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GALILEO

# GALILEO TIMING SERVICE MESSAGE OPERATIONAL STATUS DEFINITION (TSM OSD)

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| REASON FOR CHANGE | ISSUE | REVISION | DATE |
|---|---|---|---|
| First version of the document | 1 | 0 | April 2024 |

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# 1 INTRODUCTION

## 1.1 Background

GNSS Timing and Synchronisation is crucial to a variety of applications in current economy, including the use in critical infrastructures. Many critical modern systems, such as 4G/5G mobile phone networks or banking and electricity (smart) grids, demand high-accuracy time and frequency stability across specific geographic areas. Tight synchronisation between distributed nodes is fundamental for many digital networks, and more stringent network stability requirements are expected to emerge as transmission speeds increase and spectral efficiency improves with 5G networks.

The Galileo Open Service (OS) provides to the user, free of charge, positioning and timing/synchronisation information. For the current generation of Galileo, the timing service is limited to the provision of timing determination and dissemination, as part of the OS. The need to evolve the timing and synchronisation aspects beyond those currently offered in OS towards separate and enhanced services was recognized by the Galileo Programme with the definition of a proper Timing Services as part of the mission of the Galileo Second Generation. The Service will give emphasis to the Critical Infrastructure applications.

One of the main features of the Timing Service is the Timing Service Level Monitoring (TSLM) which consists in the monitoring of the GST and UTC accuracy. Another distinct feature is a Timing Service Message (TSM) disseminated by Galileo satellites and containing information specifically intended for timing users. The TSM conveys the status of the Galileo signals, outcome of the monitoring of the GST and UTC allowing the provision of various levels of trust to the users.

## 1.2 Document Scope

As for any service, the Galileo Timing receivers must process Galileo signals according to the Galileo SIS ICD. Given that the Galileo 2$^{nd}$ Generation SIS ICD is currently under development, the present document provides a description of the Timing Service Message by identifying the different TSM parameters and their use. It will be replaced by the actual Galileo SIS ICD once published.

The different TSM flags are important parameters whose value will determine the applicability of the Minimum Performance Level of the service (MPL), relevant for the future Service Definition Document (SDD), which will be published before the Galileo Timing Service is officially declared.

In anticipation to the Galileo SIS ICD version including the TSM, the content of this document is specifically targeted towards manufacturers of Galileo receivers in order to support the Standardization process of Timing Receivers – a process ongoing under the specific CEN/CENELEC Working Group 9 - as well as the testing activities foreseen in relation to Galileo TS deployment.

The first part of this technical note provides a comprehensive guide of how the TSM is formatted, including a description of the different timing status flags. In the second part, the processing of the TSM is presented. The last section provides the key principles for the processing of the Timing Flags broadcast in the TSM at receiver level.

# 2 ACRONYMS AND ABBREVIATIONS

**Table 1 – Abbreviations**

| Abbreviation | Definition |
|---|---|
| DVS | Data Validity Status |
| EUSPA | European Union Agency for the Space Programme |
| GSEG | Ground Segment |
| GST | Galileo System Time |
| ICD | Interface Control Document |
| IOD | Issue of Data |
| MTE | Maximum Tolerable Errors |
| RAIM | Receiver Autonomous Integrity Monitoring |
| SDD | Service Definition Document |
| SHS | Signal Health Status |
| SIS | Signal in Space |
| SISA | Signal in Space Accuracy |
| SL | Service Level |
| SV | Space Vehicle |
| ToA | Time of Arrival |
| TS | Timing Service |
| TSLM | Timing Service Level Monitoring |
| TSM | Timing Service Message |
| TTN | Time to Notify |
| UTC | Universal Time Coordinated |
| WWG | Working Without Guarantee |

# 3 APPLICABLE AND REFERENCE DOCUMENTS

**Table 2 – Applicable Documents**

| **Applicable Documents:** | | |
|---|---|---|
| Type | Title | Reference |
| AD 1 | The European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document | Issue 2.1, European Union, 2023 |
| AD 2 | Galileo Open Service - Service Definition Document | Issue 1.3, European Union, 2023 |

# 4 GALILEO TIMING SERVICE MESSAGE FORMAT

The Galileo Timing Service Message will be disseminated through the I/NAV message, Word Type 44. GST-UTC conversion parameters will also be disseminated through I/NAV, Word Type 6, and through F/NAV Word type 4 as described here below.

Three Service Levels for the integrity monitoring are already defined for different Maximum Tolerable Errors (MTE) thresholds. Such service Levels are intended to cover the various user needs of the different timing applications.

All data values are encoded using the following bit and byte criteria:

- For numbering, the most significant bit/byte is numbered as bit/byte 0;
- For bit/byte ordering, the most significant bit/byte is transmitted first.

## 4.1 Timing Service Message Description

Galileo Timing Service users can obtain information about the Timing Service Status through the Timing Service Message (TSM) disseminated via the SIS[1]. Each Galileo satellite will distribute the GST flags per each Galileo satellite and the UTC flag for the whole constellation, as described in sections 4.1.1 and 4.1.2. The processing of the flags is described in Chapter 5.

The main objective of the TSLM is to monitor the errors at GST and UTC level and therefore to compute the GST and UTC service levels comparing the Galileo ground data with the information provided by the satellites.

Different service levels are detected through the monitoring of the errors of the GST and UTC timing solutions and comparison against corresponding thresholds (MTE). The Service Levels MTE, for both GST and UTC, are depicted in Table 3 and Table 4 respectively.

**Table 3 – GST Service Levels MTE**

| Service Level | Maximum Tolerable Error for GST (ns) |
|---|---|
| 1 | 1000 |
| 2 | 100 |
| 3 | 15 |

[1] The dissemination via terrestrial means will be addressed in future version of the document.

**Table 4 – UTC Service Levels MTE**

| Service Level | Maximum Tolerable Error for UTC (ns) |
|---|---|
| 1 | 1000 |
| 2 | 100 |
| 3 | 30 |

In case one of the timing solutions exceed one of the envisioned Maximum Tolerable Errors (MTE) defined in the monitoring levels of Table 3 and Table 4, the GST or UTC service level flag, as identified in Table 5, are modified accordingly to notify it to the user.

Similarly, in case none of the monitoring levels are met, a notification and the state of the status flag are tagged in order to let the user know that the timing solutions are above the defined thresholds.

The provision of the different monitoring levels is done through the GST and UTC status flags, packaged in the TSM, with capacity to process 36 GST status flags identifying different Galileo satellites, and 1 UTC status flag global for the whole constellation. The TSM will be formatted in the Word Type 44 of the I/NAV navigation message[2]. Table 5 describes the structure of the TSM. Spare bits remain available for future evolutions.

**Table 5 – TSM bits allocation**

| Type = 44 | GST status flags for 36 SVIDs | | | | UTC status flag | spare | Total bits |
|---|---|---|---|---|---|---|---|
| | GST status flag (SVID #1) | GST status flag (SVID #2) | GST status flags (SVIDs #3 – SVID #35) | GST status flag (SVID #36) | | | |
| 6 | 3 | 3 | 99[3] | 3 | 3 | 11 | 128 |

### 4.1.1 GST Levels Monitoring

The GST service level can be retrieved through the GST status flag, which will be provided for each Galileo satellite through the TSM, with a capacity of 36 satellite flags processed in parallel, as depicted in Table 5.

The different GST service levels thresholds/MTE are provided in Table 3.

The GST status flag can assume the values defined in Table 6.

[2] The Galileo 2nd Generation SIS ICD is currently under consolidation.

[3] 3 bits are allocated for the GST status flags per each SVID.

**Table 6 – GST status flags bit values**

| GST status flag | Definition |
|---|---|
| 0 | Not OK |
| 1 | Timing Service Level 1 |
| 2 | Timing Service Level 2 |
| 3 | Reserved for Timing Service Level 3[4] |
| 4 | Spare |
| 5 | Spare |
| 6 | Spare |
| 7 | Monitoring not available |

### 4.1.2 UTC Levels Monitoring

The UTC service level can be retrieved through the UTC status flag. The UTC is global and applies to the entire constellation. As depicted in Table 5 only one flag valid for the constellation will be disseminated through the TSM in the I/NAV navigation message. It is remarked that the UTC status flag refers to the GST-UTC conversion parameter disseminated in I/NAV and F/NAV navigation messages. Therefore, the status of the overall UTC timing solutions is described considering both GST and UTC flags.

The different UTC service levels thresholds/MTE are provided in Table 3.

The UTC status flag can assume the values defined in Table 7.

[4] Timing Service Level 3 will may not be offered with the Initial Service but at a later Service declaration.

**Table 7 – UTC status flags bit values**

| UTC status flag | Definition |
|---|---|
| 0 | Not OK |
| 1 | Timing Service Level 1 |
| 2 | Timing Service Level 2 |
| 3 | Reserved for Timing Service Level 3[4] |
| 4 | Spare |
| 5 | Spare |
| 6 | Spare |
| 7 | Monitoring not available |

### 4.1.3 GST-UTC conversion parameters and Issue of Data

The accuracy of the UTC timing solution depends on the accuracy of the GST-UTC time conversion parameters, which will be provided in the Word Type 6 of the I/NAV navigation message[2]. The GST-UTC parameters are disseminated in data batches, each one identified by an issue of data (IOD), called $IOD_{UTC}$[5]. The identification of each batch by an $IOD_{UTC}$ value enables the users to distinguish the data in different batches received from each satellite and indicate the user receiver the validity of the data, which have to be updated by using a new $IOD_{UTC}$.

Each batch of GST-UTC parameters is identified with an $IOD_{UTC}$ according to Table 8.

**Table 8 – Issue of GST-UTC parameters**

| Parameter | Definition | Bits | Scale factor | Unit |
|---|---|---|---|---|
| $IOD_{UTC}$ | Issue of GST-UTC parameters batch | 3 | NA | dimensionless |

The $IOD_{UTC}$ will be disseminated in the I/NAV Word Type 6, and its value determines the GST-UTC parameters batches as described in Table 11 . Table 9 provides a description of the format of the GST-UTC conversion parameters and $IOD_{UTC}$ in the I/NAV message.

[5] Note that the $IOD_{UTC}$ will be included in the future versions of Galileo SIS ICD in Word Type 6 (Table 9). It is relevant to notice that the $IOD_{Nav}$ - included in Word Type 4 (Table 10) - and the $IOD_{UTC}$ are not necessarily linked. Each one conveys a piece of information, and hence users must apply them accordingly.

**Table 9 – Bits allocation for I/NAV Word type 6**

| Type = 6 | GST-UTC conversion parameters | | | | | | | | TOW | $IOD_{UTC}$ | Total bits |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_0$ | $A_1$ | $\Delta t_{LS}$ | $t_{0t}$ | $WN_t$ | $WN_{LSF}$ | DN | $\Delta t_{LSF}$ | | | |
| 6 | 32 | 24 | 8 | 8 | 8 | 8 | 3 | 8 | 20 | 3 | 128 |

F/NAV E5a-I page type 4 also contains the set of GST-UTC conversion parameters, as depicted in Table 10.

**Table 10 – Bits allocation for F/NAV E5a-I page type 4**

| Type=4 | $IOD_{nav}$ | Ephemeris (3/3) | | GST-UTC Conversion | | | | | | | | GST-GPS Conversion | | | | TOW | Spare | CRC | Tail | Total bits |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_{IC}$ | $C_{IS}$ | $A_0$ | $A_1$ | $\Delta t_{LS}$ | $t_{0t}$ | $WN_t$ | $WN_{LSF}$ | DN | $\Delta t_{LSF}$ | $t_{0G}$ | $A_{0G}$ | $A_{1G}$ | $WN_{0G}$ | | | | | |
| 6 | 10 | 16 | 16 | 32 | 24 | 8 | 8 | 8 | 8 | 3 | 8 | 8 | 16 | 12 | 6 | 20 | 5 | 24 | 6 | 244 |

The GST-UTC products are generated by the Galileo Ground Segment and they have a validity of 24 hours. 8 GST-UTC parameter batches are defined to avoid any IOD ambiguity during the validity period of parameters. After 24h the satellites enter into Extended Operations Mode and the satellites on EOM must be discarded for TS.

The issue of GST-UTC parameters batch is identified in Table 11.

**Table 11 – GST-UTC parameters batches bit values**

| $IOD_{UTC}$ | Definition |
|---|---|
| 0 | GST-UTC parameters batch 0 |
| 1 | GST-UTC parameters batch 1 |
| 2 | GST-UTC parameters batch 2 |
| 3 | GST-UTC parameters batch 3 |
| 4 | GST-UTC parameters batch 4 |
| 5 | GST-UTC parameters batch 5 |
| 6 | GST-UTC parameters batch 6 |
| 7 | GST-UTC parameters in Extended Operations Mode |

# 5 TIMING SERVICE MESSAGE PROCESSING

The processing of the timing flags broadcast as part of the TSM must consider the OS SIS Status Health flags as described in this section.

In order to determine the status of a specific SIS broadcast by a Galileo satellite, the user will have to ensure first that the navigation message has been properly received (i.e. that it successfully passes the CRC check as described in [AD 1] and [AD 2]). If the message is not dummy, the user can proceed with the determination of the SIS status.

The definition of the Signal Health Status (SHS), Data Validity Status (DVS) and Signal in Space Accuracy (SISA) is provided in the Galileo OS Service Definition Document (SDD) [AD 2], together with the mapping between flags and OS SIS status.

The Galileo Timing Receiver must take into account those flags depending on the intended Service Level. The use logic is described hereafter:

- SHS must be processed and applied for all Service Levels;
- DVS must not be processed and applied by SL1 users. DVS must be processed and applied by SL2 (and SL3 in the future[4]);
- SISA must not be processed by neither SL1 nor SL2. The processing of SISA by SL3 will be confirmed at a later declaration of the service[4].

The TSM must be decoded continuously, and the users must process the GST and UTC Status Flags, together with the $IOD_{UTC.}$

When two different GST-UTC batches are being broadcast by the constellation (nominal case every time there is an update of the navigation message), the receiver make use of the latest data set (i.e. based on the $IOD_{UTC}$ parameter described as in Table 10 and Table 11) as per logic defined in section 5.2.

Table 12 provides the mapping between the OS SIS status flags and the TSM flags.

**Table 12 – Galileo Timing Service and Open Service SIS status flags**

| OS SIS STATUS | DUMMY MESSAGE | SIS FLAGS | | | TSM FLAGS | |
|---|---|---|---|---|---|---|
| | | SHS | DVS | SISA | GST | UTC |
| Healthy | No | OK | Nav. Data Valid | Not NAPA | Use for all SL | |
| Unhealthy | No | Out of Service | Any Value | Any Value | Do not use[6] | |
| | No | in Test | Any Value | Any Value | | |
| | Yes | N/A | N/A | N/A | | |
| Marginal | No | Ok | WWG | Any Value | Use SL1 only | |
| | No | Ok | Nav. Data Valid | NAPA | Use for SL1 and SL2[7] | |
| | No | Will be out of Service/EOM | Any Value | Any Value | Do not use | |
| Extended Operations Mode | No | Will be out of Service/EOM | Any Value | Any Value | Do not use | |

Section 5.1 and section 5.2 show the combined processing logic of Galileo OS SIS status flags together with GST and UTC status flags for each Service Level.

## 5.1 GST Status Flags processing

Figure 1, Figure 2 and Figure 3 depict the combined processing logic of Galileo OS SIS Status Flags and Galileo TSM GST Status Flags for SL3, SL2 and SL1 respectively.

[6] Considering that each satellite transmits GST timing flags for the whole Galileo constellations, TSM flags for other healthy or marginal satellites can still be retrieved from unhealthy satellites.

[7] SISA must not be processed by neither SL1 nor SL2. The use of SL3 when SISA = NAPA will be confirmed in a future evolution of the service (i.e. SL3 will not be provided in the Initial Service).

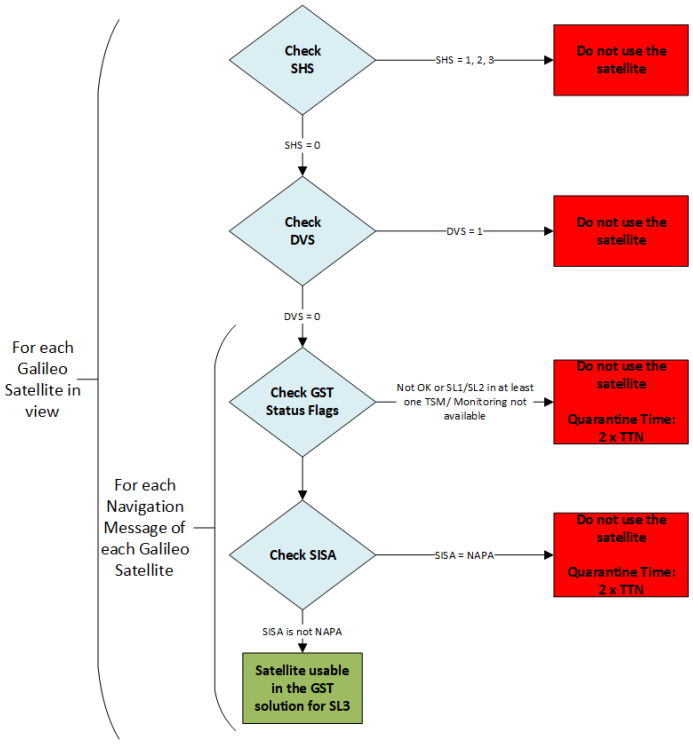


**Figure 1 – Processing Logic of OS SIS Status Flags and Galileo TSM GST Status Flags for SL3 users**

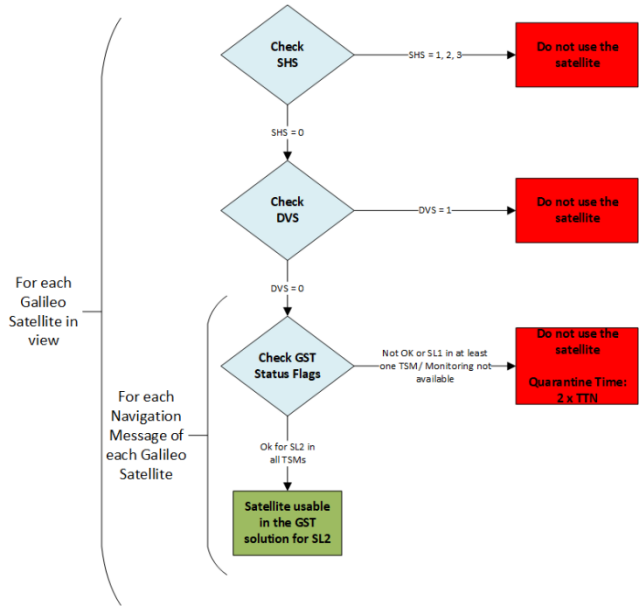


**Figure 2 – Processing Logic of OS SIS Status Flags and Galileo TSM GST Status Flags for SL2 users**

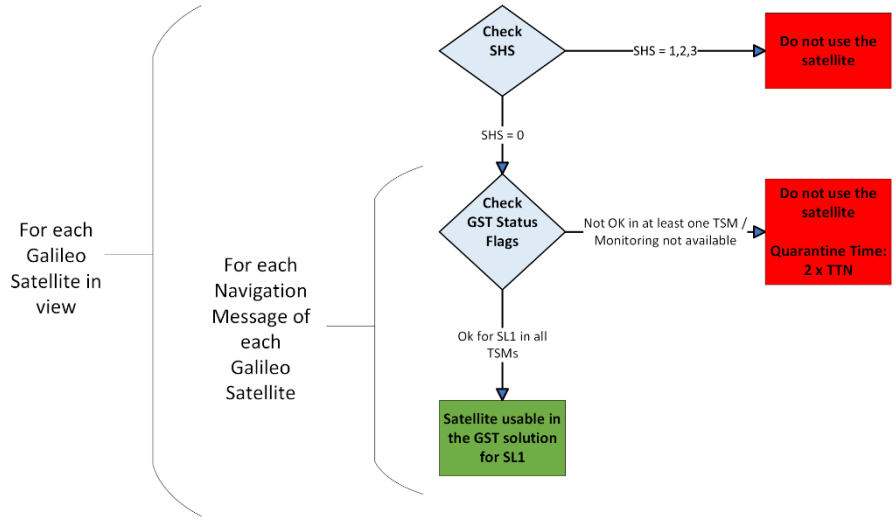


**Figure 3 – Processing Logic of OS SIS Status Flags and Galileo TSM GST Status Flags for SL1 users**

## 5.2 UTC Status Flags processing

Figure 4, Figure 5 and Figure 6 depict the combined processing logic of Galileo OS SIS Status Flags and Galileo TSM UTC Status Flags for SL3, SL2 and SL1 respectively. The GST Status Flag has to be processed prior to the UTC status Flag, given that the user has to retrieve the GST-UTC conversion parameters in order to compute the UTC timing solution. Therefore the status of the overall UTC timing solutions is described considering both GST and UTC flags.

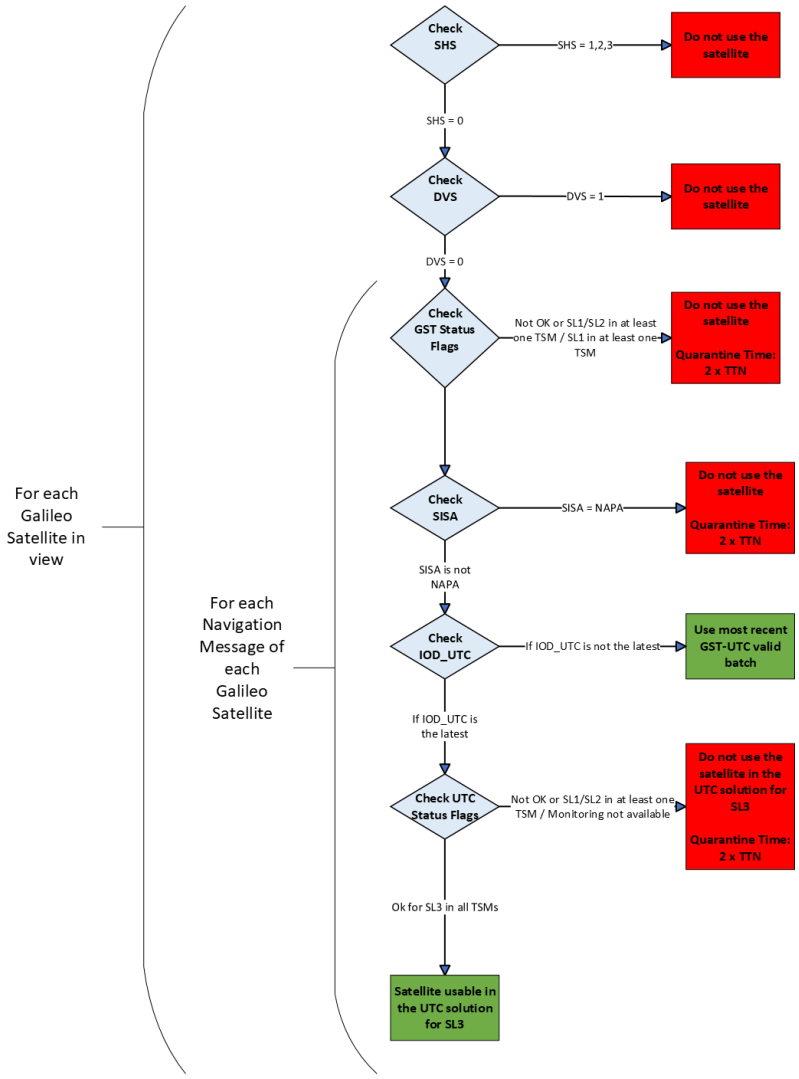


**Figure 4 – Processing Logic of OS SIS Status Flags and Galileo TSM UTC Status Flags for SL3 users**

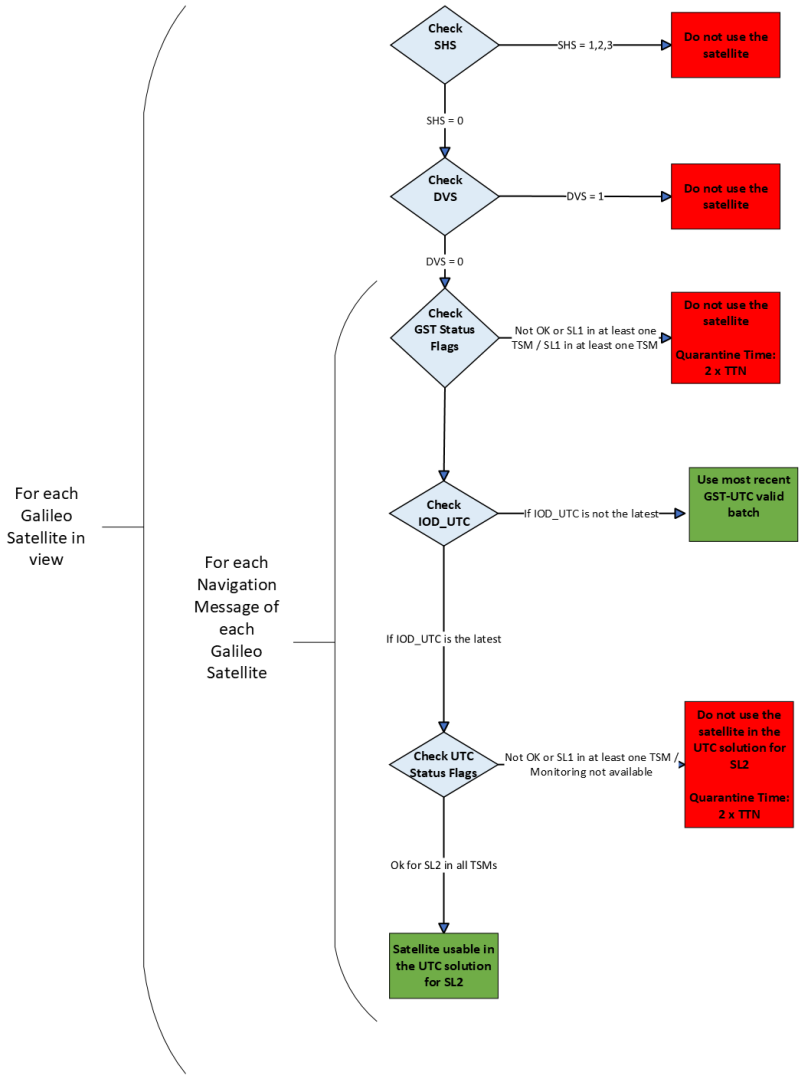


**Figure 5 – Processing Logic of OS SIS Status Flags and Galileo TSM UTC Status Flags for SL2 users**

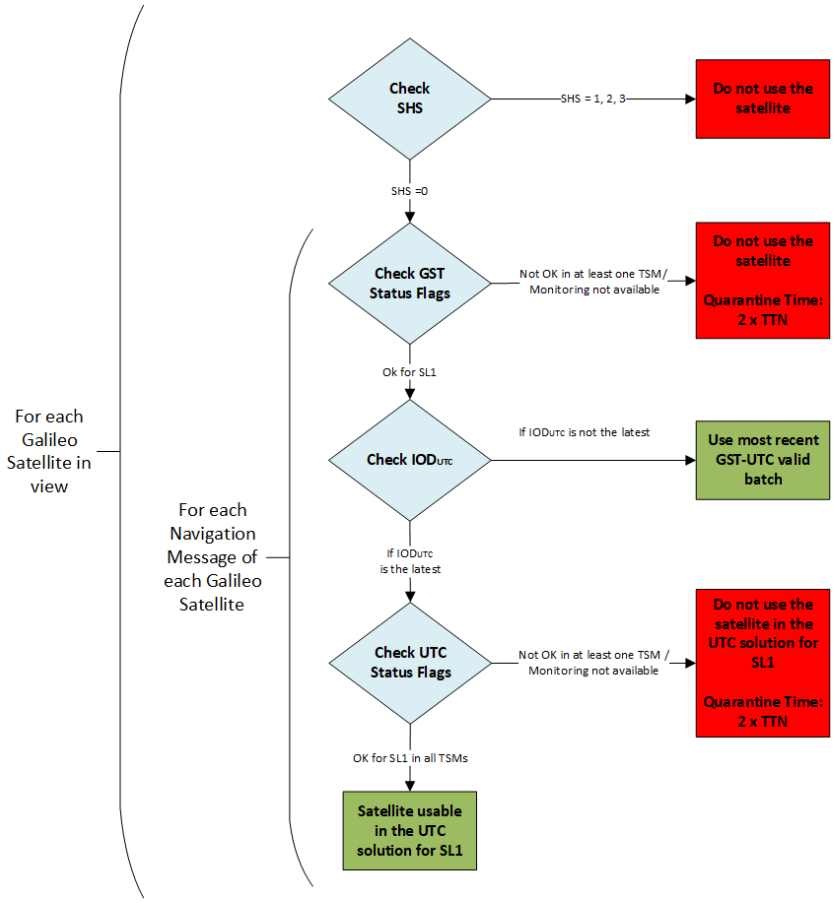


**Figure 6 – Processing Logic of OS SIS Status Flags and Galileo TSM UTC Status Flags for SL1 users**

# 6 TIMING RECEIVER OVERALL PROCESSING

The user receiver manages standard Galileo signals alongside the TSM dedicated to timing users.

In addition, Timing receivers in line with the Standard under development must implement local barriers. As a minimum the receiver's Time algorithm must implement a local barrier (i.e. T-RAIM).

T-RAIM algorithms can quickly identify flawed solutions and respond to local effects not addressed at the system level.

At each epoch, the handling of the timing flags in the TSM must be done before applying the T-RAIM algorithm, being the computation of the timing solution the last step. Section 6.1 provides a detailed description of the overall decision logic.

## 6.1 Timing Receiver Decision Logic

The Timing Service flags processing at receiver level must follow the key principles bellow:

- The Galileo Timing Receiver shall continuously decode the TSM and always apply the most recent TSM following the processing logic defined in Chapter 5.
- Once the receiver detects that the time solution is not correct, violating one or more of the MTEs, it will inform the user. The Synchronization Unit hosting the Galileo Timing Receiver can then switch to the time solution provided locally by a holdover device (providing the output meets the Service Level performance) or continue providing the GNSS solution maintaining the alert to the user, or simply stop.
- The detection can be done either through local barriers such as T-RAIM (at least 3 valid satellites shall be available to apply T-RAIM algorithms) or through the Timing Flags. Other local barriers may be implemented in the receiver.
- In case a satellite is removed from the solution following a detection, i.e. through local barriers or through the timing flags, the satellite shall not be re-introduced in the timing solution before a period of 2 x TTN since last detection (last epoch with detection through local barriers or timing flag) is elapsed. This quarantine period ensures that the situation is again the same as before the fault is detected (and thus all commitments are again applicable).
- Holdover capabilities may enable delivery of different Service Levels by using the local receiver clock (i.e. holdover mode). Holdover solutions must also be notified to user if they are no longer able to support Service Levels requirements.
- Holdover time shall be monitored with an integrity check of the local receiver clock. In case of probability that the error threshold is exceeded, the holdover period shall be stopped, or an alert shall be provided to the user.
- When in holdover mode, the Galileo Timing Receiver cannot switch back to the Galileo solution unless the following conditions are met:
    - Local checks show that the Timing Error is below the MTEs.
    - The Galileo Timing Flags received in the TSM for the corresponding Service Level (i.e. the flags for the satellites used in the solution, received through the TSM of all satellites in view) are set to “Use” in all TSMs after a period of at least 2 × TTN since the last detection

(last epoch with detection through local barriers or timing flag) causing the switch to holdover mode, is elapsed. This later check is needed to ensure that the situation is again the same as before the switch to holdover (and thus all commitments are again applicable).

- The Galileo Timing Receiver can continue in holdover mode up to a timeout limit. The timeout depends on the target Service Level and the accuracy of the local oscillator. Solutions for the Service Levels are no guaranteed beyond the validity timeout limit (i.e. when the holdover solution can no longer guarantee that the error remains bellow MTE with a probability similar to that guaranteed by the GNSS solution).
- Holdover time could be set up as part of the configuration of each receiver, depending on the target Service Level and on the quality of the holdover device.

Figure 7 depicts the receiver processing logic.

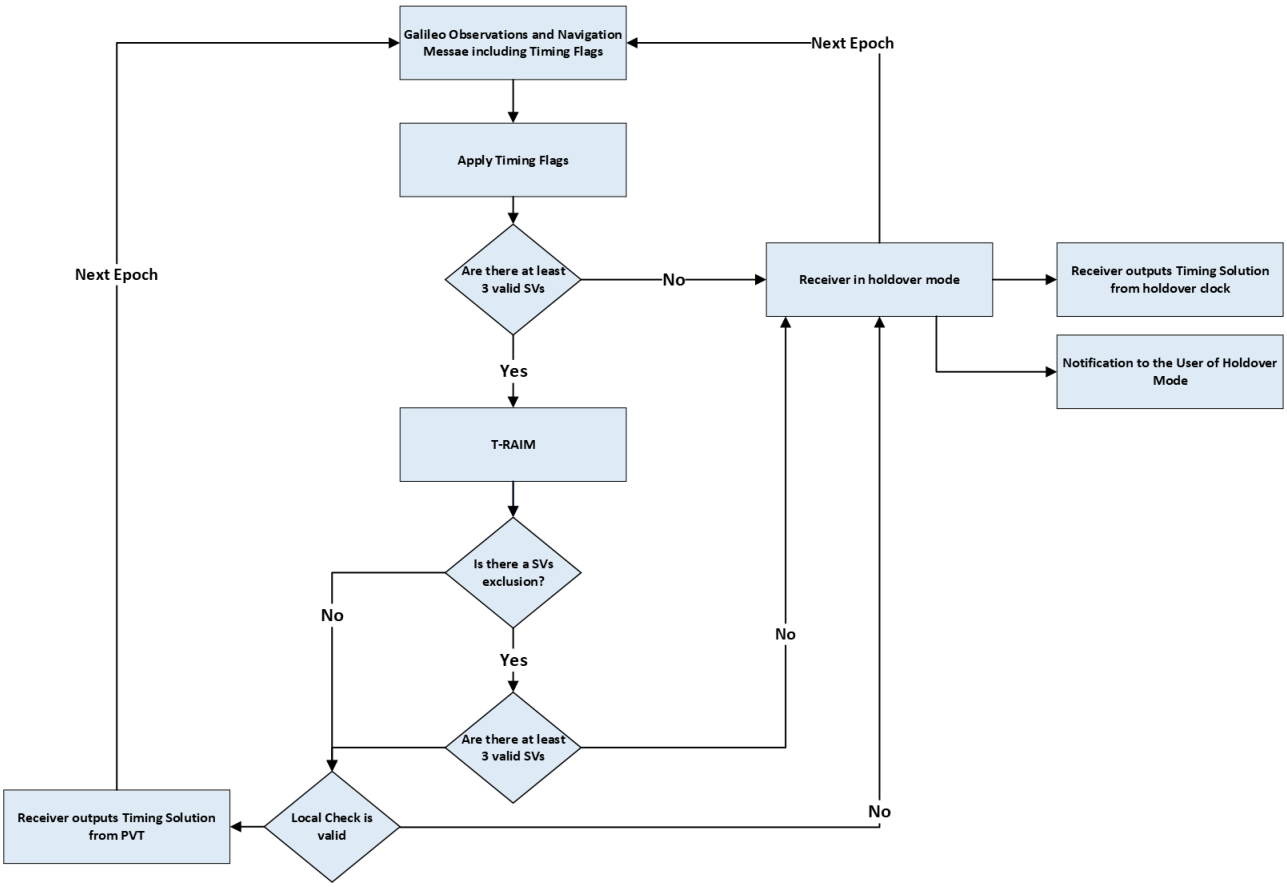


**Figure 7 – Galileo Timing Receiver decision logic**

## 6.2 Time to Alert and Time to Notify

The Time to Notify (TTN) is defined as the delay in which the Galileo Timing Receiver will receive an alert in the TSM of the Galileo Navigation Message of any satellite whenever the MTEs are not met by the Galileo System. It needs to account for the dissemination time through the SIS.

In parallel, Timing receivers must implement – at least those in line with the Standard under development - internal barriers to alert the user whenever the MTE of the corresponding Service Level is not met. These barriers will reduce the time to alert to the user if the MTE is surpassed. Indeed the Timing Service concept

establishes the Time to Alert for each Service level as the minimum time achieved through the various barriers (system and local). This is implemented through the decision logic described in section 6.1.


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