Ref. Ares(2020)3414390 - 30/06/2020

European
Global Navigation
Satellite Systems
Agency

Galileo High Accuracy Service
E6-B Signal-In-Space Message Specification
v1.2

grow.ddg3.j.1(2019)802334

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CHANGE RECORD

Reason for change	Issue	Revision	Date
First issue, for HAS Phase 1 tendering.	1	0	14/02/2019
First issue, revision 1, internal to the Galileo Program and provided for HAS Phase 1 development. C/NAV Dummy Page Definition section replaced by HAS Dummy Page Definition section. MT structure modified. MTs not covered in HAS Phase 1 removed. HAS Page Header structure modified, replacing Message Format Field with HAS Status field and restructuring the bit allocation. Parity concept is removed. Generic HAS Message Header replaced by specific headers for each MT. HAS Message structure updated. Multiple correction fields updated. Signal mask updated. HAS Message Page Encoding updated, further developing the HAS encoding and transmission, and the HAS reception and decoding processes. Nomenclature is updated. Application of Galileo HAS Corrections section added. Other minor changes implemented	1	1	11/02/2020

First issue, revision 2, internal to the Galileo Program and provided for HAS Phase 1 development. Updates to section 5.2 MT1 Body: - IOD Change Flag description updated to clarify the meaning of the values - Clock Subset Corrections block contents updated to match the contents of the Clock Full-Set Corrections block - Clock Subset Corrections block field names nomenclature aligned Updates to section 6 to unify nomenclature used for the Reed-Solomon code to RS(255, 32, 224) Updates to section 6 to include additional information on the Reed Solomon code: - Galois field - Generator polynomial - Systematic encoding using the Reed Solomon generator polynomial - Systematic encoding using the RS generator matrix - Implementation pitfalls Annex C providing the Reed Solomon generator matrix and Annex D providing encoding examples added	1	2	07/04/2020

1 INTRODUCTION AND PURPOSE

Galileo will provide a High Accuracy Service (HAS) based on the transmission of PPP (Precise Point Positioning) corrections. This document presents the Galileo HAS message transmission format. 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 is described.

This version of the HAS Message Specification is made available for development and testing within the Galileo Program. The HAS Message Specification may be modified or updated before an operational service is delivered. The European Commission, the European GNSS Agency, and the European Space Agency do not make any warranty, express or implied, including the warranty of fitness for any particular purpose, or assumes any legal liability or responsibility for the information hereby disclosed. No liability is hereby assumed for any direct, indirect, incidental, special or consequential damages resulting from the use of this specification or information therein.

2 GALILEO C/NAV ENCODING AND PAGE LAYOUT

The Galileo High Accuracy Service will be 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 [1] and complemented by [2] 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 Encoding

The FEC (Forward Error Correction) convolutional encoding for all data pages on the E6-B component is performed according to the parameters provided in Table 1. The convolutional encoding scheme described here is the same as the one used for all other Galileo data channels described in [1].

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 1: Data Coding Parameters

Figure 1 depicts this convolutional coding scheme. Decoding can be implemented using a standard Viterbi decoder.

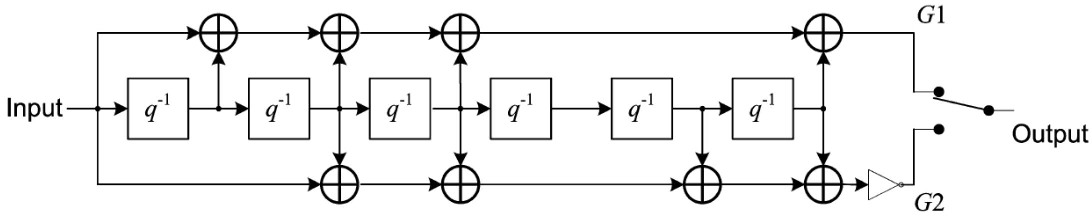

Figure 1: Convolutional Coding Scheme (note that the second branch is inverted at the end)

2.2.2 Interleaving

Analogously to the other Galileo message types described in [1], 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 2.

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

Table 2: C/NAV interleaving structure

2.3 C/NAV Page Layout

Every second, one C/NAV page can be transmitted from a Galileo satellite. The C/NAV Page layout is shown in Table 3, 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 GST (Galileo System Time) second.

Out of 492 bits available, 14 bits are reserved for other services, 24 bits are used by the CRC (Cyclic Redundancy Check) 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 3: C/NAV Page Layout

2.3.1 Synchronisation Pattern

The synchronisation pattern ("Sync" in Table 3) allows the receiver to achieve synchronisation to the page boundary. The synchronisation pattern is not encoded. The C/NAV synchronisation pattern is "b1011011101110000" (where b implies binary format).

2.3.1 Tail

The Tail field consists of 6 zero-value bits enabling completion of the FEC decoding of each page in the user receiver.

2.3.1 Checksum

Analogously to the description provided in [1] for other message types, C/NAV also uses a checksum, employing a CRC technique, to detect the reception of corrupted data. As for the other message types, the C/NAV checksum also does not include the frame 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 below.

$$G(X) = (1 + X)P(X)$$

Where $P(X)$ is a primitive and irreducible polynomial given by the following equation.

$$P(X) = X^{23} + X^{17} + X^{13} + X^{12} + X^{11} + X^9 + X^8 + X^7 + X^5 + X^3 + 1$$

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
- $m(X) = m_1 X^{k-1} + \ldots + m_{k-2} X^2 + m_{k-1} X + m_k$, with $m_1, m_2, \ldots, m_k$ the sequence of k-bits information to be protected by the CRC, and m_1 as the 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 4.

HAS Page		Total (bits)
HAS Page Header	HAS Message	
24	424	448

Table 4: HAS Page Layout

Every C/NAV page carries a 448-bit HAS Page. Every HAS Page is composed by a 24-bit header and a 424-bit HAS Message field. Full HAS Messages will be usually longer than 424 bits and may occupy more than one HAS Message field. The following sections define the name, range if applicable, the number of bits ('Bits'), the bit ordering and the units if applicable, of each field of the HAS Page Header and the HAS Message. Each field includes a description allowing its interpretation. The fields are represented either in binary or in decimal format. When binary format used, and interpretation is subject to ambiguity, the value is preceded by “b”.

2.4.1 HAS Dummy Page Definition

In case no valid HAS data is transmitted, the satellite transmits a HAS dummy page as part of the C/NAV Page layout defined in Table 3 with the sequence “*hex*[*AF3BC3*]” in the 24-bit Page Header, where *hex* implies hexadecimal format. Note that only Galileo satellites connected to the ground segment can transmit HAS messages. Due to the connectivity requirements between the Galileo ground and space segments, a subset of all operational satellites may be not connected to the ground segment at a certain time during nominal operation of the system, and transmit HAS Dummy Pages.

3 HAS PAGE HEADER

The 24-bit HAS Page Header is transmitted in every C/NAV Page, and is defined according to Table 5. See section 6.4 for more details on the interpretation of the Page Header fields MT, MID, MS and PID.

Name	Range	Bits	SF	Unit	Description
HAS Status	-	2	-	-	"b00" = Test mode. HAS data is transmitted and can be used without any guarantee. "b01" = Operational mode. HAS data is transmitted nominally. "b10" = Reserved. "b11" = Do Not Use HAS. Users shall stop using HAS from all satellites and discard previously received messages.
Reserved	-	2	-	-	
Message Type (MT)	-	2	-	-	"b01" = MT1. Contains satellite corrections. "b10", "b00", "b11" = Reserved.
Message ID (MID)	0-31	5	-	-	ID of the message.
Message Size (MS)	1-32	5	1	Pages	Size of the non-encoded message, in pages. ("0"=1 …"31"=32)
Message Page ID (PID)	0-255	8			ID of the transmitted page of the encoded message.

Table 5: HAS Page Header

4 HAS MESSAGE OVERVIEW

This section defines the 424-bit HAS Message field. Figure 2 presents an overview of the HAS message formatting and encoding process.

- First, a HAS message is defined by concatenating the Message Header and the message content. The Message Header is depicted as 'H' in Figure 2, and is a different field from the HAS Page Header. The Message Header defines the message content. For satellite corrections, it may include masks, orbit corrections, clock corrections, code biases, carrier phase biases, URA (User Range Accuracy) indicators, or combinations of them.
- Then, the message is partitioned into 424-bit pages $M_1..M_k$. If the message is not a multiple of 424-bits, the last bits of the last non-encoded page are filled by a chain of zeroes and ones "b010101…", of the required length.
- Finally, the message is encoded into n pages $C_1..C_n$, where different satellites transmit different pages at a certain time. The message can be decoded with any different k pages. The message encoding and decoding process is described in detail in section 6. The page scheduling algorithm from different satellites is out of the scope of this document.

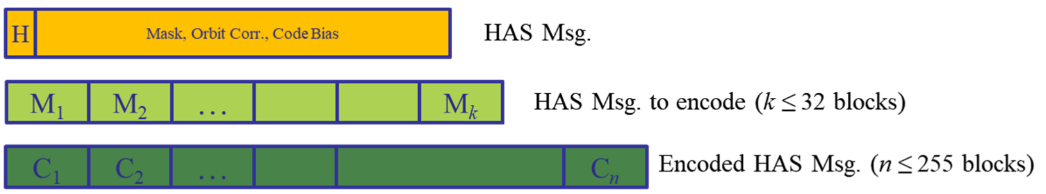

Figure 2 – Example of HAS encoding process. H stands for HAS Message Header, M for non-encoded message blocks, C for encoded message blocks

5 HAS MESSAGE TYPE 1

This Section describes HAS MT1 (Message Type 1).

5.1 MT1 Header

Every HAS MT1 has a common 32-bit HAS Message Header that is transmitted before the HAS message content, with the fields described in Table 6. A MT1 can include different combinations of sections depending on the flags. The most usual MT1 combinations are:

- A single MT1 with mask, orbit corrections, full-set clock corrections, code bias, phase bias, and URA (flag sequence: “b11101110”).
- One MT1 with mask, orbit corrections, code bias, phase bias, and URA (flag sequence: “b11001110”), plus one MT1 with clock correction full-set (flag sequence: “b00100000”).
- One MT1 with mask, orbit corrections, full-set clock corrections, code bias, phase bias, and URA (flag sequence: “b11101110”), plus one MT1 with clock correction subset (flag sequence: “b00010000”).

Other combinations are possible. The content of the message shall be read in the flag order (i.e. first, mask if present, then orbit corrections if present, etc.).

Mask ID ensures masks are properly identified in time and space, in case multiple service areas are served. Together with the IOD ID, it also relates content of different messages to the same satellite set. The satellite mask is supposed to vary regularly in case the satellite service area is not global. A receiver can relate messages both by Mask ID and IOD ID. In case of mask changes or if multiple masks are used simultaneously, there will be no more than one mask associated to the same Mask ID within +/- 15 minutes. The IOD ID is linked to the mask identified by the Mask ID field.

When Mask Flag = 1, the message defines the mask, and when Mask Flag = 0, it relates the content to an already defined mask by Mask ID. Similarly, when Orbit Corr. Flag = 1, it defines the IOD ID by linking it to the IODs of the corrected satellites. When Orbit Corr. Flag = 0, it relates the content to an already defined IOD ID in another message.

Name	Range	Bits	SF	Unit	Description
TOH	0-4095	12	1	s	Time Of Hour, based on GST, allowing to determine the message reference time[1], hence the time of applicability of the corrections if provided in the message.
Mask Flag	-	1	-	-	7-bit stream with flags defining the message content blocks. Each flag indicates if the content block is present (“1”) or not (“0”).
Orbit Corr. Flag	-	1	-	-	
Clock Full-set Flag	-	1	-	-	
Clock Subset Flag	-	1	-	-	
Code Bias Flag	-	1	-	-	
Phase Bias Flag	-	1	-	-	
URA Flag	-	1	-	-	
Reserved	-	3	-	-	
Mask ID	0-31	5	-	-	The Mask ID is a counter for 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”, it defines the mask. When Mask Flag = “0”, it relates the content of the message to an already defined mask in another message.
IOD ID	0-31	5	-	-	The IOD ID is a counter that identifies the IODs of the corrected satellites. The IOD ID only changes when the IOD of at least one satellite of the mask changes and corrections for new IOD are provided. When Orbit Corr. Flag = “1”, the IOD ID is linked to the IODs of the corrected satellites in the Orbit Corrections block of the MT1 body. When Orbit Corr. Flag = “0”, the message relates its content to an already defined IOD ID.

Table 6: MT1 Message Header. SF stands for Scale Factor.

[1] 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. The HAS message reference time shall always be below or equal to the time of reception of the full HAS message to which the TOH belongs. The GST hour associated to the TOH will generally be the current GST hour at message reception time, but in case of hour transition between HAS message generation and reception, it can be the immediately preceding GST hour.

5.2 MT1 Body

The MT1 body, divided in content blocks, is provided in Table 7.

Name	Range	BIT	SF	Unit	Description
MASK					
N_{sys}	0-15	4	1	-	Number of GNSS for which corrections are provided.
GNSS ID 1	0-15	4	-	-	As per Table 8.
Satellite mask 1	-	40	-	-	As per Table 9. Mask specifying if satellites of GNSS ID 1 are corrected ("1") or not ("0"). The MSB corresponds to satellite "1", and so forth.
Signal mask 1	-	16	-	-	As per Table 10. It indicates for which signals the bias corrections are provided in the Code Bias and/or Phase Bias content blocks.
Cell Mask 1 Availability Flag	0-1	1	-	-	Flag indicating if the Cell Mask for the GNSS is provided ("1") or not ("0"). If not, the bias content blocks include correction fields for all satellites and signals.
Cell mask 1	-	variable	-	-	For each satellite (i.e. each "1" of the satellite mask) and each signal (i.e. each "1" of the signal mask), the cell mask indicates with one bit whether biases are provided ("1") or not ("0"). Its size equals the number of ones in the satellite mask, times the number of ones in the signal mask[2].
Nav Message 1	-	3	-	-	Navigation Message Corrected in the orbit and clock content blocks, as per Table 11.
…					
GNSS ID N_{sys}	0-15	4	-	-	See GNSS ID 1 description.
Satellite mask N_{sys}	-	40	-	-	
Signal mask N_{sys}	-	16	-	-	
Cell Mask N_{sys} Provision Indicator	0-1	1	-	-	
Cell Mask N_{sys}	-	variable	-	-	
Nav Message N_{sys}	-	3	-	-	
Reserved		6		-	

[2] Cell mask 1 is formed as a table of size N_{sat} rows by N_{sig} columns, where N_{sig} is the number of ones in Signal mask 1, and N_{sat} is the number of ones in Satellite mask 1, and written/read from left to right, and from top to bottom.

Name	Range	BIT	SF	Unit	Description
ORBIT CORRECTIONS					
Validity Interval Index	0-15	4	-	-	Validity Interval as per Table 12.
GNSS IOD[3] (SV 1)	0-1023 or 0-255	variable	1		10 bits for Galileo; 8 bits for GPS.
Delta Radial (SV 1)	±16.382	14*	0.002	m	-16.384 indicates data not available
Delta Along-Track (SV 1)	±16.376	12*	0.008	m	-16.384 indicates data not available
Delta Cross-Track (SV 1)	±16.376	12*	0.008	m	-16.384 indicates data not available
......					
GNSS IOD (SV N_{sat}[4])	0-1023 or 0-255	variable	1	-	See SV 1 description.
Delta Radial (SV N_{sat})	±16.382	14*	0.002	m	
Delta Along-Track (SV N_{sat})	±16.376	12*	0.008	m	
Delta Cross-Track (SV N_{sat})	±16.376	12*	0.008	m	
CLOCK FULL-SET CORRECTIONS					
Validity Interval Index	0-15	4	-	-	Validity Interval as per Table 12.
Delta Clock C0 Multiplier (GNSS 1)	1-4	0 or 2[5]			Multiplier for all Delta Clock C0 corrections of the GNSS provided in the clock full-set corrections content. Field only provided for GNSS other than Galileo. "b00": x1 "b01": x2 "b10": x3 "b11": x4
......					
Delta Clock C0 Multiplier (GNSS N_{sys})	1-4	2			See GNSS 1 description.
IOD Change Flag (SV 1)	0-1	1	-	-	Flag to indicate whether the IOD of the satellite in IOD ID has changed with respect to the one defined in the previous IOD ID of the same Mask ID: "0": The IOD has not changed "1": The IOD has changed
Delta Clock C0 (SV 1)	±20.4775	14*	0.0025	m	-20.4800 indicates data not available
......				-	
IOD Change Flag (SV N_{sat})	0-1	1	-	-	See SV 1 description
Delta Clock C0 (SV N_{sat})	±20.4775	14*	0.0025	m	

[3] IOD refers to IOD_{nav} for Galileo satellites and IODE/IODC for GPS satellites. GNSS IOD interpretation may be expanded if other GNSS are corrected in the future.

[4] N_{sat} is the number of satellites of the mask including all GNSS.

[5] Delta Clock C0 Multiplier field is only provided for GNSS other than Galileo. For Galileo, the multiplier is always 1.

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

Name	Range	BIT	SF	Unit	Description
CLOCK SUBSET CORRECTIONS					
Validity Interval Index	0-15	4	-	-	Validity Interval as per Table 12.
N_{sys}'	0-15	4	1	-	Number of GNSS for which corrections are provided in the clock subset corrections.
GNSS ID 1	-	4	-	-	As per Table 8.
Delta Clock C0 Multiplier (GNSS ID 1)	1-4	0 or 2[6]	-	-	Multiplier for all Delta Clock C0 corrections of the GNSS. Field is only provided for GNSS other than Galileo. "b00": x1 "b01": x2 "b10": x3 "b11": x4
Satellite sub-mask (GNSS 1)	-	variable	-	-	Reports which satellites of GNSS ID of the satellite mask are corrected. The length of this field is the number of satellites in the satellite mask for the GNSS ID.
IOD Change Flag (GNSS 1 - SV 1'[7])	0-1	1	-	-	Flag to indicate whether the IOD of the satellite in IOD ID has changed with respect to the one defined in the previous IOD ID of the same Mask ID: "0": The IOD has not changed "1": The IOD has changed
Delta Clock C0 (GNSS 1 - SV 1')	±20.4775	14*	0.0025	m	-20.4800 indicates data not available
......					
IOD Change Flag (GNSS 1 - SV N_{sat}'[8])	0-1	1	-	-	See GNSS 1 – SV 1' description
Delta Clock C0 (GNSS 1 - SV N_{sat}')	±20.4775	14*	0.0025	m	
......					
GNSS ID N_{sys}'	-	4	-	-	See GNSS ID 1 description.
Delta Clock C0 Multiplier (GNSS N_{sys}')	1-4	2	-	-	
Satellite sub-mask (GNSS N_{sys}')	-	variable	-	-	
IOD Change Flag (GNSS N_{sys}' - SV 1')	0-1	1	-	-	
Delta Clock C0 (GNSS N_{sys}' - SV 1')	±20.4775	14*	0.0025	m	
......					
IOD Change Flag (GNSS N_{sys}' - SV N_{sat}')	0-1	1	-	-	
Delta Clock C0 (GNSS N_{sys}' - SV N_{sat}')	±20.4775	14*	0.0025	m	
CODE BIAS					
Validity Interval Index	0-15	4	-	-	Validity Interval as per Table 12.
Code Bias 1 (SV 1)	± 20.46	11*	0.02	m	-20.48 indicates data not available.
......				-	

[6] Delta Clock C0 Multiplier field is only provided for GNSS other than Galileo. For Galileo always 1.

[7] GNSS ID - SV 1' refers to the first satellite indicated in the satellite sub-mask of GNSS ID.

[8] GNSS ID - SV N_{sat}' refers to the last satellite indicated in the satellite sub-masks of GNSS ID.

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

Name	Range	BIT	SF	Unit	Description
Code Bias $Ncode_1$ (SV 1)	± 20.46	11[*]	0.02	m	-20.48 indicates data not available.
......					
Code Bias 1 (SV N_{sat})	± 20.46	11[*]	0.02	m	See SV 1 description.
......				-	
Code Bias Ncode $_{Nsat}$ (SV Nsat)	± 20.46	11[*]	0.02	m	
PHASE BIAS					
Validity Interval Index	0-15	4	-	-	Validity Interval as per Table 12.
Phase Bias 1 (SV 1)	±10.23	11[*]	0.01	cycle	-10.24 indicates data not available
Phase Discontinuity Indicator 1 (SV 1)	0-3	2	1	-	This counter in incremented every time there is a phase bias discontinuity which cannot be covered within the previous interval.
......					
Phase Bias $Nphase_1$ (SV 1)	±10.23	11[*]	0.01	cycle	-10.24 indicates data not available
Phase Discontinuity Indicator $Nphase_1$ (SV 1)	0-3	2	1	-	This counter in incremented every time there is a phase bias discontinuity which cannot be covered within the previous interval.
......					
Phase Bias 1 (SV N_{sat})	±10.23	11[*]	0.01	cycle	See SV 1 description.
Phase Discontinuity Indicator 1 (SV N_{sat})	0-3	2	1	-	
......					
Phase Bias $Nphase_{Nsat}$ (SV N_{sat})	±10.23	11[*]	0.01	cycle	
Phase Discontinuity Indicator $Nphase_{Nsat}$ (SV N_{sat})	0-3	2	1	-	
URA					
Validity Interval Index	0-15	4	-	-	Validity Interval as per Table 12.
URA (SV 1)	-	6	-	-	Value set to "b000000" if satellite shall not be used. Other values are reserved.
......				-	
URA (SV Nsat)	-	6	-	-	

Table 7: MT1 Message Body

5.3 Field Tables

This section presents tables for the interpretation of the HAS message fields, referred in the previous sections.

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

Table 8: GNSS ID

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

Satellite Mask	Galileo	GPS
0	1	1
1	2	2
…	…	…
39	40	40

Table 9: Satellite mask[9]

Signal mask	Galileo	GPS
0	E1 B I/NAV OS	L1 C/A
1	E1 C no data	Reserved
2	E1 B+C	Reserved
3	E5a I F/NAV OS	L1 L1C(D)
4	E5a Q no data	L1 L1C(P)
5	E5a I+Q	L1 L1C(D+P)
6	E5b I I/NAV OS	L2 L2C(M)
7	E5b Q no data	L2 L2C(L)
8	E5b I+Q	L2 L2C(M+L)
9	E5 I	L2 P
10	E5 Q	Reserved
11	E5 I+Q	L5 I
12	E6 B C/NAV HAS	L5 Q
13	E6 C no data	L5 I+Q
14	E6 B+C	Reserved
15	Reserved	Reserved

Table 10*:* Signal mask

Nav Message	Galileo	GPS
0	I/NAV	LNAV (L1 C/A)[10]
1-7	Reserved	Reserved

Table 11: NAV Message[11]

Interval Index	Interval[12]
0	5 s
1	10 s
2	15 s
3	20 s
4	30 s
5	60 s

[9] The number associated corresponds to: SVID for Galileo and PRN (Pseudo-Random-Noise) code for GPS.

[10] The clock corrections for GPS LNAV will be provided for the L1 C/A-L2P ionosphere-free combination

[11] Only GPS LNAV (L1 C/A) and Galileo I/NAV are to be implemented for HAS Phase 1.

[12] The Validity Interval of the associated content block starts at the time defined by TOW in the Message Header, and lasts according to the value defined by the Interval column.

Interval Index	Interval[12]
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 12: Interval Index

6 HAS MESSAGE PAGE ENCODING AND DECODING

The purpose of the outer layer coding of the HAS message pages is to improve reception in conditions of fading, shadowing and interference. A HAS message of k pages $(M_1,...,M_k)$ is encoded into a set **C** of n pages ($C_1,...,C_n$) and, when *any* subset **C'** of **C**, of k different pages $(C'_1,...,C'_k)$, is received, 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" small portions of the message, as described in the following subsections.

6.1 Galois Field

The Reed-Solomon is based on a Galois field of order 256, GF(256), defined by the primitive polynomial:

$$p(\alpha) = \alpha^8 + \alpha^4 + \alpha^3 + \alpha^2 + 1$$

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 13.

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}
$\alpha^7+\alpha^6+\alpha^3+\alpha^2+1$	11001101	205	α^{12}
$\alpha^7+\alpha^2+\alpha+1$	10000111	135	α^{13}
$\alpha4+\alpha+1$	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}

Polynomial representation	Octet representation	Octet representation (integer)	Power representation α^n
$\alpha^7+\alpha+1$	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 13: Polynomial, octet and power representation of the Galois field

6.2 The 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 Polynominal

The Reed-Solomon code is a narrow sense code over GF(256) where the field is represented using the primitive polynomial and α is a primitive element in the field. The corresponding generator polynomial g(x) in the indeterminate x is thus:

$$g(x) = \prod_{i=1}^{255-32} \left(x - \alpha^i\right) = \sum_{j=0}^{223} g_j \cdot x^j$$

The resulting coefficients g_j of the polynomial are tabularised in the integer octet representation in Table 14.

j	g_j	*j*	g_j	*j*	g_j	*j*	g_j	*j*	g_j	*j*	g_j	*j*	g_j
0	1	*32*	99	*64*	201	*96*	45	*128*	115	*160*	68	*192*	34
1	251	*33*	220	*65*	231	*97*	130	*129*	36	*161*	89	*193*	93
2	252	*34*	98	*66*	89	*98*	64	*130*	243	*162*	42	*194*	65
3	5	*35*	164	*67*	68	*99*	192	*131*	178	*163*	80	*195*	44
4	83	*36*	189	*68*	194	*100*	20	*132*	35	*164*	247	*196*	217
5	128	*37*	179	*69*	145	*101*	78	*133*	66	*165*	173	*197*	182
6	86	*38*	177	*70*	237	*102*	157	*134*	183	*166*	228	*198*	81
7	32	*39*	135	*71*	7	*103*	13	*135*	175	*167*	95	*199*	120
8	169	*40*	128	*72*	159	*104*	174	*136*	147	*168*	24	*200*	19
9	153	*41*	19	*73*	111	*105*	28	*137*	236	*169*	13	*201*	4
10	246	*42*	14	*74*	255	*106*	227	*138*	176	*170*	42	*202*	223
11	123	*43*	85	*75*	22	*107*	91	*139*	7	*171*	54	*203*	249
12	169	*44*	136	*76*	146	*108*	71	*140*	108	*172*	120	*204*	45
13	172	*45*	57	*77*	160	*109*	143	*141*	21	*173*	4	*205*	208
14	216	*46*	249	*78*	33	*110*	241	*142*	151	*174*	134	*206*	170
15	47	*47*	53	*79*	210	*111*	124	*143*	234	*175*	133	*207*	69
16	54	*48*	149	*80*	52	*112*	144	*144*	14	*176*	166	*208*	116
17	82	*49*	151	*81*	219	*113*	1	*145*	131	*177*	217	*209*	209
18	137	*50*	216	*82*	99	*114*	137	*146*	109	*178*	32	*210*	134
19	81	*51*	212	*83*	88	*115*	152	*147*	28	*179*	171	*211*	11
20	199	*52*	49	*84*	183	*116*	253	*148*	1	*180*	50	*212*	250
21	43	*53*	119	*85*	179	*117*	109	*149*	230	*181*	121	*213*	249
22	134	*54*	122	*86*	180	*118*	102	*150*	38	*182*	216	*214*	120
23	253	*55*	236	*87*	88	*119*	214	*151*	18	*183*	242	*215*	62

j	*gj*	*j*	*gj*	*j*	*gj*	*j*	*gj*	*j*	*gj*	*j*	*gj*	*j*	*gj*
24	31	*56*	204	*88*	165	*120*	9	*152*	223	*184*	165	*216*	81
25	121	*57*	165	*89*	43	*121*	59	*153*	243	*185*	244	*217*	79
26	97	*58*	71	*90*	252	*122*	163	*154*	108	*186*	48	*218*	82
27	148	*59*	112	*91*	193	*123*	120	*155*	118	*187*	65	*219*	111
28	170	*60*	27	*92*	171	*124*	6	*156*	51	*188*	28	*220*	23
29	188	*61*	5	*93*	229	*125*	36	*157*	112	*189*	112	*221*	195
30	230	*62*	127	*94*	46	*126*	51	*158*	181	*190*	227	*222*	216
31	241	*63*	224	*95*	39	*127*	255	*159*	81	*191*	118	*223*	88

Table 14: Octet representation (integer) of the coefficients of the generator polynomial

6.2.2 Systematic Encoding using the Reed Solomon Generator Polynomial

The information vector **c** can be represented in polynomial form:

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

The coefficients $c_0, c_1, \dots, c_{31}$ form the RS information vector:

$$\mathbf{c}^{\mathrm{T}} = [c_0, c_1, c_2, \dots, c_{31}].$$

The RS code vector $\tilde{\Gamma}$ is obtained from $c(x)$ and $g(x)$ as:

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

The function $\mathrm{R}_{\mathrm{g(x)}}[\mathrm{f(x)}]$ 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 Γ therefore consists of the information part and the parity part in exchanged order, i.e.: information part first and parity part second:

$$\mathbf{\Gamma}^{\mathrm{T}} = [\Gamma_0, \Gamma_1, \dots, \Gamma_{254}] = [\tilde{\Gamma}_{223}, \tilde{\Gamma}_{224}, \dots, \Gamma_{254}, \tilde{\Gamma}_0, \tilde{\Gamma}_1, \dots, \tilde{\Gamma}_{222}] = [c_0, c_1, c_2, \dots, c_{31}, \gamma_0, \gamma_1, \dots, \gamma_{222}].$$

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 **Γ** can be computed through a GF(256) matrix multiplication of the RS information vector **c** with the systematic generator matrix **G**:

$$\mathbf{\Gamma} = \mathbf{G} \cdot \mathbf{c}$$

or more explicitly

$$\mathbf{\Gamma} = \begin{pmatrix} \Gamma_0 \\ \Gamma_1 \\ \vdots \\ \Gamma_{254} \end{pmatrix} = \begin{pmatrix} c_0 \\ c_1 \\ \vdots \\ c_{31} \\ \gamma_0 \\ \gamma_1 \\ \vdots \\ \gamma_{222} \end{pmatrix} = \begin{pmatrix} \mathbf{c} \\ \boldsymbol{\gamma} \end{pmatrix} = \mathbf{G} \cdot \mathbf{c} = \begin{pmatrix} \mathbf{I} \\ \mathbf{P} \end{pmatrix} \cdot \begin{pmatrix} c_0 \\ c_1 \\ \vdots \\ c_{31} \end{pmatrix}.$$

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

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

This ICD provides the generator matrix G in Annex C as comma separated values in octet representation as per Table 13.

6.3 HAS Encoding and Transmission

The scheme for the outer-layer coding scheme is illustrated in Figure 3. Figure 3 shows a HAS message of k pages (M_1 to M_k) depicted as a table of k rows and J columns, encoded into a message of n 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 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. $w_{1,1}$, $w_{2,1}$,...,$w_{k,1}$ 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 1st encoded page C_1 is composed by $w'_{1,1},\ldots,w'_{1,J}$, etc., creating the n pages $C_1,\ldots,C_n$ for SIS transmission.
- After the message is encoded, the transmission of pages in the SIS is dynamically assigned to satellites in real time depending on the HAS configuration. Each encoded page is encapsulated in the 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,...,n is provided in the Message Page ID (PID) field, all in the HAS Page Header (see Table 4).

The encoded pages are allocated so that in most receiving conditions every received page will contribute to the message retrieval, with no repetitions, thanks to the high number of parity pages available. For example, a message of 20 pages (k = 20) can be encoded into $2^m – 1 – K + k = 243$ pages. Note that the pages $C_{k+1},\ldots,C_K$ are not transmitted, as they include only zeroes. Note also that the outer layer coding allows puncturing, so not all of these pages may be transmitted over time by Galileo satellites. Further details on the transmission process are beyond the scope of this version of the document.

6.4 HAS Reception and Decoding

This section presents the receiver decoding process using the RS generator matrix. 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 Table 5) and stored. Once the receiver has received any different *k* pages (*k=MS*) of the same Message ID and Message Type (i.e. MID and MT are identical to the received pages) but with different PIDs, the receiver forms an encoded message *C'* with the received pages.
- Each encoded page *C'* is divided into 53 octets (*w'*), according to their position, as for the encoding process.
- The octets in each position are grouped into the 53 vertically encoded and received words, of length *k*, where the index in the originally encoded message is given by the PID field.
- Each vertically encoded and received word is decoded by a separate Reed-Solomon erasure decoder. The decoding process uses the *k* rows of the RS encoding matrix corresponding to the $C'_1,\ldots,C'_k$ received pages. The resulting matrix is inverted. Note that only one matrix inversion is required for all vertical words.
- By multiplying each received encoded word of length *k* with the inverted *k x k* matrix, the original octets *w* are recovered[13]. The process is repeated for each vertically encoded word, until the original HAS message is retrieved.

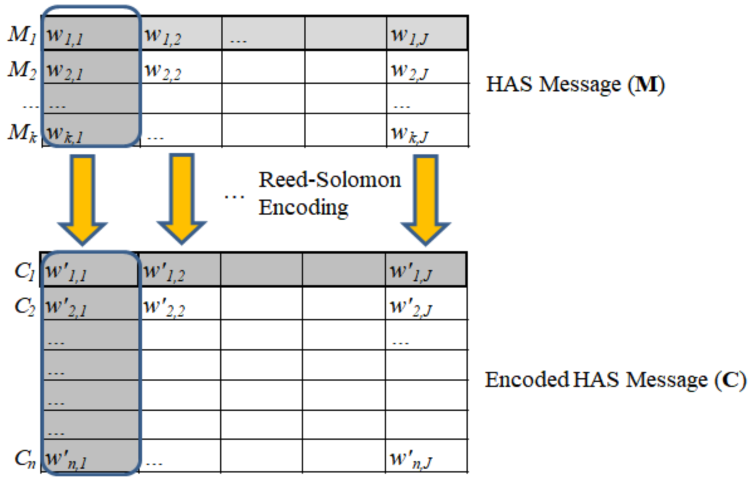

Figure 3 – HAS outer-layer encoding process

[13] This process is considered standard Reed-Solomon decoding and its full description is beyond the scope of this document.

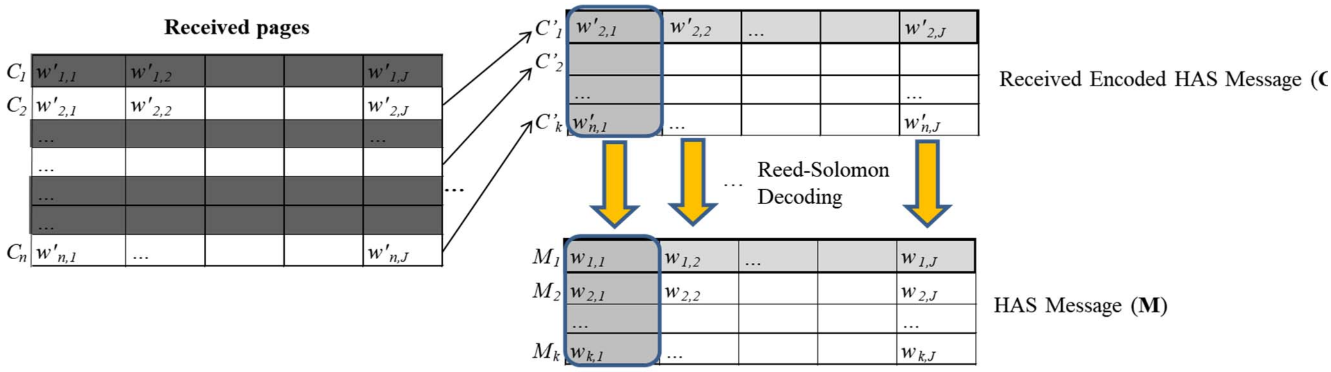

Figure 4 – HAS outer-layer decoding process

6.5 Further Notes on Reed Solomon Implementations

This section provides an example RS(255,32,224) encoding, to support implementers of the above algorithms in the verification of their implementation. The sample information vector (see Annex D for the full vector)

$$\mathbf{c}^{\mathrm{T}} = [71,\ 12,\ 25,\ 210, \dots, 179],$$

which contains 32 randomly generated Galois field symbols is encoded via the encoding algorithms described in the previous sections 6.2.2 or 6.2.3 and yields the RS code vector (see Annex D for the full vector)

$$\boldsymbol{\Gamma}^{\mathrm{T}} = [71,\ 12,\ 25,\ 210, \dots, 179,\ 133,\ 210,\ 122,\ 224, \dots, 4].$$

The complete encoding example is provided in Annex D as comma separated values in octet representation.

6.6 Implementation Pitfalls

When implementing the RS coding, special care has to be taken concerning the order of the polynomial powers in the respective implementation environment. For example, when using the polynomial representation and an implementation with descending powers, the polynomial coefficients of the information polynomial need to be provided to the encoding function in the reverse order.

Example: If the coded output sequence reads

$$[71,\ 12,\ 25,\ 210, \dots, 179,\ 0,\ 248,\ 29,\ 36, \dots, 7]$$

instead of the correct coded sequence

$$[71,\ 12,\ 25,\ 210, \dots, 179,\ 133,\ 210,\ 122,\ 224, \dots, 4]$$

this is an indicator that the implementation uses descending powers, i.e. the information vector is interpreted as

$$[c_{31}, c_{30}, c_{29}, \dots, c_0]^{\mathbf{T}}$$

instead of

$$\mathbf{c}^{\mathrm{T}} = [c_0, c_1, c_2, \dots, c_{31}].$$

Therefore, the input sequence needs to be flipped

$$[c_{31}, c_{30}, c_{29}, c_{28}, \dots, c_0] = [179,\ 130,\ 66,\ 192, \dots, 71]$$

Accordingly, the output sequence should then be in the following order

$$[c_{31}, c_{30}, c_{29}, c_{28}, \dots, c_0, \gamma_{222}, \gamma_{221}, \gamma_{220}, \gamma_{219}, \dots, \gamma_0] \\ = [179, 130, 66, 192, \dots, 71, 142, 176, 234, 117, \dots, 167]$$

Nevertheless, the ordering of the information and parity octets as described in 6.2.2 and recalled below

$$\boldsymbol{\Gamma}^{\mathrm{T}} = [\Gamma_0, \Gamma_1, \dots, \Gamma_{254}] = [\tilde{\Gamma}_{223}, \tilde{\Gamma}_{224}, \dots, \Gamma_{254}, \tilde{\Gamma}_0, \tilde{\Gamma}_1, \dots, \tilde{\Gamma}_{222}] = [c_0, c_1, c_2, \dots, c_{31}, \gamma_0, \gamma_1, \dots, \gamma_{222}].$$

needs to be restored before further processing and embedding the octets into the (RS) HAS words.

7 APPLICATION OF GALILEO HAS CORRECTIONS

This section presents additional clarifications on how to apply the HAS corrections to the measurements.

7.1 General considerations

7.1.1 Time and Reference Frames

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

The time of reference of the corrections provided by the HAS is referred to the GST. Therefore, when applying HAS corrections to GNSS other than Galileo, the computation of the broadcast ephemeris and clocks is to be done according to the corresponding GNSS system time while HAS corrections validity period is to be calculated using GST as reference. When applying the HAS correction to the corresponding computed broadcast values, the reference epoch of the computed broadcast values shall be considered as GST for all the GNSS constellations.

7.1.2 Ionosphere-free phase centre of the antenna

The ionosphere-free phase centre of the antenna of the satellite refers to the centre of phase of the satellite 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 11) of the HAS Message Type 1 Mask (Table 7).

7.1.3 Relationship with other formats

While the Galileo HAS SIS ICD is a self-standing document, it has been defined taking into account the formats of already existing messages providing high accuracy corrections. In particular, it takes into account QZSS Interface Specification of the Centimeter-Level Augmentation Service (IS-QZSS-L6-001) [3], which uses the Specification of Compact State-Space Representation (CSSR) for Satellite-Based Augmentation Messages defined under RTCM-SC-104.

7.2 Orbit Corrections

The HAS orbit $\delta\boldsymbol{R}$ corrections are provided in a Satellite Coordinate System (SCS), composed by the along-track, cross-track and radial components, and centred in the satellite's ionosphere-free centre of phase of the broadcast ephemeris indicated for the satellite in the NAV Message field of the HAS Message Type 1 Mask.

The SCS components are defined based on the position $\boldsymbol{x_b}$ and velocity $\dot{\boldsymbol{x}}_{\boldsymbol{b}}$ 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 along-track component is aligned in both direction and sign with the velocity vector.
- The cross-track component is aligned in both direction and sign with the cross product of the satellite position vector with the satellite velocity vector.
- The radial component is aligned in both direction and sign with the cross product of the along track component with the cross-track component.

The three components form a right-handed orthogonal system.

To apply the HAS orbit corrections, they need to be rotated from the SCS to the Broadcast ECEF frame using the SCS to ECEF rotation matrix, R_{ECEF}^{SCS}.

The rotation matrix from the SCS to the Broadcast ECEF frame is computed as follows:

$$\boldsymbol{e}_a = \frac{\dot{\boldsymbol{x}}_b}{|\dot{\boldsymbol{x}}_b|},$$

$$e_c = \frac{\boldsymbol{x}_b \times \dot{\boldsymbol{x}}_b}{|\boldsymbol{x}_b \times \dot{\boldsymbol{x}}_b|},$$

$$e_r = \boldsymbol{e}_a \times \boldsymbol{e}_c,$$

$$R_{ECEF}^{SCS} = [\boldsymbol{e}_r \quad \boldsymbol{e}_a \quad \boldsymbol{e}_c].$$

The rotated corrections $\delta\boldsymbol{X} = R_{ECEF}^{SCS}\delta\boldsymbol{R}$ are then added to the broadcast orbit $\boldsymbol{x}_b$ computed from the broadcast navigation message to obtain a refined orbit referred to the GTRF frame.

$$\boldsymbol{x}_p = \boldsymbol{x}_b + \delta\boldsymbol{X}.$$

After applying the corrections, the precise satellite position $\boldsymbol{x}_p$ is referred in the GTRF to the same ionosphere-free phase centre of the antenna of the reference broadcast orbit indicated in the NAV Message field (Table 11) of the HAS Message Type 1 Mask (Table 7)

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 and PCVs from the ANTEX files. For Galileo this information is provided in [4].

7.3 Clock Corrections

The HAS clock corrections δC are delta offsets to be added to the ionosphere-free clock error $t_b$computed from the broadcast message indicated in the NAV Message field (Table 11) of the HAS Message Type 1 Mask (Table 7).

$$t_p = t_b + \frac{\delta C}{c} + \delta t_r,$$

where c is the speed of light, defined as $c = 299792458.0$ m/s.

The sum of the ionosphere-free clock error t_b of the broadcast navigation message and the HAS clock corrections δC provides a refined ionosphere-free clock error t_p referred to the GST for the ionosphere-free combination of the pair of frequencies used by the reference navigation message indicated in the NAV Message field (Table 11) of the HAS Message Type 1 Mask (Table 7). The relativistic effects for the orbital eccentricity δt_r must also be corrected for both Galileo and GPS.

$$\delta t_r = -\frac{2\boldsymbol{x}_b \cdot \dot{\boldsymbol{x}}_b}{c}.$$

7.4 Code and Carrier Phase Bias Corrections

The HAS satellite code biases provide the offset between the reference combination of the HAS clock corrections (e.g. “ionosphere-free” for Galileo I/NAV and GPS LNAV L1 C/A) and the individual signals targeted by each bias. The pseudorange observations shall be corrected directly by adding these biases, so that the pseudorange observations can refer to the same phase centre of the antenna of the broadcast orbit reference indicated in the NAV Message field of the HAS Message Type 1 Mask (as per Table 11).

When using the ionosphere-free combination of the pair of frequencies used by the reference navigation message indicated in the NAV Message field of the HAS Message Type 1 Mask (e.g. E1C-E5bQ for I/NAV and L1 C/A-L2P for LNAV L1 C/A), there is no need for applying the code biases. For adopting other couples of signals or the uncombined approach, it is mandatory to apply the proper HAS code biases to measurements of the adopted signals before computing the ionosphere-free combination (e.g, using E1C and E5aQ for performing the ionosphere-free combination) or using them in an uncombined algorithm.

The HAS satellite phase biases provide the fractional part of the phase ambiguity at the message reference time. The HAS satellite phase biases cover a range of around +/- 10 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 indicated, requires a re-initialisation of the ambiguity for the indicated satellites).It might occur that a phase bias, reaching the upper or lower bound of its value range, is reset its integer part to zero. This operation will not require a reset of the user's ambiguities and therefore it will not be flagged through the Phase Discontinuity Indicators.

ANNEX A – REFERENCES

[1] European Union, “OSSISICD: Open Service Signal In Space Interface Control Document, Issue 1.3,” 2016.

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[3] Cabinet Office, “Quasi-Zenith Satellite System Interface Specification Centimeter Level Augmentation Service (IS-QZSS-L6-001),” 5 Nov 2018.

[4] European Union, “Galileo Satellite Metadata,” 2019. [Online]. Available: https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata. [Accessed 2019].

ANNEX B – LIST OF ACRONYMS

AltBOC	Alternative BOC
BOC	Binary Offset Carrier
BPSK	Binary Phase Shift Keying
C/N_0	Carrier to Noise density ratio
CLAS	Centimeter Level Augmentation Service
CRC	Cyclical Redundancy Check
CSSR	Compact SSR
ECEF	Earth-Centered Earth-Fixed
FEC	Forward Error Correction
GF	Galois Field
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GST	Galileo System Time
GTRF	Galileo Terrestrial Reference Frame
HADG	High Accuracy Data Generator
HAS	High Accuracy Service
ICD	Interface Control Document
IOD	Issue Of Data
IODclk	IOD clock
IODE	IOD ephemeris
IODnav	IOD navigation
MF	Message Format
MID	Message ID
MS	Message Size
MSB	Most Significant Bit
MT	Message Type
PCO	Phase Center Offset
PCV	Phase Center Variation
PID	Page ID
PPP	Precise Point Positioning
QZSS	Quasi Zenith Satellite System
Rsvd	Reserved
RS	Reed Solomon
RTCM	Radio Technical Commission for Maritime
SCS	Satellite Coordinate System
SF	Scale Factor
SIS	Signal in Space
SSR	State-Space Representation
ST	Sub-Type
SV	Space Vehicle
TBC	To Be Confirmed
TBD	To Be Defined
TEC	Total Electron Content
TOW	Time Of Week
URA	User Range Accuracy
WN	Week Number

ANNEX C – REED SOLOMON GENERATOR MATRIX

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100,230,38,81,137,111,224,66,144,209,150,29
54,111,92,162,94,181,80,242,110,11,251,202,169,236,203,117,76,176,91
,65,101,254,124,189,94,68,144,228,69,174,194,187
47,112,232,143,11,61,176,158,166,224,66,141,220,202,107,43,18,55,227
,5,61,32,187,54,232,33,40,172,201,18,79,116
216,219,20,210,81,212,202,36,192,151,16,4,178,3,174,69,97,148,90,78,
176,111,114,237,10,251,250,56,176,49,94,251
172,214,29,231,18,131,236,74,17,149,209,136,173,96,197,40,5,248,208,
31,166,93,130,215,114,1,97,199,221,102,29,164
169,146,38,79,223,104,123,55,232,175,190,13,141,215,144,214,203,14,9
6,159,46,59,192,10,20,224,110,53,172,220,20,110
123,3,106,17,68,55,250,130,248,172,174,172,114,101,47,154,36,127,94,
150,180,1,20,68,77,186,163,248,67,230,94,220
246,50,238,4,7,137,14,21,1,112,174,138,82,191,136,59,99,81,223,175,1
92,234,95,1,202,12,60,146,20,215,255,211
153,213,255,9,222,184,5,105,63,70,218,149,129,237,114,248,134,208,24
6,240,145,108,70,122,165,123,58,34,10,177,41,164

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169,167,37,173,49,164,64,222,203,129,109,6,144,251,29,97,27,141,72,1
85,193,12,241,206,185,55,20,110,73,11,195,90
32,191,122,8,17,183,252,99,46,101,127,215,249,22,38,95,254,203,167,8
,179,20,217,204,127,112,89,147,204,122,8,243
86,39,220,141,104,120,171,188,247,138,70,51,13,144,117,101,127,60,23
3,11,124,75,236,5,13,244,61,201,111,167,108,117
128,14,116,104,71,74,5,39,91,117,85,148,232,47,195,96,35,24,148,244,
35,15,56,24,251,14,81,27,123,163,171,172
83,183,91,34,240,134,150,30,36,20,59,93,226,41,122,21,227,115,230,50
,89,171,135,201,133,233,182,168,105,199,235,95
5,99,129,250,218,88,70,205,137,207,121,127,241,74,31,239,182,113,175
,236,235,41,219,170,149,28,28,223,38,190,153,98
252,44,226,176,1,90,252,31,125,202,23,213,196,113,203,60,77,250,116,
74,21,85,151,148,156,251,109,255,50,1,27,27
251,14,135,97,113,203,181,137,55,187,20,215,113,14,218,212,136,158,2
,159,73,73,9,231,45,49,29,221,59,180,143,19
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ANNEX D – ENCODING EXAMPLES

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Input:
71,12,25,210,178,81,243,9,112,98,196,203,48,125,114,165,181,193,71,1
74,168,42,31,128,245,87,150,58,192,66,130,179

Output:
71,12,25,210,178,81,243,9,112,98,196,203,48,125,114,165,181,193,71,1
74,168,42,31,128,245,87,150,58,192,66,130,179,133,210,122,224,75,138
,20,205,14,245,209,187,246,228,12,39,244,238,223,217,84,233,137,168,
153,8,94,26,99,169,149,203,115,69,211,43,70,96,70,38,160,1,232,153,2
23,165,93,205,101,170,60,188,198,82,168,79,95,23,118,215,187,136,24,
99,252,3,144,166,117,45,168,239,77,42,246,33,122,97,242,236,13,217,9
6,186,71,250,242,177,125,87,27,13,118,181,178,12,27,66,31,74,127,46,
112,127,116,122,190,71,240,95,78,194,113,80,46,126,74,136,118,133,10
5,176,47,230,162,195,93,157,72,119,13,232,151,200,191,143,75,161,111
,29,158,16,181,165,92,39,17,218,228,58,176,233,55,211,195,73,37,137,
232,241,150,236,152,153,53,74,81,91,160,244,21,95,176,179,141,39,61,
136,16,58,160,51,210,31,134,63,203,96,219,44,231,61,220,0,241,220,20
7,17,52,150,117,54,222,128,101,213,164,234,74,224,57,246,70,27,202,2
29,4,243,128,211,158,199,4


Input flipped:
179,130,66,192,58,150,87,245,128,31,42,168,174,71,193,181,165,114,12
5,48,203,196,98,112,9,243,81,178,210,25,12,71

Output flipped:
179,130,66,192,58,150,87,245,128,31,42,168,174,71,193,181,165,114,12
5,48,203,196,98,112,9,243,81,178,210,25,12,71,142,176,234,117,99,76,
139,225,150,151,185,174,189,2,237,43,65,1,19,10,160,31,55,71,136,204
,184,147,176,194,175,100,9,111,180,108,100,24,228,222,8,143,125,43,6
2,240,103,136,85,211,125,17,223,193,70,22,3,197,100,139,198,205,178,
173,243,36,158,218,227,215,174,120,66,196,105,216,18,136,113,88,187,
152,181,228,83,38,58,53,25,125,71,149,188,104,110,215,33,58,158,15,2
7,61,220,67,72,14,64,159,126,132,219,80,114,20,181,26,10,19,194,206,
234,101,28,161,238,46,234,2,143,33,227,54,20,210,214,42,197,38,228,1
63,86,196,128,12,162,15,255,84,178,107,168,100,240,202,7,32,148,157,
13,36,223,44,44,120,45,9,53,87,98,111,172,230,100,110,240,113,2,213,
134,157,136,17,225,51,153,16,58,225,198,16,109,168,230,135,122,24,17
8,9,70,39,59,166,206,253,28,166,206,89,169,138,114,165,94,111,158,18
2,159,138,167,172,2,139,167
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