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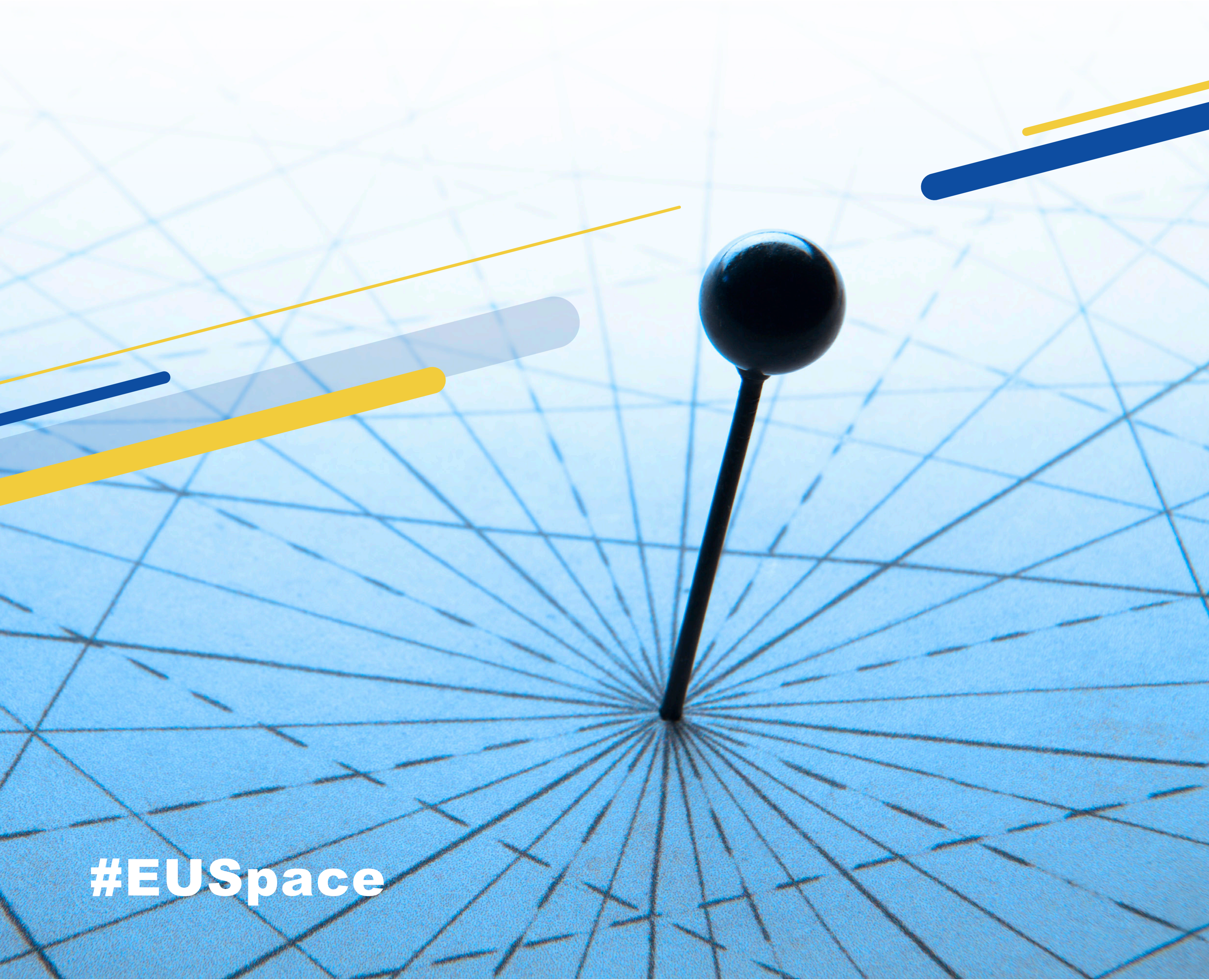
GALILEO HIGH ACCURACY SERVICE SIGNAL-IN-SPACE INTERFACE CONTROL DOCUMENT (HAS SIS ICD)

Issue 1.0, May 2022



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First issue	1	0	May 2022

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1 Introduction

1.1 Scope of the Document

This document presents the Galileo HAS (High Accuracy Service) User ICD (Interface Control Document) for the HAS Initial Service. This document is self-standing, with the exception of some publicly available ICDs and references used throughout the text.

This document presents first the general Galileo C/NAV page layout, which is followed by the description of the Galileo HAS Header and HAS Message. Later, the encoding/decoding process of HAS message pages and the application of HAS corrections are described.

1.1.1 Structure of the Document

The document is structured as follows:

- Chapter 2 describes the C/NAV page layout;
- Chapter 3 provides a description of the HAS Page Header;
- Chapter 4 provides an overview of the HAS Message;
- Chapter 5 describes the HAS Message Type 1 Header and Body, including the different content blocks that may be broadcast;
- Chapter 6 describes the HAS Message encoding and decoding operations;
- Chapter 7 describes the application of HAS corrections.

1.1.2 Applicable Documents

Id.	Document Title
[AD1]	European Union, European GNSS (Galileo) Open Service, Signal-In-Space Interface Control Document (OSSISICD), Issue 2.0, January 2021
[AD2]	European Union, Galileo E6-B/C Codes Technical Note, Issue 1, January 2019

Table 1. Applicable Documents

1.1.3 Reference Documents

Id.	Document Title
[RD1]	Navstar GPS Space Segment/Navigation User Interfaces, IS-GPS-200, Rev. M, May 2021
[RD2]	D. A. Vallado and W. D. McClain, Fundamentals of astrodynamics and applications, 4th edition, Microcosm Press, 2013.
[RD3]	European Union, Galileo Satellite Metadata, [Online]. Available: https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata. [Accessed 2022].
[RD4]	Cabinet Office, Quasi-Zenith Satellite System Interface Specification Centimeter Level Augmentation Service (IS-QZSS-L6-001), 5 Nov 2018.

Table 2. Reference Documents

1.1.4 Galileo High Accuracy Service Overview

The Galileo High Accuracy Service (HAS) is based on the provision of the information required to estimate an accurate positioning solution using a Precise Point Positioning algorithm, mainly:

- Satellite orbit corrections to the broadcast ephemerides;
- Satellite clock corrections to the broadcast ephemerides;
- Satellite biases;

Additional information may be provided in the future as part of the HAS service evolutions towards the HAS Full Operational capability.

The HAS data are transmitted within the Galileo C/NAV navigation message in the E6-B Galileo signal component at a maximum rate of 448 bits per second (bps). HAS data are transmitted only from a subset of satellites, currently up to 20, out of the total constellation.

2 Galileo C/NAV Encoding and Page Layout

The Galileo HAS is transmitted through the Signal-In-Space in the C/NAV pages of the E6-B signal component of the E6 signal, at a carrier frequency of 1278.75 MHz. The E6-B signal is presented in [AD1] and complemented by [AD2] for the spreading codes.

2.1 Bit and Byte Ordering Criteria

All data values are encoded using the following bit and byte ordering 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;

2.2 FEC Coding and Interleaving Parameters

2.2.1 FEC Coding

The Forward Error Correction (FEC) convolutional encoding for all data pages on the E6-B component is performed according to the parameters provided in Table 3. The convolutional encoding scheme described here is the same as the one used for other Galileo data channels described in [AD1].

Code Parameter	Value
Coding rate	½
Coding scheme	Convolutional
Constraint length	7
Generator polynomials	G1=171 (Octal) G2=133 (Octal)
Encoding sequence	G1 then G2

Table 3. Data Coding Parameters

Figure 1 depicts this convolutional coding scheme. Note that the second branch is inverted at the end. Decoding can be implemented using a standard Viterbi decoder.

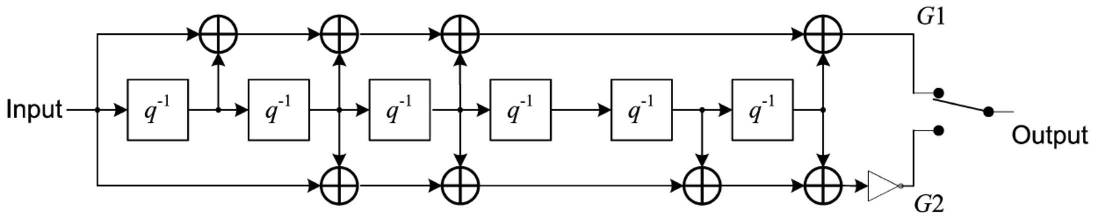

Figure 1. Convolutional Coding Scheme

2.2.2 Interleaving

Analogously to the other Galileo message types described in [AD1] , the C/NAV FEC encoded page is interleaved using a block interleaver with *n* columns (where data is written) and *k* rows (where data is read), as described in Table 4.

Parameter	Size
Block Interleaver Size (Symbols)	984
Block Interleaver Dimensions (*n* columns x *k* rows)	123 x 8

Table 4. C/NAV Interleaving Structure

2.3 C/NAV Page Layout

Every second, one C/NAV page is transmitted from a Galileo satellite. The C/NAV Page layout is shown in Table 5, where the symbol allocation and bit allocation are shown separately. The different fields composing this layout are defined in the sections below. The transmission of a page starts with the transmission of the first bit of the synchronisation pattern, which coincides with the start of an integer Galileo System Time (GST) second.

Out of 492 bits available, 14 bits are reserved, 24 bits are used for the Cyclic Redundancy Check (CRC) and 6 bits are used for the Tail.

Sync	Symbols	Total (symbols)
16	984	1000

C/NAV Page				Total (bits)
Reserved	HAS Page	CRC	Tail	
14	448	24	6	492

Table 5. C/NAV Page Layout

2.3.1 Synchronisation Pattern

The synchronisation pattern ("Sync" in Table 5) allows the receiver to achieve synchronisation to the page boundary. The synchronisation pattern is neither encoded nor interleaved. The C/NAV synchronisation pattern is “1011011101110000”.

2.3.2 Tail

The Tail field consists of six zero-value bits enabling completion of the FEC decoding of each page in the user receiver.

2.3.3 Checksum

Analogously to the description provided in [AD1] for other message types, C/NAV also uses a checksum, employing a CRC technique, to detect the reception of corrupted data. The C/NAV checksum does not include the synchronisation pattern or the tail bit fields since these do not form part of the required message information. Also for the C/NAV, the CRC of 24 bits is generated from the generator polynomial G(X) described in Eq. 1.

$$G(X) = (1 + X)P(X) \qquad \text{Eq. 1}$$

Where $P(X)$ is a primitive and irreducible polynomial given by Eq. 2.

$$P(X) = X^{23} + X^{17} + X^{13} + X^{12} + X^{11} + X^{9} + X^{8} + X^{7} + X^{5} + X^{3} + 1 \qquad \text{Eq. 2}$$

The CRC is composed of a sequence of 24 parity bits p_i; for any i from 1 to 24, p_i is the coefficient of X^{24-i} in $R(X)$ where:

- $R(X)$ is the remainder of the binary polynomial algebra division of the polynomial $m(X) \cdot X^{24}$ by $G(X)$ and
- $m(X) = m_1X^{k-1} + \ldots + m_{k-2}X^2 + m_{k-1}X + m_k$, where the coefficients $m_1, m_2, \ldots, m_k$ are the k data bits to be protected by the CRC, and m_1 is the Most Significant Bit (MSB).

The CRC shall be computed over the 462 bits of the C/NAV data bits, including the "Reserved" and "HAS Page" fields.

2.4 HAS Page

The HAS Page layout is presented in Table 6.

HAS Page		**Total (bits)**
HAS Page Header	**HAS Encoded Page**	
24	424	448

Table 6. HAS Page Layout

Every C/NAV page carries a 448-bit HAS Page. Every HAS Page is composed of a 24-bit HAS Page Header and a 424-bit HAS Encoded Page field. HAS Encoded Pages are portions of encoded HAS Messages. The HAS Message overview and decoding are described in sections 4 and 6, respectively.

The following sections define the parameters including number of bits, scale, unit and values, for each field of the HAS Page Header (section 3) and the HAS Messages (sections 4 and 5). Each field includes a definition allowing its interpretation. The fields are represented either in binary, between quotation marks (".."), or in decimal format.

2.4.1 HAS Dummy Page

In case no valid HAS data is transmitted, the satellites broadcast a HAS dummy page with the HAS Page layout defined in Table 6 and the following sequence in the 24-bit HAS Page Header:

"*hex*[AF3BC3]",

where *hex* implies hexadecimal format.

Users shall expect some of the operational satellites to broadcast dummy pages during nominal operation. In any case, HAS dummy pages shall be discarded.

3 HAS Page Header

The 24-bit HAS Page Header is transmitted in every C/NAV Page. The structure of the HAS Page Header is provided in Table 7.

HAS Page Header						
HASS	Reserved	MT	MID	MS	PID	**Total (bits)**
2	2	2	5	5	8	24

Table 7. HAS Page Header Layout

3.1 HAS Page Header Parameters

The parameters of the HAS Page Header are defined according to Table 8. See section 6.4 for more details on the interpretation of the Page Header fields MT, MID, MS and PID.

Parameter	Definition	Bits	Scale	Unit	Values
HASS	HAS Status according to 3.1.1.	2	-	-	-
MT	Type of the message as per 3.1.2.	2	-	-	-
MID	ID of the message.	5	-	-	0-31
MS	Size of the non-encoded message, in number of pages, where “0”=1 …“31”=32	5	1	Pages	1-32
PID	ID of the transmitted HAS Encoded Page. “00000000” = Reserved.	8	-	-	1-255

Table 8. HAS Page Header Parameters

3.1.1 HAS Status (HASS)

The 2-bit HASS parameter defines the status of the HAS service, the definition and the corresponding semantic for each value are defined in Table 9.

HASS	Definition	Semantic
“00”	Test mode	HAS service testing activities ongoing. Nominal performance may not be met.
“01”	Operational mode	HAS is expected to provide nominal performance.
“10”	Reserved	
“11”	Don’t use	Users shall stop using HAS from all satellites and discard previously received messages.

Table 9. HASS values and corresponding semantic

3.1.2 Message Type (MT)

The different message types and the corresponding semantic are listed in Table 10.

MT	Definition	Semantic
"01"	MT1	Contains satellite corrections.
"10"	Reserved	
"00"		
"11"		

Table 10. MT values and corresponding semantic

4 HAS Message Overview

This section presents an overview of the HAS message encoded in HAS Encoded Pages. Figure 2 presents the HAS message formatting and encoding process, which is performed as follows:

- First, a HAS message is defined by concatenating the Message Type Header and the Message Body. The Message Type Header, such as the MT1 Header defined later in Table 12, is depicted as *H* in Figure 2. The Message Type Header defines the message content. For satellite corrections the message may include masks, orbit corrections, clock corrections, code biases, phase biases, or combinations of them.
- Then, the HAS message is partitioned into *k* 424-bit non-encoded pages $M_1, ..., M_k$ ($k \leq 32$). If the length of the message is not a multiple of 424 bits, padding bits with a binary sequence of zeroes and ones "010101…" are appended to the message in order to reach a message length which is a multiple of 424 bits. Padding is represented with a shaded color in Figure 2.
- Finally, the message is encoded into N=255 HAS Encoded Pages $C_1, …, C_N$. Different portions of the message, i.e. different non-zero encoded pages, are then allocated to different satellites for dissemination. The message can be decoded when any *k* different HAS Encoded Pages are received. The message encoding and decoding process is described in detail in section 6.

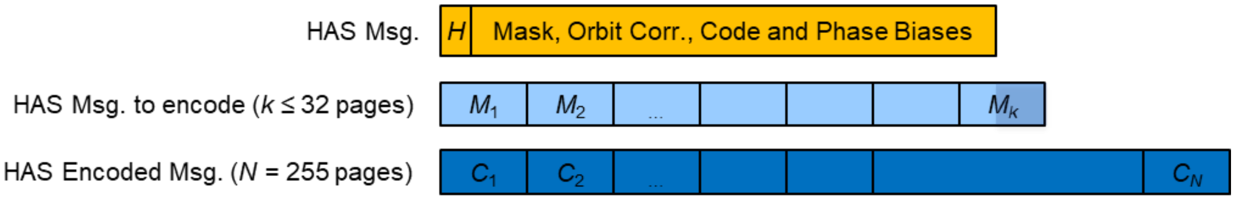

Figure 2. Example of HAS Encoding Process. *H* stands for HAS Message Type Header, M_i for Non-Encoded Message Pages and C_i for HAS Encoded Pages.

5 HAS Message Type 1

This section describes HAS MT1 (Message Type 1). The MT1 layout is described in Table 11.

MT1	
MT1 Header	**MT1 Body**
32	L_{MT1_body}

Table 11. HAS Message Type 1 Layout

5.1 MT1 Header

Every HAS MT1 has a common 32-bit HAS MT1 Header that is transmitted before the HAS MT1 Body. The MT1 Header layout is shown in Table 12.

MT1 Header										
TOH	Mask Flag	Orbit Corr. Flag	Clock Full-set Flag	Clock Subset Flag	Code Bias Flag	Phase Bias Flag	Reserved	Mask ID	IOD Set ID	**Total (bits)**
12	1	1	1	1	1	1	4	5	5	32

Table 12. MT1 Header Layout

The parameters are described in section 5.1.1. MT1 can include content blocks with different satellite information, and the flags of MT1 header indicate the content blocks included in the message. These are some of the possible MT1 combinations:

- A single MT1 with mask, orbit corrections, clock full-set corrections and code biases (flag sequence: “111010”);
- A single MT1 with mask, orbit corrections, clock full-set corrections, code biases and phase biases (flag sequence: “111011”);
- One MT1 with mask, orbit corrections, code biases and phase biases (flag sequence: “110011”), plus one MT1 with clock full-set correction (flag sequence: “001000”);
- One MT1 with mask, orbit corrections, clock full-set corrections, code biases and phase biases (flag sequence: “111011”), plus one MT1 with clock subset corrections (flag sequence: “000100”);

Other combinations are possible. The content of the message shall be read in the order of the flags for the content blocks provided (i.e. first the mask if present, then the orbit corrections if present, etc.). Note also that the 6-bit flag stream is followed by 4 reserved bits which may be used in the future to expand the available flags. Thus, forward-compatible receivers shall account for the possibility of HAS MT1 messages containing additional non-decodable information at the end of the decodable one.

The MT1 Header contains a Mask ID to ensure masks are properly identified. The Mask ID and the IOD Set ID together relate the content of different messages to a satellite set and their Reference IODs.

When Mask Flag = 1, Mask ID defines the mask in the Mask block, and when Mask Flag = 0, it relates MT1 content to an already existing Mask ID. Similarly, when Orbit Corr. Flag = 1, the message defines the IOD Set ID field by linking it to the Reference IODs provided in the orbit corrections content block, and when Orbit Corr. Flag = 0, it relates its content to an already existing IOD Set ID. Further information on the IOD Set ID and Reference IOD correspondence and their validity intervals can be found in sections 7.6 and 7.6.1 respectively.

5.1.1 MT1 Header Parameters

This section describes the MT1 Header parameters as per Table 13.

Parameter	Definition	Bits	Scale	Unit	Values
TOH	Time Of Hour of the message information, related to GST. The absolute message applicability time can be calculated as per 7.7.	12	1	s	0-3599
Mask Flag	6-bit field with flags defining the message content blocks. Each flag indicates if the content block is present ("1") or not ("0").	1	-	-	0-1
Orbit Corr. Flag		1	-	-	
Clock Full-Set Flag		1	-	-	
Clock Subset Flag		1	-	-	
Code Bias Flag		1	-	-	
Phase Bias Flag		1	-	-	
Mask ID	ID of the Mask as per 5.1.1.1.	5	-	-	0-31
IOD Set ID	ID of reference set of IODs according to 5.1.1.2.	5	-	-	0-31

Table 13. MT1 Header Parameters

5.1.1.1 Mask ID

The Mask ID is a counter that identifies the mask, which contains the information of the corrected satellites, signals, and reference navigation messages. It changes when the content of the mask changes. When Mask Flag = "1", the MT1 Body defines the mask in the Mask content block. When Mask Flag = "0", the MT1 Body is related to a mask already defined in another MT1 with the same Mask ID.

5.1.1.2 IOD Set ID

IOD Set ID is a counter that identifies the set of Reference IODs for all corrected satellites of the mask. IOD Set ID changes when the Reference IOD of at least one satellite of the mask changes and corrections for new IODs are provided. When Orbit Corr. Flag = "1", the MT1

Body defines the IOD Set ID in the Orbit Corrections content block, through the IOD Reference fields. When Orbit Corr. Flag = “0”, the MT1 Body satellite data is related to an IOD set already defined in another MT1 with the same Mask ID and IOD Set ID.

5.2 MT1 Body

The MT1 Body contains the data of the message, which are grouped into content blocks in the following order: Mask, Orbit Corrections, Clock Full-Set Corrections, Clock Subset Corrections, Code Biases and Phase Biases. The MT1 Body has a flexible structure and not all the blocks are necessarily transmitted. The content blocks provided in the MT1 Body of a message are indicated through the flags of its MT1 Header, meaning that they can be transmitted all or just a subset. The MT1 layout is shown in Table 14 and the definition of the content blocks is detailed in the following sections.

MT1 Body					
Mask Block	**Orbit Corrections Block**	**Clock Full-Set Corrections Block**	**Clock Subset Corrections Block**	**Code Biases Block**	**Phase Biases Block**
L_{MT1_body}					

Table 14. MT1 Body Layout. Block presence is defined in MT1 Header

The size of the MT1 Body message, L_{MT1_body}, is variable and depends on which blocks are actually transmitted and on their specific definition for the specific epoch, as explained in the following sections.

5.2.1 Mask Block

The layout of the Mask block is shown in Table 15.

Mask Block				
N_{sys}	**Mask_GNSS$_1$**	⋮	**Mask_GNSS$_{Nsys}$**	Reserved
4	L_{MASK_1}	…	L_{MASK_Nsys}	6

Table 15. Mask Block Layout

The 4-bit parameter N_{sys} indicates the number of GNSS for which corrections are provided, assuming values from 1 to 15 (value "0" is Reserved).

For each of the GNSS as defined in section 5.2.1.1 for which corrections are transmitted, a specific mask is provided. Note that the Mask block has a variable length, depending on how many GNSS have corrections and also on the specific definition of the mask for each of the GNSS, as defined in the following section.

The mask provided for each GNSS (GNSS$_n$) within the Mask block is defined in Table 16.

Mask_GNSS$_n$

GNSS ID	SatM	SigM	CMAF	CM	NM	**Total (bits)**
4	40	16	1	L_{CM}	3	L_{MASK_n}

Table 16. Layout of the Mask for a specific GNSS

The definition of the mask parameters are provided in Table 17.

Parameter	Definition	Bits	Scale	Unit	Values
GNSS ID	GNSS ID identifies the GNSS to which the specific mask refers. See 5.2.1.1.	4	-	-	0-15
SatM	Satellite Mask as per 5.2.1.2.	40	-	-	-
SigM	Signal Mask as per 5.2.1.3.	16	-	-	-
CMAF	Cell Mask Availability Flag. More details in 5.2.1.4.	1	-	-	0-1
CM	Cell Mask. More details in 5.2.1.5.	L_{CM}	-	-	-
NM	Navigation Message Index as per 5.2.1.6.	3	-	-	0-7

Table 17. Mask Parameters

5.2.1.1 GNSS ID

GNSS ID is defined according to Table 18.

GNSS Index	GNSS
0	GPS
1	Reserved
2	Galileo
3-15	Reserved

Table 18. GNSS Index Table

5.2.1.2 Satellite Mask (SatM)

Satellite Mask is a 40-bit field that specifies the satellites of the GNSS identified by GNSS ID which are corrected (“1”) and those which are not (“0”). The list of satellite indexes is provided in Table 19. The MSB of the field corresponds to Satellite Index = 0.

Satellite Index	Galileo SVID	GPS PRN
0	1	1
1	2	2
…	…	…
39	40	40

Table 19. Satellite Index Table

5.2.1.3 Signal Mask (SigM)

Signal Mask is a 16-bit field that indicates the signals of the GNSS identified by GNSS ID for which biases are provided in the Code Bias and Phase Bias content blocks. The list of signals is provided in Table 20. For each signal, “1” indicates that biases are provided and “0” indicates that they are not. The MSB of the field corresponds to Signal Index = 0.

Signal Index	Galileo	GPS
0	E1-B I/NAV OS	L1 C/A
1	E1-C	Reserved
2	E1-B + E1-C	Reserved
3	E5a-I F/NAV OS	L1C(D)
4	E5a-Q	L1C(P)
5	E5a-I+E5a-Q	L1C(D+P)
6	E5b-I I/NAV OS	L2 CM
7	E5b-Q	L2 CL
8	E5b-I+E5b-Q	L2 CM+CL
9	E5-I	L2 P
10	E5-Q	Reserved
11	E5-I + E5-Q	L5 I
12	E6-B C/NAV HAS	L5 Q
13	E6-C	L5 I + L5 Q
14	E6-B + E6-C	Reserved
15	Reserved	Reserved

Table 20. Signal Index Table

5.2.1.4 Cell Mask Availability Flag (CMAF)

CMAF parameter indicates if the Cell Mask (see section 5.2.1.5) is provided (“1”) or not (“0”) for the GNSS identified by GNSS ID. If the Cell Mask Availability Flag is set to “0”, the code biases and phase biases content blocks, described in sections 5.2.5 and 5.2.6 respectively, include data for all satellites and signals in the Satellite and Signal masks.

5.2.1.5 Cell Mask (CM)

The Cell Mask field indicates with one bit whether biases are provided (“1”) or not (“0”) for each satellite of the satellite mask (i.e. each “1” of the Satellite Mask described in section 5.2.1.2) and for each signal of the signal mask (i.e. each “1” of the Signal Mask described in section 5.2.1.3).

Cell Mask is defined as a table of N_{sat} rows by N_{sig} columns, where N_{sat} is the number of ones in Satellite Mask defined in section 5.2.1.2 and N_{sig} is the number of ones in Signal Mask defined in section 5.2.1.3. The table is encoded as a bit stream which corresponds to the values of the table read from left to right and from top to bottom. The size of the CM field is therefore GNSS specific and epoch specific (depending on N_{sig} and N_{sat}) and is defined by Eq. 3:

$$L_{CM} = N_{sig} \cdot N_{sat} \qquad \text{Eq. 3}$$

As a consequence, the total number of bits of the mask for a specific GNSS (as defined in Table 16) is given by Eq. 4:

$$L_{MASK} = 64 + L_{CM} \qquad \text{Eq. 4}$$

5.2.1.6 Navigation Message Index (NM)

The parameter NM defines the index of the Navigation Message corrected in the “Orbit Corrections”, “Clock Full-Set Corrections” and “Clock Subset Corrections” content blocks for the GNSS identified by GNSS ID, as per Table 21.

Navigation Message Index	Galileo	GPS
0	I/NAV	LNAV (L1 C/A)
1-7	Reserved	Reserved

Table 21. Navigation Message Index Table

5.2.2 Orbit Corrections Block

The Orbit Corrections block provides orbit corrections for all the satellites specified in the Mask block. The Orbit Corrections block layout is shown in Table 22.

Orbit Corrections Block

VI	$Orbit\_SV_1$	⋮	$Orbit\_SV_{Nsat\_all}$
4	L_{orbit}		

Table 22. Orbit Corrections Block Layout

The 4-bit parameter VI indicates the Validity Interval Index and is defined in detail in section 5.2.2.1. The Orbit Corrections are transmitted for each SV_n with $n = 1, \dots, N_{sat\_all}$ where N_{sat_all} represents the total number of satellites for which corrections are provided, i.e. the total number of ones in the Satellite Masks (SatM), as defined in section 5.2.1.2, for all GNSS. For each Orbit Correction, a specific set of parameters is transmitted, as defined in section 5.2.2.2. Note that the Orbit Corrections Block has a variable length, represented in the above figure with the parameter L_{orbit}, as explained in the following sections.

5.2.2.1 Validity Interval Index

The Validity Interval VI of the associated content block defines the time interval during which the corrections are considered valid. VI starts at the time defined by TOH in the Message Header (see section 5.1.1), and lasts according to the value defined by the Validity Interval column in Table 23.t

Validity Interval Index	Validity Interval
0	5 s
1	10 s
2	15 s
3	20 s
4	30 s
5	60 s
6	90 s
7	120 s
8	180 s
9	240 s
10	300 s
11	600 s
12	900 s
13	1800 s
14	3600 s
15	Reserved

Table 23. Validity Interval Index Table

5.2.2.2 *Orbit Corrections Parameters*

The Orbit Corrections parameters provided for each satellite are defined in Table 24 for the *n*-th SV.

Orbit_SV$_n$				
IODref	DR	DIT	DCT	**Total (bits)**
L_{IOD}	13	12	12	L_{orbit_SVn}

Table 24. Layout of the Orbit Corrections data for a specific satellite

The definition of the Orbit Corrections parameters for a specific satellite is provided in Table 25.

Parameter	Definition	Bits	Scale	Unit	Values
IODref	Reference IOD. Indicates the Orbit and Clock Data corrected. More details in Table 26.	L_{IOD}	-	-	See Table 26.
DR	Delta Radial correction. Value “1000000000000” indicates data not available.	13*	0.0025	m	±10.2375
DIT	Delta In-Track correction. Value “100000000000” indicates data not available.	12*	0.0080	m	±16.376
DCT	Delta Cross-Track correction. Value “100000000000” indicates data not available.	12*	0.0080	m	±16.376

* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the MSB.

Table 25. Orbit Corrections Parameters

See section 7.2 for additional information on the orbit corrections usage.

The reference IOD, IODref, indicates the specific set of Orbit and Clock Data corrected for SV$_n$ with $n = 1, \ldots, N_{sat\_all}$ where N_{sat_all} represents the total number of satellites for which corrections are provided, i.e. the total number of ones in the Satellite Masks (SatM), as defined in section 5.2.1.2, for all GNSS.

The IODref field size, L_{IOD}, and consequently the overall size of the Orbit Corrections data block, L_{orbit_SVn}, are GNSS specific and defined in Table 26.

GNSS	L_{IOD} [bits]	Range	L_{orbit_SVn} [bits]
GPS	8	0 – 255	45
Galileo	10	0 – 1023	47

Table 26. IODref length-GNSS Mapping

The corrected issue of data, identified by IODref, refers to the parameter IODnav for Galileo satellites (see [AD1]) and IODE/IODC for GPS satellites (see [RD1]), respectively.

5.2.3 Clock Full-Set Corrections Block

The Clock Full-Set Corrections block provides clock corrections for all the satellites specified in the Mask block. The Clock Full-Set Corrections block layout is shown in Table 27.

Clock Full-Set Corrections Block

VI	Delta Clock Multipliers (DCM)	Delta Clock Corrections (DCC)
4	L_{DCM}	L_{DCC}

Table 27. Clock Full-Set Corrections Block Layout

The Validity Interval Index VI has the same definition already provided in section 5.2.2.1. The Delta Clock Multipliers (DCM) and Delta Clock Corrections (DCC) parameters are described in sections 5.2.3.1 and 5.2.3.2, respectively.

5.2.3.1 Delta Clock Multipliers (DCM)

The Delta Clock Multipliers (DCM) parameters are represented in Table 28.

Delta Clock Multipliers (DCM)

DCM_1	…	DCM_{Nsys}	**Total (bits)**
2	…	2	L_{DCM}

Table 28. Delta Clock Multipliers (DCM) Layout

The 2-bit DCM_n parameter, with $n = 1, \ldots, N_{sys}$ (where N_{sys} is provided in the Mask Block, see section 5.2.1) indicates the multiplier to be applied to the Delta Clock Corrections for the different GNSS identified within the Mask Block as per Table 29.

The total size of the DCM parameters is therefore depending on how many GNSS are being corrected and can be expressed by Eq. 5:

$$L_{DCM} = 2 \cdot N_{sys} \qquad \text{Eq. 5}$$

Where N_{sys} can be derived from the Mask Block as described in section 5.2.1.

The 2-bit DCM for each system is defined in Table 29.

DCM Value	Multiplier
"00"	1
"01"	2
"10"	3
"11"	4

Table 29. Delta Clock Multiplier Parameter Definition

5.2.3.2 *Delta Clock Corrections (DCC)*

The Delta Clock Corrections (DCC) parameters are represented in Table 30.

Delta Clock Corrections (DCC)			
DCC_1	…	DCC_{Nsat_all}	**Total (bits)**
13	…	13	L_{DCC}

Table 30. Delta Clock Corrections (DCC) Layout

The 13-bit DCC_n parameter is the Delta clock correction for SV_n with $n = 1, \ldots, N_{sat\_all}$. See section 7.3 for further information on the clock corrections usage.

The definition of the DCC_n parameter is provided in Table 31.

Parameter	Definition	Bits	Scale	Unit	Values
DCC_n	Value "1000000000000" indicates data not available. Value "0111111111111" indicates the satellite shall not be used.	13^*	0.0025	m	-10.2375 to +10.2350

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB.

Table 31. Delta Clock Correction Parameter

The total size of the DCC parameters L_{DCC} therefore depends on how many GNSS are being corrected and on the total number of satellites being corrected for each of those systems.

5.2.4 Clock Subset Corrections Block

The Clock Subset Corrections block provides clock corrections for a subset of satellites of the applicable mask. The block includes therefore a subset mask and the corresponding clock corrections with the layout shown in Table 32.

Clock Subset Corrections Block

VI	N_{sys_sub}	**Clock Subset Corrections**		
		Clock_sub_ GNSS$_1$	…	**Clock_sub_ GNSS$_{Nsys\_sub}$**
4	4	L_{clock_sub}		

Table 32. Clock Subset Corrections Block Layout

The Validity Interval Index VI has the same definition already provided in section 5.2.2.1. The 4-bit parameter N_{sys_sub} indicates the number of GNSS within the subset for which the clock corrections are provided. Within the Clock Subset Corrections Block, clock corrections are provided for the N_{sys_sub} GNSS that are part of the subset.

The total size of the Clock Subset Corrections Block, L_{clock_sub}, is therefore depending on how many GNSS are part of the subset and on the total number of satellites being corrected for each of those systems.

The structure of the data block for each GNSS is presented in the following sub-section.

5.2.4.1 Clock Subset Corrections Parameters

The Clock Subset Corrections parameters provided for each of the GNSS system within the subset is defined in Table 33.

Clock_sub_GNSS$_n$

GNSS ID	DCM	$SatM_{sub}$	**Clock Subset Corrections (DCC$_{sub}$)**	**Total (bits)**
4	2	N_{sat}	L_{DCC_sub}	L_{GNSS_sub}

Table 33. Clock Subset Corrections Layout for a specific GNSS within the subset

The 4-bit GNSS ID is the specific GNSS to which the corrections refer, as per section 5.2.1.1. Similarly to the above, the 2-bit DCM parameter is the multiplier for all Delta Clock corrections provided for the specific GNSS, according to section 5.2.3.1.

The Satellite Subset Mask, SatM$_{sub}$, indicates which satellites of the specific GNSS present in the linked Satellite Mask field (SatM) as per section 5.2.1.2 are corrected (“1”), and which are not (“0”), in the Clock Subset Corrections. Therefore, the length of this field, N_{sat}, corresponds to the number of corrected satellites ("1") in the Satellite Mask (SatM), for the specific GNSS (GNSS$_n$).

The Clock Subset Corrections parameters are provided for all the satellites part of the subset, as indicated within SatM$_{sub}$, with structure represented in Table 34.

Clock Subset Corrections (DCC$_{sub}$)			
DCC$_1$	⋮	DCC$_{Nsat\_sub}$	**Total (bits)**
13	…	13	L_{DCC_sub}

Table 34. Clock Subset Corrections Layout (DCC$_{sub}$)

The definition of the DCC$_n$ parameter, with $n = 1, \dots, N_{sat\_sub}$, is provided in Table 31. N_{sat_sub} is the number of Clock Subset Corrections for GNSS$_n$ ($N_{sat\_sub} \leq N_{sat}$).

The total size of the DCC$_{sub}$ block, L_{DCC_sub}, therefore depends on how many satellites are part of the subset for the specific GNSS as expressed in Eq. 6:

$$L_{DCC\_sub} = 13 \cdot N_{sat\_sub} \qquad \text{Eq. 6}$$

5.2.5 Code Biases Block

The Code Biases block layout is shown in Table 35.

Code Biases Block			
	Code Biases (CB)		
VI	**Code Biases SV$_1$**	⋮	**Code Biases SV$_{Nsat\_all}$**
4	L_{code_bias}		

Table 35. Code Biases Block Layout

The 4-bit Validity Interval Index VI has the same definition already provided in section 5.2.2.1. The Code Biases (CB) message structure for each SV is represented in Table 36.

Code Biases SV$_n$			
CB$_{1,n}$	⋮	CB$_{Nsig,n}$	**Total (bits)**
11	...	11	L_{CB}

Table 36. Code Biases for the Satellite SV$_n$

The 11-bit CB$_{m,n}$ parameter is the Code Bias for the signal m of the SV$_n$, with $m = 1, \ldots, N_{sig}$ and $n = 1, \ldots, N_{sat\_all}$ (where N_{sat_all} is the number of ones in all Satellite Masks for each GNSS defined in section 5.2.2 and N_{sig} is the number of signals as per the Signal Mask defined in section 5.2.1.3, and which may be different for each GNSS). Note that if the Cell Mask Availability Flag (CMAF) as defined in section 5.2.1.4 is set to "1", the biases are provided only for the signals and the satellites identified within the Cell Mask as described in section 5.2.1.5.

The size of the CB section for a generic SV$_n$ satellite, L_{CB}, will therefore depend on the number of signals for which a code bias is provided.

The definition of the CB$_{m,n}$ parameter is provided in Table 37.

Parameter	Definition	Bits	Scale	Unit	Values
CB$_{m,n}$	Code bias for the *m*-th signal of the *n*-th SV, as indicated in Signal Mask defined in 5.2.1.3 (or in Cell Mask defined in 5.2.1.5, if available). Value "10000000000" indicates data not available.	11*	0.02	m	± 20.46

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB.

Table 37. Code Biases Parameters

See section 7.4 for further information on the code biases usage.

5.2.6 Phase Biases Block

The Phase Biases block layout is shown in Table 38.

Phase Biases Block			
	Phase Biases (PB)		
VI	**Phase Biases SV$_1$**	⋮	**Phase Biases SV$_{Nsat\_all}$**
4	L_{phase_bias}		

Table 38. Phase Biases Block Layout

The 4-bit Validity Interval Index VI has the same definition already provided in section 5.2.2.1. The Phase Biases (PB) message structure for each SV is represented in Table 39.

Phase Biases SV_n					
$PB_{1,n}$	$PDI_{1,n}$	…	$PB_{Nsig,n}$	$PDI_{Nsig,n}$	**Total (bits)**
11	2	…	11	2	L_{PB}

Table 39. Phase Biases for the Satellite SV_n

Similarly to the code biases, the 11-bit $PB_{m,n}$ parameter is the Phase Bias for the signal m of the SV_n, with $m = 1, \ldots, N_{sig}$ and $n = 1, \ldots, N_{sat\_all}$ (where N_{sat_all} is the number of ones in all Satellite Masks for each GNSS defined in section 5.2.2 and N_{sig} is the number of signals as per the Signal Mask defined in section 5.2.1.3, and which may be different for each GNSS). Note that, if the Cell Mask Availability Flag (CMAF) as defined in section 5.2.1.4 is set to “1”, the biases are provided only for the signals and the satellites identified within the Cell Mask as described in section 5.2.1.5.

Analogously, the 2-bit $PDI_{m,n}$ parameter is the Phase Discontinuity Indicator for the signal m of SV_n.

The size of the PB section for a generic SV_n satellite, L_{PB}, will again depend on the number of signals for which a phase bias is provided.

The definition of the $PB_{m,n}$ and $PDI_{m,n}$ parameters are provided in Table 40.

Parameter	Definition	Bits	Scale	Unit	Values
$PB_{m,n}$	Phase bias for the m-th signal of the n-th SV, as indicated in Signal Mask defined in 5.2.1.3 (or in the Cell Mask defined in 5.2.1.5, if available). Value “10000000000” indicates data not available.	11^*	0.01	Cycles	±10.23
$PDI_{m,n}$	Phase Discontinuity Indicator for the m-th signal of the n-th SV, as indicated in Signal Mask defined in 5.2.1.3 (or in the Cell Mask defined in 5.2.1.5, if available). 5.2.6.1 clarifies how PDI is incremented.	2	-	-	0-3

[*] Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the MSB.

Table 40. Phase Biases Parameters

See section 7.4 for further information on the phase biases usage.

5.2.6.1 Phase Discontinuity Indicator (PDI)

This counter is incremented every time there is a phase bias discontinuity which requires a re-initialisation of the fixed ambiguity for the corresponding satellite and signal.

6 HAS Message Encoding And Decoding

The HAS Message is encoded through an outer layer scheme as previously shown in Figure 2, here called High Parity Vertical Reed-Solomon (HPVRS). The purpose of the outer layer coding of the HAS message pages is to improve reception efficiency when broadcasting common data from different satellites. A HAS message **M** of k pages $(M_1, ..., M_k)$ is encoded into a set **C** of N pages $(C_1, ..., C_N)$. When *any* subset **C'** of **C**, of k different pages $(C'_1, ..., C'_k)$, is received without error, the message can be decoded.

In order to speed up reception, a large amount of parity is required. With this purpose, the encoding and decoding process is based on “vertically encoding” the message into separate Reed-Solomon codes, as described in the following subsections.

6.1 Galois Field

The Reed-Solomon codes used are based on a Galois field of order 256, GF(256), defined by the primitive polynomial in Eq. 7.

$$p(\alpha) = \alpha^8 + \alpha^4 + \alpha^3 + \alpha^2 + 1 \qquad \text{Eq. 7}$$

The resulting Galois field elements in polynomial representation, octet representation (binary and integer), and in α^n representation with primitive element α are partially provided in Table 41.

Polynomial representation	Octet representation	Octet representation (integer)	Power representation α^n
0	00000000	0	$0=\alpha^{-\infty}$
1	00000001	1	$1=\alpha^0$
α	00000010	2	α
α^2	00000100	4	α^2
α^3	00001000	8	α^3
α^4	00010000	16	α^4
α^5	00100000	32	α^5
α^6	01000000	64	α^6
α^7	10000000	128	α^7
$\alpha^4+\alpha^3+\alpha^2+1$	00011101	29	α^8
$\alpha^5+\alpha^4+\alpha^3+\alpha$	00111010	58	α^9
$\alpha^6+\alpha^5+\alpha^4+\alpha^2$	01110100	116	α^{10}
$\alpha^7+\alpha^6+\alpha^5+\alpha^3$	11101000	232	α^{11}

Polynomial representation	**Octet representation**	**Octet representation (integer)**	**Power representation α^n**
$\alpha^7+\alpha^6+\alpha^3+\alpha^2+1$	11001101	205	α^{12}
$\alpha^7+\alpha^2+\alpha+1$	10000111	135	α^{13}
$\alpha^4+\alpha+1$	00010011	19	α^{14}
⋮	⋮	⋮	⋮
$\alpha^4+\alpha^2+\alpha$	00010110	22	α^{239}
$\alpha^5+\alpha^4+\alpha^2$	00101100	44	α^{240}
$\alpha^6+\alpha^4+\alpha^3$	01011000	88	α^{241}
$\alpha^7+\alpha^5+\alpha^4$	10110000	176	α^{242}
$\alpha^6+\alpha^5+\alpha^4+\alpha^3+\alpha^2+1$	01111101	125	α^{243}
$\alpha^7+\alpha^6+\alpha^5+\alpha^4+\alpha^3+\alpha$	11111010	250	α^{244}
$\alpha^7+\alpha^6+\alpha^5+\alpha^3+1$	11101001	233	α^{245}
$\alpha^7+\alpha^6+\alpha^3+\alpha^2+\alpha+1$	11001111	207	α^{246}
$\alpha^7+\alpha+1$	10000011	131	α^{247}
$\alpha^4+\alpha^3+\alpha+1$	00011011	27	α^{248}
$\alpha^5+\alpha^4+\alpha^2+\alpha$	00110110	54	α^{249}
$\alpha^6+\alpha^5+\alpha^3+\alpha^2$	01101100	108	α^{250}
$\alpha^7+\alpha^6+\alpha^4+\alpha^3$	11011000	216	α^{251}
$\alpha^7+\alpha^5+\alpha^3+\alpha^2+1$	10101101	173	α^{252}
$\alpha^6+\alpha^2+\alpha+1$	01000111	71	α^{253}
$\alpha^7+\alpha^3+\alpha^2+\alpha$	10001110	142	α^{254}

Table 41. Polynomial, Octet and Power Representation of the Galois Field

6.2 Reed-Solomon Code

The Reed-Solomon code used for the outer layer coding of the HAS message pages is a RS(*N*,*K*,*d*) code where:

- The code vector length is $N = 2^m - 1 = 255$ with *m* = 8;
- The information vector length is $K = 32$;
- The minimum Hamming distance is $d = N - K + 1 = 224$;

The resulting code is RS(255,32,224).

6.2.1 Generator Polynomial

The Reed-Solomon code is a narrow sense code over GF(256) where the field is represented using the primitive polynomial $p(\alpha)$ and α is a primitive element in the field. The corresponding generator polynomial *g(x)* in the indeterminate x is defined in Eq. 8.

$$g(x) = \prod_{i=1}^{255-32} (x - \alpha^{i}) = \sum_{j=0}^{223} g_j \cdot x^{j} \qquad \text{Eq. 8}$$

The resulting coefficients g_j of the polynomial are tabularised in the integer octet representation in Table 42.

j	g_j	***j***	g_j	***j***	g_j	***j***	g_j	***j***	g_j	***j***	g_j	***j***	g_j
0	88	*32*	118	*64*	81	*96*	255	*128*	39	*160*	224	*192*	241
1	216	*33*	227	*65*	181	*97*	51	*129*	46	*161*	127	*193*	230
2	195	*34*	112	*66*	112	*98*	36	*130*	229	*162*	5	*194*	188
3	23	*35*	28	*67*	51	*99*	6	*131*	171	*163*	27	*195*	170
4	111	*36*	65	*68*	118	*100*	120	*132*	193	*164*	112	*196*	148
5	82	*37*	48	*69*	108	*101*	163	*133*	252	*165*	71	*197*	97
6	79	*38*	244	*70*	243	*102*	59	*134*	43	*166*	165	*198*	121
7	81	*39*	165	*71*	223	*103*	9	*135*	165	*167*	204	*199*	31
8	62	*40*	242	*72*	18	*104*	214	*136*	88	*168*	236	*200*	253
9	120	*41*	216	*73*	38	*105*	102	*137*	180	*169*	122	*201*	134
10	249	*42*	121	*74*	230	*106*	109	*138*	179	*170*	119	*202*	43
11	250	*43*	50	*75*	1	*107*	253	*139*	183	*171*	49	*203*	199
12	11	*44*	171	*76*	28	*108*	152	*140*	88	*172*	212	*204*	81
13	134	*45*	32	*77*	109	*109*	137	*141*	99	*173*	216	*205*	137
14	209	*46*	217	*78*	131	*110*	1	*142*	219	*174*	151	*206*	82
15	116	*47*	166	*79*	14	*111*	144	*143*	52	*175*	149	*207*	54
16	69	*48*	133	*80*	234	*112*	124	*144*	210	*176*	53	*208*	47
17	170	*49*	134	*81*	151	*113*	241	*145*	33	*177*	249	*209*	216
18	208	*50*	4	*82*	21	*114*	143	*146*	160	*178*	57	*210*	172
19	45	*51*	120	*83*	108	*115*	71	*147*	146	*179*	136	*211*	169
20	249	*52*	54	*84*	7	*116*	91	*148*	22	*180*	85	*212*	123
21	223	*53*	42	*85*	176	*117*	227	*149*	255	*181*	14	*213*	246

j	g_j	*j*	g_j	*j*	g_j	*j*	g_j	*j*	g_j	*j*	g_j	*j*	g_j
22	4	*54*	13	*86*	236	*118*	28	*150*	111	*182*	19	*214*	153
23	19	*55*	24	*87*	147	*119*	174	*151*	159	*183*	128	*215*	169
24	120	*56*	95	*88*	175	*120*	13	*152*	7	*184*	135	*216*	32
25	81	*57*	228	*89*	183	*121*	157	*153*	237	*185*	177	*217*	86
26	182	*58*	173	*90*	66	*122*	78	*154*	145	*186*	179	*218*	128
27	217	*59*	247	*91*	35	*123*	20	*155*	194	*187*	189	*219*	83
28	44	*60*	80	*92*	178	*124*	192	*156*	68	*188*	164	*220*	5
29	65	*61*	42	*93*	243	*125*	64	*157*	89	*189*	98	*221*	252
30	93	*62*	89	*94*	36	*126*	130	*158*	231	*190*	220	*222*	251
31	34	*63*	68	*95*	115	*127*	45	*159*	201	*191*	99	*223*	1

Table 42. Octet Representation (Integer) of the Coefficients of the Generator Polynomial

6.2.2 Systematic Encoding using the Reed-Solomon Generator Polynomial

The information vector $\mathbf{c}$ can be represented in polynomial form as shown in Eq. 9.

$$c(x) = \sum_{j=0}^{31} c_j \cdot x^j = c_0 + c_1 \cdot x + c_2 \cdot x^2 + \cdots + c_{31} \cdot x^{31} \qquad \text{Eq. 9}$$

The coefficients $c_0, c_1, \ldots, c_{31}$ form the RS information vector shown in Eq.10.

$$\mathbf{c}^{\mathrm{T}} = [c_{31}, c_{30}, \ldots, c_1, c_0] \qquad \text{Eq.10}$$

The RS code vector $\tilde{\Gamma}$ is obtained from $c(x)$ and $g(x)$ as illustrated in Eq. 11.

$$\begin{aligned} &\tilde{\Gamma}(x) = c(x) \cdot x^{n-k} - R_{g(x)}[c(x) \cdot x^{n-k}] \\ &= \sum_{j=0}^{254} \tilde{\Gamma}_j \cdot x^j = \tilde{\Gamma}_0 + \tilde{\Gamma}_1 \cdot x + \tilde{\Gamma}_2 \cdot x^2 + \cdots + \tilde{\Gamma}_{254} \cdot x^{254} \\ &= \gamma_0 + \gamma_1 x + \cdots + \gamma_{222} x^{222} + c_0 x^{223} + c_1 x^{224} + \cdots \\ &+ c_{31} x^{254} \end{aligned} \qquad \text{Eq. 11}$$

The function $R_{g(x)}[f(x)]$ denotes the remainder of the polynomial division $\frac{\mathrm{f(x)}}{\mathrm{g(x)}}$ and the coefficients γ and c denote parity symbols and information symbols, respectively.

The RS code vector $\mathbf{\Gamma}$ therefore consists of the information part and the parity part in exchanged order, i.e.: information part first and parity part second, as reported in Eq. 12.

$$\mathbf{\Gamma}^{\mathrm{T}} = [\Gamma_{254}, \Gamma_{253}, \dots, \Gamma_0] = [c_{31}, c_{30}, \dots, c_0, \gamma_{222}, \gamma_{221}, \dots, \gamma_0]. \qquad \text{Eq. 12}$$

6.2.3 Systematic Encoding using the RS Generator Matrix

Since RS codes are linear, the encoding can be equivalently expressed as matrix-vector multiplication in the respective Galois field. The following formulation of the encoding directly yields the RS code vector in the required indexing order.

The code vector $\mathbf{\Gamma}$ can be computed through a GF(256) matrix multiplication of the RS information vector $\mathbf{c}$ with the systematic generator matrix $\mathbf{G}$ as shown in Eq. 13.

$$\mathbf{\Gamma} = \mathbf{G} \cdot \mathbf{c} \qquad \text{Eq. 13}$$

or more explicitly as illustrated in Eq. 14.

$$\mathbf{\Gamma} = \begin{pmatrix} \Gamma_{254} \\ \Gamma_{253} \\ \vdots \\ \Gamma_0 \end{pmatrix} = \begin{pmatrix} c_{31} \\ c_{30} \\ \vdots \\ \mathrm{c}_0 \\ \gamma_{222} \\ \gamma_{221} \\ \vdots \\ \gamma_0 \end{pmatrix} = \begin{pmatrix} \mathbf{c} \\ \boldsymbol{\gamma} \end{pmatrix} = \mathbf{G} \cdot \mathbf{c} = \begin{pmatrix} \mathbf{I} \\ \mathbf{P} \end{pmatrix} \cdot \begin{pmatrix} c_{31} \\ c_{30} \\ \vdots \\ \mathrm{c}_0 \end{pmatrix}. \qquad \text{Eq. 14}$$

The systematic generator matrix $\mathbf{G}$ consists of 255 rows and 32 columns, shown in Eq. 15, and can be split into two submatrices $\mathbf{I}$ and $\mathbf{P}$, where $\mathbf{I}$ is the identity matrix of size 32x32 and $\mathbf{P}$ is a dense submatrix of size 223x32 which produces the parity part of the code vector, i.e. the RS parity vector $\boldsymbol{\gamma}$.

$$\mathbf{G} = \begin{pmatrix} 1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \\ g_{32,0} & g_{32,1} & g_{32,2} & \cdots & g_{32,31} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ g_{254,0} & g_{254,1} & g_{254,2} & \cdots & g_{254,31} \end{pmatrix} \qquad \text{Eq. 15}$$

This ICD provides the generator matrix $\mathbf{G}$ in Annex B as comma separated values in octet representation as per Table 41.

6.3 HAS Encoding and Transmission

The scheme for the outer layer coding scheme, illustrated in Figure 3, shows a HAS message **M** of k pages (M_1 to M_k) depicted as a table of k rows and J columns, encoded into a message **C** of $N = 255$ pages (C_1 to C_N), depicted as a table of N rows and J columns. The encoding is performed as follows:

- Each 424 bit-long HAS Message Page M_1 to M_k, hereinafter referred to as "page" for simplicity, is divided into $J = 53$ octets, e.g. $w_{1,1}$ to $w_{1,J}$ for the first page (M_1), or the first row as per Figure 3.
- The octets of each column, e.g. $w_{1,1}, w_{2,1}, \ldots, w_{k,1}$ for the first column ($j = 1$), are vertically grouped into a single information word of length $K = 32$, forming 53 information words. If the number of pages is lower (i.e. if $k < K$), the remaining $K - k$ octets are filled with zeroes (note that this is not depicted in Figure 3).
- Each vertical information word is encoded through a systematic Reed-Solomon code RS(255,32,224) using the RS encoding method described in section 6.2.
- The vertically-encoded words, composed by $N = 255$ octets, are referred to as w' in Figure 3. Note that the value of the first K octets remains the same, e.g., for the first column, $w_{1,1}, \ldots, w_{K,1} = w'_{1,1}, \ldots, w'_{K,1}$.
- Once the 53 vertically-encoded words are generated, their octets are grouped horizontally into HAS encoded pages, as per Figure 3, where the first encoded page C_1 is composed by $w'_{1,1}, \ldots, w'_{1,J}$, etc., creating the N encoded pages $C_1, \ldots, C_N$.
- Each HAS Encoded Page is encapsulated in a HAS Page, where the message **M** is identified with a given Message ID (MID), its size k is provided in the Message Size (MS) field, and the page index $(1, \ldots, N)$ is provided in the Message Page ID (PID) field, all in the HAS Page Header (see Table 6).
- HAS Encoded Pages are dynamically assigned to satellites in real time depending on the HAS configuration, in order to avoid repetitions and reduce the reception time in the receiver. Pages $C_{k+1}, \ldots, C_K$ contain only zeroes and are excluded from transmission. Since the HPVRS allows for erasures, not all non-zero pages need be transmitted.

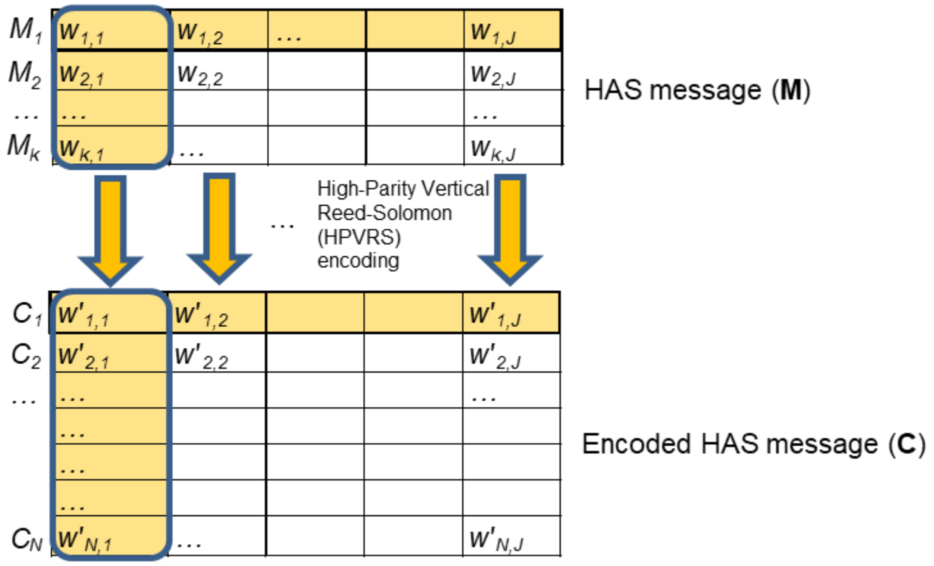

Figure 3. HAS HPVRS Encoding

6.4 HAS Reception and Decoding

This section presents the receiver decoding process using the RS generator matrix $\mathbf{G}$. The decoding process assumes that the receiver treats the transmission channel as a binary erasure channel, where the messages with failed C/NAV Page Layout 24-bit CRC are discarded. The reception and decoding process is shown in Figure 4 and is defined as follows:

- When a received page is valid the message ID (MID), type (MT), size (MS) and page ID (PID) are extracted from the 24-bit HAS Page Header (see section 3.1) and stored. Once the receiver has received any *k* different pages (*k*=*MS*) with the same Message ID and Message Type but with different PIDs, the receiver forms an encoded message **C'** with the received HAS Encoded Pages. A HAS Encoded Page is considered as valid if it is not a HAS Dummy Page and the CRC check is passed.
- Each HAS Encoded Page C_i' is divided into 53 octets (*w'*), as for the encoding process.
- The octets in each position are grouped into the vertically encoded words, of length *k*, where the index in the originally encoded message is given by the PID field.
- Each vertically encoded word $j = 1, \ldots, 53$ is decoded by a Reed-Solomon erasure decoder. The decoding process selects the decoding matrix $\mathbf{D}$ as a sub-matrix from the RS generator matrix using the *k* rows corresponding to the received PIDs and first *k* columns. The resulting $k \times k$ matrix $\mathbf{D}$ can be inverted resulting in $\mathbf{D}^{-1}$. Note that only one matrix inversion is required for all vertical words and that Galois Field arithmetic needs to be taken into account for all operations.
- By multiplying the $\mathbf{D}^{-1}$ matrix with each received encoded word *j* of length *k* with, the original octets $w_{1,j}, \ldots, w_{k,j}$ are recovered. The process is repeated for each vertically encoded word, until the original HAS message is retrieved.

The decoding process can be expressed mathematically as defined in Eq. 16 and Eq. 17.

$$\mathbf{w'}_j = \mathbf{D} \cdot \mathbf{m}_j \qquad \text{Eq. 16}$$

$\mathbf{w'}_j$ is the vector of length *k* with the encoded octects in position *j*, and $\mathbf{m}_j$ is the vertical message to be recovered, shown in Eq. 17.

$$\mathbf{m}_j = \mathbf{D}^{-1} \cdot \mathbf{w'}_j \qquad \text{Eq. 17}$$

$\mathbf{D}^{-1}$ is the inverse of $\mathbf{D}$, in the Galois Field. Eq. 16 and Eq. 17 need to be applied for each *j* until the whole message is recovered.

6.4.1 HAS Message Completion Time-out

The reception of a given Message ID shall be completed within 150 seconds. After this time-out, if the message is not completed, all the associated pages shall be discarded.

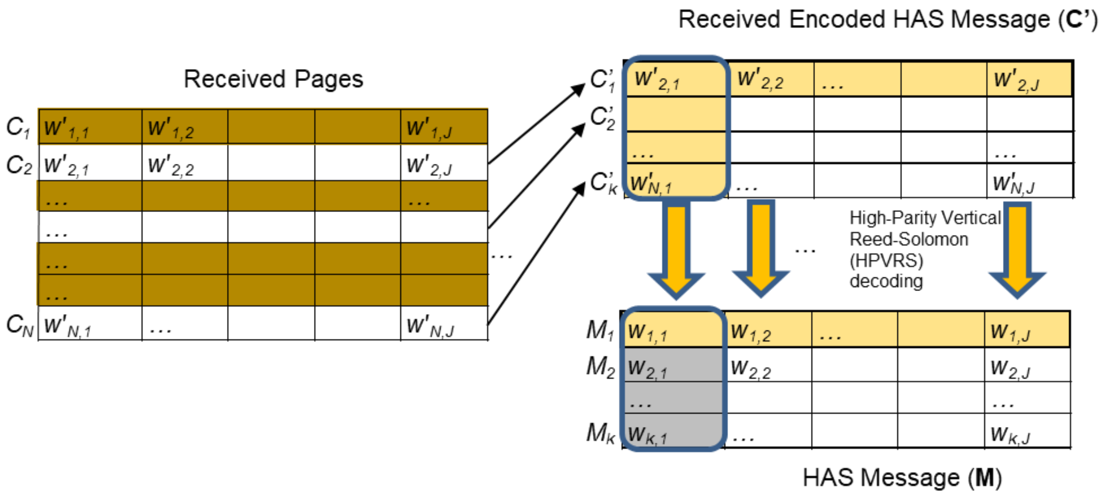

Figure 4. HAS HPVRS Decoding

7 Application of Galileo HAS Corrections

This section explains how to apply the HAS corrections to the broadcast navigation data and measurements and provides some additional clarifications.

7.1 General considerations

7.1.1 Time and Reference Frames

The reference time and reference frame used for Galileo HAS are the GST and the Galileo Terrestrial Reference Frame (GTRF), respectively.

The broadcast satellite positions and clocks to which the HAS corrections are applied shall be computed according to the corresponding GNSS ICDs [AD1] [RD1].

7.1.2 Ionosphere-free antenna phase centre

The *ionosphere-free antenna phase centre* of the satellite refers to the centre of phase of the satellite antenna for the dual-frequency ionosphere-free combination of the signals used for the clock model broadcast by the reference navigation message indicated for the satellite in the NAV Message field (Table 21) of the HAS Message Type 1 Mask (Table 15).

7.2 Orbit Corrections

The HAS orbit corrections for satellite *s*, $\delta\boldsymbol{R}^{s} = [\varepsilon_n, \varepsilon_t, \varepsilon_w]^T$ (parameters [DR, DIT, DCT] in section 5.2.2), are provided in the Satellite Coordinate System (SCS) NTW [RD2] composed of the radial (N, ε_n), tangential (T, or in-track ε_t) and normal (W, or cross-track ε_w) components, and centred in the satellite's ionosphere-free antenna phase centre indicated in section 7.1.2.

The SCS NTW components are defined based on the position $\boldsymbol{x^s}$ and velocity $\dot{\boldsymbol{x^s}}$ of the satellite's ionosphere-free phase centre of the antenna in the Earth-Centred Earth-Fixed (ECEF) reference frame of the broadcast ephemeris:

- The in-track component, $\boldsymbol{e}_t$, is aligned in both direction and sign with the velocity vector;
- The cross-track component, $\boldsymbol{e_w}$, is aligned in both direction and sign with the cross product between the satellite position vector and the satellite velocity vector;
- The radial component, $\boldsymbol{e_n}$, is aligned in both direction and sign with the cross product between the in-track component and the cross-track component.

The three components form a right-handed orthogonal system. The HAS orbit corrections need to be rotated from the SCS NTW to the Broadcast ECEF frame using the SCS NTW to ECEF rotation matrix, $\boldsymbol{R}_{NTW}^{ECEF}$. The rotation matrix from the SCS NTW to the Broadcast ECEF frame is computed as reported in Eq. 18, Eq. 19, Eq. 20 and Eq. 21.

$$\boldsymbol{e}_t = \frac{\dot{\boldsymbol{x}}^{\boldsymbol{s}}}{|\dot{\boldsymbol{x}}^{\boldsymbol{s}}|} \qquad \text{Eq. 18}$$

$$\boldsymbol{e}_w = \frac{\boldsymbol{x}^{\boldsymbol{s}} \times \dot{\boldsymbol{x}}^{\boldsymbol{s}}}{|\boldsymbol{x}^{\boldsymbol{s}} \times \dot{\boldsymbol{x}}^{\boldsymbol{s}}|} \qquad \text{Eq. 19}$$

$$\boldsymbol{e}_{\boldsymbol{n}} = \boldsymbol{e}_t \times \boldsymbol{e}_w \qquad \text{Eq. 20}$$

$$\boldsymbol{R}_{NTW}^{ECEF} = [\boldsymbol{e}_n \quad \boldsymbol{e}_t \quad \boldsymbol{e}_w] \qquad \text{Eq. 21}$$

The rotated corrections $\delta\boldsymbol{X}^{\boldsymbol{s}} = \boldsymbol{R}_{NTW}^{ECEF}\delta\boldsymbol{R}^{\boldsymbol{s}}$ are then added to the satellite position $\boldsymbol{x}^s$ computed from the broadcast orbit in the navigation message, as per its corresponding GNSS ICD, to obtain a refined orbit $\widetilde{\boldsymbol{x}}^{\boldsymbol{s}}$ referred to the GTRF frame as illustrated in Eq. 22. The IOD of the corrected navigation message for each satellite is identified by IODref (see section 5.2.2.2).

$$\widetilde{\boldsymbol{x}}^{\boldsymbol{s}} = \boldsymbol{x}^s + \delta\boldsymbol{X}^{\boldsymbol{s}} \qquad \text{Eq. 22}$$

After applying the corrections, the refined satellite position $\widetilde{\boldsymbol{x}}^{\boldsymbol{s}}$ is referred to GTRF and the ionosphere-free antenna phase centre indicated in section 7.1.2.

The HAS orbits can be referred to the centre of mass instead of the ionosphere-free phase centre of the targeted navigation message by applying the corrections to the satellite centre of mass together with the PCOs (Phase Centre Offsets) from the ANTEX files and attitude law models. For Galileo this information is provided in [RD3].

7.3 Clock Corrections

The HAS clock corrections δC^s are delta offsets to be added to the ionosphere-free satellite clock error dt^s computed from the broadcast navigation message indicated in the NAV Message field (Table 21) of the HAS Message Type 1 Mask (Table 15). The IOD of the corrected navigation message for each satellite is identified by IODref (see section 5.2.2.2).

For each corrected satellite s, δC^s is computed by multiplying the Delta Clock Correction (DCC, as per section 5.2.3.2) by its Delta Clock Multiplier (DCM, as per section 5.2.3.1).

Note that dt^s must be computed using the clock second order polynomial coefficients (a_{f0}, a_{f1}, a_{f2}) as per the Galileo [AD1] and GPS [RD1] specifications but excluding the relativistic correction term Δt_r, which shall be computed and added separately to determine the refined satellite clock error, $\widetilde{dt}^s$, as shown in Eq. 23.

$$\widetilde{dt}^s = dt^s + \Delta t_r^s + \frac{\delta C^s}{c} \qquad \text{Eq. 23}$$

where c is the speed of light (c = 299792458.0 m/s [AD1]), and the relativistic correction Δt_r^s must be computed as follows:

$$\Delta t_r^s = -\frac{2\boldsymbol{x}^s \cdot \dot{\boldsymbol{x}}^s}{c^2} \qquad \text{Eq. 24}$$

The refined satellite clock error, $\widetilde{dt}^s$, is referred to the GST for Galileo satellites. The user shall account for a possible common offset in the broadcast HAS GPS clock corrections.

Note that, as explained in the next section and also depicted in Figure 6, the HAS code biases need to be applied to all the single frequency pseudorange measurements in order to be coherent with the refined satellite clock errors.

7.4 Code Biases

The HAS satellite code biases $\tilde{d}_{,j}^s$ (parameter CB in section 5.2.5) provide the offset to be applied to the individual signals targeted by each bias, as per Table 19. The user pseudorange observations $\mathrm{P}_{U,j}^s$ for satellite *s* and signal *j* must be corrected by adding these biases in order to generate the corrected pseudorange observation $\tilde{\mathrm{P}}_{U,j}^s$ as per Eq. 25.

$$\tilde{\mathrm{P}}_{U,j}^s = \mathrm{P}_{U,j}^s + \tilde{d}_{,j}^s \qquad \text{Eq. 25}$$

Therefore, $\tilde{d}_{,j}^s$ replace the Broadcast Group Delays (BGDs) and Timing Group Delays (TGDs) provided in the broadcast navigation messages as per [AD1] and [RD1], which do not have to be applied to the pseudorange observation.

7.5 Phase Biases

The HAS satellite phase biases $\tilde{\delta}_{,j}^s$ (parameter PB in section 5.2.6) provide the correction including the fractional part of the phase ambiguity. The computation of the corrected carrier phase observation $\tilde{\Phi}_{U,j}^s$ from the user carrier phase observations $\Phi_{U,j}^s$ and phase bias $\tilde{\delta}_{,j}^s$ is shown in Eq. 26.

$$\tilde{\Phi}_{U,j}^s = \Phi_{U,j}^s + \tilde{\delta}_{,j}^s \qquad \text{Eq. 26}$$

The HAS satellite phase biases cover a range of +/- 10.23 cycles for attempting the correction of cycle slips occurring on the network side without the need to send an ambiguity value re-initialisation command through the Phase Discontinuity Indicators (which, when changed, requires a re-initialisation of the ambiguity for the indicated satellites and signals).

7.6 IOD Set ID, Reference IOD and Mask ID Correspondence

IOD Set ID identifies the Reference IODs to correct and is always transmitted in the MT1 Header (Table 13). When the MT1 transmits the mask, the Header's Mask ID defines the satellite indexes in the mask. When MT1 transmits the orbit corrections, the Header's IOD Set ID defines the Reference IODs. When MT1 only transmits other corrections, such as clock corrections, the Header's IOD Set ID and Mask ID are linked to an IOD Set ID and a Mask ID that have been previously defined in another message. The corrections in the message will be applied to the satellite indexes and Reference IODs previously linked to the IOD Set ID. This is depicted in Figure 5, where two MT1s are transmitted. The first one (MT1-slow) includes the mask and orbit corrections, and fully defines IOD Set ID and links it to a Mask ID. The second one (MT1-fast) uses the previously defined IOD Set ID and Mask ID to link the clock corrections to the Reference IODs.

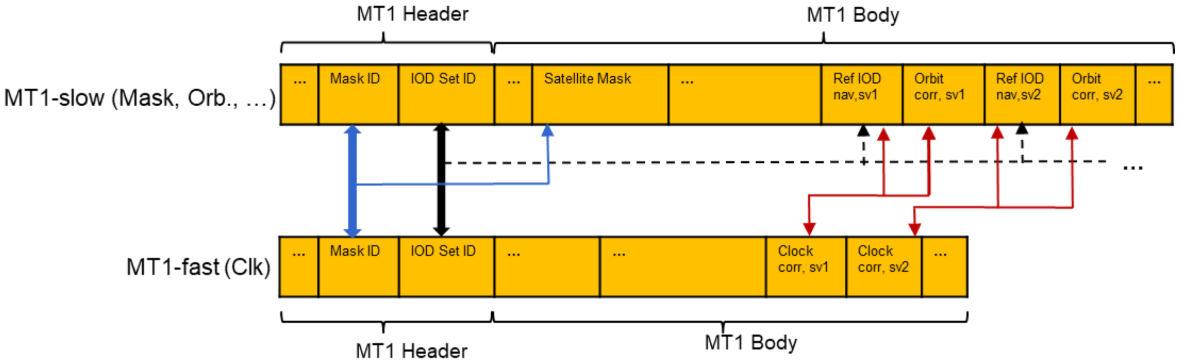

Figure 5. Mask ID and IOD Set ID link with Reference IODs and Orbit and Clock Corrections

Based on that IOD Set ID and Reference IOD correspondence, Figure 6 shows an example of how to determine the refined satellite position and satellite clock error based on the HAS orbit and clock corrections, and the Galileo I/NAV broadcast message. Single frequency pseudorange measurements, after applying the code biases, become consistent with the refined clock errors obtained from Eq. 27.

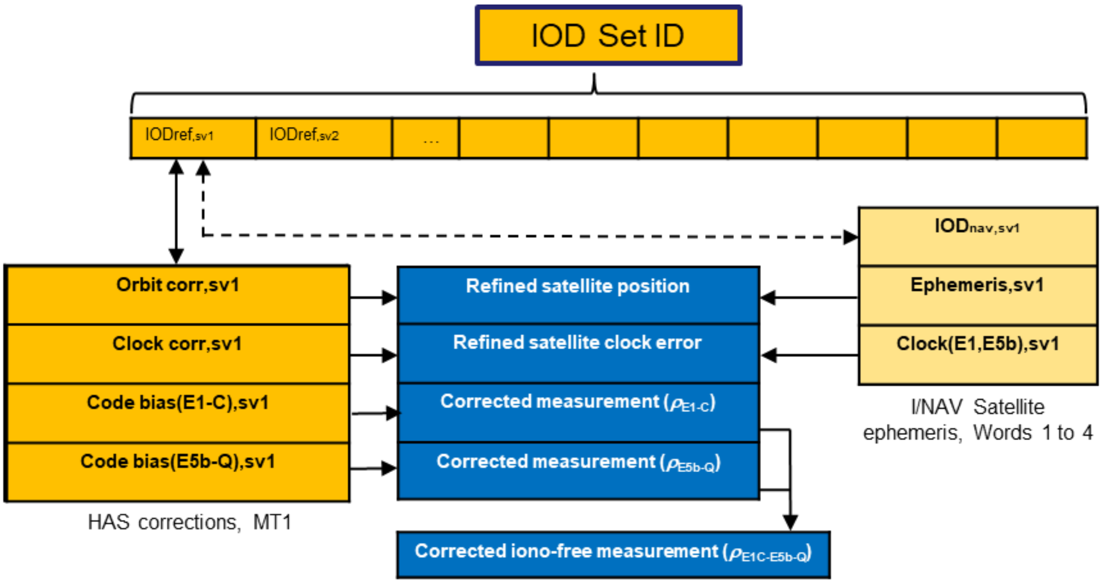

Figure 6. IOD Set ID and Reference IODs, with application to Orbit, Clock and Bias Corrections of SV 1 Galileo I/NAV Message and E1-C and E5b-Q signal components

7.6.1 IOD Set ID and Mask ID Validity Intervals

The satellite mask may vary regularly in case the satellite service area is not global. A receiver can relate messages (e.g. a mask and orbit correction MT1 and a clock correction MT1) only when both the Mask ID and IOD Set ID coincide. There will be no more than one definition for each IOD Set ID and Mask ID pair within any 30-minute window. After this period, a Satellite Mask ID or IOD Set ID rollover may occur.

7.7 Time of Application of the HAS Corrections

In order to determine the absolute time of applicability of the HAS corrections, the receiver shall be synchronized with GST by the Galileo navigation message (e.g. the I/NAV) in order to translate the TOH to an absolute message reference time, for the application of the HAS message data, including the corrections.

The HAS message reference time shall always be earlier or equal to the time of reception of the HAS message to which the TOH belongs. Therefore, the GST hour associated with the TOH is the current GST hour at message reception time, except in cases in which an hour transition occurs between HAS message generation and reception, in which case the GST hour is the immediately preceding one.

The receiver can calculate the message reference time t_{MT1} of a given message, in seconds and referred to GST, following Eq. 29 after calculating the GST hour H_r at which the message has been fully retrieved as per Eq. 28.

$$H_r = \lfloor GST_r/3600 \rfloor \qquad \text{Eq. 28}$$

where GST_r is the reception time of the message in seconds referred to GST, i.e. the time at which the message has been fully received; and $\lfloor \quad \rfloor$ is the floor operator.

$$t_{MT1} = \begin{cases} H_r \cdot 3600 + TOH_{MT1}, & if\ (H_r \cdot 3600 + TOH_{MT1}) \leq GST_r \\ (H_r - 1) \cdot 3600 + TOH_{MT1}, & otherwise. \end{cases} \qquad \text{Eq. 29}$$

where TOH_{MT1} is the time of hour, as received in the MT1 header.

7.8 Relationship with other formats

The Galileo HAS SIS ICD is a self-standing document defined taking into account the formats of already existing messages for providing high accuracy corrections. In particular, it takes into account QZSS Interface Specification of the Centimeter-Level Augmentation Service (IS-QZSS-L6-001) [RD4], which uses the Specification of Compact State-Space Representation (CSSR) for Satellite-Based Augmentation Messages defined under RTCM-SC-104.

Annex A. List of Acronyms

ANTEX	ANtenna EXchange format
APC	Antenna Phase Centre
BGD	Broadcast Group Delay
CRC	Cyclical Redundancy Check
CSSR	Compact SSR
ECEF	Earth-Centered Earth-Fixed
FEC	Forward Error Correction
GF	Galois Field
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GST	Galileo System Time
GTRF	Galileo Terrestrial Reference Frame
HAS	High Accuracy Service
HPVRS	High Parity Vertical Reed-Solomon
ICD	Interface Control Document
IOD	Issue Of Data
IODC	IOD Clock
IODE	IOD Ephemeris
IODnav	IOD navigation
MF	Message Format
MID	Message ID
MS	Message Size
MSB	Most Significant Bit
MT	Message Type
NTW	Radial, Tangential, Normal
PCO	Phase Center Offset
PCV	Phase Center Variation
PID	Page ID
PPP	Precise Point Positioning
QZSS	Quasi Zenith Satellite System
RS	Reed-Solomon
RTCM	Radio Technical Commission for Maritime
SCS	Satellite Coordinate System
SIS	Signal in Space
SSR	State-Space Representation
SV	Space Vehicle
TGD	Timing Group Delay
TOH	Time Of Hour

Annex B. Reed-Solomon Generator Matrix

The Reed-Solomon generator matrix is provided in a text file as an attachment to this document.

Annex C. Reed-Solomon Decoding Example

This Annex provides an example of HPVRS decoding for a RS(255,32,224) code. The HAS message to be decoded is assumed to be composed of *k* = *MS* = 15 pages. The table below shows a sample C/NAV page in hexadecimal, the decoded header, and the HAS Encoded Page in 53 decimal octets.

```
C/NAV Page (hex):  fffc17b8 de11ef1d 27adf5c5 d0911e23 ed151a46 30009cab af05524b
31bad569 62038986 eb8c5c68 8f742f95 8bf235bf 623988a7 0a79f632 677d0c46 90000000

HASS: 00 (“Test”)

MT:1

MID: 15

MS: 15

PID: 55

HAS Encoded Page (dec, 53 octets):  [ 132 123 199 73 235 125 113 116 36 71 136
251 69 70 145 140 0 39 42 235 193 84 146 204 110 181 90 88 128 226 97 186 227 23
26 35 221 11 229 98 252 141 111 216 142 98 41 194 158 125 140 153 223 ]
```

At least *k* HAS encoded pages need to be correctly received before starting the Reed-Solomon decoding process. The required encoded pages are provided in the table below.

```
PID: 55.

[ 132 123 199 73 235 125 113 116 36 71 136 251 69 70 145 140 0 39 42 235 193 84 146
204 110 181 90 88 128 226 97 186 227 23 26 35 221 11 229 98 252 141 111 216 142 98
41 194 158 125 140 153 223 ]

PID: 56.

[ 52 154 227 99 77 33 11 173 50 147 166 127 182 33 1 233 221 84 48 123 198 121 237
105 155 213 12 174 174 197 100 133 243 248 22 84 12 174 206 164 198 22 146 238 91
24 202 171 181 189 162 121 57 ]

PID: 57.

[ 85 1 29 145 14 230 225 85 194 242 140 77 215 250 214 40 200 226 106 5 171 215 135
151 77 226 225 111 142 246 176 156 0 215 18 228 41 8 34 151 24 174 236 105 28 5 39
243 194 63 128 181 19 ]

PID: 58.

[ 44 163 27 35 21 83 238 106 156 122 59 255 250 132 43 45 12 243 8 9 16 185 194 2
126 136 115 220 237 47 141 167 212 35 164 47 217 206 88 195 238 68 125 44 175 49
177 138 4 213 165 186 120 ]

PID: 59.

[ 55 190 96 216 35 121 141 182 26 28 152 34 238 248 75 122 213 237 99 213 34 61 152
173 145 204 133 143 64 117 119 92 224 76 187 36 160 208 177 95 127 213 58 214 134
44 121 248 82 63 169 191 75 ]

PID: 174.

[ 187 28 69 29 89 4 160 228 22 185 43 88 154 12 86 206 43 199 115 152 40 239 11 192
73 228 145 24 154 41 63 49 40 36 224 176 100 94 31 100 152 109 111 135 185 118 207
58 18 247 59 144 33 ]
```

```
PID: 175.

[ 117 25 72 154 251 194 111 69 202 191 253 159 120 178 246 68 171 41 251 163 124
202 254 239 152 25 2 5 204 223 192 231 250 120 193 179 234 80 108 166 166 167 210
195 99 135 159 118 132 143 164 128 36 ]

PID: 176.

[ 143 12 156 52 139 203 193 61 89 3 53 84 14 168 101 194 207 61 113 59 188 39 200
99 26 41 88 222 211 134 178 117 71 15 136 150 150 65 88 124 204 128 23 28 51 166
204 221 251 63 53 44 190 ]

PID: 187.

[ 203 226 36 10 145 27 54 129 243 142 43 63 242 57 243 98 229 59 74 201 41 44 96
199 124 97 197 70 118 78 134 66 106 138 68 197 64 140 187 91 201 10 138 135 16 254
109 113 144 220 128 204 93 ]

PID: 188.

[ 29 55 158 167 195 223 144 158 158 116 87 219 101 36 71 28 189 52 215 17 199 92
176 139 74 132 108 3 25 126 46 191 226 239 14 161 44 70 247 253 202 246 58 36 35
29 77 144 52 14 217 139 221 ]

PID: 239.

[ 122 57 40 21 48 65 99 21 77 50 204 30 233 166 117 3 48 3 115 250 224 78 143 108
245 144 255 199 147 114 161 38 145 41 107 172 132 82 95 202 166 152 75 83 88 143
25 25 186 202 151 159 222 ]

PID: 240.

[ 125 19 56 207 112 92 184 147 239 181 113 209 24 245 173 57 173 51 3 160 148 255
182 92 140 168 146 194 234 61 53 190 137 15 91 228 231 9 111 222 52 62 205 189 90
185 129 222 74 19 154 94 29 ]

PID: 241.

[ 161 204 117 222 253 61 201 66 207 106 21 166 117 149 224 164 249 50 45 172 71 205
29 87 112 81 177 95 215 130 214 162 83 43 182 9 188 112 183 111 5 174 231 176 103
151 117 7 232 167 19 33 234 ]

PID: 252.

[ 207 147 205 21 140 244 31 178 149 173 157 33 161 85 130 130 237 116 136 51 54 137
106 123 126 234 208 57 145 34 116 229 209 226 26 86 63 239 245 210 21 211 61 189
43 85 215 103 160 170 234 163 56 ]

PID: 253.

[ 215 200 167 19 210 166 18 96 224 77 5 145 106 148 222 103 157 196 233 132 109 61
229 187 163 152 17 62 27 210 42 67 181 2 23 108 68 206 189 76 58 39 164 43 254 9
87 41 18 228 135 212 165 ]
```

Before decoding, the octets of the received pages are grouped into 53 vertically encoded words ($\mathbf{w}'_1, \ldots, \mathbf{w}'_{53}$) of length *k*. The 53 vertical information words ($\mathbf{m}'_1, \ldots, \mathbf{m}'_{53}$) are obtained with the multiplication $\mathbf{m}'_j = \mathbf{D}^{-1} \cdot \mathbf{w}'_j$, to be repeated 53 times, where $\mathbf{D}$ is the sub-matrix created from the RS generator matrix using the *k* rows corresponding to the received PIDs and the first *k* columns. The order of the rows corresponds to the order of the PIDs provided above (PID 55, PID 56, etc.). The matrix $\mathbf{D}$ is provided below.

```
D = [

 31   50  155  253  213  220   84  174  239   85   87  105  214   81  160

113   18   35  135  205   43  156   23  127  169  162  160   15   49  202

204  239  127  208   89  187   30  192   37  152  221  214  211   49   93

 72    7   24   67    1  245  154  234   84  179   37   96  222   33   64

253  151  182  118  101  136  118  241  195   26  152   14  225   28  193

114  171  242  238   47  124   59  125   65   23   39  150  161  226    5

 33   32    3    8   36  151  121   17  218   26   98   82   65  146  162

 37  190  149   41   64   68  119   19  153   51  235  147  203  136  225

 58  217   47   14    1   13  117    8  167   10  105  226   96  158  229

169  119  204  119   80   22   46   55  120   70   39   68  156  140  150

145   19  150   65  190   97  199  178   76  115  138  198  136   18  180

235  120   75   39  150  196   72  209  145   27  180   77   11    2  154

143  165   24  101  222  187  133   80  114   98  164   11   16  227   43

15   105  201  161  101  197  235  191  127   28  238  232  231  198  234

84   157  205  255  217  251  101  194  230  208   26  232   23  201   46

]
```

A sample is given for the vertically encoded word $\boldsymbol{w'_1}$ (first column):

$\boldsymbol{w'_1}$ = [132 52 85 44 55 187 117 143 203 29 122 125 161 207 215 $]^T$

Inverting the matrix **D** and using Eq. 17 the vertical information word $\boldsymbol{m'_1}$ is obtained:

$\boldsymbol{m'_1}$ = [0 255 71 67 79 240 64 221 31 174 0 128 4 0 32 $]^T$

The full *k* HAS decoded pages are provided in the table below in decimal representation. Please note the fact that m_1 corresponds to the first element of each page.

```
[ 0 12 192 11 32 255 223 255 255 0 129 0 247 255 255 125 245 95 253 254 11 238 232
167 154 65 36 16 0 166 0 10 1 160 18 128 64 2 0 32 1 19 251 192 65 254 187 240 0
128 8 0 66

255 104 34 254 162 24 7 193 147 247 89 128 53 253 127 106 47 0 8 0 128 1 111 249 2
135 231 150 127 112 37 128 88 127 238 33 122 16 201 223 204 14 127 101 29 245 119
217 129 96 63 254 65

71 249 3 255 157 247 128 92 21 255 159 220 255 128 8 0 64 4 0 10 0 36 7 255 157 124
7 223 127 254 43 95 220 238 48 85 25 1 31 215 253 36 71 159 0 80 14 142 126 220 49
64 28

67 253 176 35 4 0 127 229 3 15 241 172 64 2 0 32 0 2 0 16 1 0 7 127 236 6 224 1 65
254 176 42 252 178 196 0 32 2 0 4 63 245 246 192 34 9 127 124 14 63 68 18 255

79 225 255 136 37 254 143 252 255 0 72 8 31 227 253 160 151 244 192 75 243 129 47
229 255 39 240 2 95 198 255 95 244 4 128 237 250 96 28 8 255 232 2 63 204 15 0 176
11 128 168 37 253
```

```
240 15 255 112 75 247 31 255 253 192 151 251 64 12 0 129 47 231 129 167 248 2 95
230 2 32 50 4 128 16 1 160 22 7 255 208 6 64 64 18 254 192 14 0 8 37 252 127 229 0
192 75 255

64 86 5 192 136 4 0 68 3 1 47 226 127 239 251 240 187 35 220 148 69 142 240 66 10
254 31 166 21 68 171 218 119 193 48 68 67 32 161 16 67 3 211 247 111 101 251 190
231 204 245 254 107

221 248 191 207 244 121 183 165 241 220 59 243 252 225 36 59 68 233 13 23 132 172
53 11 47 41 242 189 96 123 26 30 123 178 7 81 146 1 0 56 7 6 159 143 235 124 240
12 13 66 216 91 6

31 51 210 250 127 160 15 195 80 106 2 1 92 75 9 64 155 240 124 191 149 4 0 100 21
130 160 79 200 244 14 136 210 221 159 115 239 189 196 0 128 64 4 7 193 152 88 138
208 233 244 61 103

174 249 0 156 34 4 32 205 239 188 159 144 249 32 240 51 134 96 64 26 69 160 180 17
160 132 28 131 128 194 6 193 136 45 1 33 36 62 135 208 43 242 125 31 162 252 97 132
81 138 80 220 176

0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0
64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0

128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0
64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128

4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 64 2
0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4

0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 64 2 0
16 0 128 4 0 32 1 0 8 0 64 2 0 16 0 128 4 0

32 1 0 8 0 64 2 0 16 0 128 4 0 32 1 0 8 0 42 170 170 170 170 170 170 170 170 170
170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170 170
170 170 170 170 ]
```

The HAS decoded message is also provided in hexadecimal format in the table below.

```
[
000cc00b20ffdfffff008100f7ffff7df55ffdfe0beee8a79a41241000a6000a01a01280400200200
113fbc041febbf00080080042ff6822fea21807c193f7598035fd7f6a2f00080080016ff90287e796
7f702580587fee217a10c9dfcc0e7f651df577d981603ffe4147f903ff9df7805c15ff9fdcff80080
04004000a002407ff9d7c07df7ffe2b5fdcee305519011fd7fd24479f00500e8e7edc31401c43fdb0
2304007fe5030ff1ac4002002000020010010077fec06e00141feb02afcb2c400200200043ff5f6c
022097f7c0e3f4412ff4fe1ff8825fe8ffcff0048081fe3fda097f4c04bf3812fe5ff27f0025fc6ff
5ff40480edfa601c08ffe8023fcc0f00b00b80a825fdf00fff704bf71ffffdc097fb400c00812fe78
1a7f8025fe602203204801001a01607ffd006404012fec00e000825fc7fe500c04bff405605c08804
004403012fe27feffbf0bb23dc94458ef0420afe1fa61544abda77c130444320a1104303d3f76f65f
bbee7ccf5fe6bddf8bfcff479b7a5f1dc3bf3fce1243b44e90d1784ac350b2f29f2bd607b1a1e7bb2
0751920100380706 9f8feb7cf00c0d42d85b061f33d2fa7fa00fc3506a02015c4b09409bf07cbf950
400641582a04fc8f40e88d2dd9f73efbdc40080400407c198588ad0e9f43d67aef9009c220420cdef
bc9f90f920f0338660401a45a0b411a0841c8380c206c1882d0121243e87d02bf27d1fa2fc6184518
a50dcb000800400200100080040020010008004002001000800400200100080040020010008004002
001000800400200100080040020010008004002001000800400200100080040020010008004002001
000800400200100080040020010008004002001000800400200100080040020010008004002001000
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Additional information (data fields extraction, decoding of clock correction message) can be found in Annex D.

Annex D. HAS Message Decoding Example

A HAS message decoding example is provided in a text file as an attachment to this document.

Annex E. Authorisation Concerning the HAS SIS ICD IPRs

By practicing, using or copying the HAS SIS ICD IPRs or any portion thereof, YOU ACCEPT ALL TERMS AND CONDITIONS OF THIS AUTHORISATION, including in particular the limitations on use, warranty and liability. If you are acting on behalf of a company or other legal entity, you represent and warrant that you have the legal authority to bind that company or legal entity to these terms and conditions. IF YOU DO NOT HAVE SUCH AUTHORITY OR IF YOU AND/OR THAT COMPANY OF LEGAL ENTITY DO NOT WISH TO BE BOUND TO THESE TERMS DO NOT PRACTICE, USE OR COPY THE HAS SIS ICD IPRs OR ANY PORTION THEREOF.

The European Union (hereinafter "the EU") is the owner of, holds the right over, and/or controls the intellectual and industrial property rights to, the HAS SIS ICD, including the IPRs listed in section E.12.

In the interest of facilitating and encouraging the adoption of technologies using the EU GNSS, the EU represented by the European Commission hereby issues the Authorisation (as defined in section 1 below) concerning the HAS SIS ICD IPRs towards any individual, corporation or other natural or legal person worldwide, subject to the terms, conditions and limitations described herein. The Authorisation is non- exclusive and royalty- free.

The Authorisation is issued in the context where other GNSS providers provide open and free access to the information necessary to build equipment using civil GNSS signals.

E.1. Definitions

The under mentioned terms printed with an initial capital letter shall have herein the following meanings unless the context otherwise requires:

"Authorisation" – shall mean the EU's covenant that it shall not assert, seek to assert and/ or enforce any of the rights and claims it has in relation to the HAS SIS ICD IPRs against the practicing, using or copying thereof, subject to the terms, conditions and limitations described herein.

"Authorised Person" – shall mean the natural or legal person that benefits from the Authorisation under the terms, conditions and limitations described herein.

"Export Controls" – shall mean any international or national export control law or regulation applicable to activities carried out under the HAS SIS ICD IPRs that regulates, embargoes or sanctions the export of products, information and/or technology in any way.

"Field of Use" – shall mean research and development on, manufacturing, commercialisation, distribution, sale, supply and maintenance of, the Products.

"GNSS" – shall mean Global Navigation Satellite System.

"HAS SIS ICD" – shall mean the Galileo High Accuracy Service (HAS) Signal-In-Space (SIS) Interface Control Document (ICD) in the version as of the date of issuance of this Authorisation and/or, as the case may be, as modified after that date (available at https://www.gsc-europa.eu).

"HAS SIS ICD Copyright" – shall mean the copyright on and to the HAS SIS ICD document and/or its content.

"HAS SIS ICD IPRs" – shall mean the intellectual or industrial property rights listed in section E.12, including Patents and HAS SIS ICD ICD Copyright. For the purpose of this Authorisation, HAS SIS ICD IPRs also include any and all intellectual or industrial property rights and other proprietary rights on and to the Technical Data of the HAS SIS ICD.

"Patents" – shall mean any and all patents and/or patent applications mentioned in section E.12, including the inventions described and claimed therein as well as any divisions, continuations, continuations-in-part, re-examinations and reissues thereof, and any patents issued from said patent applications.

"Products" – shall mean software, electronic devices (e.g., chipsets and receivers) and Value Added Services that are developed – directly or indirectly – by the Authorised Person and that are making use of the HAS Signal.

"Technical Data of the HAS SIS ICD" – shall mean the data related to: Galileo Signal characteristics, the Galileo Spreading Codes characteristics, Galileo Message Structure, Message Data Contents and E1 and E5 Memory Codes, as such terms are used in the HAS SIS ICD.

"Territory" – shall mean, with respect to each HAS SIS ICD IPRs individually, and subject to Export Controls, the territories covered by said individual HAS SIS ICD IPR.

"Value Added Services" – shall mean any service developed based on, or by using, the HAS SIS ICD IPRs and delivering different or additional capabilities with respect to the HAS Signal.

E.2. Ownership of Rights

Ownership and/or control of the HAS SIS ICD IPRs shall remain with the EU and therefore, no title of any intellectual property right on the HAS SIS ICD IPRs under the Authorisation shall be acquired by the Authorised Person, whether by implication, estoppel or otherwise.

The Authorisation shall be withdrawn and shall not apply against any individual, corporation or other natural or legal person that challenges the validity of any of the HAS SIS ICD IPRs or participates in such a challenge, or encourages or supports any third parties in such a challenge.

E.3. Scope of Authorisation

The scope of the Authorisation is limited to the Territory and Field of Use.

The Authorisation is non-transferable and non-licensable. The Authorised Person shall not assign, transfer or license any of the rights granted under the Authorisation.

The Authorised Person shall practice, use and/or copy the HAS SIS ICD IPRs in the Field of Use under the Authorisation in a manner so as not to harm the security interests of the EU or its Member States as set forth of the Regulation (EU) No 2021/696 of the European Parliament and of the Council of 28th April 2021 establishing the Union Space Programme and the European Union Agency for the Space Programme and repealing Regulations (EU) No 912/2010, (EU) No 1285/2013 and (EU) No 377/2014 and Decision No 541/2014/EU.

The commercial exploitation of the Products in the Field of Use under the Authorisation shall be under the sole responsibility of the Authorised Person.

The Authorised Person shall not state or imply in any promotional material or elsewhere that the Products were developed by, are used by or for or have been approved or endorsed by the EU or by the owner of any of the Patents.

Pursuant to the Authorisation, the EU's covenant not to assert covers the following activities of the Authorised Person:

- the use of the Technical Data of the HAS SIS ICD, including their integration and incorporation into any Products, by the Authorised Person or by third parties contractors used by the Authorised Person for manufacturing said Products;
- the storage of the Technical Data of the HAS SIS ICD, provided the source is acknowledged;
- the reproduction of the HAS SIS ICD, in whole or in part, its distribution and its publication for non-commercial not-for-profit purposes and scale without amending the

document or adding any element;

- providing links to the EU website where the document is published, provided the source is acknowledged, in accordance with the copyright notice in the HAS SIS ICD.

This list is exhaustive. No other activity shall benefit from the Authorisation. The practice of any of the HAS SIS ICD IPRs outside of the scope of the Authorisation shall be deemed in breach of the intellectual property rights of the EU.

Subject to the foregoing, the Authorised Person shall have the discretion to select distributors and otherwise determine the commercial strategy, including all channels of distribution, regarding the distribution and sale of the Products in the Territory.

The Authorised Person shall be solely responsible for (but failure to strictly abide by a) and b) below shall not be in contradiction with the Authorisation):

- exercising its activities hereunder strictly in compliance with all laws and regulations of each of the countries in which such activity takes place;
- compliance with all Export Controls.

E.4. Additional Intellectual Property Rights and Maintenance of Patent Rights

The EU reserves the right, in the course of the Authorisation term, to acquire ownership or control of additional intellectual or industrial property rights related to the HAS Signal. In that case, the EU may update section E.12 accordingly. The EU however takes no obligation to communicate the acquisition of or licence to additional intellectual or industrial property rights related to the HAS Signal.

The Authorisation shall automatically cover any such additional intellectual or industrial property rights included in the updated section E.12, without the need to amend the Authorisation.

The EU shall have no obligation, duty or commitment whatsoever to:

- maintain the HAS SIS ICD IPRs in force, whether in full or partly, nor shall it be obliged to communicate any decision thereto to the Authorised Person;
- furnish any assistance, technical information or know-how to the Authorised Person.

E.5. Duration and Termination

With respect to each of the HAS SIS ICD IPRs, the Authorisation shall be valid for the whole duration of said HAS SIS ICD IPRs insofar as the terms, conditions and limitations of the Authorisation are respected.

The Authorisation shall terminate automatically upon any act of the Authorised Person that violates any of the terms, conditions or limitation of the Authorisation, unless the European Union agrees to the remedial measures proposed by the Authorised Person and the latter are implemented in reasonable time set by the Union.

In the event of a termination of the Authorisation for whatever reason, the Authorised Person shall:

- immediately discontinue the development or use of the Products or any other activity covered under the scope of the Authorisation as defined in Section 4 above; and
- except in cases of termination for violation of this Authorisation by the Authorised Person, as a temporary exception to point a. above, have the right, during 6 (six)

months after the termination of the Authorisation, to sell all remaining Products in stock or in process of being manufactured at that date, or within that term of 6 (six) months, have terminated, finished and/or fulfilled all agreements which have been entered into prior to the termination.

The Authorisation and its validity shall not be influenced by the fact that one or more of the HAS SIS ICD IPRs whose practice, use or copy is authorised hereunder should finally be declared not granted or invalid.

E.6. Warranties and Liability

The Authorisation is issued under the HAS SIS ICD IPRs as they are. The EU makes no representation and no express or implied warranty, and assumes no liabilities as to any matter whatsoever concerning the HAS SIS ICD IPRs, including as to:

- the condition, the patentability and/or validity and enforceability of the HAS SIS ICD IPRs;
- the freedom to practice, use or copy the HAS SIS ICD IPRs, to perform the activities that benefit from the Authorisation, or to develop, commercialise or exploit the Products;
- any third party's prior rights to use the HAS SIS ICD IPRs and/or to enjoin the activities that benefit from the Authorisation;
- the dependency of the HAS SIS ICD IPRs on third parties' intellectual or industrial property rights;
- the merchantability or fitness for a particular purpose of the HAS SIS ICD IPRs and/ or the Products.

To the full extent allowed by law, all warranties, whether expressed or implied, for any use of HAS SIS ICD IPRs or related to the Products, including on product liability, are excluded, and the EU shall not be held liable for any claim or damage related thereto, being asserted by the Authorised Person or any third party with respect to the activities of the Authorised Person under the Authorisation.

E.7. Infringements by Third Parties

The EU shall have the discretionary right and faculty to decide whether or not to bring an action for any infringements of the HAS SIS ICD IPRs in the case where a third party does not benefit from the Authorisation, even where the EU has been duly informed about such alleged infringement by the Authorised Person. The EU shall have no obligation whatsoever to bring such an action nor to notify any decision thereto to the Authorised Person.

E.8. Action for Infringement Brought by Third Parties

The Authorised Person shall defend itself and at its own expenses, and bear all the consequences, including the payment of damages and attorney fees, against any claim, suit or proceeding made or brought against the Authorised Person and arising from its activities under the Authorisation, including any claim, suit or proceeding for infringement of third parties' rights as a result of the Authorised Person's practice, use or copy of the HAS SIS ICD IPRs or commercialisation of Products. The Authorised Person shall notify the EU without undue delay about any such claim, suit or proceeding. The EU may, at its sole discretion, agree to provide the Authorised Person with any assistance which the EU considers to be appropriate, but the EU shall not in any way be obliged to do so. If the EU decides to defend either the Authorised Person or the HAS SIS ICD IPRs, the Authorised Person shall collaborate with the EU and provide the EU with all the assistance necessary to such defence.

E.9. Permits

The necessary steps for obtaining all permits and licences required for the activities under the Authorisation, under the laws and regulations in force at the place where said activities of the Authorised Person are provided or to be provided, shall be the exclusive responsibility of the Authorised Person.

E.10. Applicable Law and Dispute Resolution

The Authorisation shall be governed by European Union law, complemented where necessary by the law of Belgium.

The courts of Brussels have exclusive jurisdiction over any dispute regarding the interpretation, application or validity of the Authorisation.

E.11. Miscellaneous

The provisions of the Authorisation are severable in the sense that the invalidity or unenforceability of any provision of the Authorisation that is not fundamental to its performance shall not affect the validity and/or enforceability of the remaining provisions hereof. Such invalidity or unenforceability of such non-fundamental provision shall not relieve the Authorised Person of its obligations under the remaining provisions of the Authorisation.

This Authorisation fully and exclusively states the scope of the authorisation concerning the HAS SIS ICD IPRs that the EU wishes to issue.

The EU reserves the exclusive right to amend the Authorisation upon due public notice.

The fact that the Authorisation is self-executing and that the EU requires no signature of the Authorisation shall not be considered a waiver and shall have no effect on the binding character of the terms, conditions and limitations of the Authorisation upon the practice, use or copy of the HAS SIS ICD IPRs by the Authorised Person.

E.12. List of IPRs

The IPRs listed in the following table are an integral part of the Authorisation.

	IPR	Name of IPR	Application Number	Date of filling	Applicant	Owner	Designated Countries
1	Patent	Transmission of Satellite Navigation Message into Multiple Pages Encoded for Optimal Retrieval at Receiver in a Fully Interchangeable Way	PCT/ EP2019/ 076846	03/10/2019	The European Union, represented by the European Commission	EU	Brazil, Canada, China, Japan, Russia, USA, France, Italy, Spain, Germany, UK.

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