GNSS Timescale Description
Galileo

Reference document:
RD1: European GNSS (Galileo) Open Service Signal In Space Interface Control Document (OS SIS ICD), Issue 1.1, September 2010

Definition of System

1. System timescale: GST (Galileo System Time)

2. Generation of system timescale:
Master Clock steered to the clock ensemble at the Precise Time Facility with an option to include ground station and satellite clocks.

3. Is system timescale steered to a reference UTC timescale?
Yes

a. To which reference timescale:
UTC prediction as provided by the GTSP (Galileo Time Service Provider) based on contributions from European UTC laboratories.

b. Whole second offset from reference timescale?
Yes. As specified in Section 5.1.2 of [RD1], the GST start epoch shall be 00:00 UT on Sunday 22nd August 1999 (midnight between 21st and 22nd August). At the start epoch, GST shall be ahead of UTC by thirteen (13) leap seconds.
GST is a uniform time scale and does not apply leap seconds. TAI is ahead of GST by 19 seconds. GST is ahead of UTC by a number of seconds that depend on leap second insertions/subtractions. This whole second time offset between GST and UTC is equal to the time offset between TAI and UTC minus 19 seconds.

c. Maximum offset (modulo 1s) from reference timescale?
The offset between GST and UTC modulo 1 second shall be less than 50 ns for 95% of any period of one year.

4.**Corrections to convert from satellite to system timescale?**
Yes. **If yes:**

a. Type of corrections given; include statement on relativistic corrections
Clock bias, clock drift and clock drift rate correction coefficients are broadcast as a part of the Galileo navigation message as specified in Section 5.1.3 of [RD1]. The expression for relativistic correction is given in Section 5.1.4 of [RD1].

b. Specified accuracy of corrections to system timescale
Part of the overall Galileo system specification of the combined satellite orbit and clock contribution to the user ranging accuracy which shall be less than 65 cm (1sigma).

c. Location of corrections in broadcast messages
Page 1 of subframes 1 to 12 of the F/NAV message (Section 4.2.3 [RD1]) and Word Type 4 of the I/NAV message (Section 4.3.5 [RD1]).

d. Equations to correct satellite timescale to system timescale
The satellite time correction algorithm is defined in Section 5.1.4 of [RD1] as reported hereafter.
The satellite time correction is modelled through the following second order polynomial:

$$\Delta tSV(X) = af0(X) + af1(X)[t - t_{0C}(X)] + af2(X)[t - t_{0C}(X)]^2 + \Delta tr$$

where

- af0(X), af1(X), and af2(X) are respectively the SV clock bias, drift and drift rate correction coefficients as defined in Section 5.1.3 of [RD1],
- $t_{0c}(X)$ is the reference time for the clock correction as defined in Section 5.1.3 of [RD1],
- t is the GST time in seconds
- Δtr (s) is a relativistic correction term, $\Delta tr = F\, e\, A^{1/2} \sin(E)$

with the orbital parameters being (Section 5.1.1 of [RD1]):
e : eccentricity
A : semi-major axis
E : eccentric anomaly
and $F = -2\mu^{1/2}/c^2 = -4.442807309 \times 10^{-10}\ s/m^{1/2}$
where μ is the geocentric gravitational constant

5. Corrections to convert from system to reference UTC timescale?
Yes. **If yes:**

a. Type of corrections given
Linear coefficients and leap second terms as defined in Section 5.1.7 of [RD1].

b. Specified accuracy of corrections to reference timescale
The offset between GST and UTC modulo 1 second shall be known with a maximum uncertainty of 28 ns with 2-sigma confidence level.

c. Location of corrections in broadcast messages
Page 4 of subframes 1 to 12 of the F/NAV message (Section 4.2.3 [RD1]) and Word Type 6 of the I/NAV message (Section 4.3.5 [RD1]).

d. Equations to correct system timescale to reference timescale
As defined in Section 5.1.7 of [RD1], UTC time t_{UTC} is computed through 3 different cases depending on the epoch of a possible leap second adjustment (scheduled future or recent past) given by *DN*, the day at the end of which the leap second becomes effective, and week number WN_{LSF} to which *DN* is referenced. “Day one” of *DN* is the first day relative to the end/start of week and *WNLSF* is the Galileo week number modulo 256.

The following parameters are used in GST-UTC conversion algorithm:

- t_E is the GST as estimated by the user through its GST determination algorithm

- *WN* is the week number to which t_E is referenced, modulo 256
- A0, A1 are respectively the constant and 1st order terms of polynomial
- Δt_{LS} is the leap Second count before leap second adjustment
- Δt_{LSF} is the leap Second count after leap second adjustment
- t_{ot} is the UTC data reference Time of Week
- *WNot* is the UTC data reference Week Number

Case a
Whenever the leap second adjustment time indicated by WN_{LSF} and *DN* is not in the past (relative to the user's present time) and the user's present time does not fall in the time span which starts six hours prior to the effective time (= *DN*+3/4) and ends six hours after the effective time at (= *DN*+5/4), t_{UTC} is computed according to the following equations:

$$t_{UTC} = (t_E - \Delta t_{UTC}) \text{ modulo } 86400$$
$$\Delta t_{UTC} = \Delta t_{LS} + A0 + A1\,[(t_E - t_{ot}) + 604800\,(WN - WNot)]$$

Case b
Whenever the user's current time falls within the time span of six hours prior to the leap second adjustment time to six hours after the adjustment time, t_{UTC} is computed according to the following equations (Δt_{UTC} as defined in case a):

$$t_{UTC} = W \text{ modulo}(86400 + \Delta t_{LSF} - \Delta t_{LS})$$
$$W = (t_E - \Delta t_{UTC} - 43200) \text{ modulo } 86400 + 43200$$

Case c
Whenever the leap second adjustment time, as indicated by the WN_{LSF} and DN values, is in the "past" (relative to the user's current time) and the user's present time does not fall in the time span which starts six hours prior to the leap second adjustment time and ends six hours after the adjustment time, t_{UTC} is computed according to the following equation:

$$t_{UTC} = (t_E - \Delta t_{UTC}) \text{ modulo}(86400)$$
$$\Delta t_{UTC} = \Delta t_{LSF} + A0 + A1[\, t_E - t_{ot} + 604800(WN - WNot)]$$

6. Specified stability of system timescale
Part of the overall specification of the satellite combined orbit and clock error contribution to the user ranging accuracy as mentioned in 4b.

7. Specified stability of reference timescale
Part of the overall specification of GST-UTC prediction accuracy as mentioned in 5b.

8. Specified stability of satellite clocks
Part of the overall specification of the combined satellite orbit and clock error contribution to the user ranging accuracy as mentioned in 4b.

9. Availability of System to GNSS Time Offset (GGTO)
Galileo broadcasts GPS Galileo Time Offset correction as part of the navigation messages.

a. Systems for which corrections are given?
Galileo provides GPS Galileo Time Offset as per [RD1].

b. Type of GGTO corrections given
Linear polynomial coefficients as defined in Section 5.1.8 of [RD1].

c. Stated accuracy of GGTO correction, if available
Galileo has a stated goal of 5 ns (95 %) for a GPS Galileo Time Offset.

d. Location of corrections in broadcast messages
Page 4 of subframes 1 to 12 of the F/NAV message (Section 4.2.3 [RD1]) and Word Type 10 of the I/NAV message (Section 4.3.5 [RD1]).

e. Equations used for GGTO message
As specified in Section 5.1.8 of [RD1], the difference between the Galileo and the GPS time scales is given by the equation below:
$\Delta t_{Systems} = t_{Galileo} - t_{GPS} = A_{0G} + A_{1G}[TOW - t_{0G} + 604800((WN - WN_{0G})\text{mod}64)]$

Where :
- A_{0G} is the constant term of the offset $\Delta t_{Systems}$
- A_{1G} is the rate of change of the offset $\Delta t_{Systems}$
- t_{0G} is the reference time for GPS Galileo time offset data
- $t_{Galileo}$ is GST time (s)
- t_{GPS} is GPS time (s)
- WN is the GST Week Number
- WN_{0G} is the Week Number of the GPS Galileo time offset reference

Describe the details of the system, i.e. locations of system and reference timescale clocks, generation of timescales, and other details.

The two redundant Galileo Precise Time Facilities are located in the Galileo Control Centers in Fucino (Italy) and Oberpfaffenhofen (Germany). Each PTF is equipped with Hydrogen masers (used as Master Clocks) and Caesium clocks. These clocks, and optionally the other ground station and satellite clocks, are ensembled and the PTF Master Clocks are steered to this ensemble to produce the physical realisation of the Galileo System Time.

Describe how the timescale transfers from the reference timescale to the system timescale and finally to the satellites.
Include the nominal rate of SV updates.

The offset between GST and UTC is monitored by the GTSP (Galileo Time Service Provider) which computes a GST-UTC offset and GST-UTC steering parameters.
The offset of the satellite clocks to the GST is computed by the Galileo Ground Segment from the satellite observations as collected by a network of ground sensor stations.
The satellite clock parameters with respect to GST are nominally updated with the latency not less than 100 minutes.
The GST-UTC offset parameters are nominally updated daily.

If any other pertinent details exist concerning the generation and realization of system and/or reference time, include them as well.

According to [RD1] Section 5.1.3, the satellite clock corrections to GST as broadcast in the F/NAV message are referred to the frequency combination (E1, E5a) and the corrections broadcast in the I/NAV message are referred to the combination (E1,E5b).
The users of single-frequency receivers shall additionally apply the broadcast group delay correction as described in section 5.1.5 [RD1].