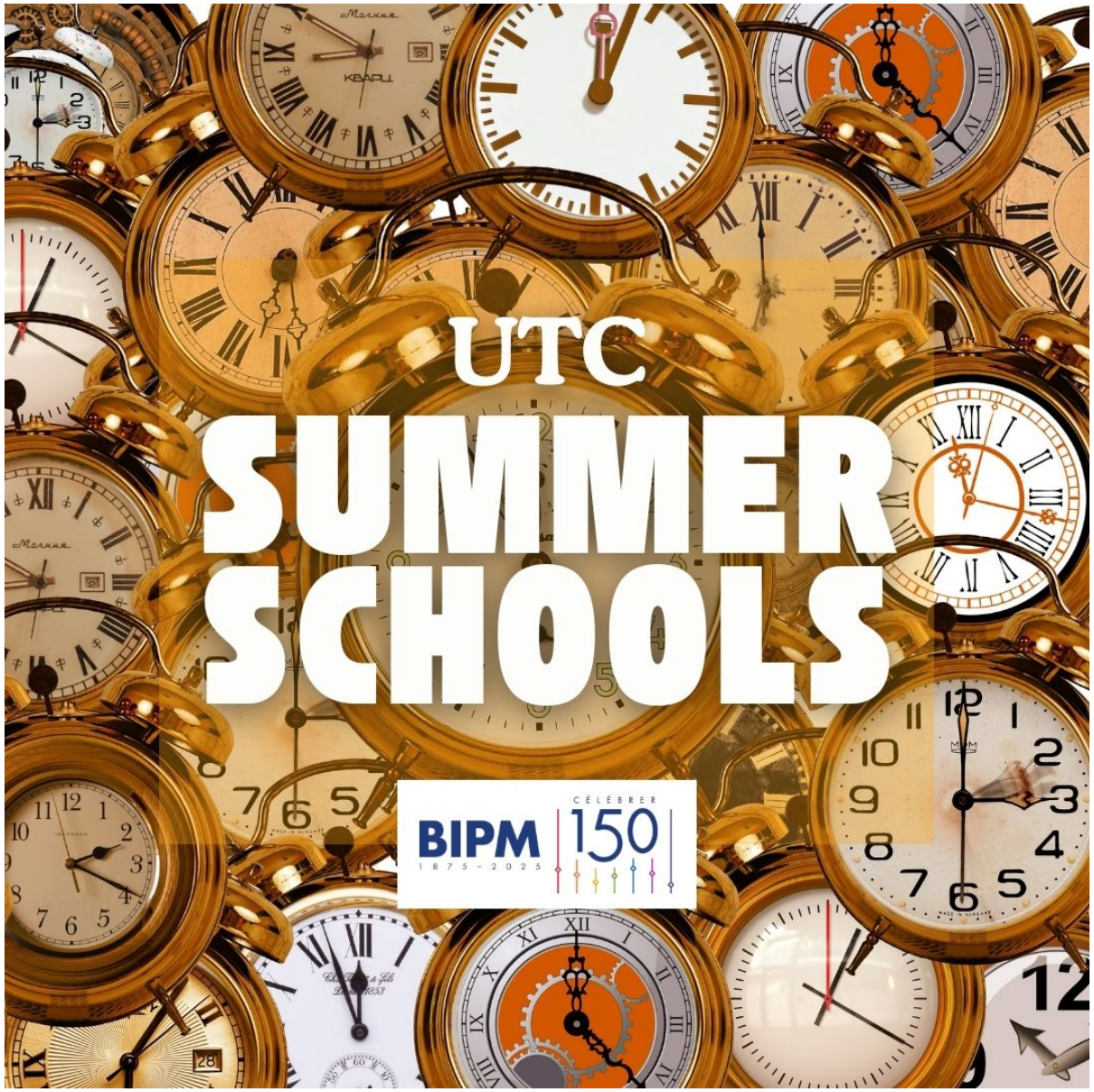


BIPM UTC Summer School

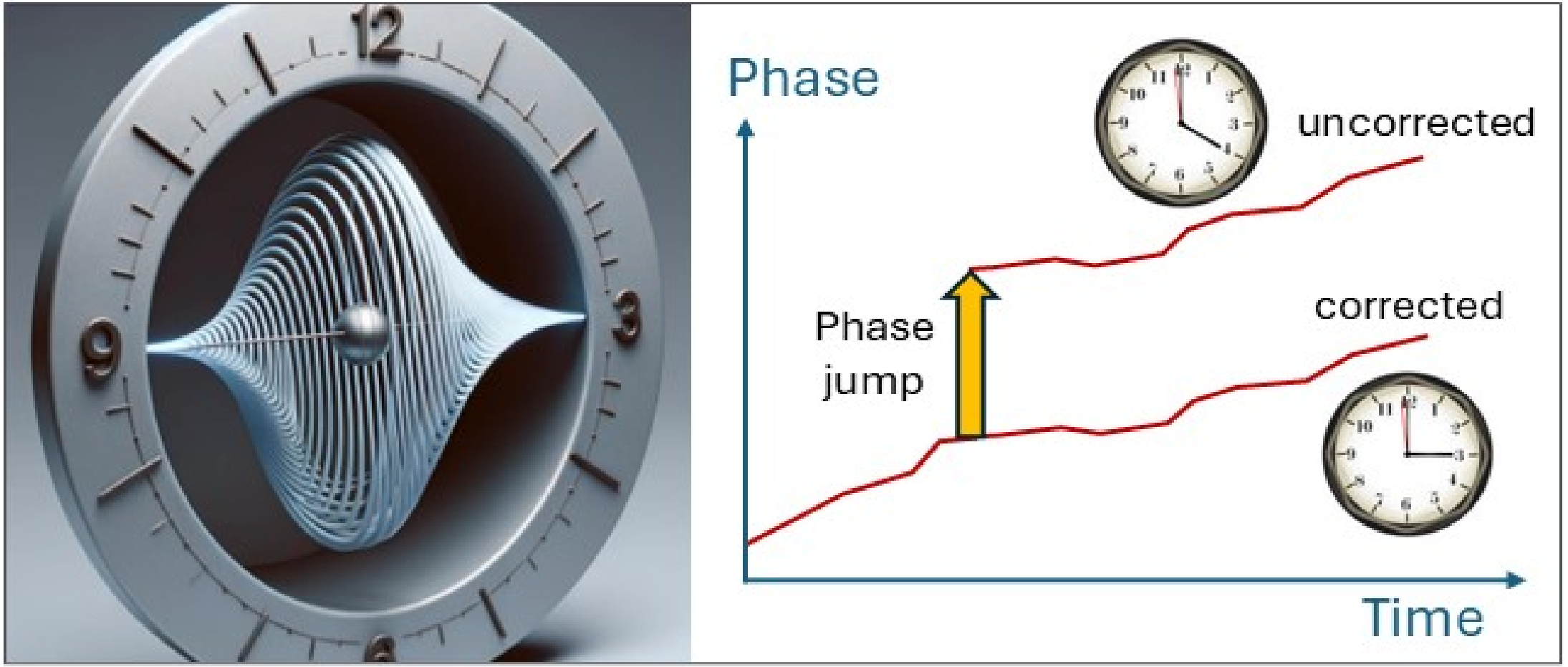
September 9-11th BIPM, Paris

Dr. Bharath Vattikonda

NPL India

Together with the BIPM Time department

E-Learning course: Validating clock data format with BIPM convention



The aim of this course is to explain the clock data file format for submission to the BIPM to contribute to UTC with proper “clock step” representation.

Content

1. How a laboratory can contribute its **clock** data to **UTC**
2. How clock's data are used in UTC computation

   2.1 Sign Convention To Represent The Clock Corrections (Time and Frequency Steps)

3. Why a UTC(k) lab might make corrections (time or frequency steps) on a free running clock.

   3.1 How to correctly report clock corrections to BIPM.

   3.2 How to verify clock data and corrections using the software named "**Validating clock data format with BIPM convention**".

General Information:

- The following description mainly concern the ***participation to UTC***.
- Similar rules are applicable for the participation to the rapid UTC, namely UTCr
- Detailed explanation on generation of UTC and UTCr from clocks data is here *(Generation of UTC and UTCr)*
- The software illustrated here is based on the open-source Python routines available here https://github.com/TheBIPM/check_bipm_data

1.How a laboratory can contribute its clock data to UTC

BIPM guidelines for the time laboratories to participate in the UTC are CCTF WGMRA Guideline 8/2017.
A UTC(k) lab should fulfill the following technical requirements to contribute its clock data to UTC

Criterion 1. Realization of local time scale, UTC(k), which represents a real time approximation of UTC:
The time scale UTC(k) shall be based on state-of-the-art commercial atomic clocks and should be maintained in close agreement versus UTC

Criterion 2. Time Transfer Link:
There should be a calibrated equipment for time transfer. Commonly a GNSS time transfer receiver operated as per the BIPM guidelines.

Criterion 3. Measurement of clock performance with respect to UTC(k):
There should be the capability to measure the instantaneous value of the offset " UTC(k) - free running clock" at 00:00 hrs UTC on BIPM standard dates. In case UTC(k) lab has one or few clocks that have to be corrected by a time or frequency step, the corresponding corrections shall be recorded as well.

Criterion 4. Sharing the data with BIPM as per the BIPM format:
Upload these measured values with required information in the standard BIPM format with the requested periodicity and schedule.

Typical Experimental Setup required

GNSS Time transfer receiver connected to UTC(k)

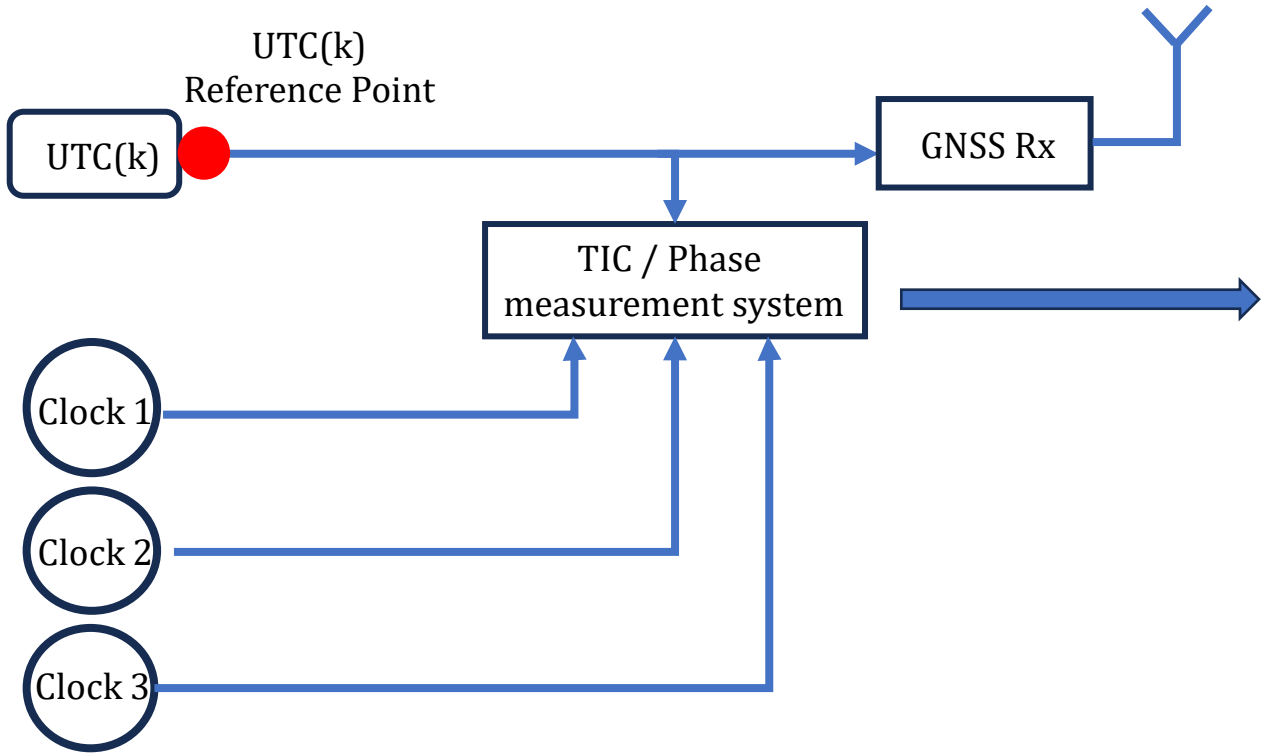
- UTC(*k*) Reference Point is the source of UTC(k) used as reference in all measurements

Calibrated receiver:

- A calibrated GNSS equipment shall have all its delay measured according to the BIPM guidelines.
- GNSS equipment calibration guidelines by BIPM are available here (Calibration guidelines)

Criterion 3. Measurement of clock performance with respect to UTC(k)

Sample Experimental Setup required



Options

a. Multichannel Time Interval Counter (TIC)
b. Multichannel phase measurement device
c. A switching unit followed by a standard 2 channel TIC

Measurements of each clock w.r.t UTC(k) to be shared with BIPM:

UTC(k) – Clock 1 [ns],
UTC(k) – Clock 2 [ns],
UTC(k) – Clock 3 [ns]

Criterion 4. Sharing the data with BIPM as per the BIPM format

- The clock data file should be in the format prescribed by the BIPM guidelines (Clock Data File guidelines).
- There is **no header** prescribed in the clock data file format, so please don't add any text in your files as header
- After the clock data lines the "**step format / clock steps**" shall start without empty lines.
- In case labs has their own free running time scale TA(k), the measurements UTC(k) – TA(k) can also be submitted in the clock data file.
- To participate in **UTC Circular T**, clock data shall be submitted monthly (within the 4th of the following month) with measurements spaced by five days (MJD ending with 4 and 9).
- To participate in **UTC Rapid**, daily clock files shall be submitted **within Monday** of the following week.
- The important components to understand the BIPM clock data file format are:

a. Day of measurement [MJD] : XXXXX [5 digit numeric value]
b. Laboratory Code : 100YY [Assigned by BIPM]
c. TA code of the Lab (if Exists) : 00200YY [Assigned by BIPM]
d. Clock Code : CCCCCCC [7 digit numeric value can be generated by the NMI get clock code]
e. UTC(k)- TA(k) : aaaaaaa.c value in ns
f. UTC(k)- clock : ccccccc.c value in ns format F9.1
g. Time step : ccccccc.c value in ns format F9.1
h. Frequency step : bbbbb.bbb value in ns/day format F9.3
i. Epoch of the step [fractional MJD] : XXXXX.XX [5 digit numeric value with decimal indicating fraction of day]

Criterion 4. Sharing the data with BIPM as per the BIPM format

Sample clock data format of a laboratory with Code 10008 for Circular T submission

MJD	Lab code	clock1 code	UTC(k) – clock1	clock2 code	UTC(k) – clock2	clock3 code	UTC(k) – clock3	clock4 code	UTC(k) – clock4	clock5 code	UTC(k) – clock5
60814	10008	0020001	167585.1	1353765	71461.1	1352027	29071.6	1352388	17834.2	1353552	46431.3
60814	10008	1351321	-19669.2	1353262	101984.7	1352647	121338.5	1355212	102109.8	1350469	-6628.9
60814	10008	1351029	6054.3	1353530	-841.0	1350355	15491.6	1411110	353139.1	1411077	8091.3
60814	10008	1411195	4121.0	1411086	313208.3	1411002	-283840.1	1411082	4761.4	1411119	38328.3
60814	10008	1411036	-37340.3	1400889	13599.1	1400810	8102.6	1400809	26820.3	1400890	22158.2
60814	10008	1411037	-13732.4								
60819	10008	0020001	167582.7	1353765	71618.9	1352027	29133.7	1352388	17930.1	1353552	46480.1
60819	10008	1351321	-19706.8	1353262	102068.7	1352647	121394.2	1355212	102091.0	1350469	-6702.7
60819	10008	1351029	6130.4	1353530	-861.7	1350355	15597.7	1411110	355102.0	1411077	8260.2
60819	10008	1411195	4183.2	1411086	313441.2	1411002	-284564.0	1411082	4772.1	1411119	38588.9
60819	10008	1411036	-28770.3	1400889	13709.2	1400810	8202.6	1400809	26961.2	1400890	22287.1
60819	10008	1411037	-13805.0								

Criterion 4. Sharing the data with BIPM as per the BIPM format

Sample clock data format of a laboratory with Code 10008 for Circular T submission

First set of clock data: MJD ending with 4

MJD	Lab code	clock1 code	UTC(k) – clock1	clock2 code	UTC(k) – clock2	clock3 code	UTC(k) – clock3	clock4 code	UTC(k) – clock4	clock5 code	UTC(k)– clock5	clock6 code	UTC(k)– clock6
60814	10008	1411036	-37340.3	1400889	13599.1	1400810	8102.6	1400809	26820.3	1400890	22158.2		
60814	10008	1411037	-13732.4										

Max 5 clocks data shall be represented in a line

Second set of clock data: MJD ending with 9

MJD	Lab code	clock1 code	UTC(k) – clock1	clock2 code	UTC(k) – clock2	clock3 code	UTC(k) – clock3	clock4 code	UTC(k) – clock4	clock5 code	UTC(k)– clock5	clock6 code	UTC(k)– clock6
60819	10008	1411036	-28770.3	1400889	13709.2	1400810	8202.6	1400809	26961.2	1400890	22287.1		
60819	10008	1411037	-13805.0										

Spacing or zeros padding to keep the format

To exactly match the format either keep sufficient spaces before the value or add ‘0’ instead.

```
60819 10008 1411036 -0028770.3 1400889 0013709.2 1400810 0008202.6 1400809 0026961.2 1400890 0022287.1
```

Or

```
60819 10008 1411036  -28770.3 1400889   13709.2 1400810    8202.6 1400809   26961.2 1400890   22287.1
```

Criterion 4. Sharing the data with BIPM as per the BIPM format

Clock step correction to be mentioned in the clock data format:

- **Only voluntary / intentional corrections** applied on a free running clock shall be reported
- Corrections applied on UTC(k) shall NOT be reported

MJD with fractional value of the day	Clock Code	Time Step (ns)	Frequency Step (ns/day)	Lab Acronym	Lab Code
60817.70	1411036	-8800.0	0.000	OP	10008

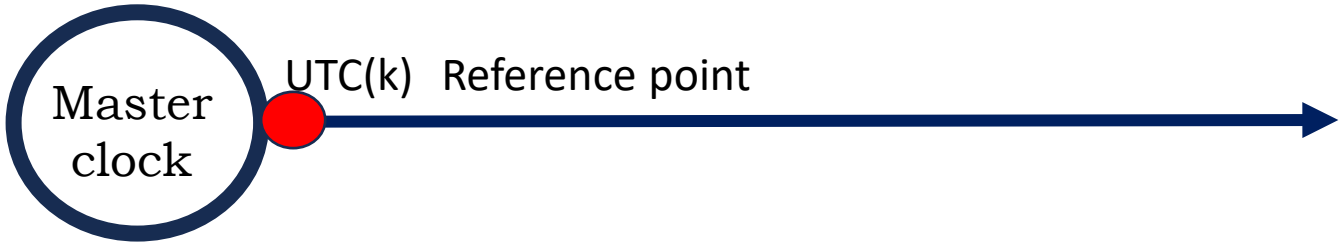
Criterion 4. Sharing the data with BIPM as per the BIPM format

Clock data format of a laboratory with Code 10008 for Circular T submission

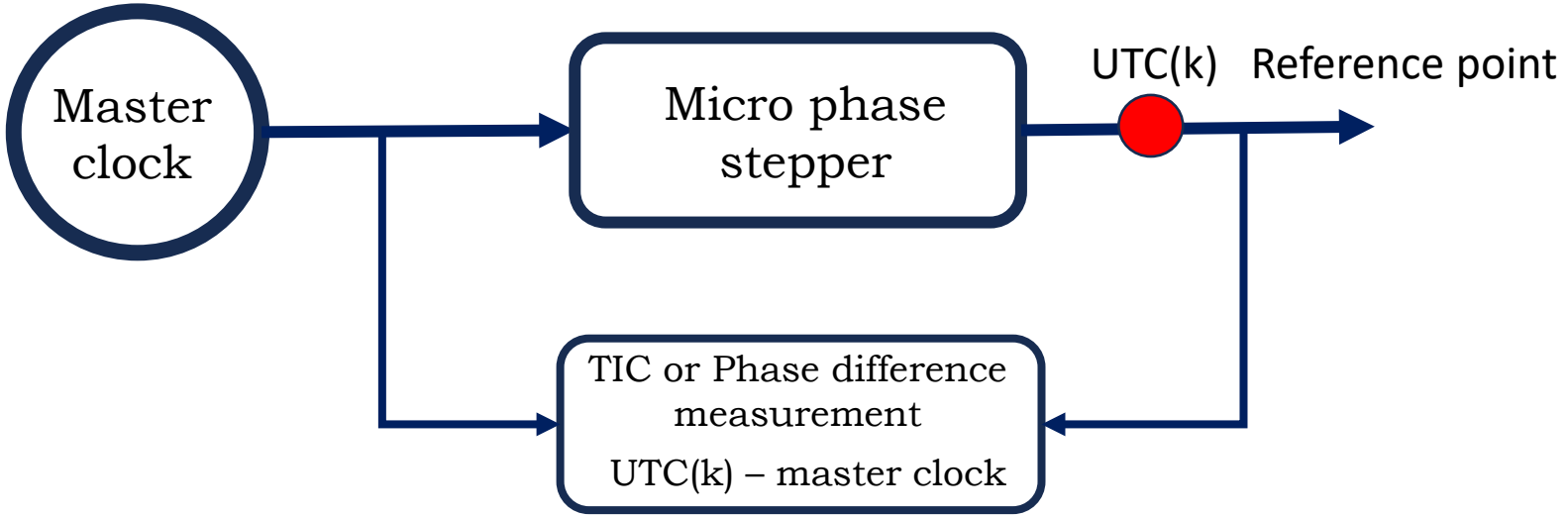
MJD	Lab code	clock1 code	UTC(k) – clock1	clock2 code	UTC(k) – clock2	clock3 code	UTC(k) – clock3	clock4 code	UTC(k) – clock4	clock5 code	UTC(k)– clock5
60814	10008	0020001	167585.1	1353765	71461.1	1352027	29071.6	1352388	17834.2	1353552	46431.3
60814	10008	1351321	-19669.2	1353262	101984.7	1352647	121338.5	1355212	102109.8	1350469	-6628.9
60814	10008	1351029	6054.3	1353530	-841.0	1350355	15491.6	1411110	353139.1	1411077	8091.3
60814	10008	1411195	4121.0	1411086	313208.3	1411002	-283840.1	1411082	4761.4	1411119	38328.3
60814	10008	1411036	-37340.3	1400889	13599.1	1400810	8102.6	1400809	26820.3	1400890	22158.2
60814	10008	1411037	-13732.4								
60819	10008	0020001	167582.7	1353765	71618.9	1352027	29133.7	1352388	17930.1	1353552	46480.1
60819	10008	1351321	-19706.8	1353262	102068.7	1352647	121394.2	1355212	102091.0	1350469	-6702.7
60819	10008	1351029	6130.4	1353530	-861.7	1350355	15597.7	1411110	355102.0	1411077	8260.2
60819	10008	1411195	4183.2	1411086	313441.2	1411002	-284564.0	1411082	4772.1	1411119	38588.9
60819	10008	1411036	-28770.3	1400889	13709.2	1400810	8202.6	1400809	26961.2	1400890	22287.1
60819	10008	1411037	-13805.0								
60817.70	1411036	-8800.0	0.000	OP	10008						

What is a Master clock?

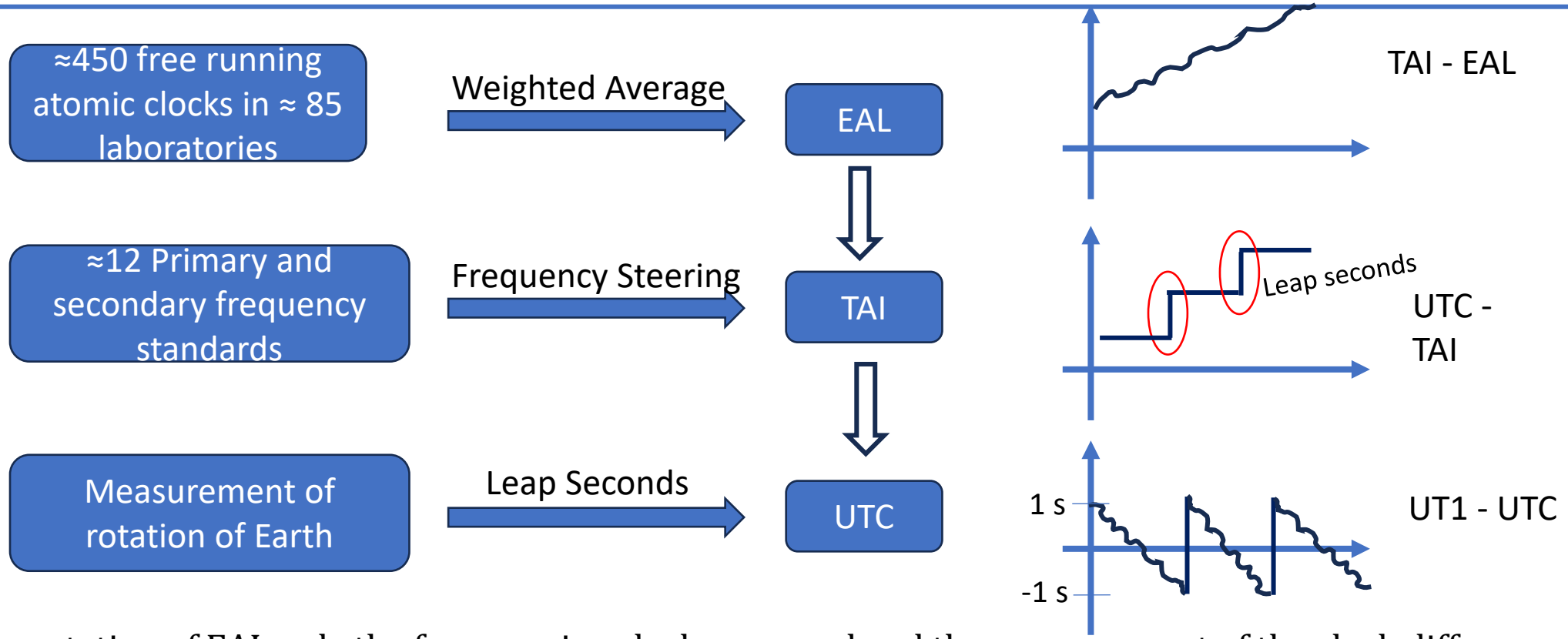
- The master clock is the clock that generates UTC(k) with/without a phase stepper.
- If the master clock is considered as UTC(k) directly, and there is no phase stepper, then the measure UTC(k) – master clock =0



- If the master clock output is corrected by a phase stepper, then the measure UTC(k) – master clock will contain the offset due to the phase stepper (constant or deterministically variable)



2. How clock's data are used in UTC computation

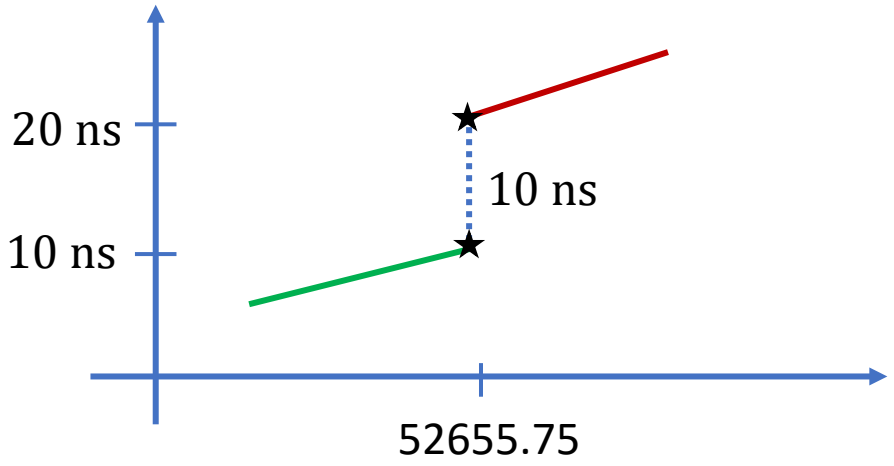


- For the computation of EAL only the free running clocks are used and the measurement of the clock differences as (clock1- clock2) are necessary.
- **The UTC(k) time scale are not weighted in the UTC computation. Any time or frequency steps on UTC(k) shall not be reported in the clock data file**
- The detailed explanation of UTC generation from clocks data through the intermediate steps of EAL and TAI is available at Co-ordinated Universal Time (PPT), The Co-ordinated UTC (Metrologia 2019) ,

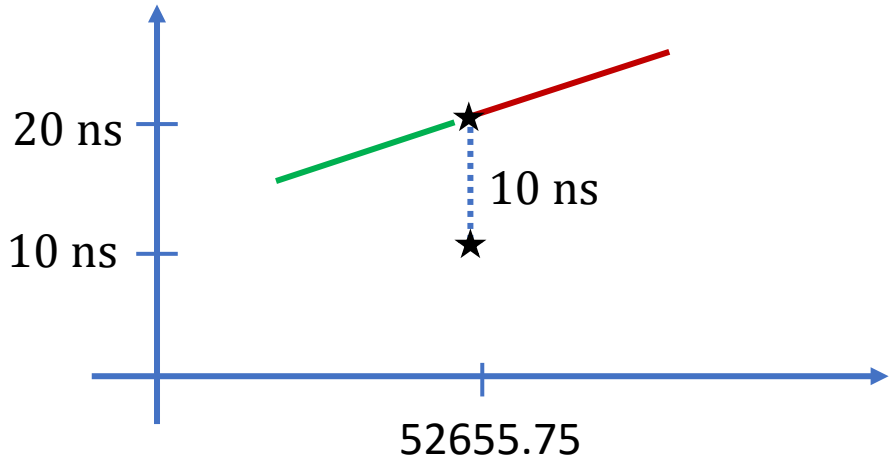
2. How clock data are used in UTC computation

≈450 free running atomic clocks in ≈ 85 laboratories → Weighted Average → EAL

Voluntary corrected clock



BIPM compensated clock



- EAL (Echelle Atomique Libre) is the weighted average of free running clocks. The clocks are weighted proportionally to their predictability and stability, which should not be artificially degraded by voluntary steps
- If a clock is **voluntary corrected** by the lab, the applied time or frequency step is to be **declared to the BIPM**
- The **BIPM will compensate** for the voluntary step to maintain continuity on the clock

2.1 Sign Convention To Represent The Clock Corrections (Time and Frequency Steps)

- To compensate for the voluntary steps applied to the clock, the **BIPM adjusts the previous data of the clock** to reconstruct a continuous smooth clock behavior representing its natural performance.
- To this aim it is essential to know exactly the **epoch** and the **amount of the step**. With the correct **sign**!

The BIPM convention is

Time Step = NEW[clock value] – OLD[clock value]

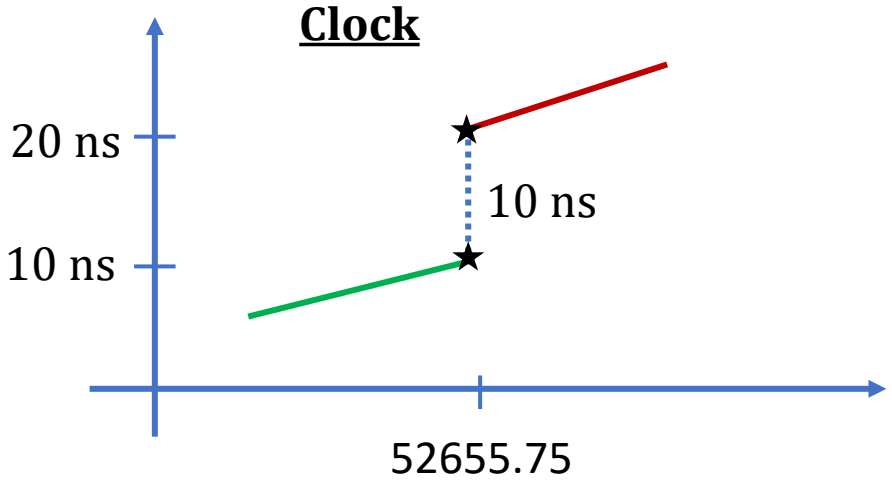
Time step = (20 – 10)= + 10 ns

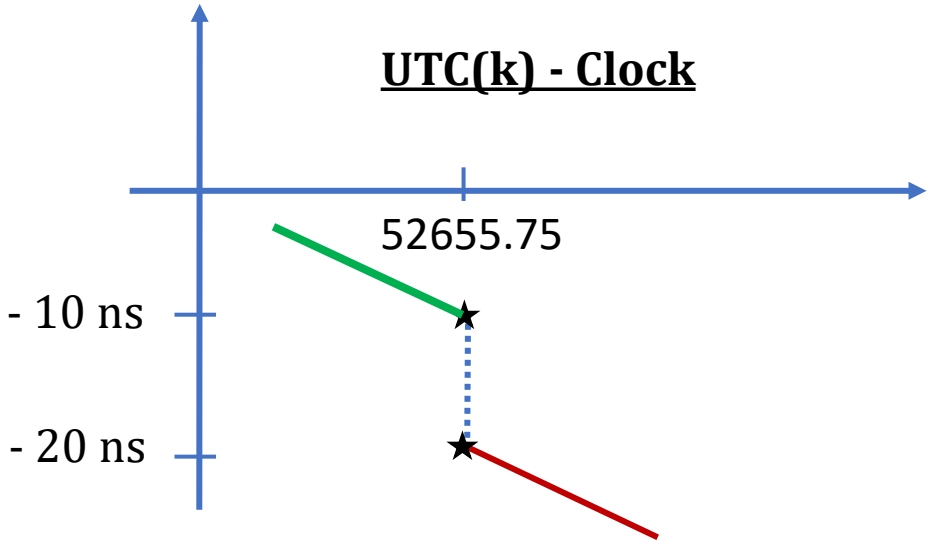
The BIPM convention in NOT

NEW[{UTC(k) - clock value} – OLD{UTC(k) – clock value}]=

= – NEW[clock value] + OLD[clock value] =

= – {NEW[clock value] – OLD[clock value]}

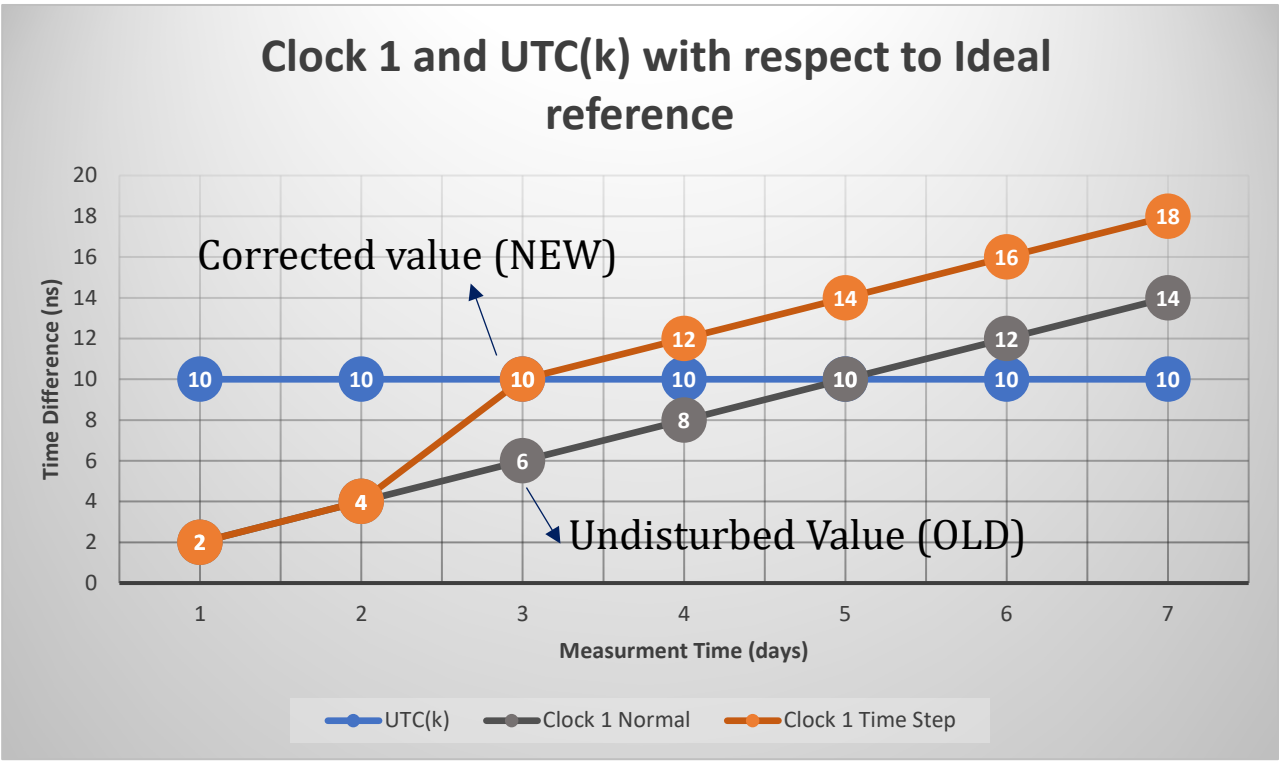




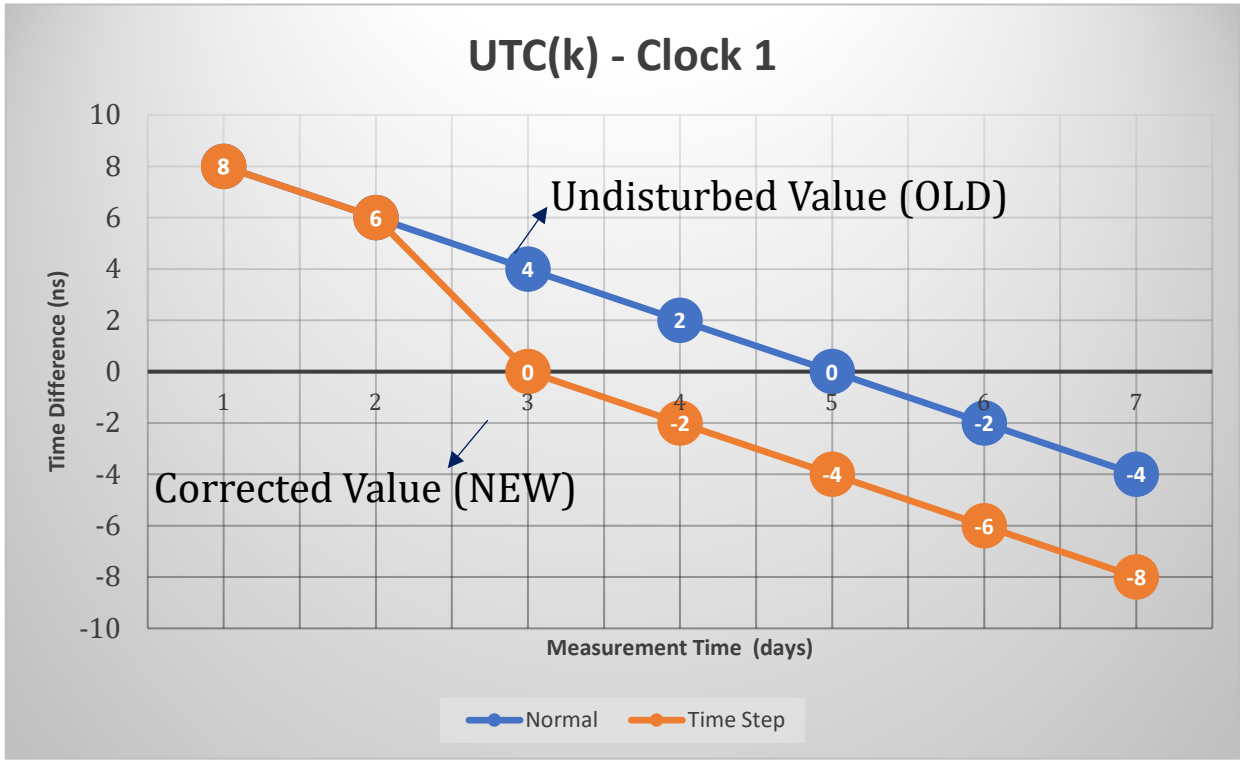
BIPM Convention: The sign of the step to be declared is the opposite of what we measure on UTC(k) - clock

2.1 Sign Convention : Time/Phase steps

clock behaviour versus ideal reference time



measurement of UTC(k) - clock



Time Step on day 3 = NEW[clock value] – OLD[clock value]
= 10 – 6
= 4 ns

Positive step on the clock 1 is to be declared

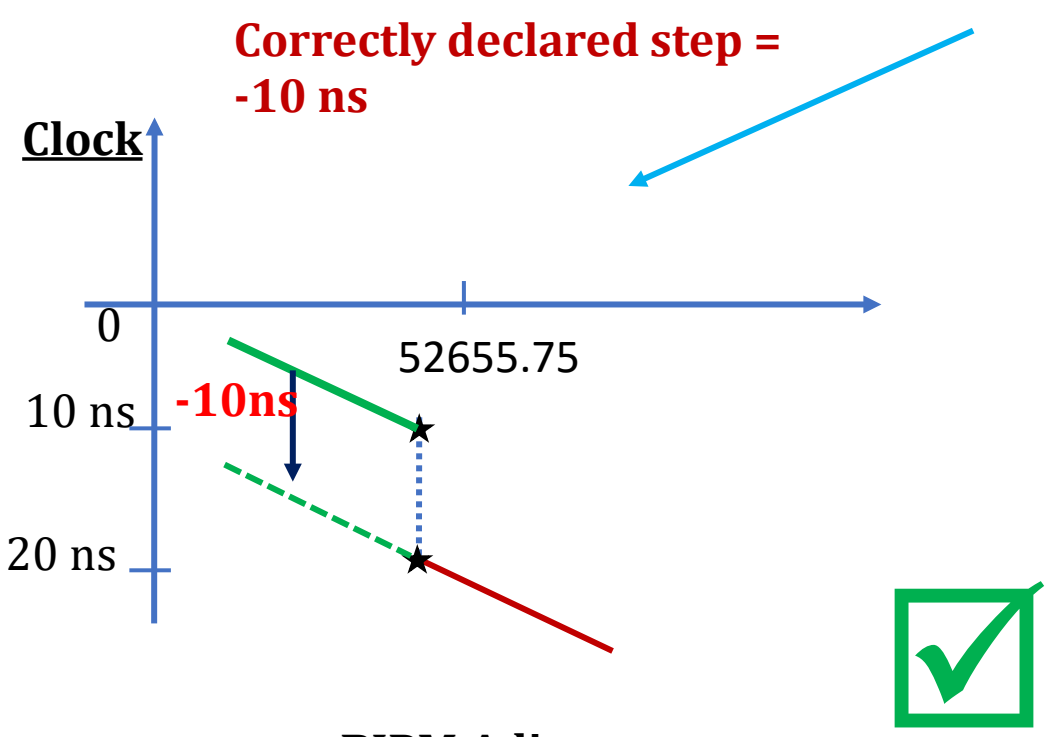
Observed Step on day 3 = NEW[{UTC(k) - clock value} – OLD{UTC(k) – clock value}]
= 0 – 4
= - 4 ns

Negative step on the time difference UTC(k) – Clock 1

2.1 Sign Convention: Time/Phase steps

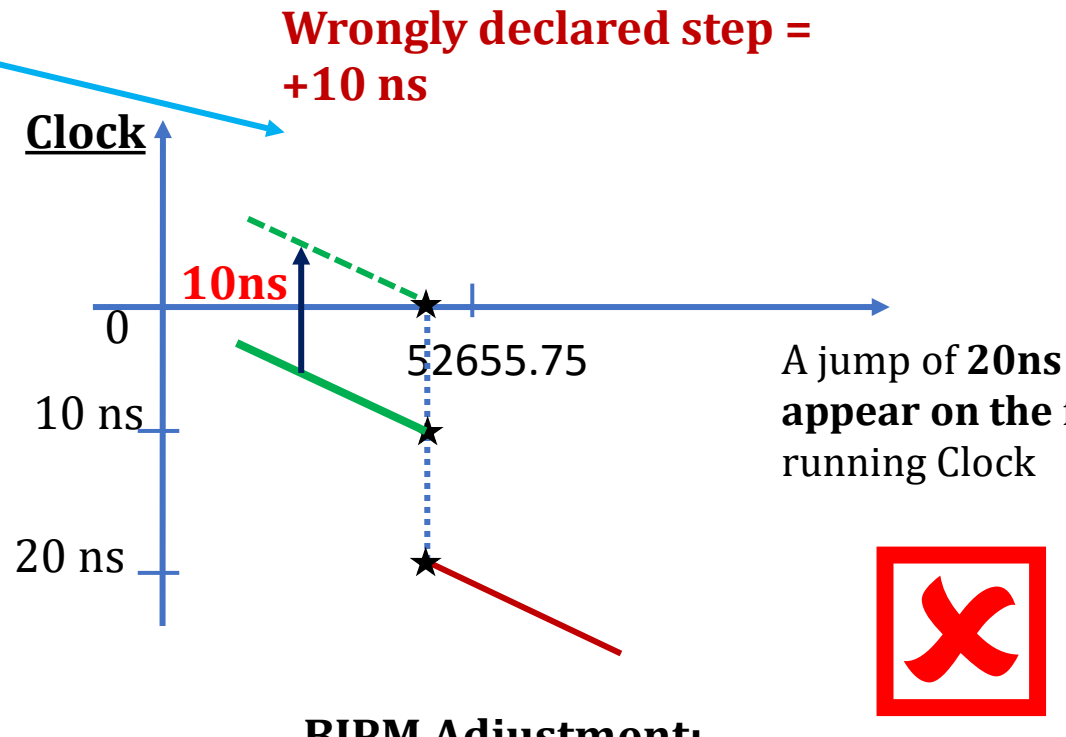
How wrong sign will affect the clock contribution to UTC computation ?

If a clock is corrected by a negative step of - 10 ns,



BIPM Adjustment:

compensate the previous data - - - - - - and recover the free running clock



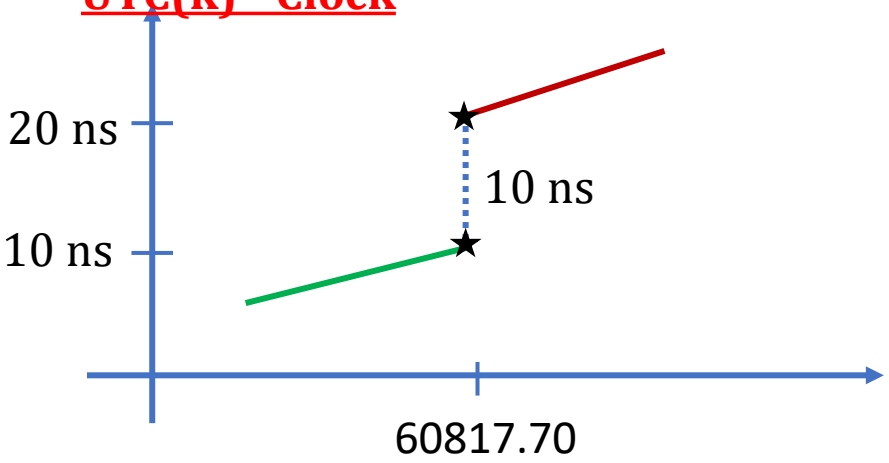
BIPM Adjustment:

compensate the previous data - - - - - - and obtain a **double jump** which is even more degrading the stability of the clock

Hence, the sign convention is very important !

2.1 Sign Convention : Time/Phase steps {Correct Sign }

- The lab reports to the BIPM the measures {UTC(k) – Clock}.
- Declared Time Step has to be NEW[clock value] – OLD[clock value]
- Declared time step has to be with **opposite sign** of the value obtained from NEW[{UTC(k) - clock value} – OLD{UTC(k) – clock value}]



Observe +10 ns on UTC(k) – clock

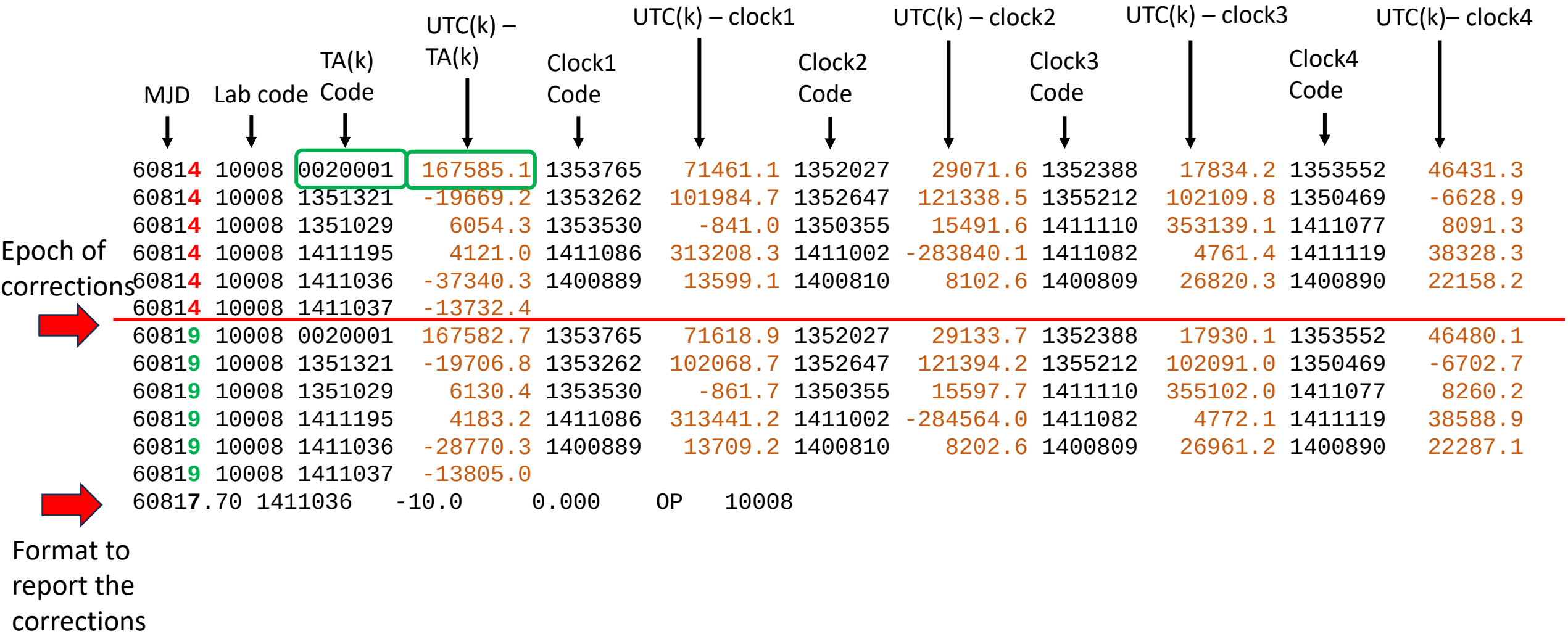
Report a step of -10 ns on the clock

MJD with fractional value of the day	Clock Code	Time Step (ns)	Frequency Step (ns/day)	Lab Acronym	Lab Code
60817.70	1411036	-10.0	0.000	OP	10008

Please Follow this Sign Convention based on NEW[clock value] – OLD[clock value]

2.1 Sign Convention : Time/Phase steps

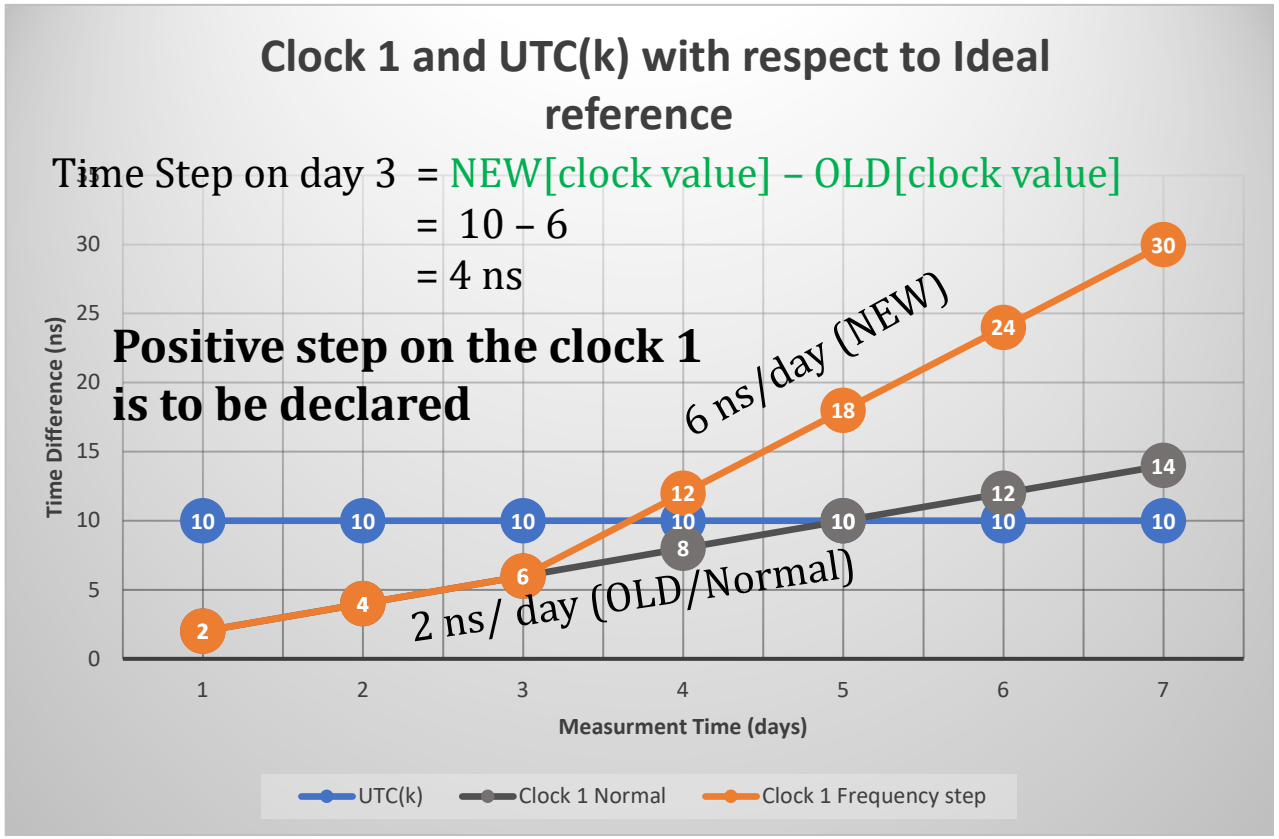
Sample Monthly Clock data with step information



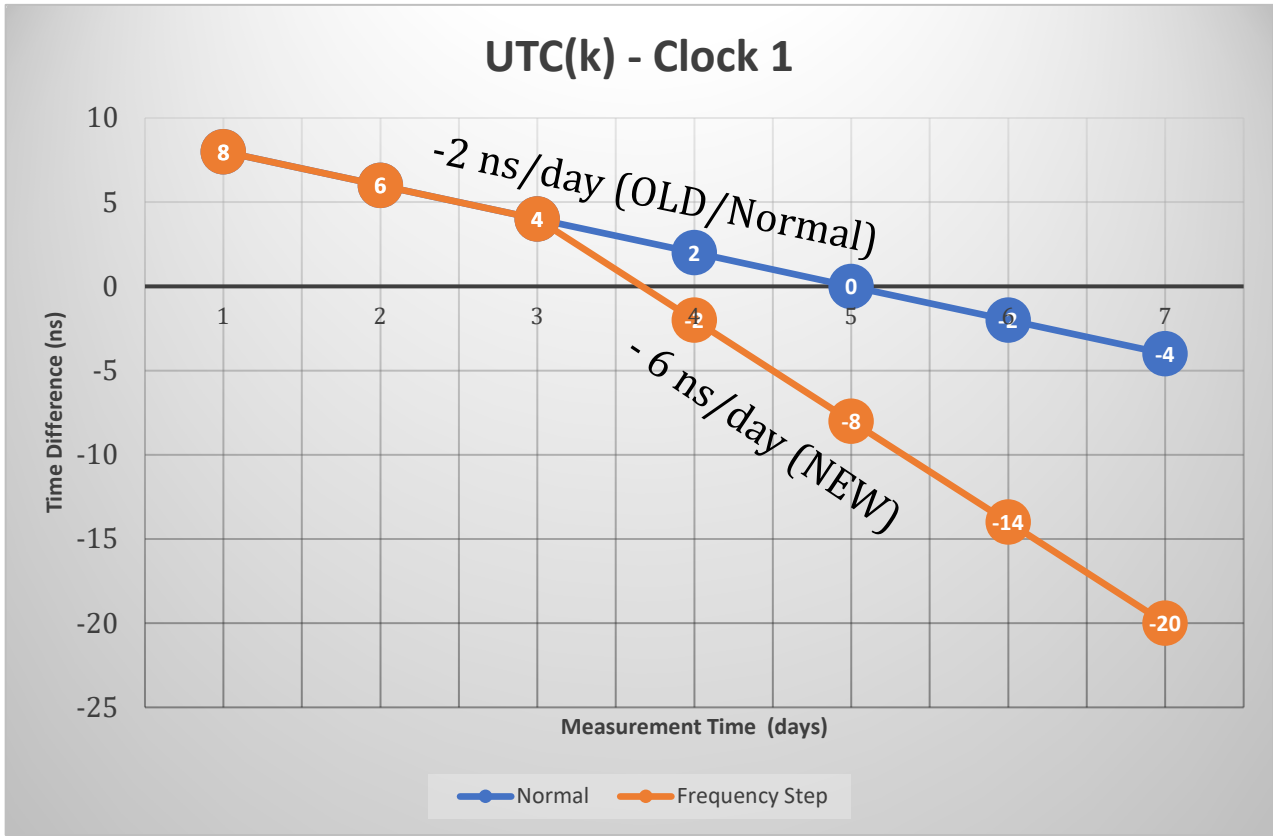

```
60814 10008 0020001   167585.1 1353765   71461.1 1352027   29071.6 1352388   17834.2 1353552   46431.3
60814 10008 1351321   -19669.2 1353262  101984.7 1352647  121338.5 1355212  102109.8 1350469   -6628.9
60814 10008 1351029     6054.3 1353530    -841.0 1350355   15491.6 1411110  353139.1 1411077    8091.3
60814 10008 1411195     4121.0 1411086  313208.3 1411002 -283840.1 1411082    4761.4 1411119   38328.3
60814 10008 1411036   -37340.3 1400889   13599.1 1400810    8102.6 1400809   26820.3 1400890   22158.2
60814 10008 1411037   -13732.4
60819 10008 0020001   167582.7 1353765   71618.9 1352027   29133.7 1352388   17930.1 1353552   46480.1
60819 10008 1351321   -19706.8 1353262  102068.7 1352647  121394.2 1355212  102091.0 1350469   -6702.7
60819 10008 1351029     6130.4 1353530    -861.7 1350355   15597.7 1411110  355102.0 1411077    8260.2
60819 10008 1411195     4183.2 1411086  313441.2 1411002 -284564.0 1411082    4772.1 1411119   38588.9
60819 10008 1411036   -28770.3 1400889   13709.2 1400810    8202.6 1400809   26961.2 1400890   22287.1
60819 10008 1411037   -13805.0
60817.70 1411036   -10.0     0.000    OP   10008
```

2.1 Sign Convention : Frequency steps

clock behavior versus ideal reference time



measurement of UTC(k) - clock



Frequency Step on day 3 = NEW[clock rate] – OLD[clock rate]
= 6 ns/day – 2 ns/day
= 4 ns/day

Positive frequency step on clock 1 is to be declared

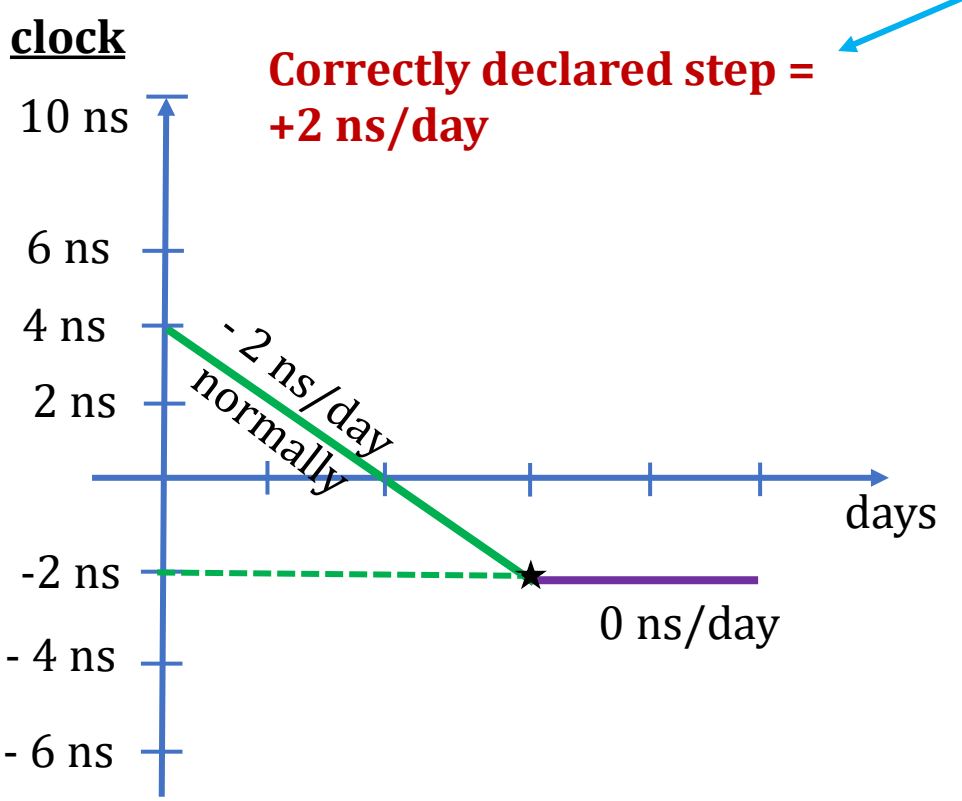
Observed Step on day 3 = NEW[{UTC(k) - clock}rate – OLD{UTC(k) – clock}rate]
= - 6 ns/day – (– 2ns/day)
= - 4 ns /day

Negative step on the rate of {UTC(k) – Clock 1}

2.1. Sign Convention: Frequency step

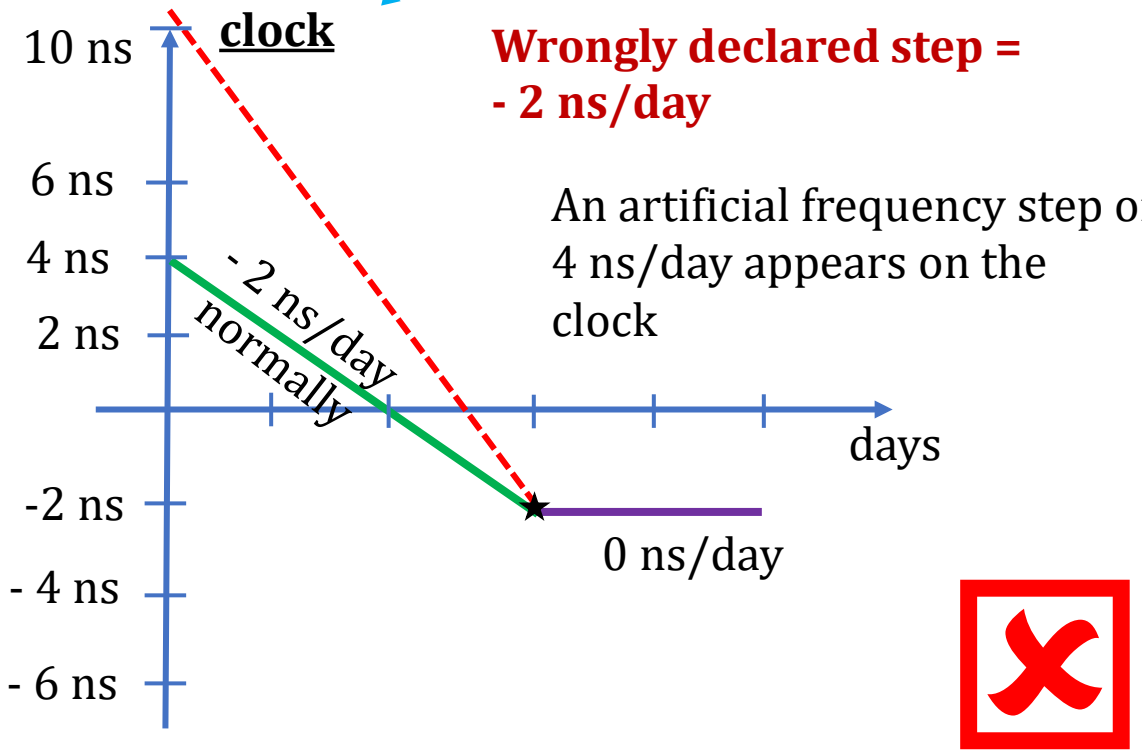
How wrong sign will affect the clock contribution to UTC computation ?

If a clock is corrected to go faster by 2 ns/day



BIPM Adjustment:

compensate the previous data ------ and recover the free running clock



An artificial frequency step of 4 ns/day appears on the clock

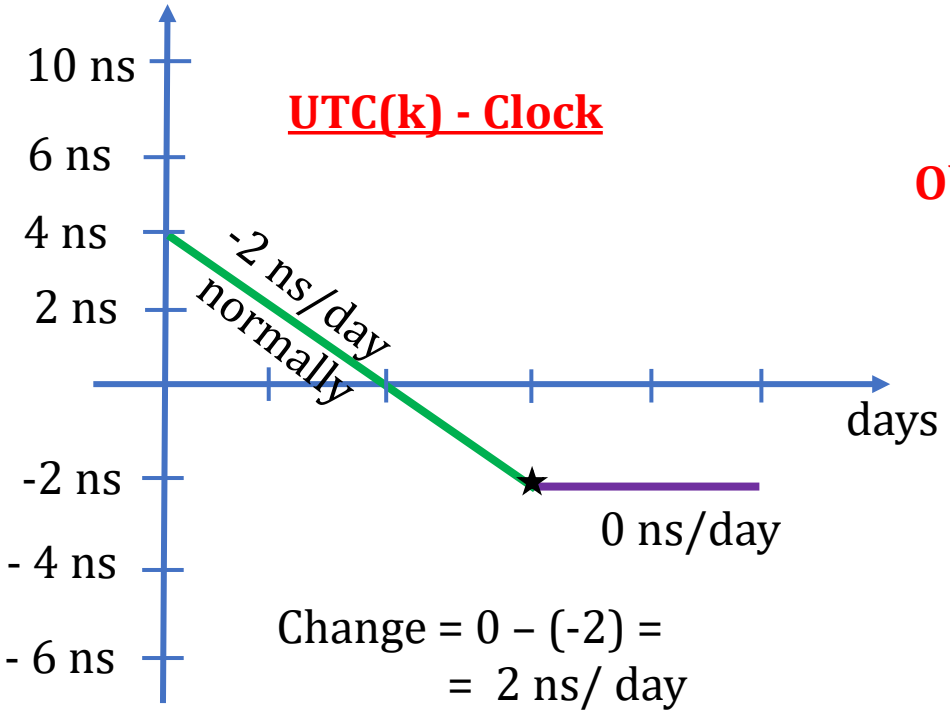
BIPM Adjustment:

compensate the previous data ------ and the clock rate appears even more unstable

Hence, the sign convention is very important !

2.1 Sign Convention: Frequency step {Correct Sign }

- The lab reports to the BIPM the quantity {UTC(k) – Clock}
- Declared frequency/rate step has to be NEW[clock rate] – OLD[clock rate]
- Declared frequency step has to be with **opposite sign** of the value obtained from NEW[{UTC(k) - clock}rate – OLD{UTC(k) – clock}rate]



Observe +2 ns/day on UTC(k) – clock

Report a step of -2ns/day on the clock

MJD with fractional value of the day	Clock Code	Time Step (ns)	Frequency Step (ns/day)	Lab Acronym	Lab Code
60817.70	1411036	0.0	-2.000	OP	10008

Please Follow this Sign Convention as NEW[clock rate] – OLD[clock rate]

Time and Frequency steps to be declared

= NEW[clock] – OLD[clock]

The BIPM convention is based on Clock values

The sign is from NEW clock value – OLD clock value

If you observe {UTC(k) – Clock} Measures

OPPOSITE sign of the {New_measures – Old_measures}

3. Why a UTC(k) lab might make corrections (time or frequency steps) on a free running clock.

1. When the clock has an offset versus UTC which is too large to be reported as per the format.
   Example: When UTC(k) – clock value is more than 99999999.9 ns {cccccccc.c ns } .

2. When the clock rate is considered too large
   Example: When it is 50 ns/day instead of about 1 ns/day.

3. To adjust one of the clock to match another clocks
   Example: If there are only two atomic clocks in the lab and you want to keep them aligned

4. Correcting the clock time or frequency to improve its accuracy

5. Change in the time scale setup (cable added)

6. Others ….

Summary

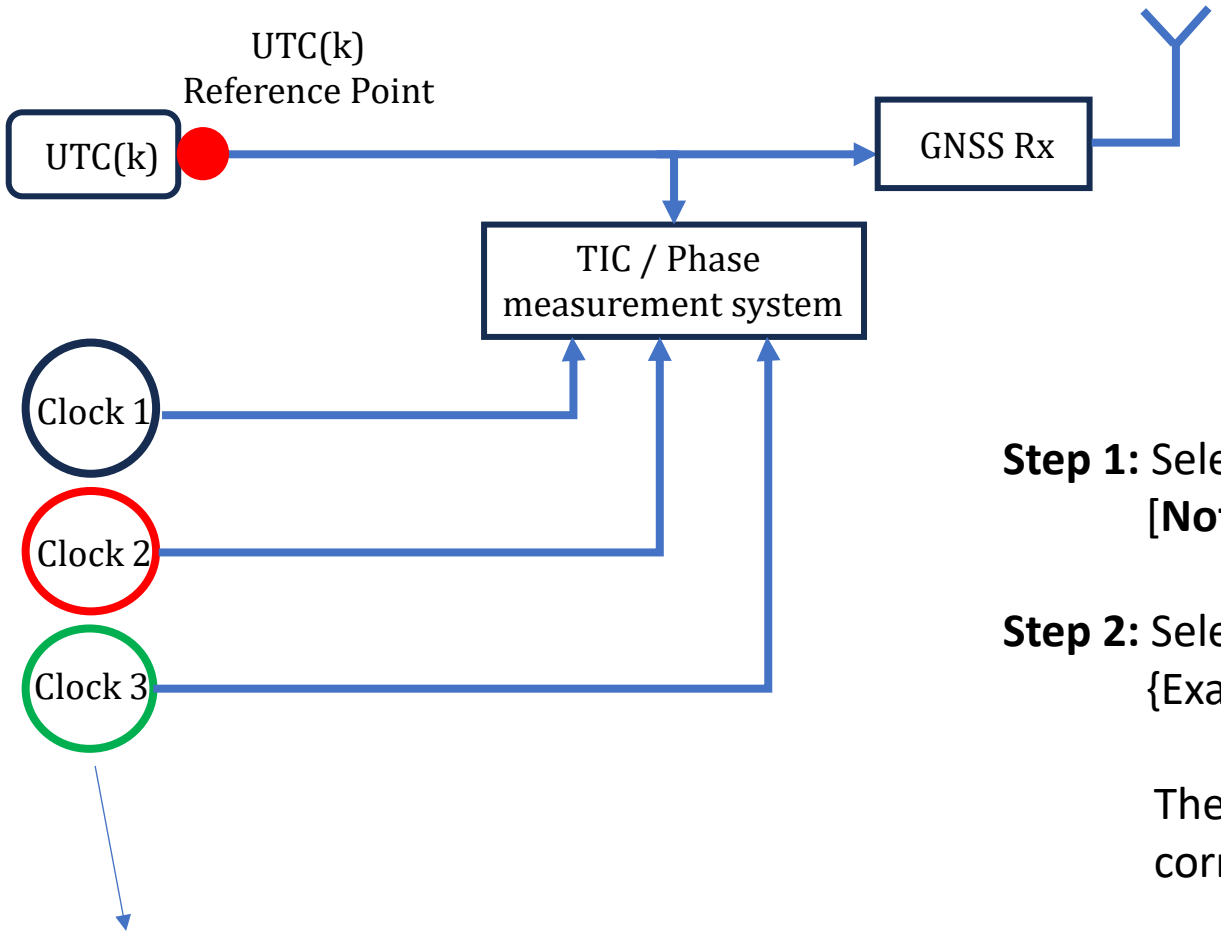
- If you steer the UTC(k) time scale, no steps should be reported in the BIPM clock file.

- No matter what clock you steer (master clock or another clock), the time or frequency step should be reported always with the recommended sign convention.

- If you have more than one clock in your lab, the difference between two clocks should always looks like an undisturbed clock once the voluntary steps are compensated as the BIPM does.

This last point can be used in the following online tool to verify if you have applied the sign correctly.

3.2 How to verify clock data and corrections using the software named "Validating clock data format with BIPM convention".



Methodology

Step 1: Select a Pivot Clock {Example: Clock 2 or Clock 1}
[**Note:** Free running clock with no gaps and steps]

Step 2: Select the clock you want to check for the step correction applied
{Example: Clock 3}

The software plots the data and provide options to apply the corrections on {Clock 2 – Clock 3} data.

Step 3: Select a suitable metric and apply the correction to get visual confirmation and data validation.

3.2 How to verify clock data and corrections using the software named "Validating clock data format with BIPM convention".

- Upload the clock data files in BIPM format (You can upload multiple data files)
- Clocks which are continuous for the whole period are proposed as "pivot clock". It can be UTC(k) or any another continuous clock
- Select your pivot clock.
- The performance of the other clocks w.r.t the pivot clock can be visualized, they represent "Pivot clock – other clock"
- The time and frequency steps declared in the clock file are visualized
- Apply the corrections in sequence to verify that the step is correctly compensated
- Visually get a conclusion from the residual plots about the correctness of the step declaration
- If only one clock is available and it realizes UTC(k) directly, no test can be performed (check the CGGTTS file in this case)

Software Demo

https://cbkt-time.bipm.org/bipm-clock-format/

The current version of the software assumes that at least one of the clocks (for example the Master clock) is continuous without any step corrections and without any gaps for the entire month.

Thank you

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