PROGRESS ON GPS STANDARDIZATION

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Abstract

It has been clear for some time that a desirable and necessary step for improvement of the accuracy of GPS time comparisons is to establish GPS standards which may be adopted by receiver designers and users. For this reason, a formal body, the CCDS Group on GPS Time Transfer Standards (CGGTTS), was created in 1991. It operates under the auspices of the permanent CCDS Working Group on TAI, with the objective of recommending procedures and models for operational time transfer by the GPS common–view method. It works in close cooperation with the Subcommittee on Time of the Civil GPS Service Interface Committee.

The members of the CGGTTS have met in December 1991 and in June 1992. Following these two formal meetings, a number of decisions have been taken for unifying the treatment of GPS short–term data and for standardizing the format of GPS data files. A formal CGGTTS Recommendation is now being written concerning these points. This paper relates on the work carried out by the CGGTTS.

INTRODUCTION

At present the accuracy of worldwide time transfer using GPS in common view can reach the level of a few nanoseconds provided that some precautions are taken (accurate GPS coordinates, measured ionospheric delays and precise ephemerides) [1]. But at such a level of accuracy other problems arise. These arise mainly from the lack of standardization in commercial GPS receiver software and hardware, and there is also a need to remove SA effects [2, 3].

A group of fifteen experts has been formed for drawing on user and manufacturer standards for GPS time receivers to be used for common–view time transfer. This group, the CCDS Group on GPS Time Transfer Standards (CGGTTS) operates under the auspices of the permanent Working Group on TAI of the Comité Consultatif pour la Définition de la Seconde.

The CGGTTS can undertake formal actions. These actions are considered by the CCDS, which in turn may choose to transmit some of them in the form of recommendations to the Comité

International des Poids et Mesures and then to the Conférence Générale des Poids et Mesures. The CGGTTS is complementary to the Subcommittee on Time of the CGSIC (Civil GPS Service Interface Committee) which is mainly a forum for the exchange of information between the US military operators of GPS and the civil timing community.

The CGGTTS organized an open forum on GPS standardization, which was immediately followed by the first formal meeting in Pasadena (California, USA) in December 1991. The minutes are available from the Secretary of the CGGTTS (BIPM). These minutes, sent in March 1992 to national timing centers and to GPS receiver manufacturers, include a proposed GPS data format and a letter calling for feedback. The discussion was then open and the members of the CGGTTS, taking the opportunity offered by the CPEM'92, decided to meet in Paris on 11 June 1992. The objective set for this 2nd formal meeting was to take a final decision about the GPS data format and to agree on its schedule of implementation. Formally, these decisions should be written in a CGGTTS Recommendation.

DECISIONS TAKEN DURING THE 2ND FORMAL MEETING

The detailed discussion held during the 2nd formal meeting in Paris can be found in 'The Report of the 2nd Meeting of the CCDS Group on GPS Time Transfer Standards'. This Report is available from the Secretary of the CGGTTS (BIPM). Here only a brief summary is given.

1. Implementation of new software in GPS time receivers

The National Institute of Standards and Technology (NIST, Boulder, Colorado, USA) is ready to prepare new EPROMs to incorporate in present GPS time receivers of the NIST type. The final version of these available by June 1993.

The NIST–type GPS time receivers are either prototypes, made by NIST, or commercially available devices made by Allen Osborne Associates (California, USA). NIST will send new EPROMs to laboratories equipped with NIST prototypes. Allen Osborne Associates should provide new EPROMs to laboratories equipped with commercial NIST type receivers. These EPROMs will be copies of NIST EPROMs. Other GPS time receiver manufacturers will have to prepare and distribute their own EPROMs.

2. Reference time scale, start–time and mid–point of a GPS track

The CGGTTS adopted the international time scale UTC as unique reference time scale to monitor GPS tracks. It follows that the BIPM must issue a new type of International GPS Tracking Schedule in which start–times of tracks, defined as the actual first UTC second of satellite observation, are explicitly given. Possibly Schedule n22 (December 1993) will be of this new type. In addition, the track–length is definitively chosen by the CGGTTS to be 13 minutes (780s).

The choice of UTC as the reference time scale, of the actual first second of observation as the definition of the start–time of a track, and of 780s as the fixed track–length, allows the computation of strict common–views (i.e. synchronised to within the 1s) necessary to reduce on–board clock dither effects, brought about by SA, to less than a nanosecond.

The CGGTTS next decided that most of the quantities reported in the GPS data files should be reported at the actual mid–point of the track, defined as the mid–point of the actual observation.

3. Short–term data processing

The CGGTTS defined a standard for how short–term data should be processed in the receiver. This is explicitely given in Annex I of this paper.

The CGGTTS also insisted on the necessity of using standardized models, in particular for estimating ionospheric and tropospheric delays, when these models are already proposed in the Interface Control Document of the US Department of Defense or in the NATO Standardization Agreement (STANAG).

The observation results, i.e. the time differences [Local reference clock – GPS time] reported for each track, must include the estimation of ionospheric and tropospheric delays as obtained through these models. Room is available somewhere else in the GPS data file for reporting measured atmospheric delays.

4. Data format

The detailed data format chosen by the CGGTTS is given in Annex II of this paper. Only some specific remarks are given here:

- The Modified Julian Date (MJD) is not truncated, i.e. it is given in 5 columns.
- All quantities, including satellite elevation and azimuth, results of observations and estimates of modelled or measured tropospheric and ionospheric delays, are reported at the mid–point of the track, except the time of the track, given in hours, minutes and seconds, which is reported at the start–time of the track.
- A file header is created. It includes the name of the receiver maker, the receiver type, the receiver serial number, the software version number, the channel number, the description of the ionospheric measurement system, the name of the laboratory, the coordinates of the station and different delays entered in the receiver.
- The parameter Issue of Data Ephemeris, which identifies the broadcast ephemerides used by the receiver to compute pseudo–ranges during a given track is added to the format.
- Occasionaly missing data are represented by a series of successive 9s.

5. Other problems

The CGGTTS recalled that an additional step towards increased accuracy would be the use of a semi–empirical model for estimating tropospheric delays. It would be then necessary to record outside environmental parameters such as temperature, humidity and pressure.

The CGGTTS could take the opportunity of EPROMs change to ask makers for the implementation of an option allowing the output of short–term data and of all parameters and fundamental constants used by the receiver. The CGGTTS also suggested that GPS time receivers should be able to cover the 24 hours of a day with regular tracks.

CONCLUSIONS

A Draft Recommendation including the conclusions of the discussions held during the 2nd formal meeting of the CGGTTS has been prepared and is given below. A 3rd formal meeting of the CGGTTS will be necessary for reaching a definitive agreement about this Recommendation, which may be proposed at the CCDS during its next meeting (March 1993).

REFERENCES

[1] Lewandowski W., Petit G., Thomas C., *"Accuracy of GPS Time Transfer Verified by the Closure around the World,"* In Proc. 23rd PTTI, 1991, 331–339.

[2] Lewandowski W., Petit G., Thomas C., *"GPS Standardization for the Needs of Time Transfer,"* In Proc. 6th EFTF, 1992, 243–248.

[3] Lewandowski W., Petit G., Thomas C., *"The Need for GPS Standardization,"* In Proc. 23rd PTTI, 1991, 1–13.

DRAFT RECOMMENDATION

The CCDS Group on GPS Time Transfer Standards,

considering

- that the observation, using the common–view method, of satellites of the Global Positioning System, is one of the most precise and accurate methods for time comparison between remote clocks kept on the Earth or in its close vicinity,

- that this method has demonstrated capabilities for providing accuracy at the level of 1ns, when using accurate GPS antenna coordinates, post–processed precise satellite ephemerides, measured ionospheric delays and the results of campaigns of differential receiver calibration,

- the need for removing the effects of Selective Availability, currently implemented on Block II satellites,

- the lack of standardization in commercial GPS time receiver software, which threatens the sub–nanosecond level in the accuracy of GPS time transfer,

recommends,

- the use of UTC as the unique reference time scale for monitoring GPS satellite tracks,
- that the BIPM continues to prepare the regular International GPS Tracking Schedule, for observation of GPS satellites in common–view, in which the *time of a track* is characterized by the start of the first second of observation and in which the length of each track is fixed to 780s,
- that short–term data processing be performed according to a unique method detailed in Annex I,
- that all modelled procedures, parameters and constants, needed in short–term data processing be deduced from the information given in the Interface Control Document of the US Department of Defense or in the NATO Standardization Agreement (STANAG), and be updated at each new issue,
- that short–term data, parameters and constants used by GPS time receiver software be output according to the user's will, thanks to the implementation of an adequate option in the receiver operation,
- that GPS time receiver should be able to cover the twenty–four hours of a day with regular tracks,
- that GPS data be recorded and transmitted in data files arranged according to the data file format given in Annex II, including in particular a header with detailed information, and where most of the quantities are reported at the actual mid–time of tracks.
- that GPS time receiver manufacturers act towards the concrete implementation of these new dispositions.

ANNEX I

GPS short–term data processing

Short–term data processing is performed as follows:

i) Pseudo–range data measurements are taken every second, the first second corresponding to the nominal starting time of the track.

ii) A least–squares quadratic fit is applied to periods of 15s length, the quadratic fit result is estimated at the mid–point of the 15s period.

iii) Broadcast ephemeris and other broadcast and modelled parameters are evaluated at the time corresponding to the mid–point of the same 15s period; these corrections are applied to the results of ii).

iv) The nominal track length is 780s.

v) At the end of the track, a least–squares linear fit is performed to all the data resulting from iii). The result of this linear fit is made up of an estimate of the quantity to be measured, reported at the mid–point of the actual track, and of a slope and a rms given in the GPS data file.

ANNEX II

CCDS GPS Data Format Version 1

The CCDS GPS Data Format Version 1 is composed of:

i) a file header with detailed information on the GPS equipment (line 1 to 12),

ii) a blank line (line 13),

iii) a line header with the acronyms of the reported quantities (line 14),

iv) a unit header with the units used for the reported quantities (line 15),

v) a series of data lines, one line corresponding to one GPS track. The data lines are ordered in increasing chronological order (line 16, 17, 18, etc.).

Note: * stands for a blank and text to be written in the data file is indicated between ' '.

1. File header

Line 1: 'CCDS*GPS*DATA*FORMAT*VERSION*1'
Title to be written. Minimum 30 columns.

Line 2: MAKER*TYPE*SERIAL NUMBER*YEAR*SOFTWARE NUMBER
Name, type, serial number, first year of operation,
and eventually software number of the GPS time receiver.
As many columns as necessary.

Line 3: 'CH*=*'CHANNEL NUMBER
Number of the channel used to produce the data included in the file,
CH = 1 for a one-channel receiver. Minimum 5 columns.

Line 4: MAKER*TYPE*SERIAL NUMBER*YEAR (IONO CALIB)
Name, type, serial number, and first year of operation of the equipment used for ionospheric measurements. Blank if none.
Similar to line 2 if included in the time receiver.
As many columns as necessary.

Line 5: LABORATORY
Acronym of the laboratory where observations are performed.
As many columns as necessary.

Line 6: 'X*=*' X COORDINATE 'm'
X coordinate of the GPS antenna, in m and given with 2 decimals.
As many columns as necessary.

Line 7: 'Y*=*' Y COORDINATE 'm'
Y coordinate of the GPS antenna, in m and given with 2 decimals.
As many columns as necessary.

Line 8: 'Z*=*' Z COORDINATE 'm'
Z coordinate of the GPS antenna, in m and given with 2 decimals.
As many columns as necessary.

Line 9: 'INT*DLY*=*' INTERNAL DELAY 'ns'
Internal delay entered in the GPS time receiver,
in ns and given with 1 decimal. As many columns as necessary.

Line 10: 'CAB*DLY*=*' CABLE DELAY 'ns'
Delay coming from the cable length from the GPS antenna to the main unit, entered in the GPS time receiver,
in ns and given with 1 decimal. As many columns as necessary.

Line 11: 'REF*DLY*=*' REFERENCE DELAY 'ns'
Delay coming from the cable length from the reference output to the main unit, entered in the GPS time receiver,
in ns and given with 1 decimal. As many columns as necessary.

Line 12: REFERENCE
Identifier of the time reference entered in the GPS time receiver,
it can be for instance a clock number or a local UTC.
As many columns as necessary.

Line 13: blank line.

2. Line header

Line 14: 'PRN*CL**MJD**HHMMSS*TRKL*ELV*AZTH***REFSV*****
*SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*'
Line to be written when no ionospheric measurement system is in operation. The acronyms are explained in 4. 101 columns.

or

Line 14: Line 14: 'PRN*CL**MJD**HHMMSS*TRKL*ELV*AZTH***REFSV*****
*SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*
MSIO*SMSI*ISG*'
Line to be written when a ionospheric measurement system is in operation. The acronyms are explained in 4. 115 columns.

3. Unit header

Line 15: '**************UTC****s**.1dg*.1dg****.1ns*****
.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s'
Line to be written when no ionospheric measurement system is in operation. 101 columns.

or

Line 15: '**************UTC****s**.1dg*.1dg****.1ns*****
.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s
.1ns.1ps/s.1ns'
Line to be written when a ionospheric measurement system is in operation.
115 columns.

4. Data line

Line 16: column 1: blank.

Line 16: columns 2-3: '12' PRN
Satellite vehicle PRN number. No unit.

Line 16: column 4: blank.

Line 16: columns 5-6: '12' CL
Hexadecimal class byte. No unit.

Line 16: column 7: blank.

Line 16: columns 8-12: '12345' MJD
Modified Julian Day. No unit.

Line 16: Line 16, column 13: blank.

Line 16: Line 16, columns 14-19: '121212' HHMMSS
Hour, minute, second at the beginning of the track.
In hour, minute and second referenced to UTC.

Line 16: column 20: blank.

Line 16: columns 21-24: '1234' TRKL
Track length. In s.

Line 16: column 25: blank.

Line 16: columns 26-28: '123' ELV
Satellite elevation at the mid-point of the track. In 0.1 degree.

Line 16: column 29: blank.

Line 16: columns 30-33: '1234' AZTH
Satellite azimuth at the mid-point of the track. In 0.1 degree.

Line 16: column 34: blank.

Line 16 columns 35-45: '+1234567890' REFSV
Time difference resulting from the treatment of Annex I, applied on short-term measurements of [Reference Clock - Satellite Clock], reported at the mid-point of the track. In 0.1ns.

Line 16: column 46: blank.

Line 16: columns 47-52: '+12345' SRSV
Slope resulting from the treatment of Annex I, applied on short-term measurements of [Reference Clock - Satellite Clock]. In 0.1ps/s.

Line 16: column 53: blank.

Line 16: columns 54-64: '+1234567890' REFGPS
Time difference resulting from the treatment of Annex I, applied on short-term measurements of [Reference Clock - GPS time], reported at the mid-point of the track. In 0.1ns.

Line 16: column 65: blank.

Line 16: columns 66-71: '+12345' SRGPS
Slope resulting from the treatment of Annex I, applied on short-term measurements of [Reference Clock - GPS time]. In 0.1ps/s.

Line 16: column 72: blank

Line 16: columns 73-76: '1234' DSG
[Data Sigma] Root mean square of the linear fit performed on data measurements (see Annex I). In 0.1ns.

Line 16: column 77: blank.

Line 16: columns 78-80: '123' IOE
[Index of Ephemeris] Three digit decimal code (0-255) indicating the ephemeris used for this computation. No unit.

Line 16: column 81: blank.

Line 16: columns 82-85: '1234' MDTR
Modelled tropospheric delay at the mid-point of the track.
In 0.1ns.

Line 16: column 86: blank.

Line 16: columns 87-90: '+123' SMDT
Slope of the modelled tropospheric delay over all the track.
In 0.1ps/s.

Line 16: column 91: blank.

Line 16: columns 92-95: '1234' MDIO
Modelled ionospheric delay at the mid-point of the track.
In 0.1ns.

Line 16: column 96: blank.

Line 16: columns 97-100: '+123' SMDI
Slope of the modelled ionospheric delay over all the track.
In 0.1ps/s.

Line 16: column 101: blank.

Line 16: columns 102-105: '1234' MSIO
Measured ionospheric delay at the mid-point of the track.
In 0.1ns.

Line 16: column 106: blank.

Line 16: columns 107-110: '+123' SMSI
Slope of the measured ionospheric delay over all the track.
In 0.1ps/s.

Line 16: column 111: blank.

Line 16: columns 112-114: '123' ISG
[Ionospheric Sigma] Root mean square of the ionospheric measurement.
In 0.1ns.

Line 16: column 115: blank.

5. Conclusions

The format for one line of data can be represented as follows:

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0000000000000000000000000000000000000000000000
0000000001111111111222222222233333333334444444
1234567890123456789012345678901234567890123456
PRN*CL**MJD**HHMMSS*TRKL*ELV*AZTH***REFSV*****
**************UTC****s**.1dg*.1dg****.1ns*****
*12*12*12345*121212*1234*123*1234**+1234567890*
```

```
0000000000000000000000000000000000000000000000000011
4445555555555666666666677777777778888888888999999999900
7890123456789012345678901234567890123456789012345678901
*SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*
.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s
+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*
```

```
11111111111111
00000000111111
23456789012345
MSIO*SMSI*ISG*
.1ns.1ps/s.1ns
1234*+123*123*
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An example, made up with fictitious data is proposed in the formal Report of the 2nd Meeting of the CGGTTS, available from the BIPM.

QUESTIONS AND ANSWERS

Judah Levine, NIST, Boulder, Colorado: It would be very helpful if the new format maintained some form of error detection and error correction from the point of view of automatic receivers. We run a real time network of receivers in which all the data is acquired by machine in real time. It would be very helpful for us to have methods of detecting transmission errors. I think that it is particularly important in the header, since errors in the header field may result in interpreting the transmission differently. An error in the header field may result in the data becoming unreadable.

Mr. Petit: You are right. Actually, this format is the present status of the format, and is nearly the final form. If anything is to added, is is some kind of parity check, or a similar thing to make sure that, for example, each line is constituted correctly.