Rapport BIPM-93/6

TECHNICAL DIRECTIVES

FOR STANDARDIZATION OF GPS TIME RECEIVER SOFTWARE

to be implemented for improving the accuracy of GPS common-view time transfer

by

the Group on GPS Time Transfer Standards

a Sub-Working Group of the CCDS Working Group on improvements to TAI

October 1993

Foreword

Significant progress has been made by the Group on GPS Time Transfer Standards. Key experts from some of the principal timing centres along with some representation from the GPS manufacturing community have worked together as part of this Group toward the goal of one nanosecond accuracy for GPS common-view time transfer. This goal is necessary as we accommodate the improved clocks contributing to TAI and UTC.

The Group has identified two main areas contributing to inaccuracy:

> *1) limitations in the software and hardware of the different GPS receiver manufacturers, and*
> *2) limitations in past procedures as dictated by the past data format and methods of acquiring the data.*

Good cooperation has been found as the Group has shared the findings regarding limitations in receiver design. In addition a new format and set of procedures have been developed. This approved format is being shared with the international timing centres, the appropriate user community and with timing receiver manufacturers.

We anticipate with continued cooperation we shall continue to move towards the desired goal.

David W. Allan
Chairman GGTTS
July 1993

Contents

The members of the Group on GPS Time Transfer Standards are:
(in alphabetical order)

Dr. D.W. Allan, Allan's TIME, Fountain Green, UT, USA, *Chairman*,
Mr. D. Davis, NIST, Boulder, CO, USA,
Prof. T. Fukushima, NAO, Tokyo, Japan,
Mr. M. Imae, CRL, Kashima, Japan,
Ing. G. De Jong, VSL, Delft, The Netherlands,
Dr. D. Kirchner, TUG, Graz, Austria,
Prof. S. Leschiutta, Politecnico, Torino, Italy
Dr. W. Lewandowski, BIPM, Sèvres, France,
Mr. G. Petit, BIPM, Sèvres, France,
Dr. C. Thomas, BIPM, Sèvres, France, *Secretary*,
Dr. P. Uhrich, LPTF, Paris, France,
Dr. M.A. Weiss, NIST, Boulder, CO, USA,
Dr. G.M.R. Winkler, USNO, Washington, D.C., USA,

The following persons also gave their expert advice by participating to some of the meetings of the Group:

Mr J. Danaher, 3S NAVIGATION, Laguna Hills, CA, USA,
Dr. W. Klepczynski, USNO, Washington, D.C., USA,
Dr N. B. Kosheyalevsky, VNIIFTRI, Mendeleevo, Russia,
Mr. J. Levine, NIST, Boulder, CO, USA,
Mr P. Moussay, BIPM, Sèvres, France.
Dr. D. Sullivan, NIST, Boulder, CO, USA,
Dr. F. Takahashi, CRL, Tokyo, Japan,

Introduction

The observation, using the common-view method [1], of satellites of the Global Positioning System, is one of the most precise and accurate methods for time comparison between remote clocks on the Earth or in its close vicinity. This method has already demonstrated the capability to provide accuracy at the level of a few nanoseconds when using accurate GPS antenna coordinates, post-processed precise satellite ephemerides, measured ionospheric delays and results derived from exercises of differential receiver calibration [2].

Further improvement of the common-view method, towards a sub-nanosecond level of accuracy, is threatened by:

- the effects of Selective Availability (SA), an intentional degradation of GPS satellite signals now currently implemented on Block II satellites, and
- the lack of standardization in commercial GPS time receiver software, which do not treat short-term data according to unified procedures.

A group of experts has been formed to draw up standards to be observed by the users and manufacturers concerned with the use of GPS time receivers for common-view time transfer. This group, the Group on GPS Time Transfer Standards (GGTTS) operates under the auspices of the permanent Working Group on improvements of TAI, chaired by Dr G.M.R. Winkler, of the Comité Consultatif pour la Définition de la Seconde (CCDS). The Group is complementary to the Subcommittee on Time of the Civil GPS Service Interface Committee (CGSIC) which is mainly a forum for the exchange of information between the military operators of GPS and the civil timing community [3].

The Group organized an open forum on GPS standardization on 2 December 1991 in Pasadena, California, USA, and three formal meetings on 5 December 1991 in Pasadena, California, USA, on 11 June 1992 in Paris, France, and on 23 March 1993 at the BIPM, in Sèvres, France. A summary of the activities of the Group was presented during the 12th Session of the CCDS, on 24-26 March 1993 at the BIPM, in Sèvres, France, which, in turn, adopted the following Recommendation:

GPS time transfer standardization

Recommendation S 6 (1993)

The Comité Consultatif pour la Définition de la Seconde,

considering

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

- that this method has the potential for reaching an accuracy approaching 1 ns,

- the need for removing the effects of Selective Availability,

- the lack of standardization in GPS timing equipment,

- the need for absolute as well as relative calibration of GPS timing receiving equipment,

recommends

- that GPS timing receiver manufacturers proceed towards the implementation of the technical directive produced by the Group on GPS Time Transfer Standards,

- that methods be developed and implemented for frequent and systematic calibration of GPS timing receiving equipment.

The CCDS Recommendation S 6 (1993) is addressed to GPS timing receiver manufacturers and recommends them to implement the decisions of the Group on GPS Time Transfer Standards. It also emphasizes the need for both absolute and relative calibration methods.

The present document makes explicit Technical Directives for software standardization of single frequency C/A-Code GPS time receivers, eventually operating in tandem with a Ionospheric Measurement System, and to be implemented for improving the accuracy of GPS common-view time transfer performed with such devices. It lists the definitive conclusions of the Group, a more detailed account of its work being given in Refs 3 to 9.

Technical Directives

The Technical Directives issued by the Group on GPS Time Transfer Standards, for standardization of GPS time receiver software, and to be implemented for improving the accuracy of GPS common-view time transfer, are as follows:

1. The unique reference time scale to be used for monitoring GPS satellite tracks is Universal Coordinated Time, UTC, as produced and distributed by the BIPM.

2. Each GPS common-view track is characterized by the date of the first observation, given as a Modified Julian Date (MJD) together with a UTC hour, minute and second. The length of each track corresponds to the recording of 780 successive short-term observations, at intervals of 1 second, as described in Annex I.

3. The regular International GPS Tracking Schedule, for observation of GPS satellites in common-view, is prepared by the BIPM. The time of a track given in the BIPM International GPS Tracking Schedule is the date of the first observation.

Note:

A period of order 2 minutes is usually required to lock the receiver onto the satellite signal. The characteristic date of a track, as defined by Technical Directive No 2, is not given as the date of the beginning of the lock-on procedure, but as the date of the first actual observation used in short-term data reduction as explained in Annex I and Annex II. Following the practical implementation of the Technical Directives given in the present document, the dates given in the BIPM International GPS Tracking Schedule thus have a different meaning from that of earlier schedules.

4. The unique method approved for short-term data processing is that detailed in Annex II.

5. All modelled procedures, parameters and constants, needed in short-term data processing are deduced from the information given in the Interface Control Document of the US Department of Defense or in the NATO Standardization Agreement (STANAG). These are updated at each new issue.

6. The receiver software allows the local antenna coordinates to be entered in the form X, Y and Z.

7. An option in the operation of the receiver allows short-term data taken every second, data resulting from the standard treatment over 15 seconds detailed in Annex II, parameters and constants used in the software for the GPS time receiver to be output according to the user's will.

8. The GPS time receiver should have the capability to cover the twenty-four hours of a day with regular tracks, the number of daily tracks not being subject to artificial limitation.

Note:

A full-length track lasts 13 minutes, the receiver usually needs about 2 minutes for locking onto the signal, and 1 additional minute is helpful for data-processing and preparation for a new track, so that two consecutive

tracks are reasonably distant by 16 minutes. The twenty-four hours of a day correspond to 90 successive intervals of 16 minutes and are then covered with 89 full-length tracks, taking into account the 4-minute day-to-day recurrence of the satellite observation which prevents to have another 90th full-length track.

9. The GPS data are recorded and transmitted in data files arranged according to the data file format given in Annex III, which comprises in particular:
- a file header with detailed information concerning the receiver operation,
- a check-sum parameter for each data line in order to minimize errors in data transmission,
- most of the quantities reported at the actual mid-time of tracks, and
- optional additional columns, not included in the value of the check-sum, for comments and additional data.

Each line of the data file is terminated by a carriage-return and a line feed.
For multichannel GPS time receivers, one data file is created for each channel.

CONCLUSIONS

The technical directives listed in this document have been established by the members of the Group on GPS Time Transfer Standards after careful studies and numerous discussions. The Group is well aware of the volume of work which is requested of the receiver manufacturers and also of consequential changes for national laboratories.

The implementation of these directives however, will unify GPS time receiver software and avoid any misunderstandings concerning the content of GPS data files. Immediate consequences will be an improvement in the accuracy and precision of GPS time links computed through strict common views, as used by the BIPM for the computation of TAI, and improvement in the short-term stability of reference time scales like UTC.

REFERENCES

1. ALLAN D.W. and WEISS M.A., Accurate time and Frequency Transfer during Common-View of a GPS Satellite, In *Proc. 34th Ann. Symp. on Frequency Control,* 1980, 334-346.

2. LEWANDOWSKI W., PETIT G. and THOMAS C., Accuracy of GPS Time Transfer Verified by the Closure around the World, In *Proc. 23rd PTTI,* 1991, 331-339.

3. LEWANDOWSKI W., THOMAS C. and ALLAN D.W., CGSIC Subcommittee on Time and CCDS Group of Experts on GPS Standardization, In *Proc. ION GPS-91 4th International Technical Meeting,* 1991, 207-214.

4. LEWANDOWSKI W., PETIT G. and THOMAS C., The need for GPS standardization, *Proc. 23rd PTTI*, 1991, 1-13.

5. Minutes of the Open Forum on GPS Standardization, *BIPM publication*, 1991, 6 pages.

6. LEWANDOWSKI W., PETIT G. and THOMAS C., GPS standardization for the needs of time transfer, *Proc. 6th EFTF*, 1992, 243-248.

7. THOMAS C., Report of the 2nd meeting of the CCDS Group on GPS Time Transfer Standards, *BIPM publication*, 1992, 22 pages.

8. THOMAS C. (on behalf of the CGGTTS members), Progress on GPS standardization, In *Proc. 24th PTTI*, 1992, 17-30.

9. THOMAS C., Report of the 3rd meeting of the CCDS Group on GPS Time Transfer Standards, *BIPM publication*, 1993, 5 pages.

ANNEX I

STRUCTURE OF SHORT-TERM OBSERVATIONS

The GPS short-term observations are pseudo-range data taken every second. The pseudo-range data are measurements of a laboratory reference 1pps (1 pulse-per-second) signal against the 1pps signal received from the satellite, obtained using a time-interval counter or some equivalent method. Each pseudo-range measurement includes a value of the received signal integrated over a time which depends on the receiver hardware. This integration time should be 1 second or less.

In the following one given pseudo-range data is characterized by its date, *ie.* by a label with MJD and UTC hour, minute and second, corresponding to the date of the laboratory 1pps. The start time of a track, as given in the International GPS Tracking Schedule according to the Technical Directive No 3, is thus the date of the first pseudo-range data, which corresponds, in reality, to a received signal integrated over a time interval ending on this date. The International GPS Tracking Schedule is thus composed of a list of satellites to observe at a nominal start time referenced to UTC. Additional hexadecimal numbers, called common-view classes (CL) are added to characterize the common views between different regions of the Earth.

Here, for simplification, the start time of a track is designed as second 0. The successive pseudo-range data can be represented as in Figure AI.1.

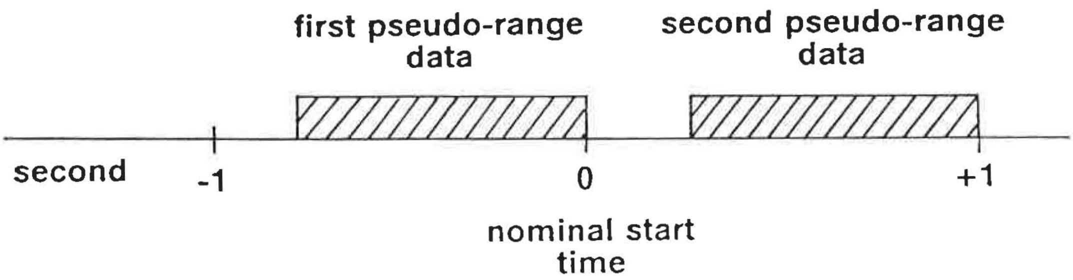

Figure AI.1. Successive pseudo-range data.

According to Annex II, the pseudo-range data are first processed through quadratic fits applied to successive and non-overlapping sets of 15 pseudo-range data. The first quadratic fit is thus applied to the pseudo-range data dated at seconds 0, 1,...14. The result of this first quadratic fit is given for the date corresponding to the midpoint, *ie.* to second 7.

The second quadratic fit is applied to the 15 following pseudo-range data, dated at seconds 15, 16,...29, thus each pseudo-range data is used once and only once. The result of this second quadratic fit is estimated at second 22.

The first dates of quadratic fits are thus seconds 0 [mod 15], the last dates of quadratic fits are seconds 14 [mod 15] and the dates of quadratic fit results are seconds 7 [mod15]. This can be represented as shown in Figure AI.2.

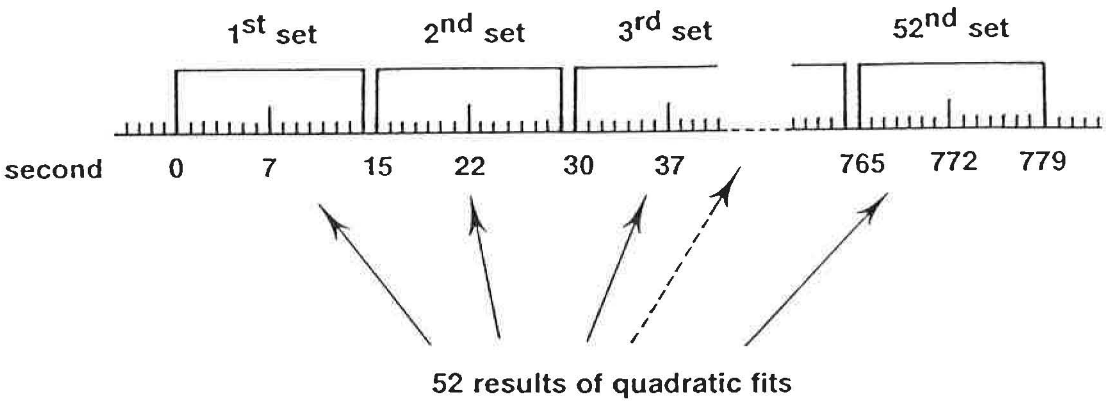

Figure AI.2. First dates of quadratic fits and dates of the results of quadratic fits.

According to Technical Directive No 2, each full track corresponds to the recording of 780 pseudo-range data, which are dated from second 0 to second 779. The process thus uses 52 sets of 15 data and performs 52 quadratic fits, whose results are dated at second 7, 22, ... 772. A linear fit is then applied to these results (see Annex II).

Notes:

- From the above, it appears that the duration of a full-length is equal to 779 s and not to 780 s, as is usually said. In fact, this is not true: as pseudo-range measurements are integrated over a time interval, the first begins before second 0 and the last ends at second 779. For simplification, the track length, appearing under the acronym TRKL, *is taken to be 780 s for full-length tracks, or to be the number of pseudo-range measurements for shorter tracks.*

- Several linear fits are performed to further reduce the quadratic fit results. The results of these linear fits are then estimated at the date corresponding to the middle of the actual track (see Annex III). This particular date does not appear in the data file, as only the starting date is reported. Rigourously it should be labelled second 389,5 for full-length tracks and does not correspond to an even second.

ANNEX II

PROCESSING OF GPS SHORT-TERM DATA TAKEN OVER A FULL TRACK

Data processing is performed as follows:

i) Pseudo-range data are recorded for times corresponding to successive dates at intervals of 1 second. The date of the first pseudo-range data is the nominal starting time of the track. It is referenced to UTC and appears in the data file under the acronyms MJD and STTIME.

ii) Least-squares quadratic fits are applied on successive and non-overlapping sets of 15 pseudo-range measurements dated according to Annex I. The quadratic fit results are estimated at the date corresponding to the midpoint of each set.

iii) Corrections listed below are evaluated at the dates corresponding to the results of ii) (see Annex I) and applied to these results:

iii-1) geometric delay from ground-antenna coordinates and broadcast ephemerides (fixed for a track),
iii-2) ionospheric delay from broadcast parameters,
iii-3) tropospheric delay,
iii-4) Sagnac correction,
iii-5) periodic relativistic correction due to the eccentricity of the GPS satellite's orbit*,
iii-6) L_1-L_2 broadcast correction,
iii-7) receiver delay,
iii-8) antenna and local-clock cable delays.

iv) Clock corrections for access to GPS time, as derived from a 2nd-order polynomial (usually written as $a_0+a_1t+a_2t^2$) whose coefficients are contained in the GPS message, are evaluated at the dates corresponding to the results of ii) and applied to the results of iii).

v) The nominal track length corresponds to the recording of 780 short-term measurements. The number of successive and non-overlapping data sets treated according to ii), iii) and iv) is then equal to 52 (see Annex I). For full tracks, the track length, TRKL, is taken equal to 780 s (see Annex I).

vi) At the end of the track, a number of least-squares linear fits are performed.

vi-a) One linear fit treats all the data resulting from iii); the result of this linear fit takes the form of an estimate of the quantity to be measured, REFSV, reported at the date corresponding to the midpoint of the actual track, and a slope, SRSV, given in the GPS data file.

vi-b) One linear fit treats all the data resulting from iv); the result of this linear fit takes the form of an estimate of the quantity to be measured, REFGPS, reported at the date corresponding to the midpoint of the actual track, a slope, SRGPS, and a rms, DSG, given in the GPS data file.

vi-c) One linear fit treats the modelled ionospheric corrections evaluated in iii-2); the result of this linear fit takes the form of an estimate of the modelled ionospheric delay, MDIO, reported at the date corresponding to the midpoint of the actual track, and a slope, SMDI, given in the GPS data file.

vi-d) One linear fit treats the modelled tropospheric corrections evaluated in iii-3); the result of this linear fit takes the form of an estimate of the modelled tropospheric delay, MDTR, reported at the date corresponding to the midpoint of the actual track, and a slope, SMDT, given in the GPS data file.

vi-e) One linear fit treats the measured ionospheric corrections obtained from a Ionospheric Measurement System, if available, at the dates corresponding to the results of ii); the result of this linear fit takes the form of an estimate of the measured ionospheric delay, MSIO, reported at the date corresponding to the midpoint of the actual track, a slope, SMSI, and a rms, ISG, given in the GPS data file.

* The constant part of the relativistic correction to the frequency, consisting of the gravitational red shift and the second order Doppler effect, is applied before launch to the satellite oscillators as a frequency offset.

Note:

The Group on GPS Time Transfer Standards gives a tolerance for data which is not in the form of pseudo-ranges at intervals of 1 second if the hardware of the GPS time receiver currently in operation does not generate such data.
For existing receivers which takes short-term observations every 0,6 second, the data processing could copy closely the one given in this Annex, with quadratic fits over durations of about 15 s followed by a linear fit.
For existing receivers which takes short-term observations every 6 seconds, it seems reasonable to process directly 6-second data through a linear fit.
It is expected that new receivers will operate in accordance with the basic 1 second pseudo-range data.

ANNEX III

GGTTS GPS DATA FORMAT VERSION 01

The GGTTS GPS Data Format Version 01 comprises:

i) a file header with detailed information on the GPS equipment (line 1 to 16),

ii) a blank line (line 17),

iii) a line header with the acronyms of the reported quantities (line 18),

iv) a unit header with the units used for the reported quantities (line 19),

v) a series of data lines (line 20, 21, 22,..., (n-1), n,... etc.), one line corresponding to one GPS track. The GPS tracks are ordered in chronological order, the track reported in line n occuring after the track reported in line (n-1).

Each line of the data file is limited to 128 columns and is terminated by a carriage-return and a line feed.

Notes:

*- A * stands for a space, ASCII value 20 (hexadecimal).*
Text to be written in the data file is indicated by ' '.

- The line order described in v) does not correspond to the line order output by most receivers at present time.

1. File header

Line 1: 'GGTTS*GPS*DATA*FORMAT*VERSION*=*' N

Title to be written.
N = 01.
34 columns (as long as N < 100).

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 the GPS time receiver.
As many columns as necessary.

Line 4: 'CH*=*' CHANNEL NUMBER

Number of the channel used to produce the data included in the file,
CH = 01 for a one-channel receiver.
7 columns (as long as CH < 100).

Line 5: 'IMS*=*' MAKER'*'TYPE'*'SERIAL NUMBER'*'YEAR'*' SOFTWARE NUMBER

Maker acronym, type, serial number, first year of operation, and eventually software number of the Ionospheric Measurement System.
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 of the GPS antenna, in m and given with at least 2 decimals.
As many columns as necessary.

Line 8: 'Y*=*' Y COORDINATE '*m'

Y coordinate of the GPS antenna, in m and given with at least 2 decimals.
As many columns as necessary.

Line 9: 'Z*=*' Z COORDINATE '*m'

Z coordinate of the GPS antenna, in m and given with at least 2 decimals.
As many columns as necessary.

Line 10: 'FRAME*=*' FRAME

Designation of the reference frame of the GPS antenna coordinates.
As many columns as necessary.

Line 11: 'COMMENTS*=*' COMMENTS

Any comments about the coordinates, for example the method of determination or the estimated uncertainty.
As many columns as necessary.

Line 12: '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 13: '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 14: '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 15: 'REF*=*' REFERENCE

Identifier of the time reference entered in the GPS 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 the 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 'G' of 'GGTTS' in Line 1, including all spaces indicated as * and corresponding to the ASCII value 20 (hexadecimal), ending with the space after '=' of Line 16 just preceding the actual check sum value, and excluding all carriage returns or line feeds.
10 columns.

Line 17: blank line.

2. Line header

2.1. No measured ionospheric delays available

Line 5 of the header indicates: `IMS = 99999`

No ionospheric measurements are available, the specific format of the line header is as follows:

Line 18.1: `'PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV***** *SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*CK'`

Line to be written.
The acronyms are explained in 4.
103 columns.

2.2. Measured ionospheric delays available

Line 5 of the header indicates, for instance:

`IMS = AIR NIMS 003 1992`
(Example with fictitious data of Section 6.)

Ionospheric measurements are available, the specific format of the line header is as follows:

Line 18.2: `'PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV***** *SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI* MSIO*SMSI*ISG*CK'`

Line to be written.
The acronyms are explained in 4.
117 columns.

3. Unit header

3.1. No measured ionospheric delays available

Line 19.1: `'*************hhmmss**s**.1dg*.1dg****.1ns*****.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s**'`

Line to be written
103 columns.

3.2. Measured ionospheric delays available

Line 19.2: `'*************hhmmss**s**.1dg*.1dg****.1ns*****.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s.1ns.1ps/s.1ns**'`

Line to be written
117 columns.

4. Data line

Line 20, column 1: space, ASCII value 20 (hexadecimal).

Line 20, columns 2-3: `'12'` PRN
Satellite vehicle PRN number.
No unit.

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

Line 20, columns 5-6: `'12'` CL
Common-view hexadecimal class byte.
No unit.

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

Line 20, columns 8-12: `'12345'` MJD
Modified Julian Day.
No unit.

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

Line 20, columns 14-19: `'121212'` STTIME
Date of the start time of the track (see Annex I).
In hour, minute and second referenced to UTC.

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

Line 20, columns 21-24: `'1234'` TRKL
Track length, 780 for full tracks (see Annex I).
In s.

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

Line 20, columns 26-28: `'123'` ELV
Satellite elevation at the date corresponding to the midpoint of the track.
In 0.1 degree.

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

Line 20, columns 30-33: `'1234'` AZTH
Satellite azimuth at the date corresponding to the midpoint of the track.
In 0.1 degree.

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

Line 20, columns 35-45: '+1234567890' REFSV

Time difference resulting from the treatment vi-a) of Annex II.

In 0.1 ns.

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

Line 20, columns 47-52: '+12345' SRSV

Slope resulting from the treatment vi-a) of Annex II.

In 0.1 ps/s.

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

Line 20, columns 54-64: '+1234567890' REFGPS

Time difference resulting from the treatment vi-b) of Annex II.

In 0.1 ns.

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

Line 20, columns 66-71: '+12345' SRGPS

Slope resulting from the treatment vi-b) of Annex II.

In 0.1 ps/s.

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

Line 20, columns 73-76: '1234' DSG

[Data Sigma] Root mean square of the residuals to the linear fit vi-b) of Annex II.

In 0.1 ns.

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

Line 20, columns 78-80: '123' IOE

[Index of Ephemeris] Three digit decimal code (0-255) indicating the ephemeris used for the computation.

No unit.

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

Line 20, columns 82-85: '1234' MDTR

Modelled tropospheric delay resulting from the linear fit vi-d) of Annex II.

In 0.1 ns.

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

Line 20, columns 87-90: '+123' SMDT

Slope of the modelled tropospheric delay resulting from the linear fit vi-d) of Annex II.
In 0.1 ps/s.

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

Line 20, columns 92-95: '1234' MDIO

Modelled ionospheric delay resulting from the linear fit vi-c) of Annex II.
In 0.1 ns.

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

Line 20, columns 97-100: '+123' SMDI

Slope of the modelled ionospheric delay resulting from the linear fit vi-c) of Annex II.
In 0.1 ps/s.

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

4.1. No measured ionospheric delays available

Line 20.1, columns 102-103: '12' CK

Data line check-sum: hexadecimal representation of the sum, modulo 256, of the ASCII values of the characters which constitute the data line, from column 1 to column 101 (both included).

Line 20.1, columns 104-128: '1234567890123456789012345'

Optional comments on the data line, constituted of characters which are not included in the line check-sum CK.

4.2. Measured ionospheric delays available

Line 20.2, columns 102-105: '1234' MSIO

Measured ionospheric delay resulting from the linear fit vi-e) of Annex II.
In 0.1 ns.

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

Line 20.2, columns 107-110: '+123' SMSI

Slope of the measured ionospheric delay resulting from the linear fit vi-e) of Annex II.
In 0.1 ps/s.

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

Line 20.2, columns 112-114: '123' ISG
[Ionospheric Sigma] Root mean square of the residuals to the linear fit vi-e) of Annex II.
In 0.1 ns.

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

Line 20.2, columns 116-117: '12' CK
Data line check-sum: hexadecimal representation of the sum, modulo 256, of the ASCII values of the characters which constitute the data line, from column 1 to column 115 (both included).

Line 20.2, columns 118-128: '12345678901'
Optional comments on the data line, constituted of characters which are not included in the line check-sum.

Notes:

- Any missing data should be replaced by series of 9.

- When the number of columns reserved for reporting a quantity is too large, the value of the corresponding quantity must be preceded by spaces, ASCII value 20 in hexadecimal (see Section 6 of Annex III).

5. Conclusions

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

5.1. No measured ionospheric delays available

```
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111111111111111111111111
00000000011111111112222222222333333333344444444445555555555666666666677777777778888888888999999999900000000001111111111222222222
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*CK
*************hhmmss**s**.1dg*.1dg****.1ns*****.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s**
*12*12*12345*121212*1234*123*1234*+1234567890*+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*12optionalcommentsoptionalc
```

5.2. Measured ionospheric delays available

```
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111111111111111111111111
00000000011111111112222222222333333333344444444445555555555666666666677777777778888888888999999999900000000001111111111222222222
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*MSIO*SMSI*ISG*CK
*************hhmmss**s**.1dg*.1dg****.1ns*****.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s.1ns.1ps/s.1ns**
*12*12*12345*121212*1234*123*1234*+1234567890*+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*1234*+123*123*12optcomments
```

6. Example (fictitious data)

6.1. No measured ionospheric delays available

GGTTS GPS DATA FORMAT VERSION = 01
REV DATE = 1993-05-28
RCVR = AOA TTR7A 12405 1987 14
CH = 15
IMS = 99999
LAB = XXXX
X = +4327301.23 m
Y = +568003.02 m
Z = +4636534.56 m
FRAME = ITRF88
COMMENTS = NO COMMENTS
INT DLY = 85.5 ns
CAB DLY = 232.0 ns
REF DLY = 10.3 ns
REF = 10077
CKSUM = C3

PRN	CL	MJD	STTIME	TRKL	ELV	AZTH	REFSV	SRSV	REFGPS	SRGPS	DSG	IOE	MDTR	SMDT	MDIO	SMDI	CK
			hhmmss	s	.1dg	.1dg	.1ns	.1ps/s	.1ns	.1ps/s	.1ns		.1ns	.1ps/s	.1ns	.1ps/s	
3	8D	48877	20400	780	251	3560	-3658990	+100	+4520	+100	21	221	64	+90	452	-27	BBhello
18	02	48877	35000	780	650	910	+56987262	-5602	+5921	-5602	350	123	102	+61	281	+26	52
15	11	48878	110215	765	425	2700	+45893	+4892	+4269	+4890	306	55	54	-32	620	+15	A9
15	88	48878	120000	780	531	2850	+45992	+4745	+4290	+4745	400	55	57	-29	627	+16	18receiv. out of operation

6.2. Measured ionospheric delays available

GGTTS GPS DATA FORMAT VERSION = 01
REV DATE = 1993-05-28
RCVR = AOA TTR7A 12405 1987 14
CH = 15
IMS = AIR NIMS 003 1992
LAB = XXXX
X = +4327301.23 m
Y = +568003.02 m
Z = +4636534.56 m
FRAME = ITRF88
COMMENTS = NO COMMENTS
INT DLY = 85.5 ns
CAB DLY = 232.0 ns
REF DLY = 10.3 ns
REF = 10077
CKSUM = 49

PRN	CL	MJD	STTIME	TRKL	ELV	AZTH	REFSV	SRSV	REFGPS	SRGPS	DSG	IOE	MDTR	SMDT	MDIO	SMDI	MSIO	SMSI	ISG	CK
			hhmmss	s	.1dg	.1dg	.1ns	.1ps/s	.1ns	.1ps/s	.1ns		.1ns	.1ps/s	.1ns	.1ps/s	.1ns	.1ps/s	.1ns	
3	8D	48877	20400	780	251	3560	-3658990	+100	+4520	+100	21	221	64	+90	452	-27	480	-37	18	F4hello
18	02	48877	35000	780	650	910	+56987262	-5602	+5921	-5602	350	123	102	+61	281	+26	9999	9999	999	89no meas ion
15	11	48878	110215	765	425	2700	+45893	+4892	+4269	+4890	306	55	54	-32	620	+15	599	+16	33	29
15	88	48878	120000	780	531	2850	+45992	+4745	+4290	+4745	400	55	57	-29	627	+16	601	+17	29	00rec out

PRACTICAL RECAPITULATION

GGTTS GPS DATA FORMAT VERSION = 01

No measured ionospheric delays available

```
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111111111111111111111111
00000000011111111112222222222333333333344444444445555555555666666666677777777778888888888999999999900000000001111111111222222222
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*CK
*************hhmmss**s**.1dg*.1dg****.1ns*****.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s**
*12*12*12345*121212*1234*123*1234*+1234567890*+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*12optionalcommentsoptionalc
```

Measured ionospheric delays available

```
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111111111111111111111111
00000000011111111112222222222333333333344444444445555555555666666666677777777778888888888999999999900000000001111111111222222222
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
PRN*CL**MJD**STTIME*TRKL*ELV*AZTH***REFSV******SRSV*****REFGPS****SRGPS**DSG*IOE*MDTR*SMDT*MDIO*SMDI*MSIO*SMSI*ISG*CK
*************hhmmss**s**.1dg*.1dg****.1ns*****.1ps/s*****.1ns****.1ps/s*.1ns*****.1ns.1ps/s.1ns.1ps/s.1ns.1ps/s.1ns**
*12*12*12345*121212*1234*123*1234*+1234567890*+12345*+1234567890*+12345*1234*123*1234*+123*1234*+123*1234*+123*123*12optcomments
```

Example (fictitious data)

```
GGTTS GPS DATA FORMAT VERSION = 01
REV DATE = 1993-05-28
RCVR = AOA TTR7A 12405 1987 14
CH = 15
IMS = 99999 or IMS = AIR NIMS 003 1992
LAB = XXXX
X = +4327301.23 m
Y = +568003.02 m
Z = +4636534.56 m
FRAME = ITRF88
COMMENTS = NO COMMENTS
INT DLY = 85.5 ns
CAB DLY = 232.0 ns
REF DLY = 10.3 ns
REF = 10077
CKSUM = C3 or CKSUM = 49
```

No measured ionospheric delays available

```
PRN CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFGPS    SRGPS  DSG IOE MDTR SMDT MDIO SMDI CK
             hhmmss  s  .1dg .1dg   .1ns     .1ps/s     .1ns    .1ps/s .1ns     .1ns.1ps/s.1ns.1ps/s
  3 8D 48877  20400  780 251 3560   -3658990   +100       +4520    +100   21 221   64  +90  452  -27 BBhello
 18 02 48877  35000  780 650  910  +56987262  -5602       +5921   -5602  350 123  102  +61  281  +26 52
 15 11 48878 110215  765 425 2700     +45893  +4892       +4269   +4890  306  55   54  -32  620  +15 A9
 15 88 48878 120000  780 531 2850     +45992  +4745       +4290   +4745  400  55   57  -29  627  +16 18receiv. out of operation
```

Measured ionospheric delays available

```
PRN CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFGPS    SRGPS  DSG IOE MDTR SMDT MDIO SMDI MSIO SMSI ISG CK
             hhmmss  s  .1dg .1dg   .1ns     .1ps/s     .1ns    .1ps/s .1ns     .1ns.1ps/s.1ns.1ps/s.1ns.1ps/s.1ns
  3 8D 48877  20400  780 251 3560   -3658990   +100       +4520    +100   21 221   64  +90  452  -27  480  -37  18 F4hello
 18 02 48877  35000  780 650  910  +56987262  -5602       +5921   -5602  350 123  102  +61  281  +26 9999 9999 999 89no meas ion
 15 11 48878 110215  765 425 2700     +45893  +4892       +4269   +4890  306  55   54  -32  620  +15  599  +16  33 29
 15 88 48878 120000  780 531 2850     +45992  +4745       +4290   +4745  400  55   57  -29  627  +16  601  +17  29 00rec out
```