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GALILEO

GALILEO TIMING SERVICE MESSAGE OPERATIONAL STATUS DEFINITION (TSM OSD)

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DOCUMENT CHANGE RECORD

REASON FOR CHANGE	ISSUE	REVISION	DATE
First version of the document	1	0	April 2024
The text of various sections of the document has been improved or updated: • Renaming of UTC status Flag to GST-UTC status Flag. • Removal of IOD_UTC. • Definition of TSM Status flag which includes Test mode. Updated flag processing logic.	1	1	December 2024

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1 INTRODUCTION

1.1 Background

GNSS Timing and Synchronisation is crucial to a variety of applications in the 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 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 (referred to as “receiver” in the document) must process Galileo signals according to the future Galileo SIS ICD. Given that the Galileo 2nd 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 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
TS	Timing Service
TSLM	Timing Service Level Monitoring
TSM	Timing Service Message
TTN	Time to Notify
UTC	Universal Time Coordinated
WN	Week Number
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 (TSM) will be disseminated through the I/NAV message, Word Type 44. GST-UTC conversion parameters are also disseminated through I/NAV Word Type 6, and through F/NAV Page type 4, as described below.

Three Service Levels for 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 TSM disseminated via the SIS[1].

Users of the Galileo TSM can obtain information about the TSM Status through a dedicated TSM Status flag disseminated in the TSM, as indicated in Table 6. Table 3 outlines the various values that TSM Status can assume, these values apply to the entire content of the message. This document describes the TSM format only applicable to “TSM Operational”, that is TSM Status = 1.

Table 3 - TSM Status bit values

TSM Status	Definition
0	TSM in Test
1	TSM Operational
2	Spare
3	Spare

Each Galileo satellite will distribute the GST flags per each Galileo satellite and the GST-UTC Status flag for the whole constellation, as described in sections 4.1.1 and 4.1.2. The processing of the flags is described in section 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.

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

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 4 and Table 5 respectively.

Table 4 – GST Service Levels MTE

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

Table 5 - UTC Service Levels MTE

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

In case any of the timing solutions exceeds one of the envisioned Maximum Tolerable Errors (MTE) defined in the monitoring levels of Table 4 and Table 5, the GST or GST-UTC service level flag, as identified in Table 6, are modified accordingly to notify it to the user.

Similarly, if none of the monitoring levels are met, a notification is issued by setting the status flag to “Not OK” to inform the user that the timing solutions exceed the defined thresholds.

The provision of the different monitoring levels is done through the GST and GST-UTC status flags, packaged in the TSM, with capacity to process 36 GST status flags identifying different Galileo satellites, and 1 GST-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 6 describes the structure of the TSM. Spare bits remain available for future evolutions.

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

Table 6 - TSM bits allocation

Type = 44	TSM Status	GST status flags for 36 SVIDs				GST-UTC status flag	Spare	Total bits
		GST status flag (SVID #1)	GST status flag (SVID #2)	GST status flags (SVIDs #3 to #35)	GST status flag (SVID #36)			
6	2	3	3	99[3]	3	3	9	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 6.

The different GST service levels thresholds/MTE are provided in Table 4.

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

Table 7 - GST status flags bit values

GST status flag	Definition
0	Not OK
1	Timing Service Level 1
2	Timing Service Level 2
3	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 GST-UTC status flag. The UTC is global and applies to the entire constellation. As depicted in Table 6 only one flag valid for the constellation will be disseminated through the TSM in the I/NAV navigation message. It is remarked that the GST-UTC status flag refers to the

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

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

latest GST-UTC conversion parameters[5] disseminated in I/NAV and F/NAV navigation messages. Therefore, the status of the overall UTC timing solutions is described considering both GST and GST-UTC status flags.

The different UTC service levels thresholds/MTE are provided in Table 5.

The GST-UTC status flag can assume the values defined in Table 8.

Table 8 – GST-UTC status flags bit values

GST-UTC status flag	Definition
0	Not OK
1	Timing Service Level 1
2	Timing Service Level 2
3	Timing Service Level 3[6]
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 Word Type 6 of the I/NAV navigation message, and Page Type 4 of the F/NAV navigation message[7]. The TS user must apply the latest GST-UTC batch by checking the WN0t (UTC date reference Week Number) and t0t (UTC data reference Time of Week). Further details about the GST-UTC conversion algorithm and parameters are found in section 5.1.7 of the OS SIS ICD [AD 1].

[5] The latest GST-UTC conversion parameters is determined as described in Section 4.1.3.

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

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

5 TIMING SERVICE MESSAGE PROCESSING

The TSM must be decoded continuously for all satellites. The users must apply the TSM Status flag, GST Status flags and GST-UTC Status flag coming from the last received TSMs, regardless of whether the status of the OS SIS transmitted by the satellite is “Healthy”, “Marginal”, “Unhealthy” or “Extended Operations Mode”. If the user does not have any “TSM Operational” in view for a given satellite, no TSM shall be used for that satellite. However, when computing the timing solution, users must process the TSM flags (i.e. The GST Status Flag and GST-UTC Status Flag), together with the health status of the satellites according to the OS SIS Status flags, retaining the satellite for timing solution when is not “Unhealthy”, as per Table 10.

It is underlined that the TSM is not providing any information about the SIS health status of satellites. The TSM Status parameter is strictly linked to its operational status, as such “In Test” TSM does not prevent the user to estimate the usual navigation parameters (e.g. GST, UTC, GGTO, etc.).

A received TSM is considered usable if the TSM status is set to “TSM Operational”.

Different satellites might broadcast simultaneously TSMs with different TSM Status. Table 9 identifies the TSM processing logic with the TSM Status flag.

Table 9 - TSM Status processing logic

TSM Status	TSM processing
TSM Operational	TSM usable
TSM in Test	TSM usable under test conditions[8]
Spare	TSM not usable

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 mapping between the values of the SIS Status flags and the supported Service Levels is outlined in Table 10. Please note that Table 10 identifies whether a satellite is available for TS, while its actual usability is determined by the corresponding GST Status flags and GST-UTC Status flags, as described in Sections 5.1 and 5.2.

[8] Further details about the test TSM processing logic will be provided at a later stage.

Table 10 – Galileo SIS Status flags vs TS availability

OS SIS STATUS	SIS FLAGS			TS availability	
	SHS	DVS	SISA	GST	GST-UTC
Healthy	OK	Nav. Data Valid	Not NAPA	As per TSM	As per TSM
Unhealthy	Out of Service	Any Value	Any Value	Not usable for TS	
	in Test	Any Value	Any Value		
Marginal	OK	WWG	Any Value	As per TSM	As per TSM
	OK	Nav. Data Valid	NAPA	As per TSM	As per TSM
Extended Operations Mode	Will be out of Service/EOM	Nav. Data Valid	Any Value	As per TSM	As per TSM

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

5.1 GST Status Flags processing

A satellite is usable for the GST timing solution if the satellite is not “Unhealthy” and for all usable TSMs (i.e. TSM Status set to “TSM Operational”), the GST flag for that satellite indicates the intended SL, or a higher (i.e. better) one.

For instance, if the GST flags for E10 indicate SL2 and SL3 in all usable TSMs (i.e. TSM Operational), the satellite can be used for both SL1 and SL2. Consequently, a satellite is not usable for the GST timing solution if the corresponding GST flag indicates either “Not OK” or “Monitoring not available” in at least one usable TSM.

Figure 1 depicts the combined processing logic of GST Status flags and Galileo OS SIS Status flags as described in Table 10.

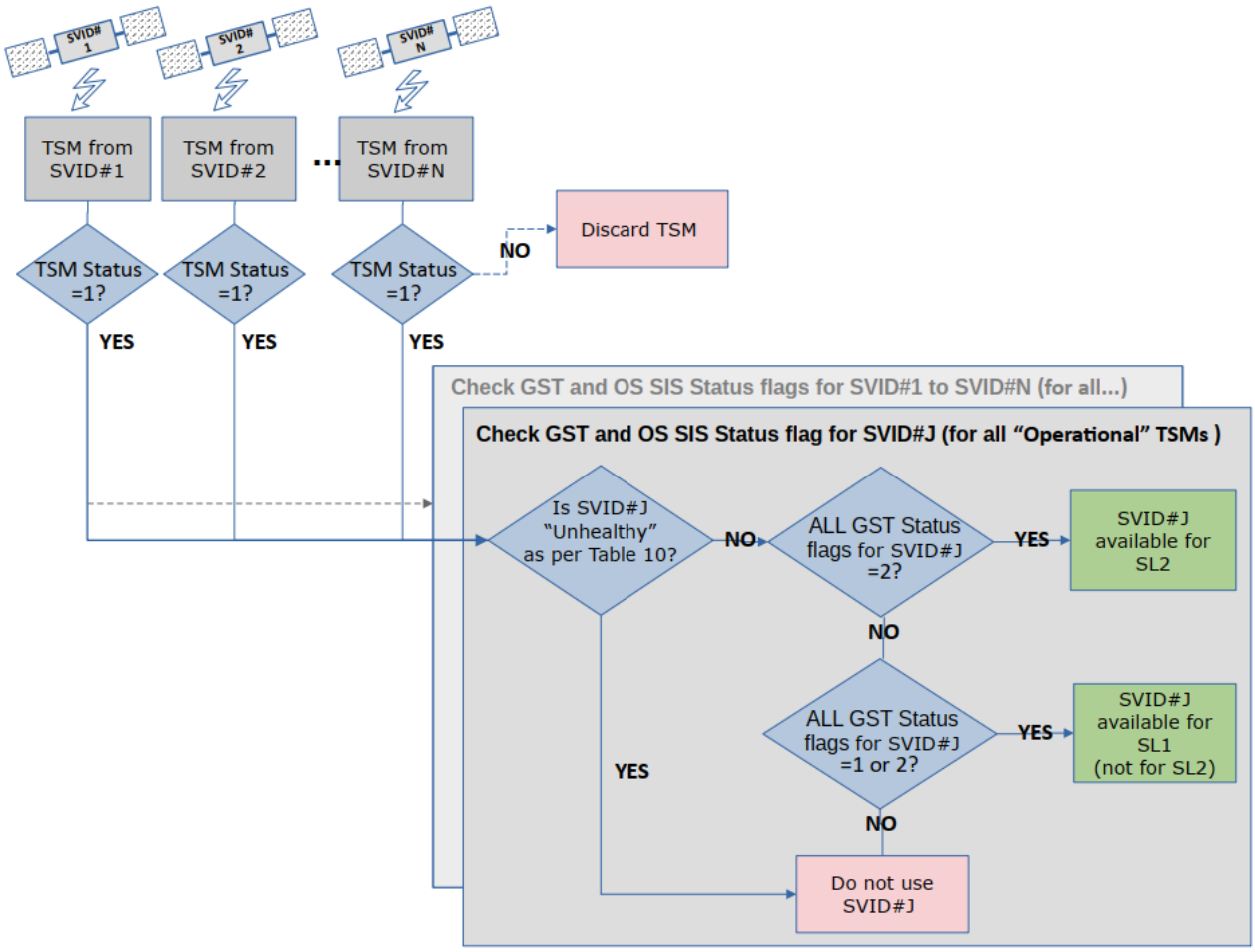

Figure 1 – Processing logic of GST Status flags and Galileo OS SIS Status flags

5.2 UTC Status Flags processing

The UTC timing solution relies on a valid GST solution plus the conversion GST to UTC. A valid UTC timing solution requires that for all usable TSMs (i.e. TSM Status set to "TSM Operational"), the GST-UTC flag indicates the intended SL, or a higher (i.e. better) one.

For instance, if the GST-UTC flags indicate SL2 and SL3 in all valid TSMs, the UTC timing solution can support both SL1 and SL2. Consequently, the UTC timing solution is not valid if any of the GST-UTC flags indicates either "Not OK" or "Monitoring not available" in at least one usable TSM.

Figure 2 depicts the combined processing logic of GST-UTC Status flags and GST solution validity.

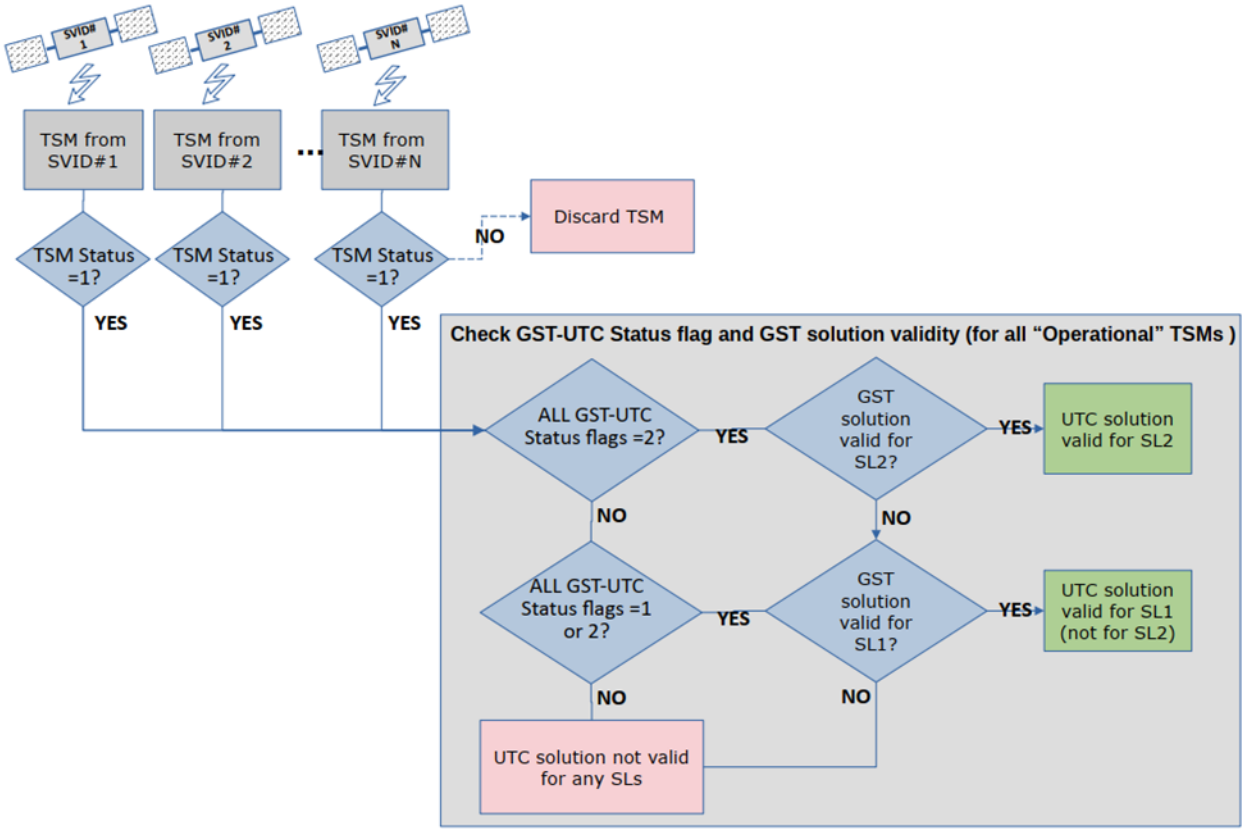

Figure 2 - Processing logic of GST-UTC Status flag and GST solution validity

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 Galileo Timing Receivers Standard, 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 Galileo timing 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 Section 5. Timing receivers can retrieve TSM flags from 1 single operational TSM (as identified in Table 9),
- 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 not guaranteed beyond the validity timeout limit (i.e. when the holdover solution can no longer guarantee that the error remains below 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 3 depicts the receiver processing logic.

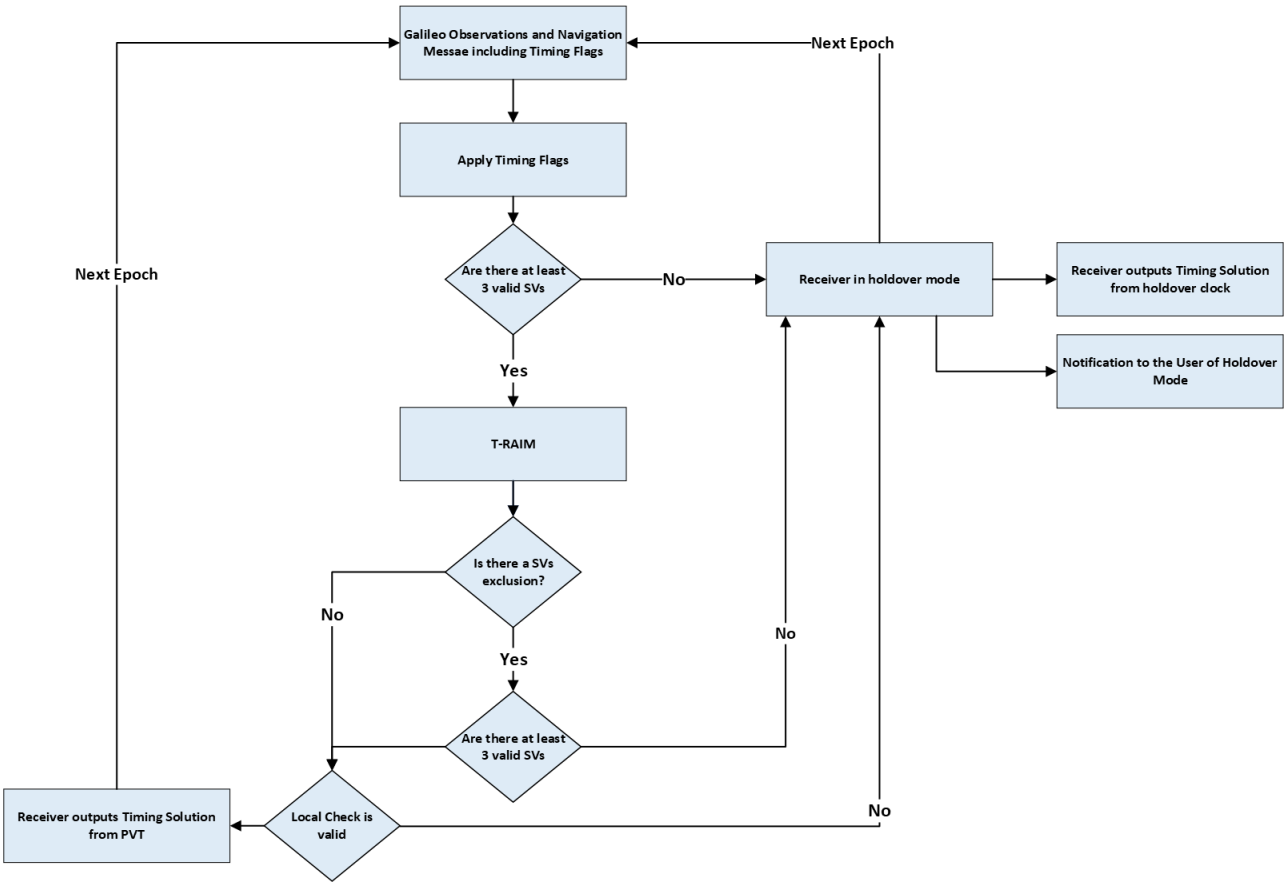

Figure 3 – Galileo Timing Receiver decision logic

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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