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CGGTTS-Version 2E : an extended standard for GNSS Time Transfer

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Abstract

The standard for GNSS time transfer was first defined in 1984, associated to the use of GPS signals, which were at that time degraded by the Selective Availability. It was updated at a few instances to follow the evolution of GPS, of the receivers, and the inclusion of GLONASS. With the emergence of additional navigation systems like Galileo, BeiDou, QZSS, the standard has to be further adapted. This paper prepared by the CCTF Working Group on GNSS Time Transfer details the associated extended standard, named CGGTTS for Common GNSS Generic Time Transfer Standard, and the corresponding Version 2E of the format[1].

1. INTRODUCTION

The GPS Common-View (CV) time transfer [1] has been used by the Bureau International des Poids et Mesures (BIPM) since the eighties to compare the UTC realizations of timing labs in order to generate the International Atomic Time (TAI). The same approach has then been used widely for synchronization of local time scales with the legal time references available in National Metrological Institutes.

The principle is to connect the local clock (or realization of UTC) to a GPS receiver and to determine, from the pseudorange measurements, the synchronization difference between the local clock and GPS time scale. Simultaneous measurements in two labs give then access to the synchronization difference between the clocks of these two labs. A GPS time transfer standard was defined [2] for both the pseudorange analysis procedure and the format of the results: the "GGTTS" as defined by the Group on GPS Time Transfer Standards. The name and format was later modified into "CGGTTS Version 02", for Common GPS GLONASS Time Transfer Standard [3], so as to include the results corresponding to GLONASS satellites.

The CGGTTS computation procedure is based on the analysis of measured pseudoranges for conventional 13-minute tracks appearing in the international BIPM tracking schedules. This 13-minute length was originally fixed as the needed time for the receiver to get a full navigation

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[1] If required, updates to the format will be posted on the web page of the working group on GNSS time transfer at http://www.bipm.org/wg/AllowedDocuments.jsp?wg=WGGNSS

message. A minimum of 3 minutes was then foreseen in the BIPM schedule to give to the receiver the time to track the following scheduled satellite. The common-view method proposed in the 1980s by Allan & Weiss [1] and the associated CGGTTS format was based on one-channel C/A code receivers. Following the improvements of atomic frequency standards in terms of precision and accuracy, GPS (or more generally GNSS) time and frequency transfer underwent major evolutions both at the algorithmic levels and at the hardware level. A first improvement was found in the use of a multi-channel approach (see e.g. [4]), increasing the number of satellites which reduces correspondingly the noise of clock solutions. For applications requiring the highest precision, as for example the computation of TAI, the CGGTTS results are improved by adding a correction for satellite orbits and clocks using the products of the International GNSS Service (IGS). Also, the ionospheric correction used in the CGGTTS results, based on the broadcast ionospheric model of the constellation, is replaced by a new estimation based on the IONEX maps delivered by the IGS analysis center CODE [5]. A further upgrade of the CGGTTS was the use of dual-frequency receivers measuring the GPS P codes, enabling to remove the ionosphere delays at the first order, and leading to a factor 2 improvement in the precision of the intercontinental time links [6]. Notice that for short baselines, the increase of noise in the ionosphere-free combination with respect to the single-frequency time transfer solution can be larger than the residual ionospheric errors associated with the Klobuchar model or with the IONEX maps; a similar ionospheric delay is indeed suffered by the GNSS signals when they arrive in stations close to each other. However, the timing community prefers using the ionosphere-free combination so that the CGGTTS files can be used easily whatever the distance of the second clock entering into the comparison.

The CGGTTS files can either be produced directly by the receiver or reconstructed from raw measurements and navigation data provided by the receiver in the RINEX (Receiver INdependent EXchange) format, the standard used by the IGS, see e.g. http://igscb.jpl.nasa.gov/components/formats.html). To that aim, a software tool named R2CGGTTS and developed at the Royal Observatory of Belgium [7], is made available on the BIPM server (ftp://tai.bipm.org/temp). The latest version provides CGGTTS files in Version 02, for both GPS and GLONASS satellites [8], starting from RINEX files version 2.11.

The CGGTTS Version 02 standard only applies for GPS and GLONASS measurements. Considering the emergence of Galileo, BeiDou and QZSS, the Working Group on GNSS Time Transfer prepared the new version of the standard, with the name CGGTTS, for Common Generic GNSS Time Transfer Standard, version 2E. It is well known that GNSS time transfer using Precise Point Positioning (PPP) provides currently time transfer solutions with a significant higher precision and stability than the results based on the CGGTTS (see e.g. [9]). The long term goal of the timing community will be a progressive replacement of the CGGTTS format by techniques using carrier-phase and codes, like the PPP. In view of the fact that currently near half of the laboratories participating to TAI can still only be compared using the CGGTTS, these laboratories will be encouraged, when buying new equipment for the use of new GNSS

constellations, to choose dual-frequency receivers measuring code and carrier phases, and providing the RINEX format files so that the PPP can be applied. The CCTF Working Group on GNSS time transfer however decided to maintain and extend the CGGTTS for the following reasons; (i) almost all the industrial and commercial end users continue to use the CGGTTS or its adapted data format for the clock comparisons and the time transfer facility calibrations; (ii) unlike the PPP, which requires some expertise to validate the results of a post-data-processing, the CGGTTS shows its advantages in providing a remote clock comparison very easily.
The main features of the extended standard are:

- to provide extension for all GNSS systems in development;
- to be fully compatible with the previous versions GGTTS-V01 (GPS) and CGGTTS-V02 (GPS+GLONASS) for the computation algorithm and data format; in particular it is explicitly decided not to change the 16-minute data interval with 13-minute averaging so that common-view time transfer is possible between receivers providing any version of the format;
- to provide more flexibility in specifying the calibration information in the header, allowing a more synthetic presentation of the calibration delays.

The second section of the paper reviews the CGGTTS V2E analysis procedure, for both single and dual-frequency receivers, while the new format is described in full details in Section 3. Some comments and discussions are then related in the last sections of the paper.

2. STANDARD COMPUTATION PROCEDURE

2.1 Conventional Observation schedule

The CGGTTS computation procedure is based on the analysis of measured pseudoranges for conventional 13-minute tracks. Each satellite track is characterized by the date of the first observation of the track, given as Modified Julian Day (MJD) together with a UTC hour, minute and second. These tracking epochs are offset by 4 minutes each day; this offset was originally fixed in order to stay aligned with the sidereal period of the GPS constellation and to follow each day the same common-view comparison schedule. Even if the daily repeatability is not needed any more and is not valid for the constellations other than GPS, it has been decided to keep the same tracking schedule in order to assure the full compatibility with the previous version of the CGGTTS. The time transfer results will therefore be reported for all the visible satellites at the epochs defined by the conventional tracking schedule given in [10]:

- Start of 13-minute tracks for MJD 50722

  Time_ref(i) = 00h02m00s + (i-1) * 16 minutes with i=1,89

- Start of 13-minute tracks for any MJD :

  Time(i)=Time_ref(i) - 4 * (MJD-50722) minutes

Until December 2014, an explicit list of satellites to be observed by single-channel receivers from each continent was provided by the BIPM so as to be sure that the common view is possible also for inter-continental baselines. These tracking schedules were provided twice a year, for both GPS and GLONASS. Because single-channel receivers are no longer marketed, the BIPM schedule was discontinued at the end of 2014 and it is not expected that a similar list would be provided for Galileo and BeiDou. It is expected that receivers can track all satellites in view, and that single channel receivers still in use will track using a procedure by default, all following the conventional time schedule presented here above. Users willing to compare two single channel receivers by common-view processing may be somewhat affected by the absence of a common schedule. However, should the case occur, they can resolve by developing their own observing schedule adapted to their specific needs.

2.2 Input parameters

2.2.1 Station coordinates

The CGGTTS procedure is considering the position of the antenna as a precisely known parameter. The coordinates of the phase center of the antenna should be given in the International Terrestrial Reference Frame (ITRF) with an accuracy of 3 cm in order to match the 0.1 ns numeric precision of the format. Due to the tectonic motions, the station position should be updated regularly.

Furthermore it is important that the position used for the CGGTTS is the Antenna Phase Center (APC) corresponding to the frequency or frequency combination used. The difference between the positions of the antenna phase center for different frequencies can indeed reach some cm. Precise Point Positioning can determine antenna coordinates very accurately but it generally provides the Antenna Reference Point (ARP). The ARP is a unique physical marker corresponding to the point where the antenna is fixed. The phase center APC is a virtual (no physical marker) point, which depends on the antenna type and to some level on the code and frequency used. The APC for a given frequency can be determined from the ARP using the eccentricity vector (from the ARP to the APC) which is provided, for each antenna type and each frequency, in the IGS Antex file (currently –early 2015– igs08.atx available as ftp://igs.org/pub/station/general/igs08.atx). No azimuth/elevation-dependent APC correction should be used for the CGGTTS as this correction is well below the noise level of the code measurements. Note that if the PPP tools also provide the position of an APC, this one corresponds, unless otherwise specified, to the ionosphere-free combination of GPS L1 and L2 and should be used only for the CGGTTS based on GPS P3.

Because the difference between the position of the antenna phase center for different frequencies can reach some cm, the position used to generate the CGGTTS data should be given accordingly. As only one position can be given in a CGGTTS file, separate CGGTTS files will be used to report the results from different constellations, or from different frequencies.

2.2.2 Station hardware delays

A second set of input parameters contains all hardware delays of the GNSS receiving system. In the CGGTTS format, they are separated into three parameters: REFDLY, INTDLY and CABDLY.

REFDLY is the time offset between the receiver internal clock (or its conventional realization by an external signal) and the local clock at the station, which can be a realization of UTC. In most cases, this time offset contains two components to be measured: the cable delay between the local clock and the receiver input connector and the time offset between the input connector and the internal reference. This second parameter should be determined following the instructions provided by the receiver manufacturer, also available in the BIPM guidelines for Calibration (see at ftp://tai.bipm.org/TFG/GNSS-Calibration-Results/Guidelines/).

INTDLY is the combined electric delay of the GNSS signal inside the antenna and the receiver. This delay is frequency-dependent and code-dependent, so that it should be provided for each signal used in the CGGTTS. Two values are therefore expected when the CGGTTS is based on an ionosphere-free linear combination of dual-frequency measurements. The hardware delays entering in INTDLY have to be determined through a calibration campaign as detailed in the BIPM guidelines for Calibration.

CABDLY is the signal group delay inside the antenna cable, including both end connectors.

CGGTTS Version 2E introduces several possible options to express hardware delays:

- If CABDLY cannot be measured, this parameter can also be included in the receiver+antenna hardware delay. The combined hardware delay will then be called SYSDLY = INTDLY+CABDLY.
- Finally it is possible to combine the total hardware delay into a single parameter TOTDLY = INTDLY+CABDLY-REFDLY. This option is not recommended as it does not keep track of the REFDLY value so that any change in the set-up cannot be accounted for.

Like INTDLY, the parameters TOTDLY and SYSDLY are code-dependent.

The hardware delays resulting from a calibration are identified through a calibration identifier (cal_id) that uniquely references calibration exercises submitted to the BIPM. Note that REFLDY (and possibly CABDLY) can be modified due to a setup change in the laboratory; the calibration cal_id is then still valid, but the changes should be entered accordingly in the header.

If corrections such as the satellite-dependent C-code/P-code bias are applied, it is important that a comment be inserted to enable the user to determine what they were.

2.2.3 GNSS-UTC leap seconds

The reference time scale for the observations and reporting of results is UTC, while the date of GNSS observations is that of the GNSS reference time scales. In order to use the right observations in UTC for computing and reporting the CGGTTS results, it is necessary to make the conversion between the observation time reference and UTC. GLONASS time is aligned on UTC and follows the leap seconds while GPS, Galileo and BeiDou are continuous time scales without leap second, with GPS and Galileo 19 second behind TAI, and BeiDou 33 second behind TAI.

2.3 Data processing

The data to be used are the pseudorange measurements collected during the 13 minutes starting with the date specified in the BIPM tracking schedule. The original GGTTS directives [2] asked for 1-second measurements grouped into blocks of 15 seconds. Each 15-second data block is then smoothed using a quadratic polynomial. The data to be kept for the next part of the procedure are the quadratic fit results at the midpoint of each data block, a total of 52 data per 13-minute track. It must be noted that this raw data smoothing was justified by the noise associated with Selective Availability. This latter being deactivated since May 2000, such smoothing is no longer necessary and the raw measurements can be used directly. In order to be aligned with the standards of the geodetic community, Defraigne et al [11] proposed the use of a 30-second sampling rate, giving a total of 26 data per 13-minute track. These authors showed that the differences between the CGGTTS results based on either approach (1-second with smoothing or 30-second raw data) is less than 0.1 ns, well below the noise of the solutions.

The 52 (resp. 26) pseudorange data are then corrected for their frequency-dependent hardware delays as:

$$\bar{P}_i = P_i - c(INTDLY(f_i) + CABDLY - REFDLY) \quad (1)$$

where P_i, expressed in meters, is the pseudorange measurement on the frequency f_i, and c is the velocity of the light. The next step of the procedure is then to be regarded separately for single or dual-frequency analysis.

2.3.1 Single-frequency users

The single-frequency CGGTTS standard is to use the measured pseudorange in the L1 frequency band. This means C1 or P1 for GPS and GLONASS, E1 for Galileo and B1I for BeiDou. For single-frequency users the offset between the local clock and the satellite clock will be obtained as

$$t_{clock} - t_{sat} = \frac{1}{c}\left[\bar{P}_1 - \left\|\overrightarrow{x_{sat}} - \overrightarrow{x_{rec,1}}\right\| - S\right] + \Delta t_{rel} - \Delta t_{iono,1} - \Delta t_{tropo} - GD \qquad (2)$$

where $\overrightarrow{x_{sat}}$ is the satellite position in the ITRF at the emission time, $\overrightarrow{x_{rec,1}}$ is the position in the ITRF of the phase center of the antenna for the frequency f_1, as given by the input parameters (see previous section), S is the Sagnac correction associated with the Earth rotation, Δt_{rel} is the relativistic clock correction associated with the variable redshift experienced by the satellite along its orbit, $\Delta t_{iono,1}$ is the signal delay due to ionospheric refraction at the frequency f_1, Δt_{tropo} is the signal delay due to tropospheric refraction and GD is the broadcast group delay associated with the broadcast satellite clock.

The ionospheric delay should be estimated, for GPS and BeiDou satellites, using the Klobuchar model and the ionospheric parameters delivered in the respective navigation messages. The ionospheric delay of Galileo satellites is computed using the NeQuick-G model and the parameters broadcast in the navigation message. No ionospheric correction is broadcast by the GLONASS satellites so that either a model from another GNSS has to be used, or the correction can also be not applied. The ionospheric correction anyway appears in the output CGGTTS file so that it can possibly be replaced by an improved correction in a post-processing. This is classically done by the BIPM in the computation of TAI: the ionospheric correction computed from broadcast models is replaced by a correction based on Global Ionospheric Maps delivered by the IGS [12].

2.3.2 Dual-frequency users

For dual-frequency users, the ionosphere-free combination is first formed as

$$\bar{P}_{IF} = \alpha_{ij}\bar{P}_i + (1 - \alpha_{ij})\bar{P}_j \qquad \text{with } \alpha_{ij} = \frac{f_i^2}{f_i^2 - f_j^2} \qquad (3)$$

with f the frequency. The dual-frequency CGGTTS for the different constellations will be based on the ionosphere-free combinations of the following signals:

- GPS and GLONASS: C1 or P1 & C2 or P2
- Galileo: E1 & E5a
- BeiDou: B1I & B2I
- QZSS: C1 & C2

The corresponding equation for the offset between the local clock and the satellite clock is:

$$t_{clock} - t_{sat} = \frac{1}{c}\left[\bar{P}_{IF} - \left\|\overrightarrow{x_{sat}} - \overrightarrow{x_{rec,IF}}\right\| - S\right] + \Delta t_{rel} - \Delta t_{tropo} - GD \qquad (4)$$

where the group delay GD is equal to zero if the broadcast satellite clock corresponds to the same dual-frequency combination. Note that the position is here $\overrightarrow{x_{rec,IF}}$, i.e. the antenna phase center corresponding to the ionosphere-free combination used.

Dual-frequency users should also determine the "measured ionospheric delay" which would be the ionospheric delay for the pseudorange of the highest among the two frequencies used in the ionosphere-free combination. This measured ionospheric delay can be easily obtained as

$$m_{iono} = \frac{1}{c}\,(1-\alpha_{ij})[\bar{P}_i - \bar{P}_j] - GD \tag{5}$$

2.3.3 Corrections common to Single- and Dual-frequency users

The satellite position, the group delay and the relativistic clock correction have to be computed using the broadcast navigation messages, which are identified by the Issue of ephemeris (IOE). The same IOE for a given satellite should be used for the whole 13-minute track. Only the freely accessible FNAV message will be used for the Galileo satellites, as it is associated with the dual-frequency combination of E1 and E5a which is the one to be used for a dual-frequency CGGTTS. The group delay to be used for the different constellations is TGD (Total Group Delay) for GPS (P1-P2), $-T_{GD1}$ for BeiDou (B1-B3), TGD for QZSS (L1C/A-L2C) and BGD (Broadcast Group Delay) for Galileo (E1-E5a); no group delay is to be considered for GLONASS.

The tropospheric refraction delay correction is computed using the standard NATO hydrostatic model given in [13] for the satellites of all the systems:

$$\Delta t_{tropo} = f(e) * \Delta R(h) \tag{6}$$

where *f(e)* is a function of the elevation:

$$f(e) = \frac{1}{\sin(e) + \frac{0.00143}{\tan(e) + 0.0455}}$$

and $\Delta R(h)$ is the total tropospheric delay at the zenith: for a receiver located at an altitude h (in km). $\Delta R(h)$ is to be computed as

$$\Delta R(h) = \frac{1}{c}[2162 + N_s(1-h) + 0.5\Delta N(1-h^2)]10^{-3} \quad \text{for } h < 1 \text{ km}$$

$$\Delta R(h) = \frac{1}{c}\left[732 - 8\frac{N_s+\Delta N}{Nslog}\left(e^{-Nslog} - e^{0.125(1-h)Nslog}\right)\right]10^{-3} \text{ for } h > 1 \text{ km}$$

where N_s=324.8 is the refractivity index at the mean sea level

$\Delta n = -7.32\, e^{0.005577Ns}$

$Nslog = ln((N_s+\Delta n)/105)$

For each of the 52 (resp. 26) epochs, the broadcast satellite clock offset with respect to the reference time scale of the GNSS is then added to the result of (2) or (4), which gives:

$$t_{clock} - t_{ref} = (t_{clock} - t_{sat}) + \Delta t_{sat} \quad (7)$$

with $\Delta t_{sat} = t_{sat} - t_{ref}$.

2.3.4 Final results to be provided

At the end of the track, a number of linear fits are performed:

A. One linear fit treats the 52 (resp. 26) data resulting from equations (2) and (4). The estimation of this fit at the midpoint of the 13-minute interval is then retained as REFSV and the slope is named as SRSV.
B. One linear fit treats the 52 (resp. 26) data resulting from equation (7). The estimation of this fit at the midpoint of the 13-minute interval is then retained as REFSYS, the slope is named as SRSYS and the root mean square of the individual data around the regression is named as DSG.
C. One linear fit treats the 52 (resp. 26) data obtained for the modeled tropospheric delay Δt_{tropo} from equation (6). The estimation of this fit at the midpoint of the 13-minute interval is then retained as MDTR and the slope is named as SMDT.
D. One linear fit treats the 52 (resp. 26) data obtained for the modeled (for single-frequency users) or measured (for dual-frequency users) ionospheric delay as in equations (2) and (5). The estimation of this fits at the midpoint of the 13-minute interval is then retained as MDIO and the slope SMDI.
E. One linear fit treats the 52 (resp. 26) data obtained for existing measured ionospheric delay, if available. The estimation of this fit at the midpoint of the 13-minute interval is then retained as MSIO and the slope is named as SMSI. These results are the same as MDIO and SMDI for dual-frequency users.

The other columns to be provided contain the starting epoch of each track, the satellite elevation and azimuth at the mid-point of the track, the issue of ephemeris IOE. This is given in the navigation message of GPS, Galileo and QZSS satellites. For GLONASS navigation messages the IOE will correspond to the item number from 1 to 96, corresponding to the date of the ephemeris used, given by the number of the quarter of an hour in the day, with 1 being the ephemeris date (Time of clock) 00h00m00s. For BeiDou satellites, the hour of the Time of Clock will be used, from 0 to 23.

These results are then all reported in the output CGGTTS file using the format described in the next section.

3. STANDARD FORMAT

3.1 File name

As the position of the antenna phase center is frequency-dependent, and as the signals of the different constellations are measured on different frequencies, the antenna phase center coordinates are different for the different constellations. For this reason, the CGGTTS results will be provided in separate files for the different constellations, and for a given constellation the files will report only for one given single-frequency code, or one given dual-frequency combination.

The BIPM data submission guideline giving the standard names for the GNSS data files is therefore updated accordingly. The files names should be on the form: XFLLmodd.ddd
where

- X is the code character indicating the constellation, using the same convention as in the RINEX standard :
  "G" for a GPS ,
  "R" for a GLONASS (R stands for Russia),
  "E" for Galileo (Europe),
  "C" for BeiDou (China),
  "J" for QZSS (Japan),
- F is the code character indicating the frequencies and channels:
  "S" a Single-frequency single-channel observation file
  "M" for a single-frequency multi-channel observation file
  "Z" for a dual frequency observation file (always multi-channel)
- LL is the two alphabetical character code for the laboratory
- m is the receiver identification first character (to be chosen by the laboratory), it can be "_" if not applicable or "0 to 9"
- o is the receiver identification second character (to be chosen by the laboratory), it can be "_" if not applicable or "0 to 9"
- dd.ddd is the MJD of the first observation in the file

3.2 File header

Line 1: `"CGGTTS•••••GENERIC•DATA•FORMAT•VERSION•=•2E"`
Title to be written,
18 columns.

Line 2: `REV•DATE•=•YYYY-MM-DD`
Revision date of the header data, changed when 1 parameter given in the header is changed. YYYY-MM-DD for year, month, and day.
21 columns.

Line 3: `RCVR•=•MAKER•TYPE•SERIAL_NUMBER•YEAR•SOFTWARE_NUMBER`
Maker acronym, type, serial number, first year of operation, and eventually software number of GNSS time receiver or of a R2CGGTTS software.
As many columns as necessary.

Line 4: `CH•=•NUMBER_OF_CHANNELS`
Number of receiver channels separately for GPS, GLONASS, GALILEO, BEIDOU, …
As many columns as necessary.

Line 5: `IMS•=•MAKER•TYPE•SERIAL_NUMBER•YEAR•SOFTWARE_NUMBER`
Ionospheric Measurement System (if any): Maker acronym, type, serial number, first year of operation, and eventually software number.
`IMS•=•99999` if none.
Similar to line 3 if included in the time receiver.
As many columns as necessary.

Line 6: `LAB•=•LABORATORY`
Acronym of the laboratory where observations are performed.
As many columns as necessary.

Line 7: `X•=•X_COORDINATE•m`
X coordinate in the ITRF of the antenna phase center for the frequency or combination used, in m and given with at least 2 decimals.
As many columns as necessary.

Line 8: `Z•=•Y_COORDINATE•m`
Y coordinate in the ITRF of the antenna phase center for the frequency or combination used, in m and given with at least 2 decimals.
As many columns as necessary.

Line 9: `Z•=•Z_COORDINATE•m`
Z coordinate in the ITRF of the antenna phase center for the frequency or combination used, in m and given with at least 2 decimals.
As many columns as necessary.

Line 10: `"FRAME•=•FRAME"`
Designation of the reference frames, and if necessary transformation parameters between GNSS frames.
As many columns as necessary.

Line 11: "COMMENTS•=•COMMENTS"

Any comments about the coordinates, for example the method of determination or the estimated uncertainty. Any comments about the corrections, such as the identification of the set of any C-code/P-code biases applied.
As many columns as necessary.

In the standard situation, line 12 provides INTDLY values and line 13 CABDLY values. If SYSDLY values are provided instead of INTDLY in line 12, line 13 is omitted and the line numbers given after should be decreased by 1.
If only the TOTDLY is provided, then it will appear in Line 12, lines 13 and 14 are omitted and the line numbers given after should be decreased by 2.
Line 12 will provide the information corresponding to the codes used in the data lines.

Line 12:

For single-frequency CGGTTS:
"INT•DLY•=•DDD.D•ns•(cons•code1)•••••CAL_ID•=•cccccccccccc"
For dual-frequency CGGTTS:
"INT•DLY•=•DDD.D•ns•(cons•code1), DDD.D•ns•(cons•code2) •••••CAL_ID•=•cccccccccccc"

The Internal delays (receiver + antenna) should be entered in ns and given with 1 decimal, only for the constellation and the code(s) used in the file. The parameter 'cons' will be GPS, GLO, GAL, BDS or QZS, and 'code1' and 'code2' will follow the convention provided in the third column of Table 1. The parameter "CAL_ID" is the reference to the calibration report where the internal delays are provided; its expression is detailed in the BIPM guidelines for calibration.
As many columns as necessary.

Line 13: "CAB•DLY•=•DDD.D•ns•"

Delays from the antenna to the main unit including delays in the filters, electronics and cable length, entered in the receiver and corresponding to the constellation of the file (GPS, GLONASS, GALILEO, QZSS, BDS), in ns and given with 1 decimal.
As many columns as necessary.

Line 14: "REF•DLY•=•DDD.D•ns"

Time delay between the local clock (or realization of UTC) and the receiver internal clock (or its conventional realization by an external signal), in ns and given with 1 decimal.
As many columns as necessary.

Line 15: "REF•=•REFERENCE"

Identifier of the time reference entered in the GNSS time receiver. For laboratories contributing to TAI it can be the 7-digit code of a clock or the 5-digit code of a local UTC, as attributed by BIPM.
As many columns as necessary.

Line 16: `"CKSUM•=•XX"`

Header check-sum: hexadecimal representation of the sum, modulo 256, of the ASCII values of the characters which constitute the complete header, beginning with the first letter "C" of line 1, including all spaces indicated as "␣" and corresponding to ASCII value 20 (hexadecimal), ending with the space after "=" of line 20 just preceding the actual check sum value, and excluding all carriage returns or line feeds.
10 columns.

Line 17: blank line.

3.3 Line header

3.3.1 Case 1: no measured ionospheric delays available (single-frequency results only),

For no ionospheric measurements available (IMS = 99999 in the header) the line header is as follows:

Line 18.1:

```
"SAT•CL••MJD••STTIME•TRKL•ELV•AZTH•••REFSV••••••SRSV•••••REFSYS••••SRSYS••DSG•IOE•MDTR•SMDT•MDIO•
SMDI•FR•HC•FRC•CK"
```

The acronyms are explained below.
113 columns.

3.3.2 Case 2: measured ionospheric delays available (single-frequency or dual-frequency results)

With ionospheric measurements available line header is as follows:

Line 18.2:

```
"SAT•CL••MJD••STTIME•TRKL•ELV•AZTH•••REFSV••••••SRSV•••••REFSYS••••SRSYS••DSG•IOE•MDTR•SMDT•MDIO•
SMDI•MSIO•SMSI•ISG•FR•HC•FRC•CK"
```

The acronyms are explained below.
127 columns.

3.4 Unit header

3.4.1 Case 1: measured ionospheric delays available (single-frequency or dual-frequency results)

Line 19.1:

```
"•••••••••••••hhmmss••s••.1dg•.1dg••••.1ns•••••.1ps/s•••••.1ns••••.1ps/s•.1ns•••••.1ns.1ps/s.1ns.
1ps/s••"
```

3.4.2 Case 2: no measured ionospheric delays available (single-frequency results only)

Line 19.2:

```
"•••••••••••••hhmmss••s••.1dg•.1dg••••.1ns•••••.1ps/s•••••.1ns••••.1ps/s•.1ns•••••.1ns.1ps/s.1ns.
1ps/s••••••••••••"
```

3.5 Data line

Line 20, columns 1–3: SAT

column 1 : the constellation code, and column 2-3: the satellite number, i.e. :

GPS – "G" followed by satellite PRN number, 01 to 38.
GLONASS – "R" followed by almanac slot number 01 to 24.
GALILEO – "E" followed by satellite PRN number, 01 to 30.
QZSS – "J" followed by broadcast satellite PRN minus 192, 01 to 05.
BEIDOU – "C" followed by satellite PRN number, 01 to 40.

Line 20, column 4: space, ASCII value 20 (hexadecimal).

Line 20, columns 5–6: CL

Common-view hexadecimal class byte. For multi-channel files, use "FF".

Line 20, column 7: space, ASCII value 20 (hexadecimal).

Line 20, columns 8–12: MJD

Modified Julian Day.

Line 20, column 13: space, ASCII value 20 (hexadecimal).

Line 20, columns 14–19: STTIME

Date of the start time of the 13-minute track .
In hour (2 characters), minute (2 characters) and second (2 characters), referenced to UTC.

Line 20, column 20: space, ASCII value 20 (hexadecimal).

Line 20, columns 21–24: TRKL

Track length. This value is 780 for full 13-minute tracks.
Unit: seconds.

Line 20, column 25: space, ASCII value 20 (hexadecimal).

Line 20, columns 26–28: ELV

Satellite elevation at the date corresponding to the midpoint of the track.
Unit: 0.1 degree.

Line 20, column 29: space, ASCII value 20 (hexadecimal).

Line 20, columns 30–33: AZTH

Satellite azimuth at the date corresponding to the midpoint of the track.

Unit: 0.1 degree.

Line 20, column 34: space, ASCII value 20 (hexadecimal).

Line 20, columns 35–45: `REFSV`
Time difference corresponding to the solution A in section 2.3.3
Unit: 0.1 ns.

Line 20, column 46: space, ASCII value 20 (hexadecimal).

Line 20, columns 47 – 52: `SRSV`
Slope corresponding to the solution A in section 2.3.3.
Unit: 0.1 ps/s.

Line 20, column 53: space, ASCII value 20 (hexadecimal).

Line 20, columns 54–64: " `REFSYS`
Time difference corresponding to the solution B in section 2.3.3
Unit: 0.1 ns.

Line 20, column 65: space, ASCII value 20 (hexadecimal).

Line 20, columns 66–71: `SRSYS`
Slope corresponding to the solution B in section 2.3.3.
Unit: 0.1 ps/s.

Line 20, column 72: space, ASCII value 20 (hexadecimal).

Line 20, columns 73–76: `DSG`
[Data Sigma] Root-mean-square of the residuals to linear fit from solution B in section 2.3.3.
Unit: 0.1 ns.

Line 20, column 77: space, ASCII value 20 (hexadecimal).

Line 20, columns 78–80: `IOE`
[Issue of Ephemeris] Three-digit decimal code indicating the ephemeris used for the computation. As no IOE is associated with the GLONASS navigation messages, the values 1-96 have to be used to indicate the date of the ephemeris used, given by the number of the quarter of an hour in the day, starting at 1=00h00m00s. For BeiDou, IOE will report the integer hour in the date of the ephemeris (Time of Clock).

Line 20, column 81: space, ASCII value 20 (hexadecimal).

Line 20, columns 82–85: `MDTR`
Modeled tropospheric delay corresponding to the solution C in section 2.3.3.
Unit: 0.1 ns.

Line 20, column 86: space, ASCII value 20 (hexadecimal).

Line 20, columns 87–90: `SMDT`
Slope of the modeled tropospheric delay corresponding to the solution C in section 2.3.3.
Unit: 0.1 ps/s.

Line 20, column 91: space, ASCII value 20 (hexadecimal).

Line 20, columns 92–95: `MDIO`
Modelled ionospheric delay corresponding to the solution D in section 2.3.3.
Unit: 0.1 ns.

Line 20, column 96: space, ASCII value 20 (hexadecimal).

Line 20, columns 97–100: `SMDI`
Slope of the modelled ionospheric delay corresponding to the solution D in section 2.3.3.
Unit: 0.1 ps/s.

Line 20, column 101: space, ASCII value 20 (hexadecimal).

3.5.1 Case 1: single-frequency results, no measured ionospheric delays available

Line 20.1, columns 102–103: `FR`
GLONASS transmission frequency channel number, 1 to 24. For other GNSS set to 0.

Line 20.1, column 104: space, ASCII value 20 (hexadecimal).

Line 20.1, columns 105–106: `HC`
Receiver hardware channel number. 0 to 99 (0 if unknown).

Line 20.1, column 107: space, ASCII value 20 (hexadecimal).

Line 20.1, columns 108–110: `FRC`
GNSS observation code according to the same denomination as in the 4th column of Table 1.

Line 20.1, column 111: space, ASCII value 20 (hexadecimal).

Line 20.1, columns 112–113: `CK`
Data line check-sum for columns 1 to 111: hexadecimal representation of the sum modulo 256, of the ASCII values of the characters which constitute the data line from column 1 to column 111 (both included).

Line 20.1, columns 114–140:
Optional comments on the data line, constituted of characters which are not included in the line check-sum CK.

3.5.2 Case 2: measured ionospheric delays available (single-frequency or dual-frequency results)

Line 20.2, columns 102–105: `MSIO`
Measured ionospheric delay corresponding to the solution E in section 2.3.3.
Units: 0.1 ns.

Line 20.2, column 106: space, ASCII value 20 (hexadecimal).

Line 20.2, columns 107–110: `SMSI`
Slope of the measured ionospheric delay corresponding to the solution E in section 2.3.3.
Units: 0.1 ps/s.

Line 20.2, column 111: space, ASCII value 20 (hexadecimal).

Line 20.2, columns 112 – 114: `ISG`
[Ionospheric Sigma] Root-mean-square of the residuals corresponding to the solution E in section 2.3.3.
Units: 0.1 ns.

Line 20.2, column 115: space, ASCII value 20 (hexadecimal).

Line 20.2, columns 116–117: `FR`
GLONASS transmission frequency channel number. 1 to 24. For other GNSS set to 0.

Line 20.2, column 118: space, ASCII value 20 (hexadecimal).

Line 20.2, columns 119–120: `HC`
Receiver hardware channel number. 0 to 99 (0 if unknown).

Line 20.2, column 121: space, ASCII value 20 (hexadecimal).

Line 20.2, columns 122–124: FRC
GNSS observation code according to the denomination as in the 4th column of Table 1.

Line 20.2, column 125: space, ASCII value 20 (hexadecimal).

Line 20.2, columns 126–127: CK
Data line check-sum for columns 1 to 125: hexadecimal representation of the sum modulo 256, of the ASCII values of the characters which constitute the data line from column 1 to column 125 (both included).

Line 20.2, columns 128–154:
Optional comments on the data line, constituted of characters which are not included in the line check-sum CK.

Table 1. Code denomination to be used in CGGTTS V2E

RINEX convention (RINEX 3.02)	Detail	Header INTDLY/SYSDLY/TOTDLY	Column FRC
C1C	GPS/GLONASS/QZSS/SBAS L1 C/A,	C1	L1C
C1P	GPS/GLONASS L1P	P1	L1P
C1x*	GALILEO E1 QZSS L1C BEIDOU B1i	E1 C1 B1	•E1 L1C B1i
C2C	GLONASS L2 C/A	C2	
C2P	GPS/GLONASS L2P	P2	
C2x*	GPS/QZSS L2C	C2	
C5x*	GALILEO E5a	E5a	
C7x*	BEIDOU B2i	B2	
Dual-Frequency Combinations			
GPS	C1 or P1 & C2 or P2		L3P
Galileo	E1 & E5a		L3E
BeiDou	B1i & B2i		L3B
GLONASS	C1 or P1 & C2 or P2		L3P
QZSS	C1 & C5		L3Q

*where x is the channel attribute in Rinex 3.02.

4. LIST OF CHANGES BETWEEN CGGTTS V02 AND V2E

This section reproduces the list of the changes in the CGGTTS format from 02 to 2E. The changes in the result lines are provided only for GPS and GLONASS.

1. No mixed CGGTTS files will be provided, each file will contain only the results for a given constellation and all the results reported will be associated with the same code measurement or the same ionosphere-free combination.
2. The CGGTTS applies only for single-frequency results in the L1 frequency band, and only one ionosphere-free combination per constellation (see Table 1).
3. The first line of the header is now:
   CGGTTS GENERIC DATA FORMAT VERSION = 2E
4. The number of lines in the header can be variable as the hardware delays can be presented as SYSDLY (INTDLY+CABDLY) or TOTDLY (INTDLY+CABDLY+REFDLY)
5. The CAL_ID must appear after the INTDLY (or SYSDLY or TOTDLY)
6. The title "PRN" in the line header is replaced by "SAT"
7. The constellation code (first column of result lines) for GPS was blank, it is now "G"
8. The constellation code (first column of result lines), was "1" for GLONASS, is now "R"
9. The Issue of Ephemeris (IOE) for GLONASS which was not specified is now defined as the index between 1 and 96

An example of CGGTTS files is provided in Annex 1 for two particular cases, GPS single-frequency with no ionospheric measurements available, and GLONASS dual-frequency measurements.

5. DISCUSSION AND CONCLUSION

This paper presents the Version 2E of the standard for time transfer CGGTTS, i.e. Common GNSS Generic Time Transfer Standard. This extended version includes all the constellations presently available, i.e. GPS, GLONASS, BeiDou, Galileo, and QZSS. The compatibility has been assured so that both V2E and V02 can be combined without any degradation of the performances, and software reading V02 require a minimum adaptation to read V2E. The conventional tracking schedule as well as the 13-minute track length was maintained in order to assure an optimal compatibility between current version 02 and this extended version 2E. Some different schedule and track length were proposed in the past [14], allowing a more regular sampling of the clock solutions, and a use of more data samples. Of course this kind of approach can exist for specific studies, but should not be called CGGTTS and should not follow CGGTTS file naming conventions in order to avoid confusion in case of data exchange. The choice of GNSS signals to be used in the CGGTTS has also been limited to one single-frequency and one dual-frequency combination per constellation. In the case of pseudo-CGGTTS files created following a different track length and/or observation schedule, the user should take care of the differences at the processing stage, e.g. in interpolating one of the files.

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ANNEX

Examples of CGGTTS V2E files

Case 1: no ionospheric measurements available, single-frequency results only.

```
CGGTTS     GENERIC DATA FORMAT VERSION = 2E
REV DATE = 2014-02-20
RCVR = RRRRRRRRR
CH = 12
IMS = 99999
LAB = ABC
X = +4027881.79 m (GPS)
Y =  +306998.67 m (GPS)
Z = +4919499.36 m (GPS)
FRAME = ITRF
COMMENTS = NO COMMENTS
SYS DLY =  237.0 ns (GPS C1)     CAL_ID = 1nnn-yyyy
REF DLY =  149.6 ns
REF = UTC(ABC)
CKSUM = 3B

SAT CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFSYS    SRSYS  DSG IOE MDTR SMDT MDIO SMDI FR HC FRC CK
             hhmmss  s  .1dg .1dg    .1ns     .1ps/s     .1ns    .1ps/s .1ns     .1ns.1ps/s.1ns.1ps/s
G 6 FF 57000 000600  780 185  754     -234764   -125         -36      -52   26  57  252  -36   64  +25  0  0 L1C E8
G17 FF 57000 000600  780  80  367    +1426632    -13         -34      -37   33   1  559 +393   67  +64  0  0 L1C D0
G25 FF 57000 000600  780 494 2568     -103408    +28         -35       +7    8  38  106  -11   57   -9  0  0 L1C A8
```

Case 2: ionospheric measurements available, single-frequency or dual-frequency results

```
CGGTTS     GENERIC DATA FORMAT VERSION = 2E
REV DATE = 2014-02-20
RCVR = RRRRRRRRR
CH = 12
IMS = IIIIIIIII
LAB = ABC
X = +4027881.79 m
Y =  +306998.67 m
Z = +4919499.36 m
FRAME = ITRF, PZ-90->ITRF Dx = 0.0 m, Dy = 0.0 m, Dz = 0.0 m, ds = 0.0, Rx = 0.0, Ry = 0.0, Rz = 0.000000
COMMENTS = NO COMMENTS
INT DLY =   53.9 ns (GLO C1),   49.8 ns (GLO C2)     CAL_ID = 1nnn-yyyy
CAB DLY =  237.0 ns
REF DLY =  149.6 ns
REF = UTC(ABC)
CKSUM = 3B

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
R24 FF 57000 000600  780 347  394    +1186342     +0         163     +0   40   2  141  +22   23   -1   23   -1  29 +2  0 L3P 5C
R05 FF 57000 000600  780  70 2325      +22617     +6         165     -3   53   2  646 +606  131   -9  131   -9  37 +1  0 L3P 8C
R17 FF 57000 000600  780 539 1217    -1407831    -36         154    -54   20   2  100   -8   24   +0   24    0  13 +4  0 L3P 7A
R16 FF 57000 000600  780 370 3022     +308130    -18         246    -28   29   2  134  -22   63   +4   63    4  21 -1  0 L3P 80
```