The background is a dark blue space scene. On the left, a purple and blue rocket with a red flame is launching upwards. On the right, a purple astronaut is floating in space, tethered to a red line that loops across the bottom. Various celestial bodies are scattered throughout, including a red planet with white spots, a ringed planet, and several white four-pointed stars.

# GNSS for precise time and frequency measurements and comparisons

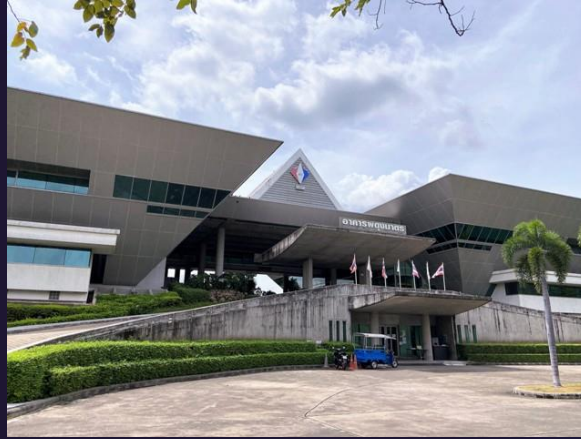
Thayathip Thongtan  
National Institute of Metrology Thailand  
5 December 2022

UN international meetings on applications of GNSS,  
Vienna, Austria

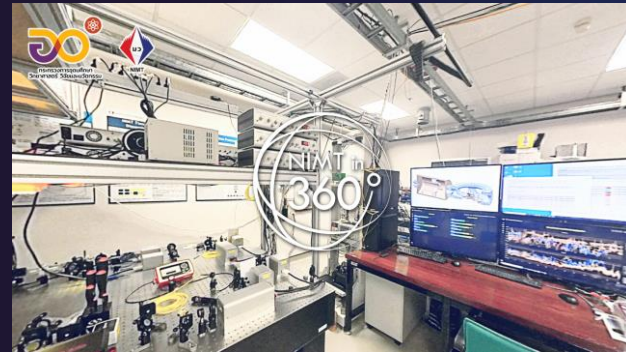
# Presentation outline

- Introduction on NIMT and time and frequency laboratory
- Time and frequency keeping and international comparisons
- Time and frequency distributions
- Research works
- Conclusions

# National Institute of Metrology Thailand



<https://www.nimt.or.th/main/>  
<https://www.facebook.com/NIMT2541>  
<https://www.youtube.com/user/nimt2541>  
<https://mx.nimt.or.th/>  
([https://mx.nimt.or.th/VT/Final%20VTL\\_1-305/](https://mx.nimt.or.th/VT/Final%20VTL_1-305/))



# Time and frequency laboratory



- Time and frequency keeping and international comparisons
- Experiments on Yb ion atomic clocks
- Internet time services: Network Time Protocol (NTP)
- Calibration services

# International Systems of Units

(SI)



SI base units

| Unit          | Measurement of            |
|---------------|---------------------------|
| Second (s)    | time                      |
| Mole (mol)    | amount of substance       |
| kilogram (kg) | mass                      |
| candela (cd)  | luminous intensity        |
| kelvin (K)    | thermodynamic temperature |
| metre (m)     | length                    |
| ampere (A)    | electric current          |

**1 second** is the duration of **9,192,631,770** periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the **caesium-133** atom, defined in 1967



# Time and frequency laboratory



## Atomic clocks

- Caesium frequency standards
- Active hydrogen masers



## GNSS receivers

- Timing
- Geodetic



## GNSS antenna

- Choke ring with radome

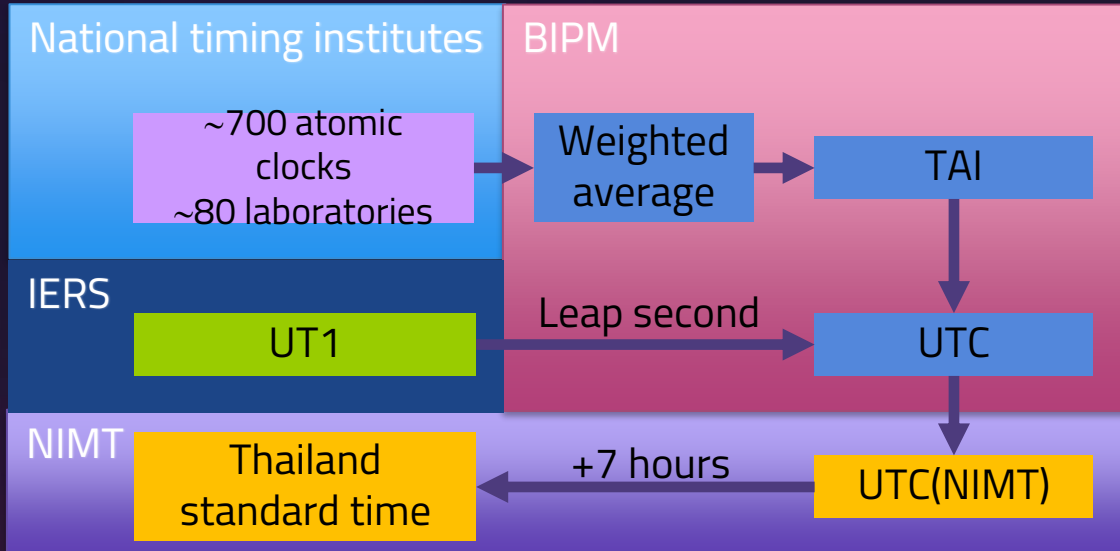
# Time and frequency laboratory

- Keep time links with the TAI and UTC scale (rinex 3.x and cggts 2E) using 3 sets of receivers (mtti and mtme)
  - GNSS timing receivers: two MESIT GTR55 units
  - GNSS antennas: two NOV-850 units
  - GNSS receivers need to be calibrated mtti Cal\_ID 2002-2021 and mtme Cal\_ID 2003-2022
- Provide positioning and timing references (mtth and mtmi)
  - GNSS : multi-constellations, multi-frequency, multi-channels
  - Post-processing and real-time positioning services (NRTK)

<http://103.150.106.114/>

<http://103.150.106.117/>

# Time and frequency keeping



BIPM resolutions on leap seconds:

- Leap seconds creates discontinuities that risk serious malfunction in critical digital infrastructures including GNSS, telecommunication and energy transmission systems
- Leap seconds would possibly be negative because of recent Earth observations on rotation rate (UT1-UTC)

<https://www.bipm.org/.../20126464811223/Resolutions-2022.pdf>

✦ International Atomic Time (TAI)  
✦ Coordinate Universal Time (UTC)  
✦ Universal Time (UT)





# Time and frequency comparisons

CIRCULAR T 409  
2022 FEBRUARY 10, 15h UTC

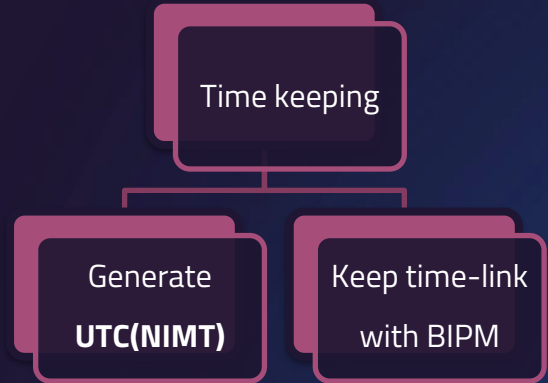
ISSN 1143-1393

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PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 tai@bipm.org

The contents of the sections of BIPM Circular T are fully described in the document "Explanatory supplement to BIPM Circular T" available at [https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory\\_supplement\\_v0.6.pdf](https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf)

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties.  
From 2017 January 1, 0h UTC, TAI-UTC = 37 s.

| Date                   | 2021/22 0h UTC | DEC 31          | JAN 5    | JAN 10   | JAN 15   | JAN 20   | JAN 25   | JAN 30   | Uncertainty/ns | Notes |          |  |
|------------------------|----------------|-----------------|----------|----------|----------|----------|----------|----------|----------------|-------|----------|--|
|                        | MJD            | 59579           | 59584    | 59589    | 59594    | 59599    | 59604    | 59609    | uA             | uB    | u        |  |
| Laboratory k           |                | [UTC-UTC(k)]/ns |          |          |          |          |          |          |                |       |          |  |
| AGGO (La Plata)        |                | 370.8           | 370.5    | 378.0    | 390.6    | 402.5    | 412.8    | 423.9    | 1.0            | 20.0  | 20.0     |  |
| AOS (Borowiec)         |                | -0.9            | -1.3     | -2.3     | -3.2     | -4.2     | -5.2     | -6.4     | 0.3            | 3.0   | 3.0      |  |
| APL (Laurel)           |                | 3.6             | 5.0      | 3.8      | 2.2      | 2.6      | 2.9      | 3.3      | 0.3            | 19.7  | 19.7     |  |
| AUS (Sydney)           |                | -560.0          | -560.5   | -562.0   | -550.4   | -557.0   | -557.9   | -543.2   | 0.3            | 11.2  | 11.2     |  |
| BEV (Wien)             |                | -29.6           | -15.3    | 5.1      | 14.4     | 40.1     | 61.3     | 67.5     | 0.3            | 3.5   | 3.5      |  |
| BFKH (Budapest)        |                | 3994.6          | 4017.2   | 4051.1   | -        | 4113.4   | 4149.4   | 4181.1   | 1.5            | 20.0  | 20.1     |  |
| BIM (Sofiya)           |                | 15646.8         | 15687.2  | 15704.7  | 15719.0  | 15725.7  | 15754.4  | 15770.4  | 0.3            | 7.1   | 7.1      |  |
| BIRM (Beijing)         |                | 4.8             | 13.7     | 16.2     | 16.9     | 15.4     | 13.9     | 11.3     | 0.3            | 2.9   | 2.9 (1)  |  |
| BOM (Skopje)           |                | -               | -28.9    | -194.9   | -340.3   | -501.1   | -657.6   | -813.2   | 0.3            | 3.5   | 3.5      |  |
| BY (Minsk)             |                | -1.2            | 0.5      | 3.7      | 3.9      | 2.2      | 0.7      | 0.6      | 1.5            | 2.8   | 3.2      |  |
| CAO (Cagliari)         |                | -32783.9        | -32897.1 | -33014.0 | -33126.3 | -33244.8 | -33350.7 | -33466.1 | 1.5            | 20.0  | 20.1     |  |
| CH (Bern-Wabern)       |                | 0.1             | 0.2      | 0.0      | -0.3     | -0.7     | -0.7     | -0.7     | 0.3            | 1.5   | 1.5      |  |
| CNES (Toulouse)        |                | 6.6             | 1.5      | -2.4     | -6.3     | -8.8     | -9.3     | -7.1     | 0.3            | 2.6   | 2.6      |  |
| CNM (Queretaro)        |                | 0.5             | 2.6      | 2.9      | -2.1     | 8.0      | -0.7     | 11.0     | 1.5            | 4.0   | 4.2      |  |
| CNMP (Panama)          |                | -2.6            | 0.8      | 8.9      | 20.8     | -5.4     | 26.6     | 18.3     | 0.7            | 5.2   | 5.2      |  |
| DFMT (Tunis)           |                | 2883.5          | 2972.1   | 3078.9   | 287.3    | 401.4    | 501.4    | 599.2    | 0.7            | 20.0  | 20.0 (2) |  |
| DLR (Oberpfaffenhofen) |                | -28.5           | -34.0    | -39.2    | -35.6    | -        | 53.1     | 61.3     | 0.7            | 2.9   | 3.0      |  |
| DMDM (Belgrade)        |                | -20.5           | -17.4    | -17.7    | -19.0    | -15.4    | -21.6    | -18.0    | 0.3            | 3.5   | 3.5      |  |
| DTAG (Frankfurt/M)     |                | -10.6           | -14.6    | -21.9    | -29.4    | -39.2    | -35.7    | -39.2    | 0.3            | 2.9   | 2.9      |  |
| EIM (Thessaloniki)     |                | 4.0             | 3.7      | 4.9      | 3.2      | 5.0      | 6.1      | -2.6     | 4.0            | 11.2  | 11.9     |  |
| ESA (Noordwijk)        |                | 2.3             | 2.5      | 2.3      | 1.7      | 0.8      | 0.4      | -0.7     | 0.3            | 2.7   | 2.7      |  |
| HKO (Hong Kong)        |                | 27.8            | 30.0     | 38.8     | 44.9     | 52.3     | 57.0     | 56.3     | 0.7            | 3.1   | 3.2      |  |
| TCF (San Jose)         |                | 45.5            | 41.4     | 66.1     | 62.8     | 82.1     | 80.7     | 82.4     | 2.5            | 7.2   | 7.7      |  |



<https://webtai.bipm.org/ftp/pub/tai/Circular-T/cirhtml/cirt.409.html>

**NIMT (Pathumthani)**      **-2.8**      **-9.9**      **-14.1**      **-17.8**      **-8.3**      **-3.1**      **1.9**      **0.7**      **20.0**      **20.0**

|                   |        |        |        |        |       |       |       |     |      |          |
|-------------------|--------|--------|--------|--------|-------|-------|-------|-----|------|----------|
| INCP (Lima)       | 1093.8 | 1196.0 | 1302.5 | 1421.4 | -27.2 | 101.6 | 81.8  | 5.0 | 20.0 | 20.6 (3) |
| INM (Bogota D.C.) | 325.8  | 341.1  | 353.4  | 361.6  | 374.4 | 394.3 | 412.1 | 1.5 | 20.0 | 20.1     |

# Time and frequency comparisons

CIRCULAR T 415  
2022 AUGUST 11, 14h UTC

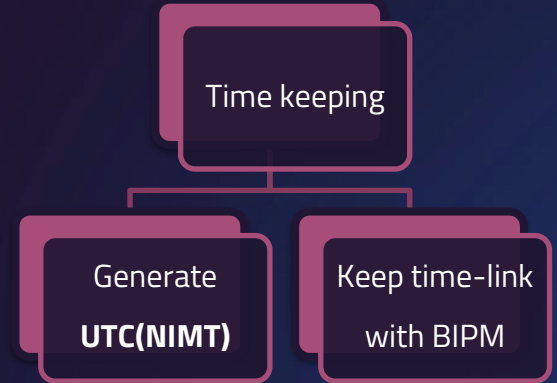
ISSN 1143-1393

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The contents of the sections of BIPM Circular T are fully described in the document "Explanatory supplement to BIPM Circular T" available at [https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory\\_supplement\\_v0.6.pdf](https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf)

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties.  
From 2017 January 1, 0h UTC, TAI-UTC = 37 s.

| Date 2022              | 0h UTC | JUN 29          | JUL 4    | JUL 9    | JUL 14   | JUL 19   | JUL 24   | JUL 29   | Uncertainty/ns | Notes |         |
|------------------------|--------|-----------------|----------|----------|----------|----------|----------|----------|----------------|-------|---------|
| MJD                    |        | 59759           | 59764    | 59769    | 59774    | 59779    | 59784    | 59789    | uA             | uB    | u       |
| Laboratory k           |        | [UTC-UTC(k)]/ns |          |          |          |          |          |          |                |       |         |
| AGGO (La Plata)        |        | 711.2           | 740.6    | 772.3    | 763.3    | 784.3    | 791.8    | 808.6    | 1.0            | 20.0  | 20.0    |
| AOS (Borowiec)         |        | -1.0            | -0.7     | -1.2     | -1.8     | -2.4     | -2.8     | -3.2     | 0.3            | 3.1   | 3.1     |
| APL (Laurel)           |        | 0.4             | 0.9      | 0.4      | -0.4     | -1.1     | -1.5     | -1.9     | 0.3            | 20.0  | 20.0    |
| AUS (Sydney)           |        | -508.5          | -508.5   | -495.5   | -487.7   | -471.6   | -493.6   | -505.9   | 0.3            | 11.2  | 11.2    |
| BEV (Wien)             |        | 5.7             | 6.3      | 15.4     | 21.0     | 19.5     | 20.9     | 17.6     | 0.3            | 2.7   | 2.7     |
| BFKH (Budapest)        |        | 5183.6          | 5218.5   | 5249.6   | 5280.1   | 5319.0   | 5345.1   | 5375.7   | 1.5            | 20.0  | 20.1    |
| BIM (Sofiya)           |        | 16366.8         | 16422.2  | 16439.6  | 16478.6  | 16488.6  | 16509.2  | 16502.8  | 0.3            | 7.2   | 7.2     |
| BIRM (Beijing)         |        | 54.8            | 58.2     | 60.0     | 65.6     | 64.5     | 63.0     | 51.1     | 0.3            | 3.0   | 3.0     |
| BOM (Skopje)           |        | -               | -        | -        | -        | -        | -        | -        | -              | -     | -       |
| BY (Minsk)             |        | -2.1            | -1.5     | -0.4     | 0.2      | 1.0      | 1.3      | 0.9      | 1.5            | 2.8   | 3.2     |
| CAO (Cagliari)         |        | -36930.9        | -37046.1 | -37168.8 | -37290.4 | -37407.7 | -37523.6 | -37636.9 | 1.5            | 20.0  | 20.1    |
| CH (Bern-Wabern)       |        | -0.1            | 0.4      | -0.1     | -0.9     | 0.0      | 16532.4  | 16534.6  | 0.5            | 1.5   | 1.6 (1) |
| CNES (Toulouse)        |        | -6.2            | -7.0     | -6.2     | -3.8     | 1.5      | 9.1      | 16.0     | 0.3            | 2.7   | 2.7     |
| CNM (Queretaro)        |        | 7.5             | 4.2      | 8.8      | 6.8      | 5.6      | 8.7      | 6.3      | 1.5            | 4.0   | 4.2     |
| CNMP (Panama)          |        | 11.7            | 22.6     | -2.0     | -1.3     | -4.4     | 15.6     | -3.2     | 0.3            | 5.2   | 5.2     |
| DFNT (Tunis)           |        | 3558.1          | 3636.1   | 3725.4   | 3814.4   | 3906.0   | 4007.7   | 4096.0   | 0.7            | 20.0  | 20.0    |
| DLR (Oberpfaffenhofen) |        | -5.0            | -3.8     | -2.2     | -1.5     | -0.2     | -1.2     | -2.1     | 0.7            | 2.7   | 2.8     |
| DMDM (Belgrade)        |        | -               | -        | -        | -        | -        | -        | -        | -              | -     | -       |
| DTAG (Frankfurt/M)     |        | 29.4            | 26.7     | 28.6     | 31.5     | 30.8     | 33.6     | 37.9     | 0.3            | 3.0   | 3.0     |
| EIM (Thessaloniki)     |        | 6.0             | 2.5      | 3.9      | 6.5      | 13.8     | -0.8     | 10.7     | 4.0            | 11.2  | 11.9    |

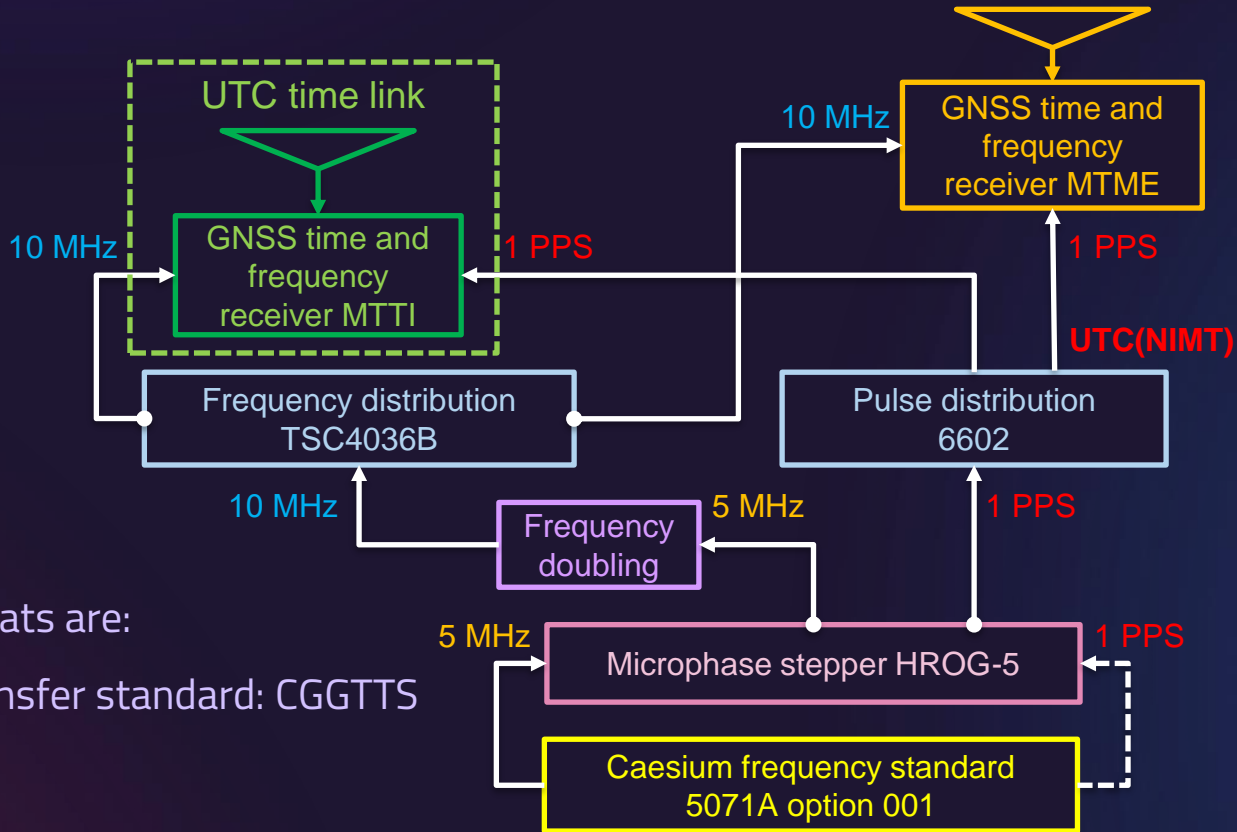


<https://webtai.bipm.org/ftp/pub/tai/Circular-T/cirhtml/cirt.415.html>

**NIMT (Pathumthani)**      -80.7    -161.4    -257.2    -362.9    -465.9    -547.8    -627.6    0.3    7.0    7.0 (4)

|                         |        |        |        |        |        |        |        |     |     |         |
|-------------------------|--------|--------|--------|--------|--------|--------|--------|-----|-----|---------|
| IDN (Serpong-Tangerang) | 1984.7 | 2020.6 | 2035.4 | 150.8  | 188.1  | 238.0  | 244.5  | 0.3 | 3.1 | 3.1 (2) |
| IFAG (Wetzell)          | -867.9 | -876.9 | -872.8 | -870.2 | -874.8 | -871.4 | -868.3 | 0.3 | 2.7 | 2.7     |

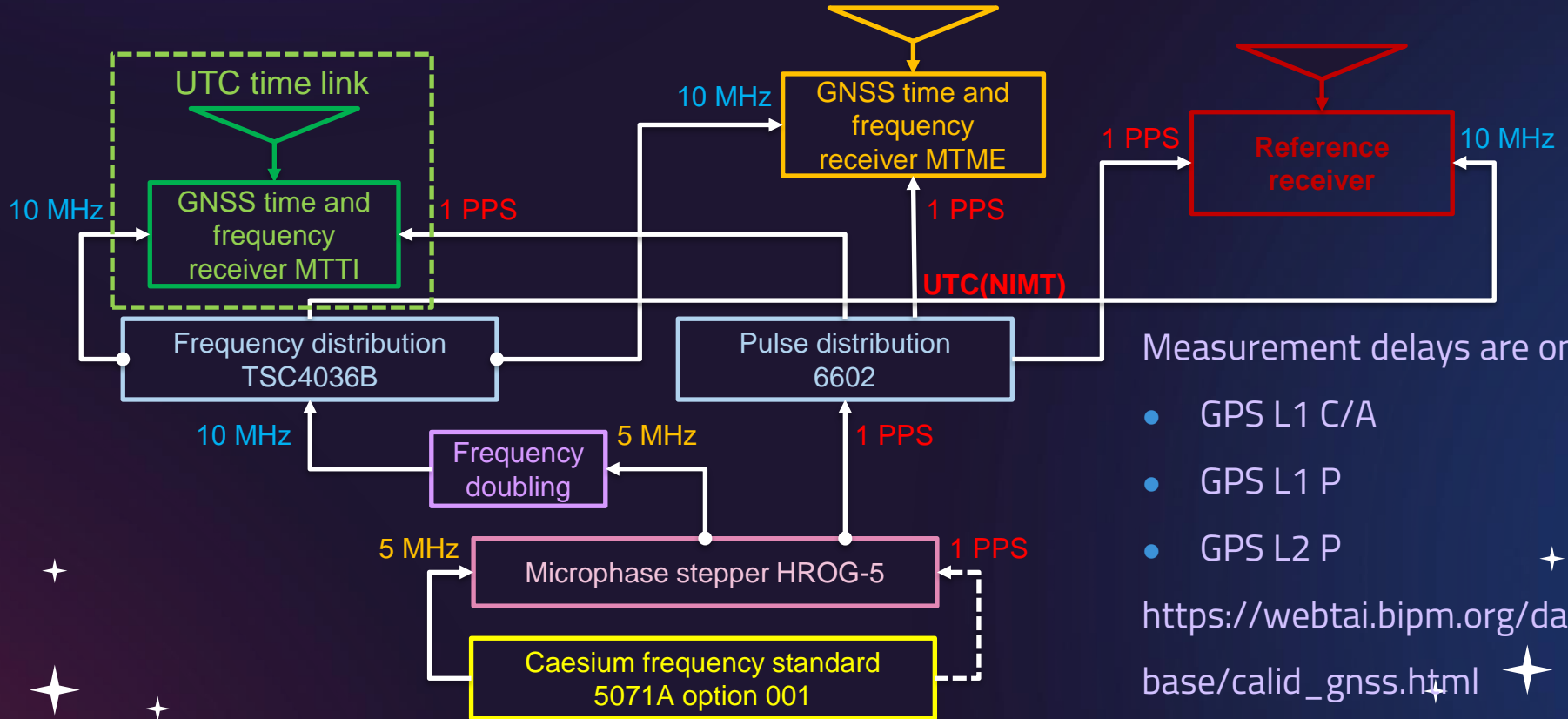
# Time and frequency comparisons



Output formats are:

- Time transfer standard: CGGTTS
- RINEX

# Time and frequency comparisons



Measurement delays are on:

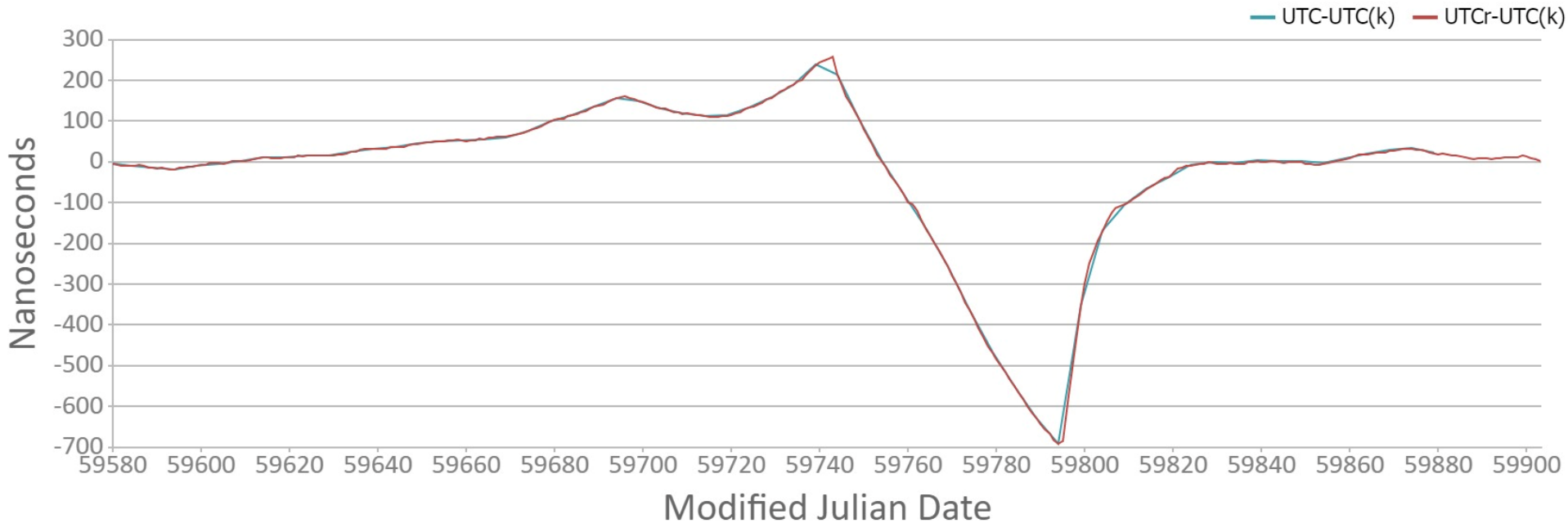
- GPS L1 C/A
- GPS L1 P
- GPS L2 P

[https://webtai.bipm.org/data  
base/calid\\_gnss.html](https://webtai.bipm.org/data/base/calid_gnss.html)




# Time and frequency comparisons

## UTC-UTC(NIMT)





# Time and frequency disseminations

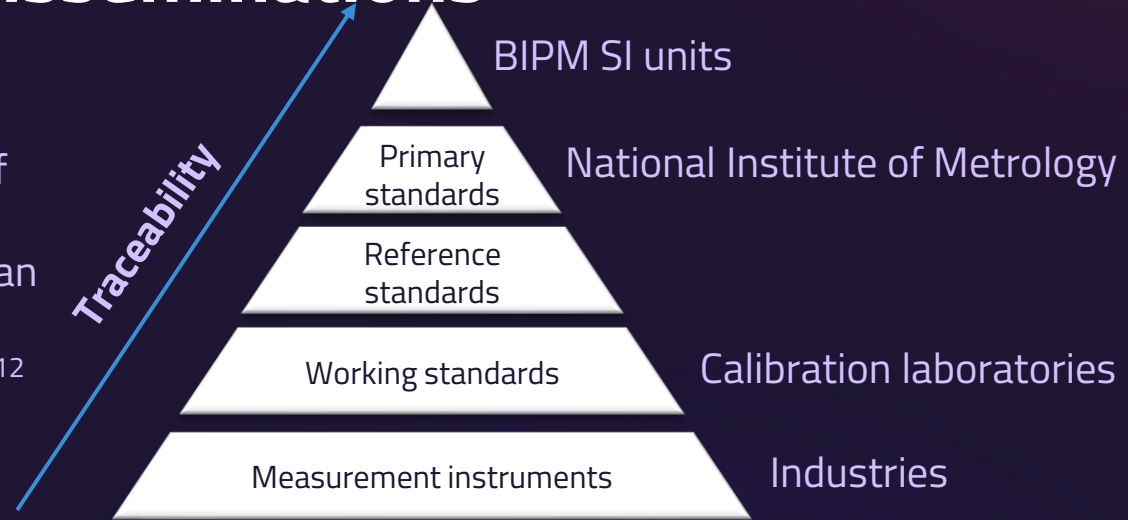
- **Calibrations**
  - **Internet time transfers**
  - **Speaking clocks**
- 

# Time and frequency disseminations

## Calibration

GNSS allows us to:

- compare atomic clock at the level of  $1 \cdot 10^{-13}$  to  $1 \cdot 10^{-14}$
- synchronisation to UTC of better than 10 ns
- obtain stability of better than  $1 \cdot 10^{-12}$  per day



Traceability is:

“the property of result of a measurement or the value of standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.”

# Time and frequency disseminations

Calibration



Caesium frequency standard



Rubidium frequency standard



Universal frequency counter

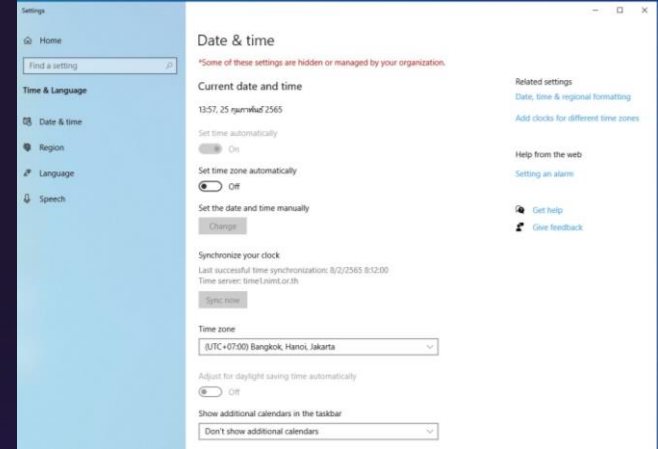
# Time and frequency disseminations

## Internet time



## Internet time servers

- time1.nimt.or.th
- time2.nimt.or.th
- time3.nimt.or.th
- time4.nimt.or.th
- time5.nimt.or.th





# Time and frequency disseminations

## Speaking clocks

- The **Royal Hydrographic Department, Royal Thai Navy** announce Thailand Standard Time with traceability to UTC(NIMT) through a standard method for time comparison called GNSS common-view.
- Access by dial **1811** and listen to the time via speaking clock and make a setting at the beep!



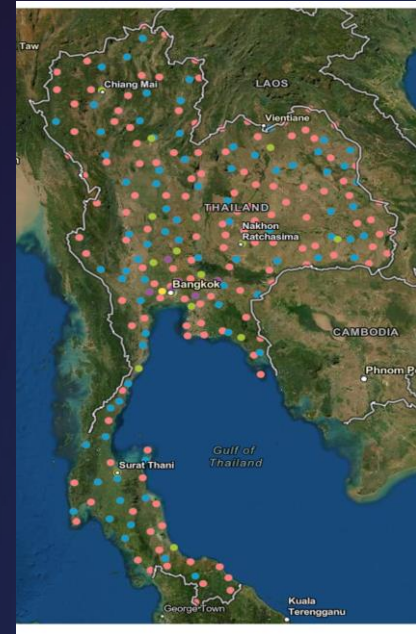
# Time and frequency

## GNSS ground station network for positioning and timing **disseminations**

- 228 stations: homogenously distributed nationwide
- Provide positioning, GNSS observation achieves, online data post-processing and NRTK services (VRS)
- Fit international terrestrial reference frame version 2005, 2008 and 2014
- Collaborative project amongst government institutes, academics and international agencies

<https://ncdc.in.th/portal/apps/sites/#/ncdc>

T. Thongtan, S. Sawatdiaree and C. Satirapod, "GNSS time and frequency transfers through national positioning, navigation and timing infrastructure," Journal of Applied Geodesy, vol. 16, no. 2, pp. 123-130, 2022.



# Thanks

!

Do you have any questions?

