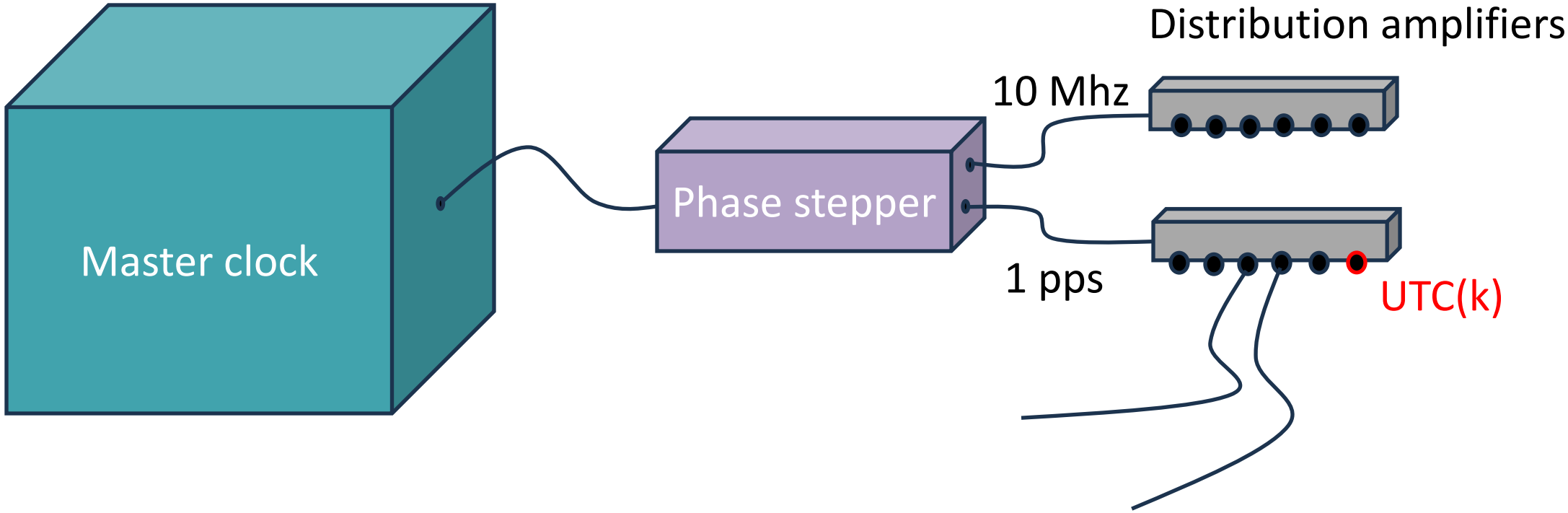
CCTF

GNSS calibration

Pascale Defraigne
Chair of the WG on GNSS

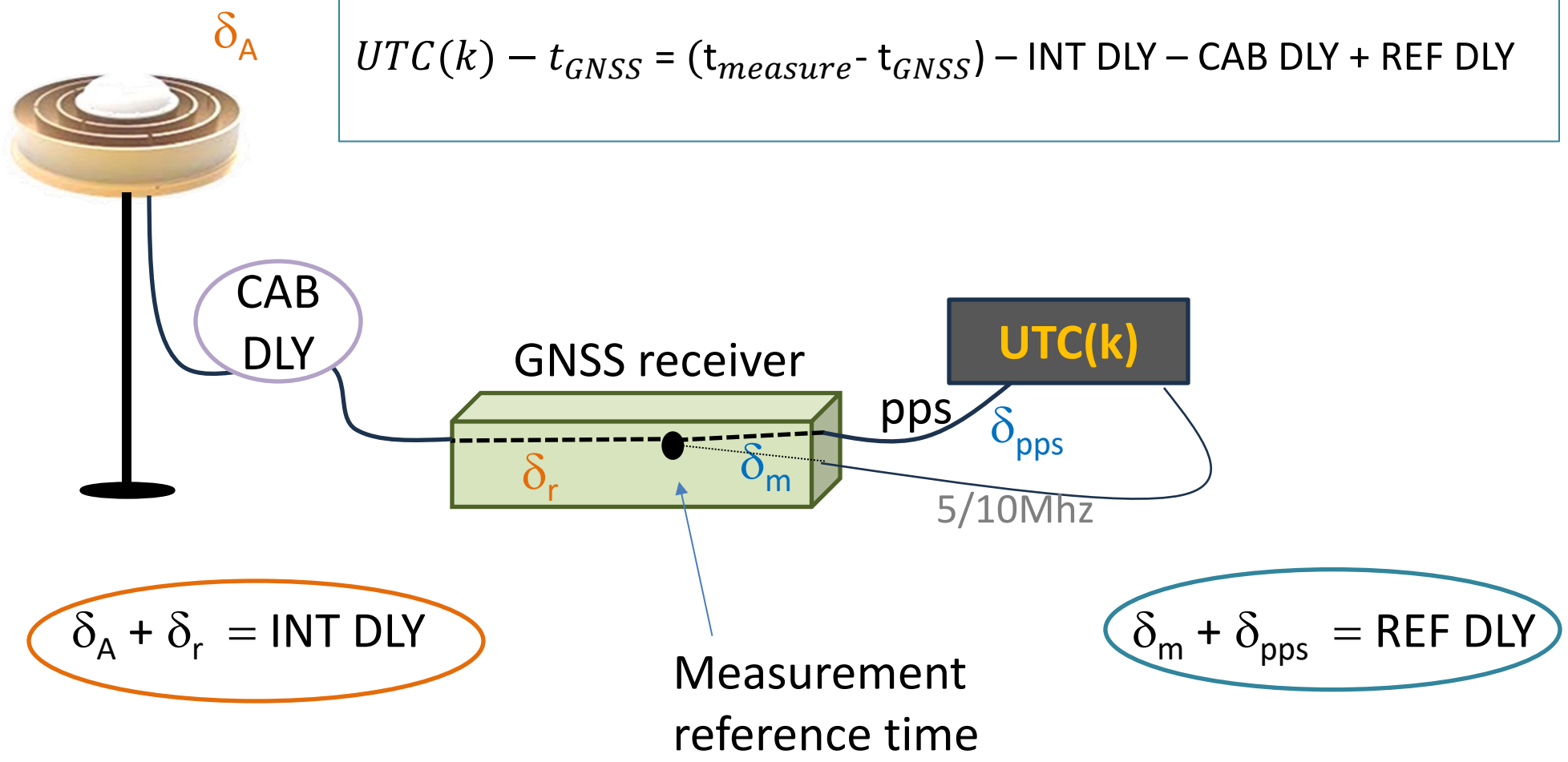
CONSULTATIVE COMMITTEE
FOR TIME AND FREQUENCY

UTC(k) reference point

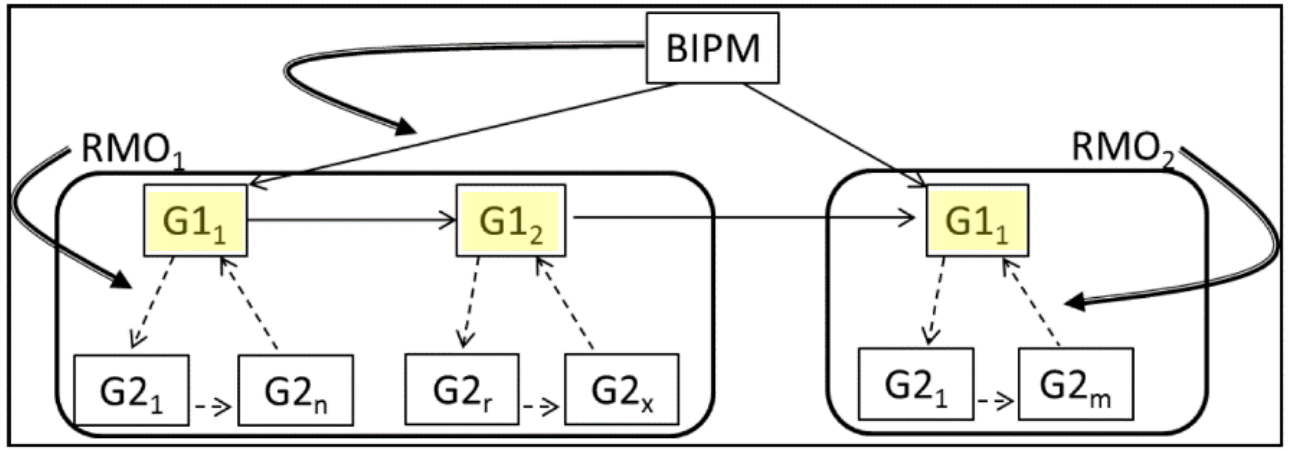


GNSS hardware delays

$UTC(k) - t_{GNSS}$ = ($t_{measure}$ - t_{GNSS}) – INT DLY – CAB DLY + REF DLY



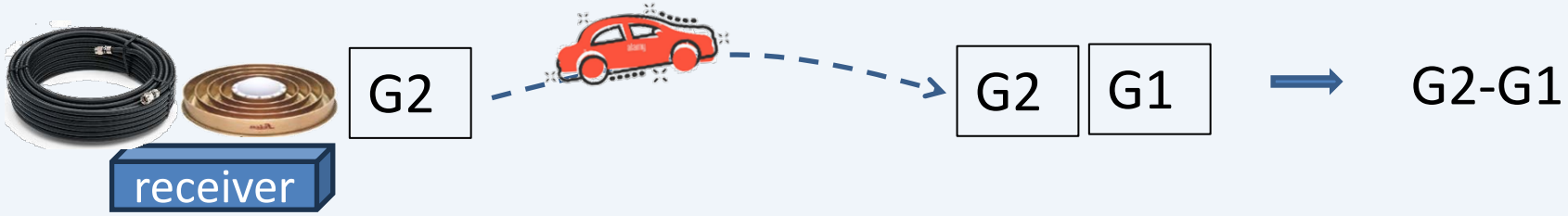
BIPM-RMO collaboration for GNSS calibration



- BIPM database for all calibration results
  https://webtai.bipm.org/database/calid_gnss.html
- Each calibration report will be identified by a unique Cal_Id to be used as a reference for the calibration info
- Calibration reports:
  https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/group2/

Calibration Procedures for G2 Labs

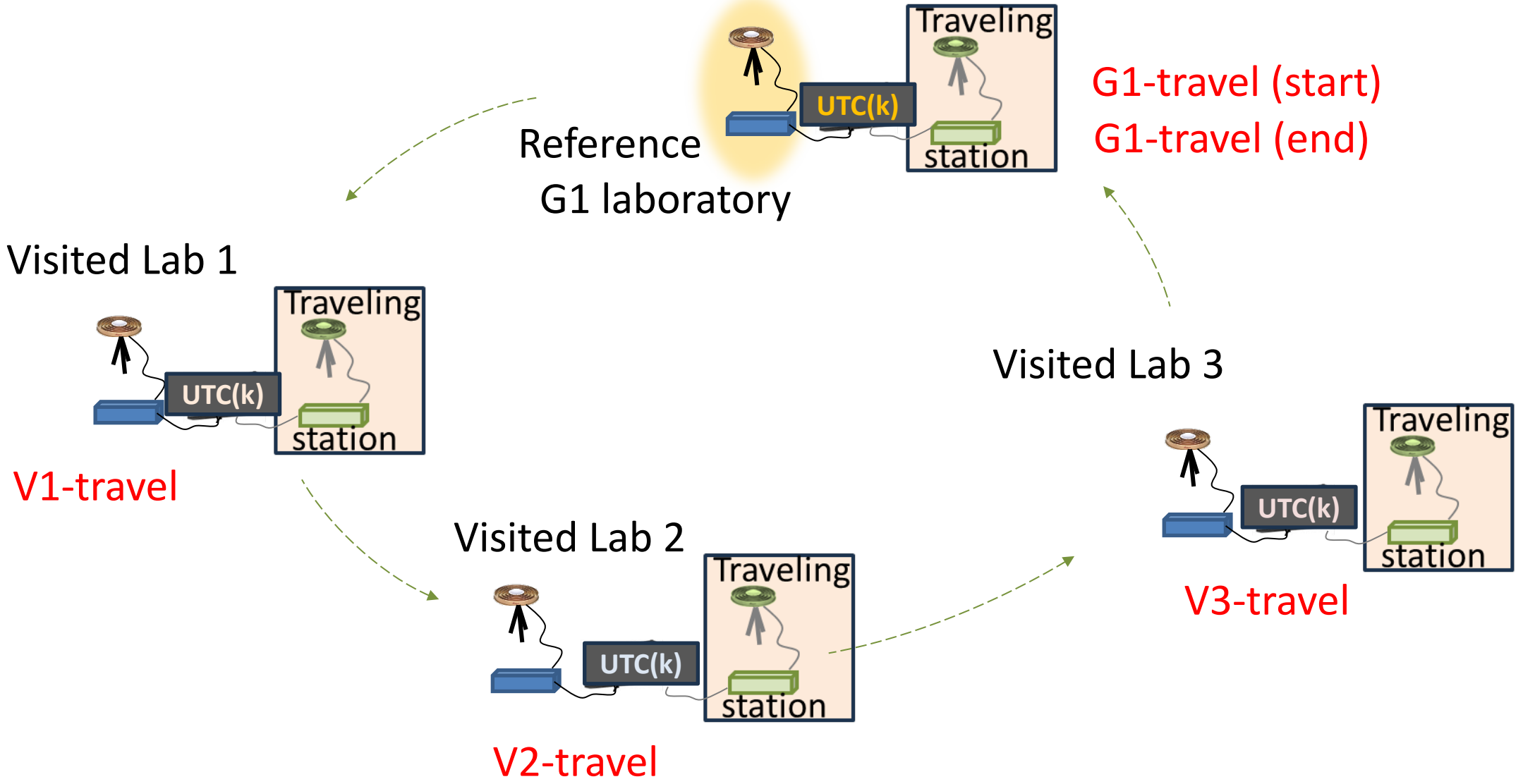
1. **Direct calibration**



No work for G2
But G2 calibrated at another place

2. **Calibration trip with closure**

Calibration trip / traveling station



Calibration in the CGGTTS header

```
CGGTTS     GENERIC DATA FORMAT VERSION = 2E
REV DATE = 2020-10-07
RCVR = PolaRx5TR                    R2CGGTTS v8.3
CH = 12
IMS = PolaRx5TR
LAB = ORB
X = +4027881.69 m
Y =  +306998.74 m
Z = +4919499.37 m
FRAME = ITRF
COMMENTS =           NO COMMENTS
INT DLY =   28.0 ns (GPS P1),   23.8 ns (GPS P2)
CAB DLY =  237.5 ns
REF DLY =   68.5 ns
REF = UTC(ORB)
CKSUM = 9B
```

CAL_ID = 1011-2020

SAT	CL	MJD	STTIME	TRKL	ELV	AZTH	REFSV	SRSV	REFSYS	SRSYS	DSG	IOE	MDTR	SMDT	MDIO	SMDI	MSIO	SMSI	ISG	FR	HC	FRC	CK
			hhmmss	s	.1dg	.1dg	.1ns	.1ps/s	.1ns	.1ps/s	.1ns		.1ns	.1ps/s	.1ns	.1ps/s	.1ns	.1ps/s	.1ns				
G10	FF	60132	000200	780	243	3033	+441338	+4	64	-10	26	98	195	-3	150	-3	150	-3	19	0	0	L3P	C9
G12	FF	60132	000200	780	373	2172	+3975611	+2	-15	-45	20	43	133	-24	150	-4	150	-4	12	0	0	L3P	F0
G13	FF	60132	000200	780	270	1456	-5437388	-54	-4	-4	26	24	177	+44	171	+29	171	29	19	0	0	L3P	24
G14	FF	60132	000200	780	105	526	-1141226	-166	-8	-44	26	224	432	+248	172	+37	172	37	19	0	0	L3P	48
G15	FF	60132	000200	780	476	1805	-556231	-43	-24	-7	10	98	109	+14	135	+9	135	9	7	0	0	L3P	E4
G17	FF	60132	000200	780	347	704	-7204379	-1462	-566	-1453	60	8	141	+1	132	-6	132	-6	12	0	0	L3P	44
G19	FF	60132	000200	780	360	1000	-3404201	-104	-32	-53	13	47	137	-12	144	-2	144	-2	10	0	0	L3P	02
G23	FF	60132	000200	780	263	2625	-405233	-95	-15	-55	30	98	181	+27	167	+51	167	51	26	0	0	L3P	2E
G24	FF	60132	000200	780	754	2907	+2493908	+123	-31	-2	6	4	83	-3	88	-8	88	-8	3	0	0	L3P	B8

In the CGGTTS:

- **INT DLY** : receiver + antenna delays
  Depends on the GNSS code
  Determined through G1/G2 calibration
- **CAB DLY**: antenna cable delay
  measured by the lab (optional)
- **REF DLY**: offset between UTC(k) time and the receiver measurement time
  measured by the lab (optional)
- **SYS DLY** : INT DLY + CAB DLY (if CAB DLY not measured by the lab)
  Determined through G1/G2 calibration
- **TOT DLY** : INT DLY + CAB DLY - REF DLY (if CAB DLY and REF DLY not measured by the lab)
  Determined through G1/G2 calibration

Measuring REF DLY and CAB DLY?

- When you install a new station, you can :
  - measure (or not) CABDLY (antenna cable)
  - measure (or not) the REFDLY

  - The advantages of using TOTDLY/SYSDLY instead
    - Avoid complex measurements (REFDLY / CABDLY)
    - Reduce uncertainty

  - Disadvantage
    - Need to re-calibrate whenever change cables
    - More difficult to understand when measurement problems

Measure of REFDLY

REF = time tag of the GNSS measurement
OR “considered as”
but must be close, and the different between REF and the time tag of the GNSS measurement must be constant.

REF DLY = REF – UTC(k)

WHAT IS REF ? Depends on the receiver

e.g. Septentrio PolaRx3, PolaRx4: Setup: choose 1 pps out = RXCLOCK → REF = PPS OUT
Septentrio PolaRx5 : Setup: choose 1 pps out = RXCLOCK
Auto compensation OFF (recommended) → REF = PPS OUT
Auto compensation ON → REF = PPS IN
Mesit Receiver: REF = PPS IN
TTS receiver: REF = calculated by the receiver from PPS IN + the measured difference between PPS IN and 10 MHz IN

Measure of REFDLY

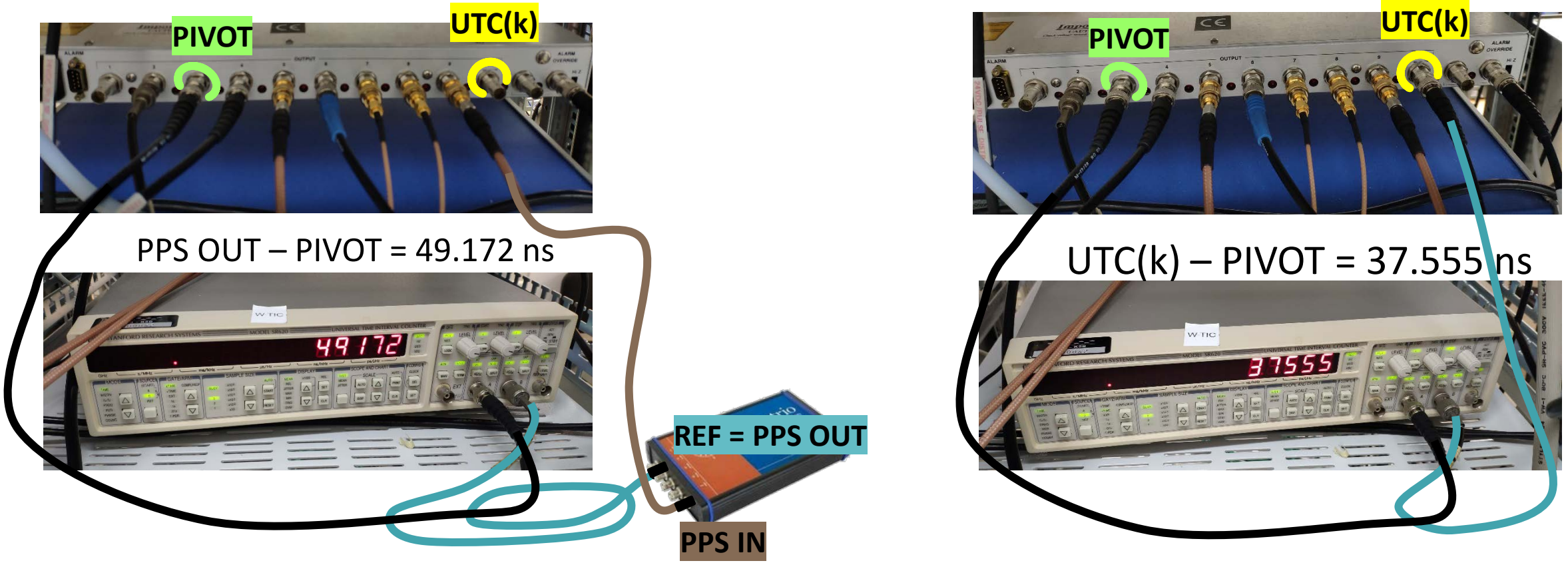
1. Calibrate your Time Interval Counter

   + set the trigger level at the same value in A and B (usually 1V)

Measure of REF DLY

Use the PIVOT method : 2 measures

If REF is the PPS OUT



REF DLY = PPS OUT – UTC(k) = (49.172 - 37.555) = 11.617 ns

Measure of REF DLY

Use the PIVOT method : 2 measures

If REF is the PPS IN

PPS IN – PIVOT = 49.172 ns

REF = PPS IN

UTC(k) – PIVOT = 37.555 ns

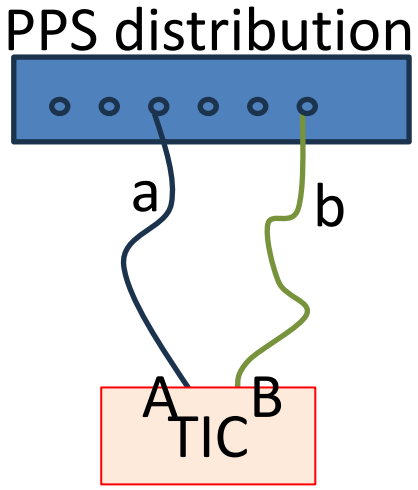
REF DLY = PPS IN – UTC(k) = (49.172 - 37.555) = 11.617 ns

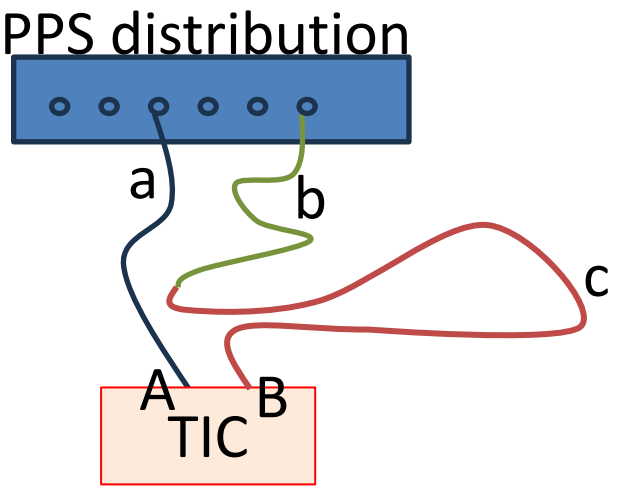
Measure CABDLY = antenna cable delay - OPTIONAL

Several techniques (see Rovera et al. [10.1109/FCS.2015.7138832](10.1109/FCS.2015.7138832))

Here we only propose the easiest technique, with no need for additional equipment, but with uncertainty of ~500 ps.

For antenna cable delay, we recommend to use trigger at low level 0.5 V



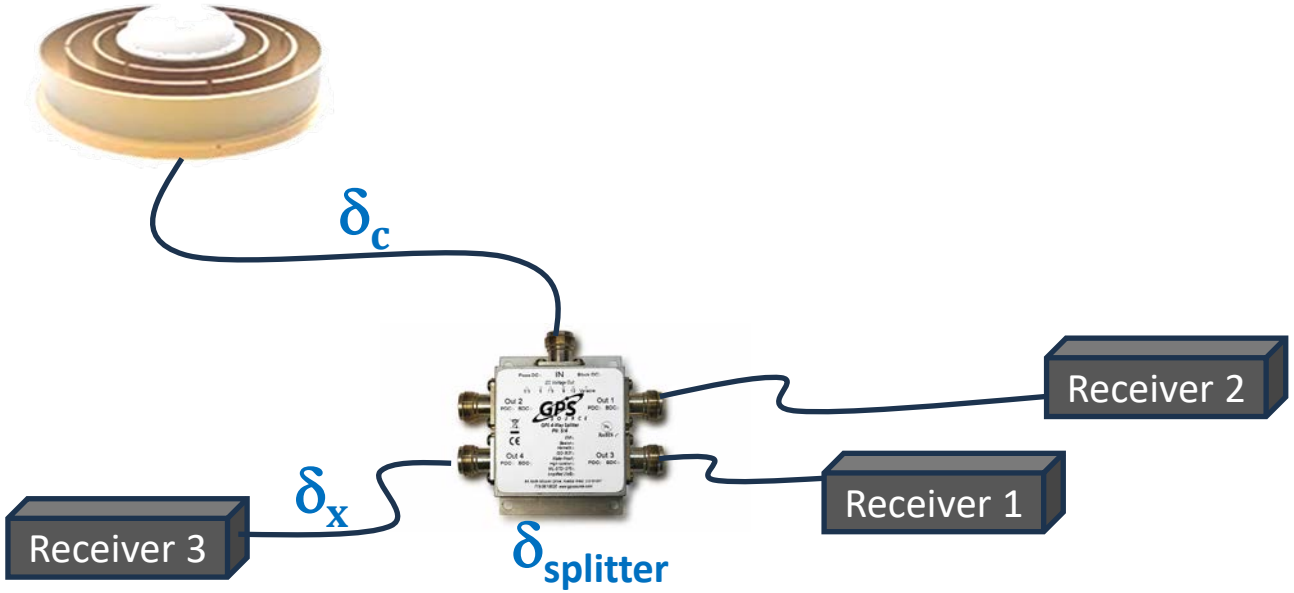


$c = (B-A)_2 - (B-A)_1$

Measure: $(B-A)_1 = b-a$

Measure: $(B-A)_2 = (b+c)-a$

If using a splitter... NOT RECOMMENDED !



$$\text{CAB DLY} = \delta_c + \delta_{splitter} + \delta_x$$

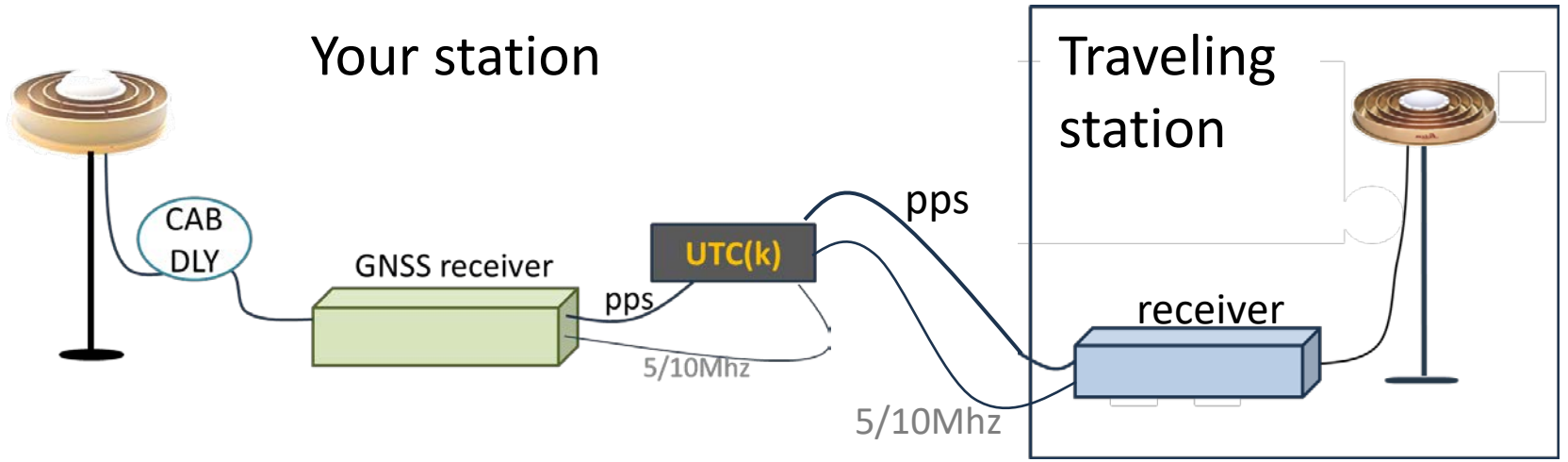
You want a calibration?
Procedure for G2 to request a calibration

- If your RMO is covered by G1:
  Contact the TCTF G1 Coordinator, or a G1 laboratory of your RMO
- If there is no G1 laboratory in your RMO (i.e. AFRIMETS and GULFMET):
  contact either a G1 from another RMO or the BIPM that will help you
- Once you have an agreement with a G1 lab, ask for the instruction manual to ensure you have the required equipment and abilities
- Inform the G1 lab about the needed antenna cable length to install the traveling station at your premises
- Make sure all practical aspects of the calibration trip (shipment, customs administrative procedures…) are ok before planning the trip

Synthetic document: “How to get GNSS calibration for UTC(k) laboratories” (July 2021)
https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/How-to-get-calibration-July2021.pdf

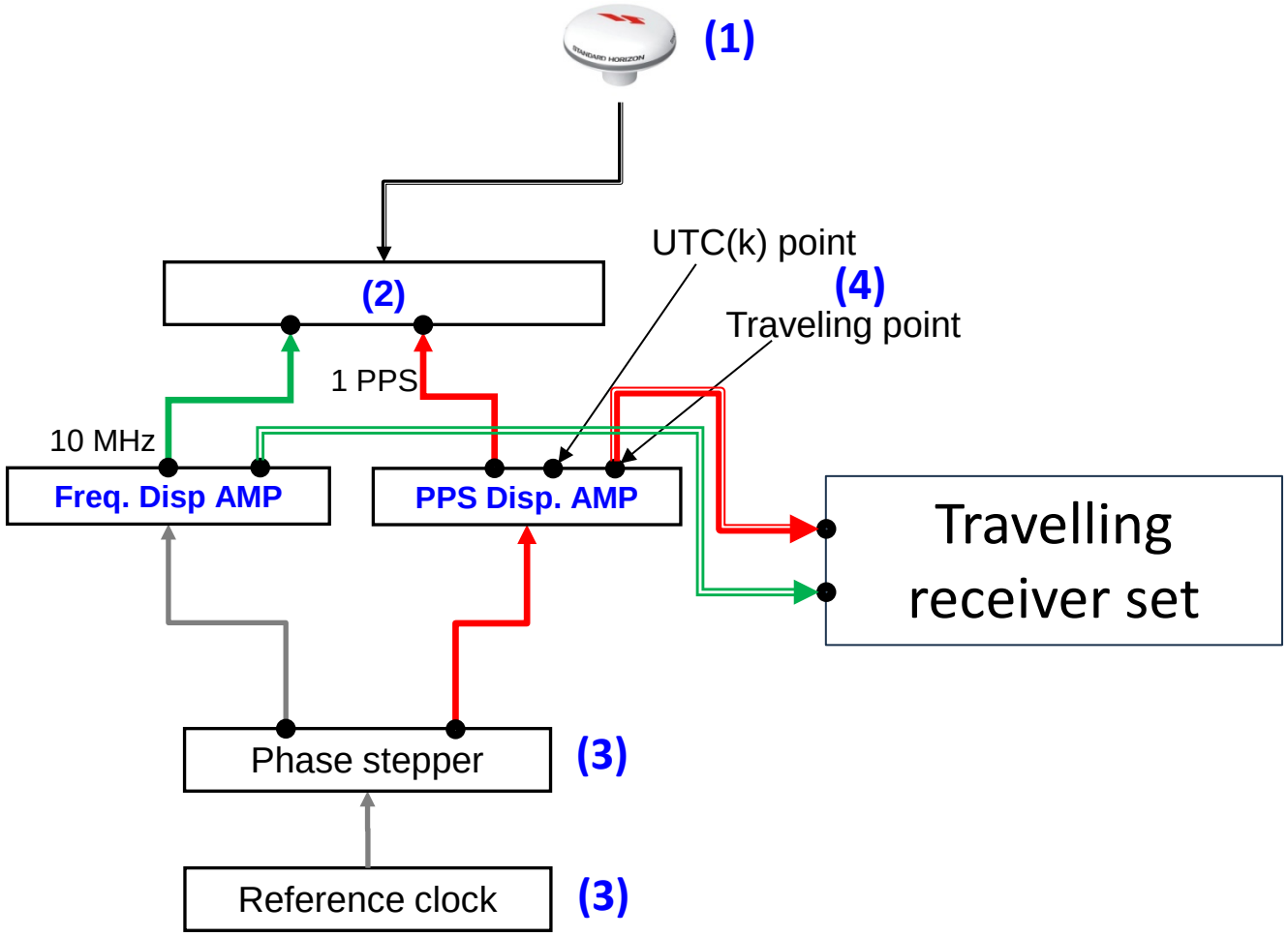
you receive the traveling station

- Follow the instructions of the G1 labs
  - Install the station
  - Measure the REFDLY (or the delay from UTC(k) point to the calibration point) of the traveling station as explained in the instructions
  - Collect at least 5 days of measurement



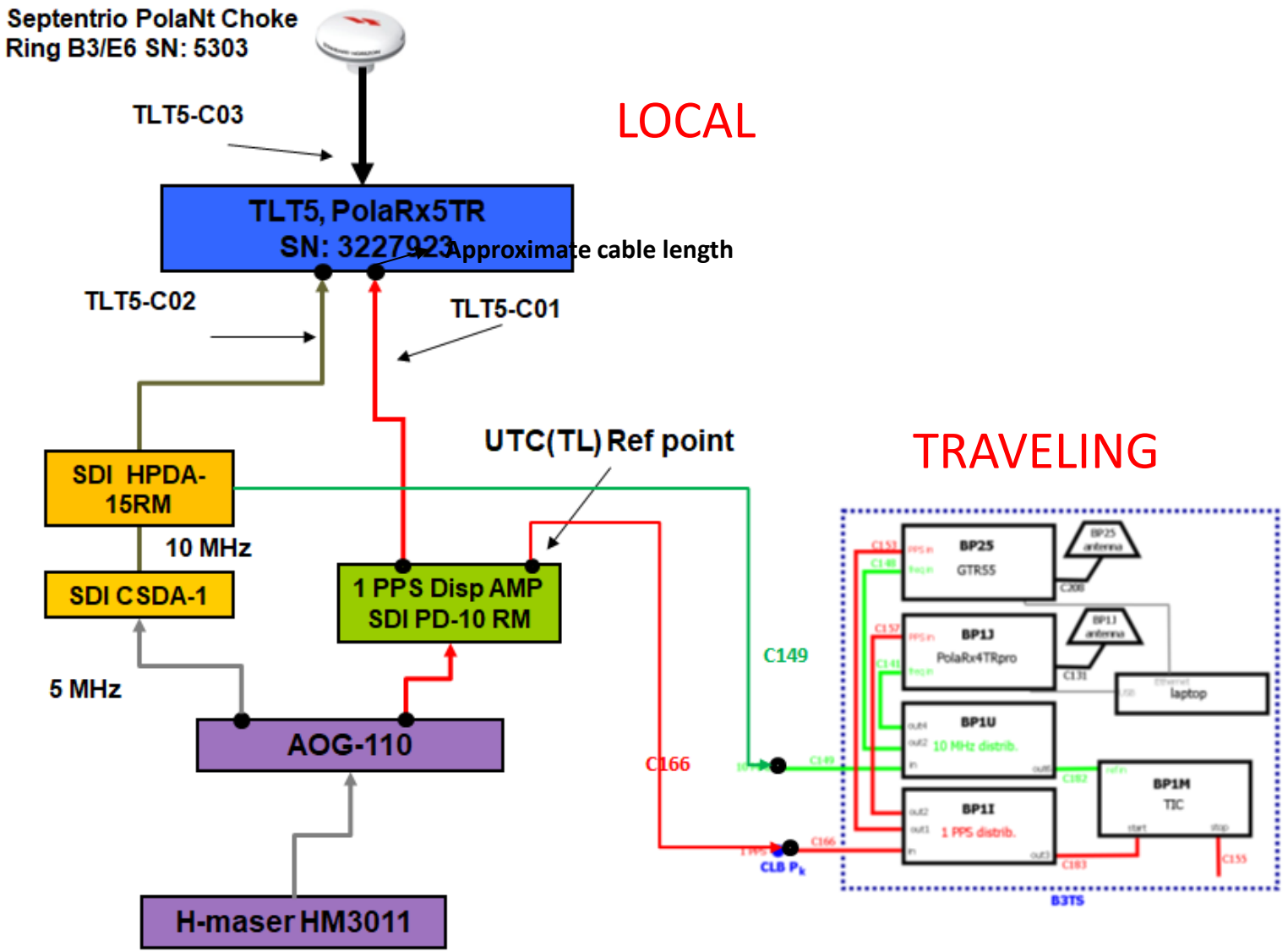
Before dismounting, send one day of data to the G1 lab for rapid verification

Provide a Diagram of the setup (I)



1. Local Antenna, please mark the model number and serial number
2. Local receiver, please mark the model number and serial number
3. Mark the model number of frequency and PPS distribution amplifier if possible
4. Mark the UTC(k) point and the point providing UTC(k) signal for the traveling station (these can be the same).

EXAMPLE: 2022 G1 trip diagram of the receivers at the TL.



1 PPS Cable	
Antenna Cable	
10 MHz Cable	
5 MHz Cable	

Information sheet (I)

Available in Annex 1, in https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/

For each calibration, it is necessary to fill an information sheet.

Annex A - Information Sheet

(to be repeated for each calibrated system)

Laboratory:		
Date and hour of the beginning of measurements:	(1)	
Date and hour of the end of measurements:		
Information on the system		
	Local:	**Travelling:**
4-character BIPM code	(2)	
• Receiver maker and type: Receiver serial number:	(3)	
1 PPS trigger level /V:	(4)	
• Antenna cable maker and type: Phase stabilised cable (Y/N):	(5)	
Length outside the building /m:		
• Antenna maker and type: Antenna serial number:	(6)	
Temperature (if stabilised) /°C		

(5) 

1. Fill the name of your lab, and the dates of the calibration
2. The first 2 letters of your 4-character code is assigned by BIPM; you can set the other 2 letters by yourselves
3. Fill the receiver model and S/N
4. The 1 PPS trigger level is the same as your TIC setting
5. The manufacturer of the antenna cable can be found in the information printed on the cable. Ask your supplier to confirm your antenna cable is phase stabilized or not.
6. Fill the antenna model and S/N

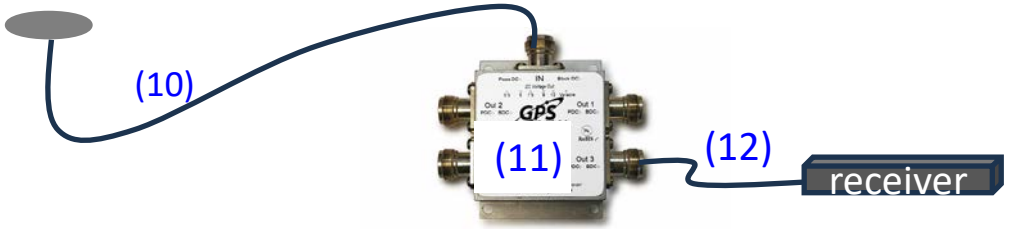
Information sheet (II)

Measured delays /ns Please tick the correct box depending on the receiver (1)		
	Local:	**Travelling:** / reference
(7)	REF point is PPSIN ☐	REF point is PPSIN ☐
• Delay from local UTC to receiver 1 PPS-in (REFDLY):		
• **Optional** Delay from local UTC to receiver 1 PPS-Out:		
(7)	REF point is PPSOUT ☐	REF point is PPSOUT ☐
• Delay from local UTC to receiver 1 PPS-Out (REFDLY):		
• **Optional** Delay from local UTC to receiver 1 PPS-in:		
(7)	REF point. TTS 4/5 ☐	REF point. TTS 4/5 ☐
• Delay from local UTC to receiver 1 PPS-in:		
• Delay from 1 PPS-in to10 MHz input receiver:		
• Computed 1PPS frequency offset correction:		
• Computed REFDLY by the receiver:		
	(Not to be filled)	REF point is calibration point ☐ (9)
• Delay from local UTC to traveling box calibration point:	(Not to be filled)	
(7)	Other case ☐	Other case ☐
Please describe measurements and final REFDLY value		
• Antenna cable delay:	(10)	(2)
Splitter delay (if any):	(11)	(2)
Additional cable delay (if any):	(12)	(1)

7. Choose the right REF point option (see slide 10 for explanation + also in Annex 1)
8. Local UTC is your UTC(k) definition point.
9. If you use a calibration point for the traveling station
10. The delay of your antenna cable

IF YOU HAVE A SPLITTER:

11. the delay of your GNSS signal splitter (if you use it to share antenna signal)
12. The delay from the splitter to the receiver



GNSS signal splitter
(not recommended !)

Information sheet (III)

Splitter delay (if any):		(2)
Additional cable delay (if any):		(1)

Data used for the generation of CGGTTS files

Complete this section only if CGGTTS-format data were used for the calibration.
Please fill with the parameter values as configured in the receiver at the time of calibration

• INT DLY (GPS) /ns:	
• INT DLY (Galileo) /ns:	
• INT DLY (BDS) /ns:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	
• REF DLY /ns:	
• Coordinates reference frame:	
Latitude or X /m:	
Longitude or Y /m:	
Height or Z /m:	

(11)

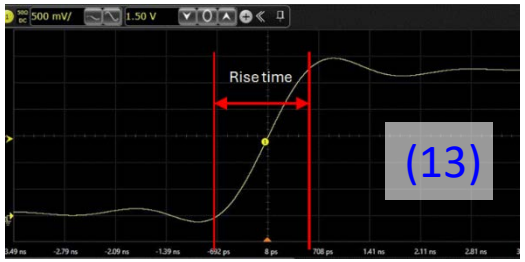
(12)

General information

• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

(13)

(14)



11. If CGGTTS are used, fill them by checking the header of the CGGTTS files.
12. Use "ITRF" as coordinate reference frame, the roughly X, Y, Z coordinate can be read from your receiver measurement, or the header of its CGGTTS files.
13. rise time is the time taken by a signal to change from a specified low value (10%) to a specified high value (90%), use oscilloscope to measure the rise time
14. Example of the set temp/hum value and uncertainty: 23 ± 2 °C, 50 ± 15 %

- *ITU-T Recommendation V.11*

The G1 will provide a calibration report.

Uncertainty Contributions:

- Misclosure (in case of a travelling receiver)
  - *Difference between $RAWDIF_{R-T}$ at initial and closure stages*
- RAWDIF measurement
  - *Time deviation of each RAWDIFs, typically at one day, or floor value.*
- Position error
  - *Antenna position error at reference and visited sites*
- Multipath effect
  - *at reference and visited sites*
- REF cable delay measurement
- Antenna cable delays measurement

Once the report is validated by the BIPM,

- You will be informed
- You will use the new values (and new cal_ID) for the CGGTTS and BIPM will use the new values for the PPP

TRANSFER OF CALIBRATION

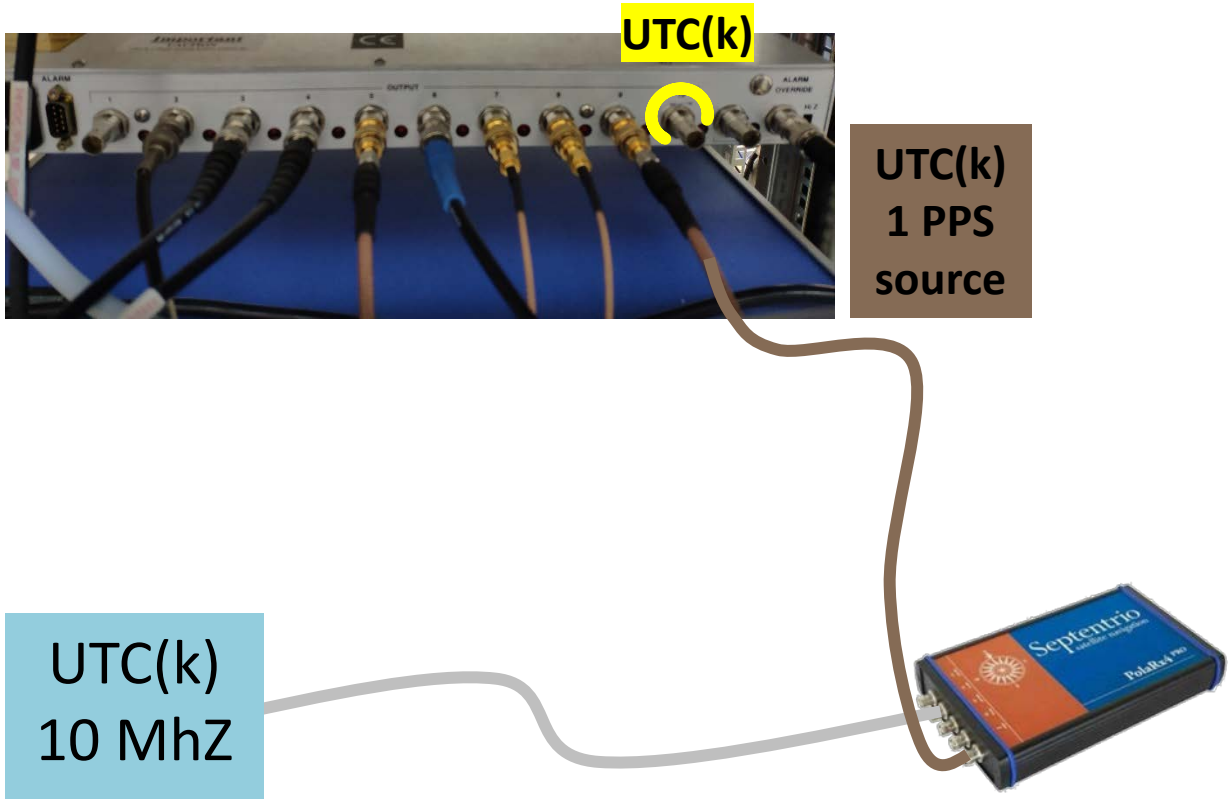
- If you change one cable
- If you install and want to use a new GNSS equipment

You should:

- Make a « transfer of calibration » to get your new or updated station calibrated
- Send a report to the BIPM

Transfer of CALIBRATION

Change of Cable UTC(k)-receiver



1. Measure the NEW REF DLY
2. Prepare a report for the BIPM
   - Name of the station
   - Time of the change
   - Old value REF DLY
   - New value REF DLY
   - Measurement details of the new REF DLY
3. Update the headers of CGGTTS:
   - change the REV DATE
   - change the REF DLY
   - not change the cal_ID

Transfer of CALIBRATION
Change of **Antenna Cable**

2 options :

1. You use another GNSS station continuously working in parallel and connected to the same clock (UTC(k)).

2. You measure the difference of the old and new cable delays

IF none of them are possible, you must wait for a new G2 calibration.
In the mean time, your station is « not calibrated »

Transfer of CALIBRATION
Change of **Antenna Cable** in GNSB

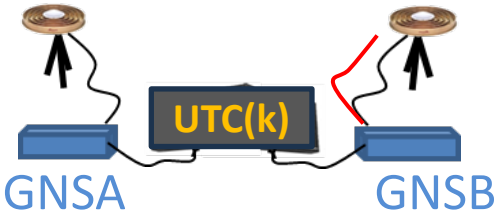
1. You have another GNSS station (GNSA) continuously working in parallel and connected to UTC(k).

Compute CV (GNSA-GNSB) in e.g. P3

Before the change, cable delay C1:
Average (CV) = K1

After the change, cable delay C2:
Average (CV) = K2

→ C2-C1 = K2-K1



Report to the BIPM : Name of the stations GNSA et GNSB
Time of the change
K1 + CV plot + Tdev @ 1 day for CV (GNSA-GNSB) before → needs > 4 days of data
K2 + CV plot + Tdev @ 1 day for CV (GNSA-GNSB) after change → needs > 4 days of data

In the CGGTTS header : - if you have CAB DLY → change C1 into C2 where C2=C1+(K2-K1)
- if you have SYS DLY or TOT DLY, add (K2-K1) to the previous value.
- change the REV DATE but not the Cal_ID

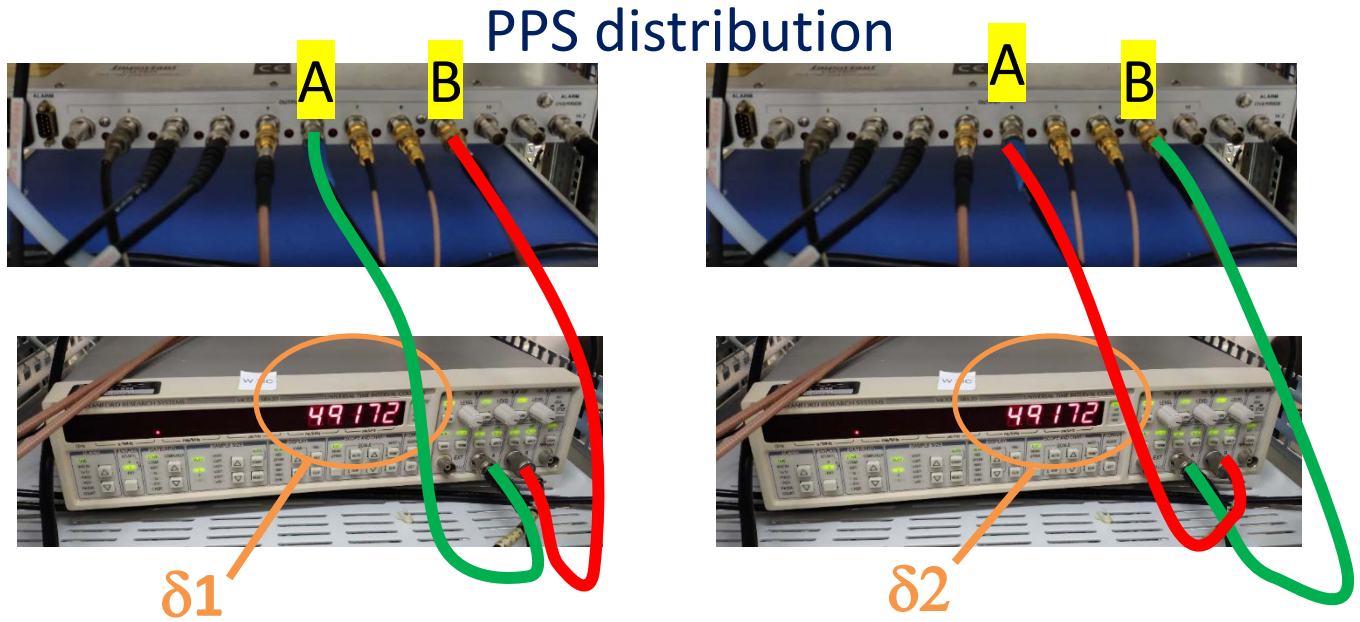
Transfer of CALIBRATION
Change of **Antenna Cable**

2. You measure the difference of the old and new cable delays

   - (i) You measure each cable delay using a given technique (see slide 7)

   Or

   - (ii) You measure directly the difference of C1-C2 = **δ2-δ1**



Report to the BIPM :

Name of the station

Time of the change

cable delay measurements done

(i) or (ii)

In the CGGTTS header : same as in slide 23

Transfer of CALIBRATION
Change of **antenna**

Options :

1. You have another GNSS station continuously working in parallel and connected to the same clock (UTC(k)).

2. Otherwise, you must ask for a new G2 calibration.
   In the mean time, your station is « not calibrated »

Transfer of CALIBRATION
Change of **antenna**

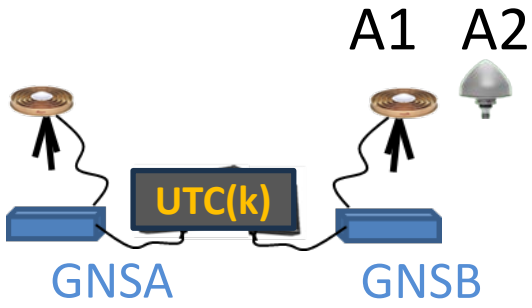
1. You have another GNSS station (GNSA) continuously working in parallel and connected to UTC(k).

Compute CV (GNSA-GNSB) for each GNSS code or use dclrinex

Before the change,
Average CV(code) = K1(code)

After the change,
Average CV(code) = K2(code)

→ δ(code) = K2 (code) -K1(code)



Report to the BIPM : Name of the stations GNSA et GNSB
Time of the change
For each GNSS code : K1(code) + CV plot + Tdev @ 1 day for CV(code) (GNSA-GNSB) before
K2(code) + Tdev @ 1 day for CV (code) (GNSA-GNSB) after change

In the CGGTTS header : - Change INT DLY / SYS DLY / TOT DLY for each code:
add δ(code) to the previous value.
- change the REV DATE but not the Cal_ID

Transfer of CALIBRATION
Change of **receiver**

Options :

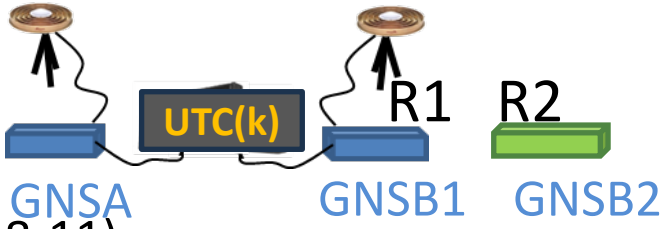
1. You have another GNSS station continuously working in parallel and connected to the same clock (UTC(k)).

2. Otherwise, you must ask for a new G2 calibration.
   In the mean time, your station is « not calibrated »

Transfer of CALIBRATION

Change of **receiver or receiver firmware**

You have another GNSS station (GNSA) continuously working in parallel and connected to the same clock (UTC(k)).



1. Connect the new receiver, wait a few hours, and measure the REF DLY (slides 8-11)
2. Compute CV (GNSA-GNSB) for each GNSS code
   or use dclrinex

Before the change, using the previous REF DLY
Average CV(code) = K1(code)

After the change, using the new REF DLY
Average CV(code) = K2(code)

→ δ(code) = K2 (code) -K1(code)

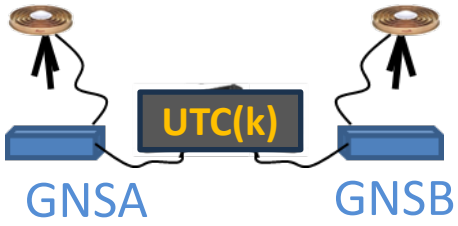
Report to the BIPM :

Name of the stations GNSA et GNSB
Time of the change
New REF DLY
For each GNSS code : K1(code) + Tdev @ 1 day for CV(code) (GNSA-GNSB) before
K2(code) + Tdev @ 1 day for CV (code) (GNSA-GNSB) after change

In the CGGTTS header : - Change INT DLY / SYS DLY / TOT DLY for each code:
add δ(code) to the previous value.
- Change the REF DLY into the new value
- change the REV DATE but not the Cal_ID

Transfer of CALIBRATION
install a **new station**

You have another GNSS station (GNSA) continuously working in parallel and connected to the same clock (UTC(k)).



1. Once you have the first days of RINEX data,
   determine the position of your new station
   this can be done through online PPP services
   (choose the position of the phase center of the antenna)
2. Compute CV (GNSA-GNSB) for each GNSS code or use dclrinex
3. The differences will give TOT DLY for each code
   if you measured REF DLY : then SYS DLY = TOT DLY + REF DLY
   if you have also measured CAB DLY: then INT DLY = TOT DLY + REF DLY –CAB DLY
4. Report to BIPM following the BIPM Report Guideline:
   annex-4_template-calibration-report_v31.pdf

Use DCLRINEX

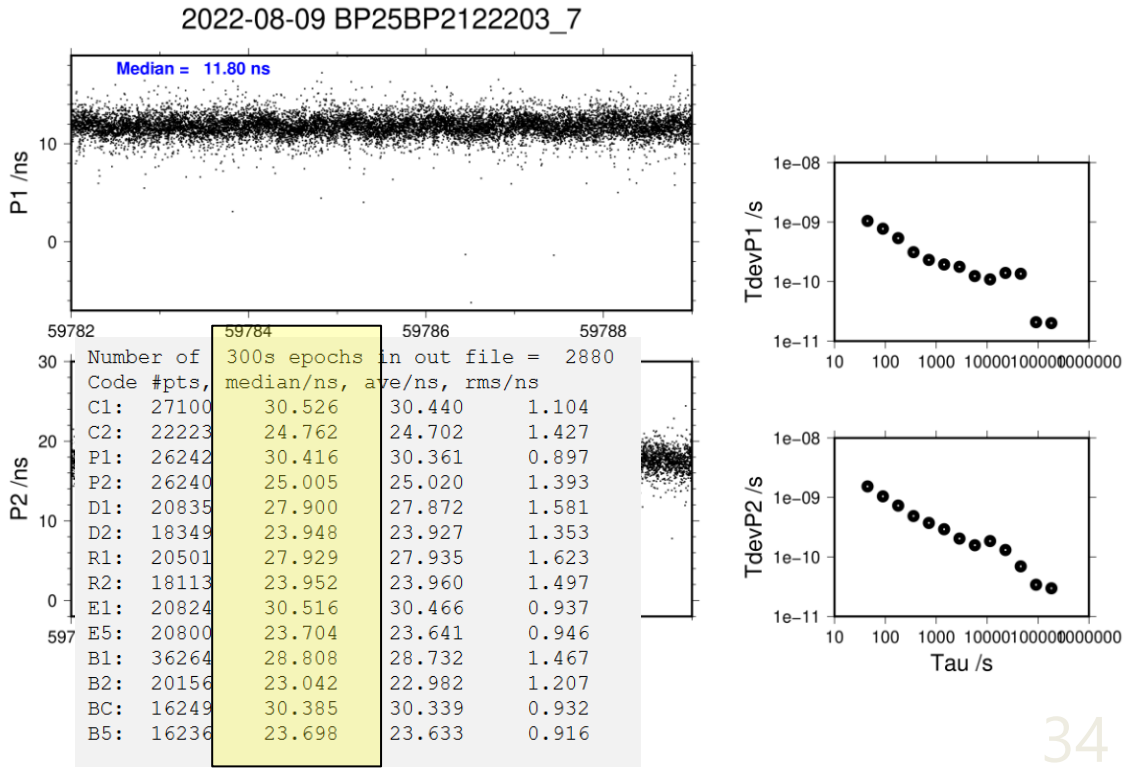
– To compute the RAWDIFF from rinex the free software DCLRINEX is made available on the BIPM ftp:
https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/doc-soft/

RINEX from reference receiver

RINEX from new receiver

RINEX of broadcast ephemerids

DCLRINEX



https://cbkt-time.bipm.org/dclrinex/ 140%

Also possible on the web app:
https://cbkt-time.bipm.org/dclrinex/

DCLRINEX web interface

Web interface to the dclrinex software (https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/doc-soft/). You can upload your RINEX data and download the dclrinex outputs. If you input REFDLY a CABDLY values and reference receiver INTDLY values the programm will also computer calibration values for the receiver to be calibrated.

READ BEFORE USE:

- **IMPORTANT:** both data and nav RINEXes should span exactly the same days

- **IMPORTANT:** Rinex data should be uncrompressed: no hatanaka, no guzip, no zip, etc..

- Please introduce the REFDLY and CABDLY for both receiver. If you do not care, just put 0.0 . If you you dont fill the cell, the program will not run.

- INTDLYs will be computed only for the codes for which you insert a numerical value in the reference receiver section.

- DCLRINEX will produce results for all supported code present in the rinex file no matter what you put in the reference receiver section.

- if you encounter any error please write to tf.cbkt@bipm.org

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Navigation Files

Rinex Navigation files

Browse... No files selected.

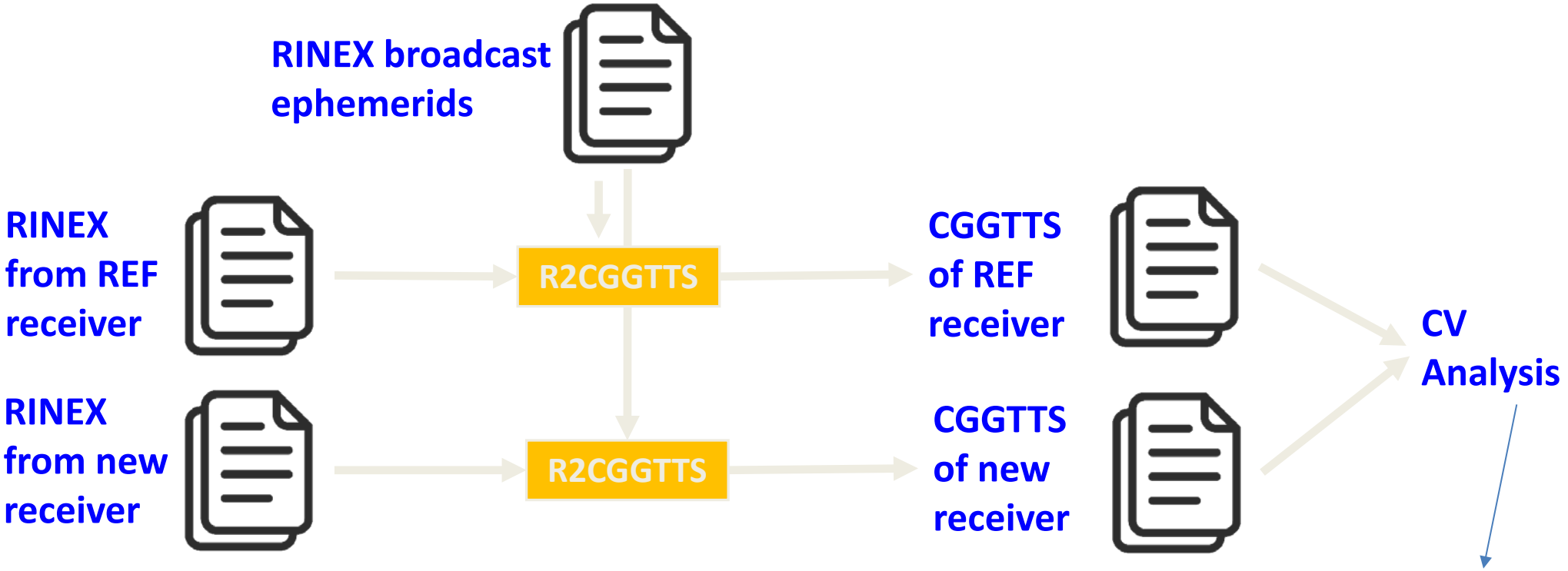
Receiver to be calibrated

REFDLY (ns)

CABDLY (ns)

Use R2CGGTTS + CV

- Transfer the RINEX files into CGGTTS using the r2cggtts software from ORB.
- Perform CGGTTS Common View



https://cbkt-time.bipm.org/cggtts-data-analyser/

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AFRIMETS				
GULFMET				

*After the next G1 campaign (2025-2026)

Thank You

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CCTF

How to get GNSS calibration

- Synthetic document: “How to get GNSS calibration for UTC(k) laboratories” (July 2021, following the CCTF survey)

https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/How-to-get-calibration-July2021.pdf