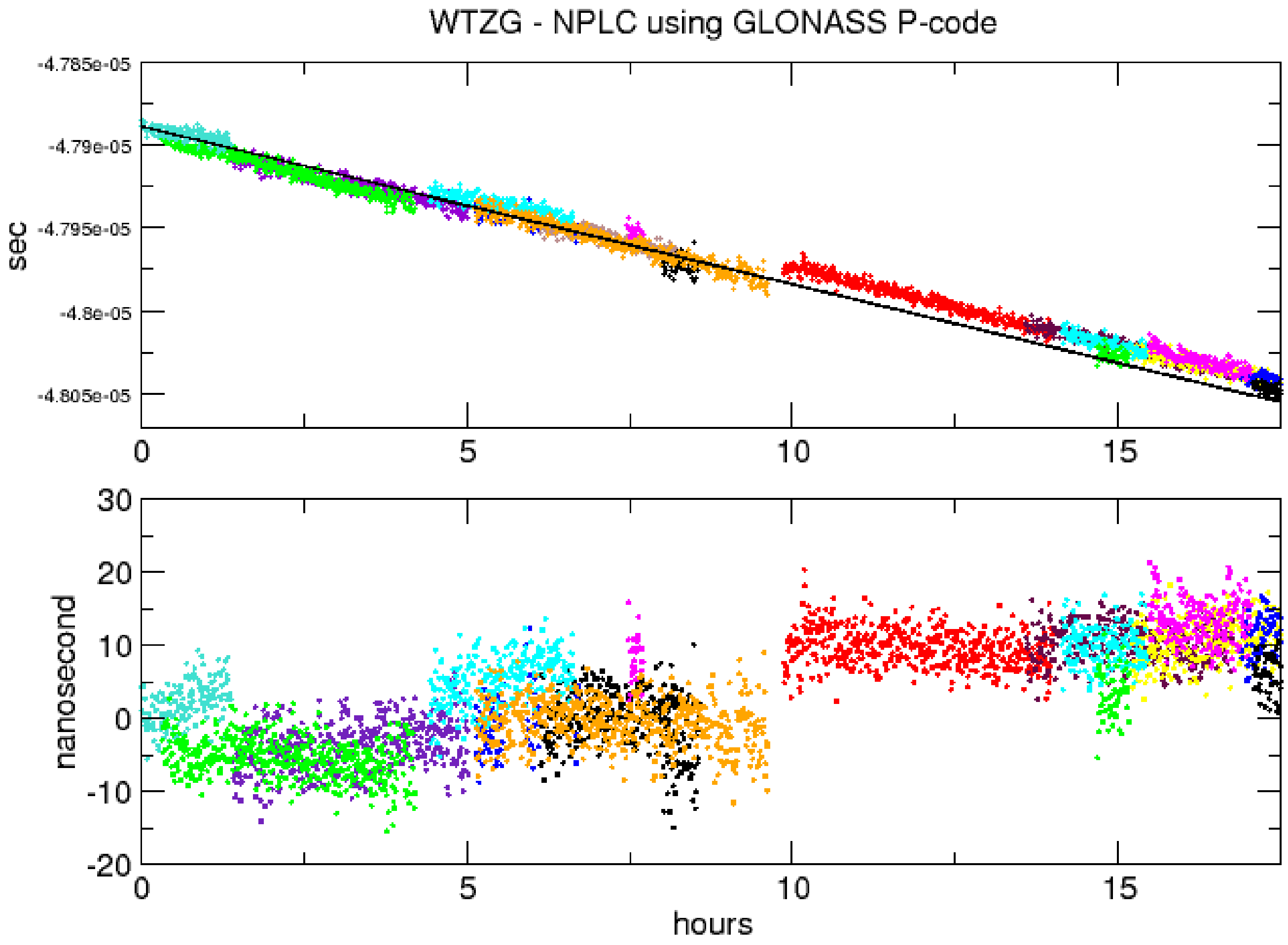




Effect of near field effects



GLONASS (2)



WTZG - NPLC using GLONASS P-code
sec
-4.785e-05
-4.79e-05
-4.795e-05
-4.8e-05
-4.805e-05
0
5
10
15
30
20
10
0
-10
-20
nanosecond
hours

GPS time transfer : some history

1984

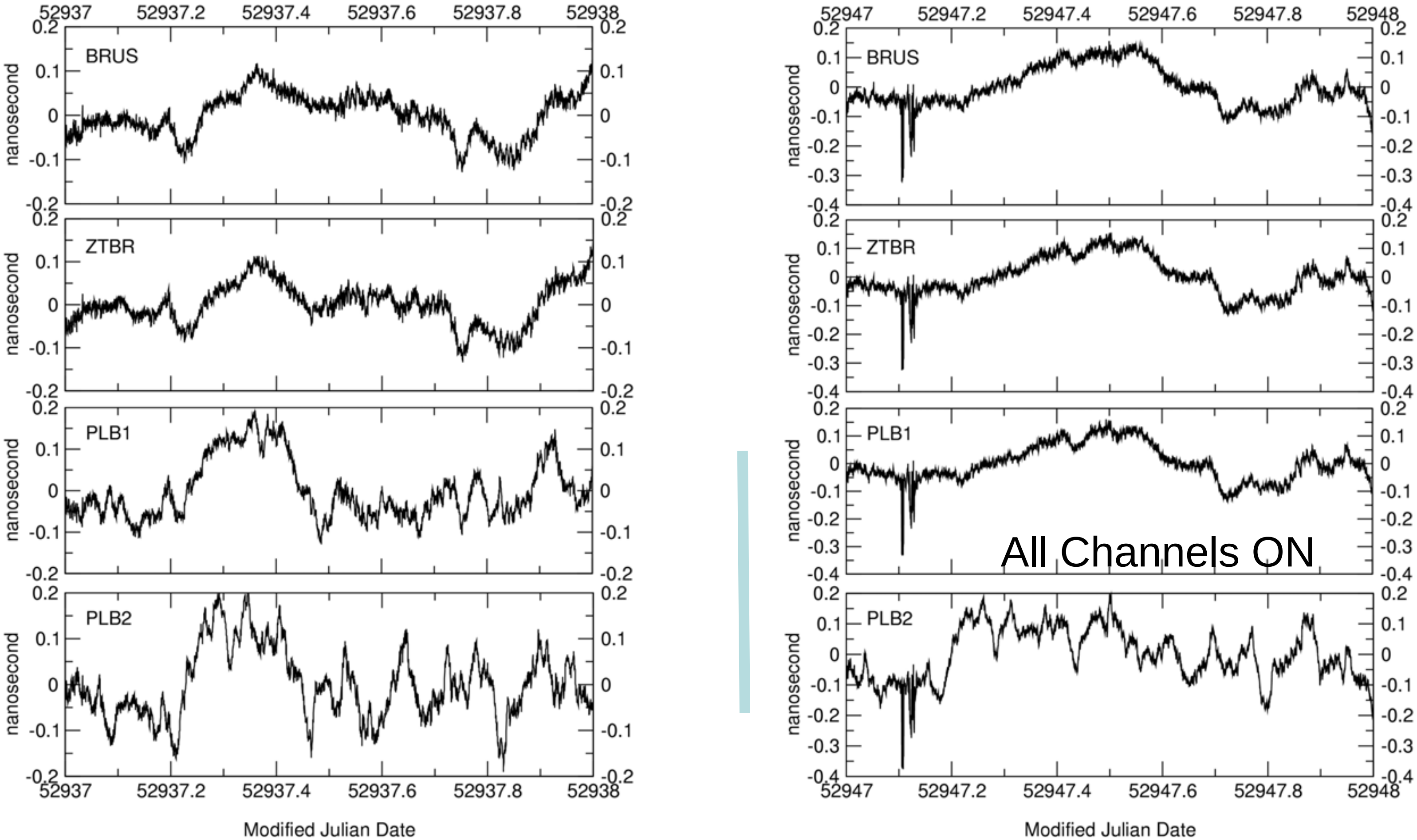
- One-channel
- C/A code measurements
- Output=CCTF files,
  - results for a given observation schedule,
  - 1 point (from 1 sat)/16 min.

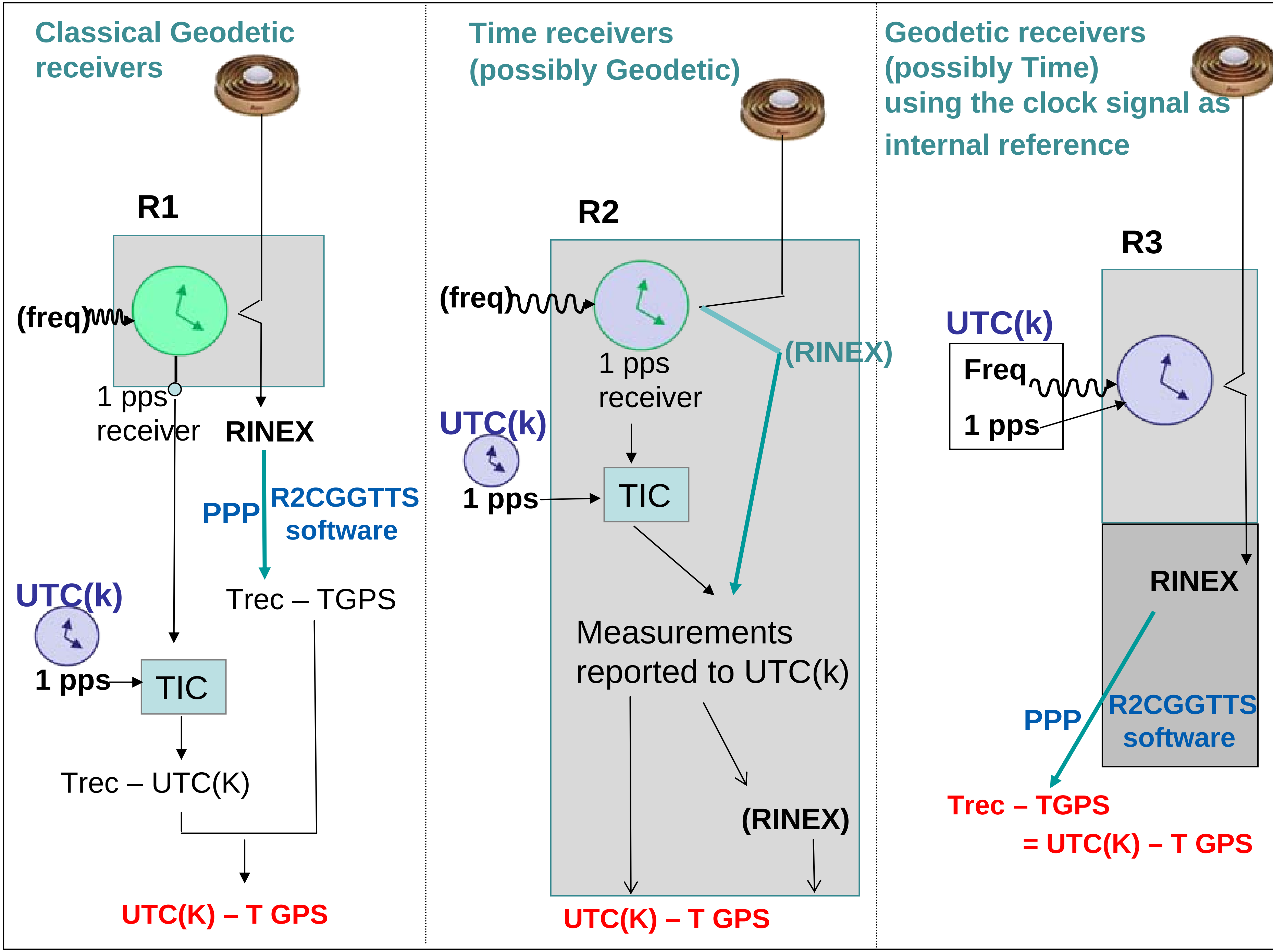
Later ~ 2000 ~

- Multi-channel
- P1 (C/A) and P2 code measurements
  → Ionosphere-free combination
- Carrier-phase data
  → geodetic time transfer
- Output : CGGTTS / RINEX (→ PPP)

Noise and temperature variations inside the receiver due to processor activity

UTC(ORB)-USNO(MC3)




Classical Geodetic receivers
R1
(freq)
1 pps receiver
RINEX
PPP
R2CGGTTS software
UTC(k)
1 pps
TIC
Trec – TGPS
Trec – UTC(K)
UTC(K) – T GPS
Time receivers (possibly Geodetic)
R2
(freq)
1 pps receiver
(RINEX)
UTC(k)
1 pps
TIC
Measurements reported to UTC(k)
(RINEX)
UTC(K) – T GPS
Geodetic receivers (possibly Time) using the clock signal as internal reference
R3
UTC(k)
Freq
1 pps
RINEX
PPP
R2CGGTTS software
Trec – TGPS
= UTC(K) – T GPS