EUROPEAN GNSS (GALILEO) OPEN SERVICE

SIGNAL-IN-SPACE
INTERFACE CONTROL
DOCUMENT

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Document Change Record

Reason for change	Issue	Revision	Date
First issue	Draft	0	May 2006
CBOC Modulation added, 'lossless atmosphere' assumption removed from Tx power definition (issue under study), SAR data, update of the bit allocations of some F/NAV and I/NAV pages, editorial corrections etc.	Draft	1	February 2008
Update of the 'Terms of Use and Disclaimers' section and namely the licensing policy for R&D and standardisation purposes as well as commercial purposes. Assignment of the primary and secondary codes to satellites in section in section 3.6. More details on the I/NAV alert page content in section 4.3.2.3. Clarification of the power sharing between the different Galileo signal components in section 2.7.1. Addition of Galileo E1 sub-carriers plots in section 2.3.3 Clarification that Galileo E5a and E5b signals can be processed as QPSK signals in section 2.3.1.2. Update of the acronym list with QPSK in annex A. In section 4.2.4, for Page Type 6, parameter 'i' has been replaced by ω, the argument of perigee. In section 5.1.2, Time of Week an entire week from 0 to 604799 seconds, not up to 604800.	Issue 1	0	February 2010
Licence Agreement has been made easier to be adopted by licensees. Terms of use and disclaimers have been amended accordingly.	Issue 1	1	September 2010
"Reference Documents" section 1.3 added. Update of the constellation description and Earth radius in section 1.3. Correction of DC_{X-Y} and $rect_T(t)$ definitions in Table 4. E1-B, E1-C and E5 Primary Codes now delivered only in the electronic version of this ICD: sections 3.4.1 and 3.4.2, Annex C. Secondary Codes $CS100_{37}$ to $CS100_{39}$ added in Table 20. I/NAV usage updated in section 4.1.1. Correction of "Dummy Data (2/2)" bits allocation in Table 53. Correction of "start bit" value (equal 0 instead of 1) in part (5/8) of long RLM in Table 58. Added "start bit" value (equal 1) in Table 59. Correction of "GTRF coordinates" formula in Table 61 (last row): "y" is the sum of the two terms. Updated description of GST start epoch in section 5.1.2. Section 5.1.6 (Ionospheric Correction) reviewed. Clarification of "Day Number" value range in Table 68. Confirmation of "Data validity Status Bit" values in Table 73. E1 B/C Signal Health Status parameter definition updated in Sections 5.1.9.3 and 5.1.10. Updates of section 5.2 relevant to the SAR Return Link Message to include RLM data content. New Annex D "FEC Coding and Interleaving Numerical Examples" added. Correction of expression "(ΔA)1/2"(Difference with respect to the square root of the nominal semi-major axis) of Table 46 into the correct expression "Δ(A1/2)" The licence agreement has been revised and simplified. Miscellaneous minor typographical and wording corrections.	Issue 1	2	November 2015

Reason for change	Issue	Revision	Date
Section 2.7.1 has been reworded to clarify that the Galileo satellites provide a specified power level on ground starting from 5 degrees satellite elevation angle. Annex G – Authorisation Concerning the OS SIS ICD IPRs has been updated and 6 items (rows) have been added to the table in section G.12, which contains the list of OS SIS ICD related Intellectual Property Rights, to reflect the new licences granted to the EU on 6 patents.	Issue 1	3	December 2016
With this issue three new features are introduced to the I/NAV message transmitted within the Galileo E1 OS signal *(Secondary Synchronisation Pattern, Reduced Clock and Ephemeris and Reed-Solomon Outer Forward Error Correction)*. The following changes have been made to introduce all the necessary elements: • I/NAV Nominal Sub-Frame Layout within section 4.3.3 updated • New I/NAV word types (16, 17, 18, 19, 20) added within section 4.3.5 • New section 5.1.9.5 describing Secondary Synchronisation Pattern introduced • New section 5.1.11 describing Reduced Clock and Ephemeris Data introduced • New section 5.1.13 describing Protection of I/NAV Clock and Ephemeris Data by means of Reed-Solomon Outer Forward Error Correction • New Annexes E *(Reference Algorithm for Exploitation of FEC2 Reed-Solomon Words)* and F *(Reference Algorithm for Exploitation of FEC2 Reed-Solomon Words)* added In addition, sections 2.3.2 (E6 signal) and 2.7 (Received Power Levels on Ground) have been updated and a new Annex H (Authorisation Concerning use of the Galileo Trade Marks) has been added.	Issue 2	0	January 2021

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1. Introduction

1.1. Document Scope

The present European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (OS SIS ICD) Issue 2.0 contains the publicly available information on the Galileo Signal-In-Space. It is intended for use by the Galileo user community and it specifies the interface between the Galileo Space Segment and the Galileo User Segment.

1.2. Document Overview

The present document is organised as follows:

- Chapter 1 is this introduction which provides the scope of the document and an overview of the Galileo system
- Chapter 2 provides the Signal-In-Space radio frequency characteristics
- Chapter 3 provides the characteristics of the spreading codes
- Chapter 4 provides the message structures
- Chapter 5 provides the characteristics of the navigation message data contents

1.3. Reference Documents

[RD1]   European GNSS, Galileo Open Service, Ionospheric Correction Algorithm for Galileo Single Frequency Users, Issue 1.1.
http://www.gsc-europa.eu/electronic-library/programme-reference-documents

[RD2]   COSPAS – SARSAT, Specification for Cospas – Sarsat 406MHz Distress Beacons, C/S T.001

1.4. Galileo System Overview

Galileo is the European global navigation satellite system providing a highly accurate and global positioning service under civilian control. It is interoperable with GPS and GLONASS, the two other current global satellite navigation systems.

The fully deployed Galileo system consists of 24 operational satellites and up to 6 active spares, positioned in three circular Medium Earth Orbit planes. The nominal values of the main parameters for the Galileo constellation are defined in Table 1.

Parameter	Explanation	Value
$e_{nominal}$	Nominal orbit eccentricity	0
$i_{nominal}$	Nominal orbit inclination with reference to the equatorial plane	56°
$A_{nominal}$	Nominal orbit semi-major axis	29 600 000 m

Table 1.   Main orbit characteristics of the nominal Galileo constellation

Galileo provides enhanced distress localisation and call features for the provision of a Search and Rescue (SAR) service interoperable with the COSPAS – SARSAT system.

Figure 1 specifies the radio-frequency air interface between space and user segments. Three independent CDMA signals, named E5, E6 and E1, are permanently transmitted by all Galileo satellites. The E5 signal is further sub-divided into two signals denoted E5a and E5b.
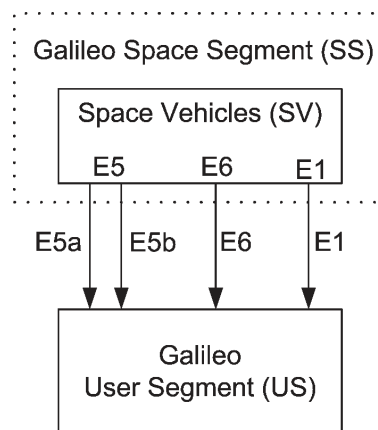
Figure 1.   Space Vehicle/Navigation User Interface

2. Galileo Signal Characteristics

2.1. Frequency Plan

2.1.1. Frequency Bands

The Galileo navigation Signals are transmitted in the four frequency bands indicated in Figure 2. These four frequency bands are the E5a, E5b, E6 and E1 bands. They provide a wide bandwidth for the transmission of the Galileo Signals.
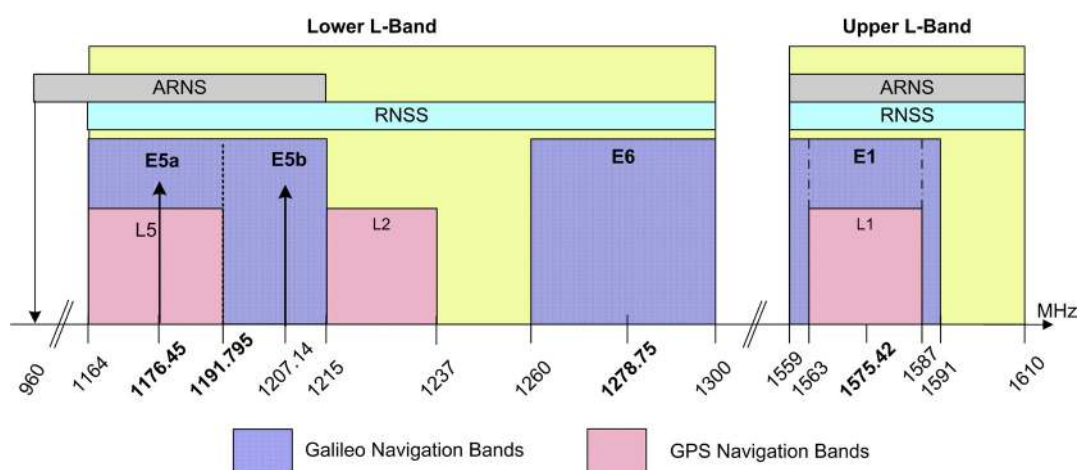
Figure 2. Galileo Frequency Plan

The Galileo frequency bands have been selected in the allocated spectrum for Radio Navigation Satellite Services (RNSS) and in addition to that, E5a, E5b and E1 bands are included in the allocated spectrum for Aeronautical Radio Navigation Services (ARNS), employed by Civil-Aviation users, and allowing dedicated safety-critical applications.

2.1.2. Carrier Frequencies

Galileo carrier frequencies are shown in Table 2. The names of the Galileo signals are the same than the corresponding carrier frequencies.

Signal	Carrier Frequency (MHz)
E1	1575.420
E6	1278.750
E5	1191.795
E5a	1176.450
E5b	1207.140

Table 2. Carrier Frequency per Signal

Note: The E5a and E5b signals are part of the E5 signal in its full bandwidth.

2.1.3. Receiver Reference Bandwidths

The receiver reference bandwidths centred on the carrier frequencies of Table 2 are specified in Table 3. Those reference bandwidths are considered when computing the correlation losses provided in paragraph 2.8.

Signal	Receiver Reference Bandwidth (MHz)
E1	24.552
E6	40.920
E5	51.150
E5a	20.460
E5b	20.460

Table 3.   Galileo Signals Receiver Reference Bandwidths

2.2. Signal Polarisation

The transmitted signals are Right-Hand Circularly Polarised (RHCP).

2.3. Modulation

In the following sections, modulation expressions are given for the power normalised complex envelope (i.e. base-band version) $s_X(t)$ of a modulated (band-pass) signal $S_X(t)$. Both are described in terms of their in-phase $s_{X-I}(t)$ and quadrature $s_{X-Q}(t)$ components by the following generic expressions in Eq. 1.

$$S_X(t) = \sqrt{2P_X}\left[s_{X-I}(t)\cos(2\pi f_X t) - s_{X-Q}(t)\sin(2\pi f_X t)\right]$$

$$s_X(t) = s_{X-I}(t) + j\, s_{X-Q}(t)$$

Eq. 1

Table 4 defines the signal parameters used in this chapter, with the indices:

- 'X' accounting for the respective carrier (E5, E5a, E5b, E6 or E1) and
- 'Y' accounting for the respective signal component (B, C, I or Q) within the signal 'X'.

Parameter	Explanation	Unit
f_X	Carrier frequency	Hz
P_X	RF-Signal power	W
L_{X-Y}	Ranging code repetition period	chips
$T_{C,X-Y}$	Ranging code chip length	s
$T_{S,X}$	Sub-carrier period	s
$T_{S,X-Y}$	Sub-carrier period	s
$T_{D,X-Y}$	Navigation message symbol duration	s
$R_{C,X-Y}$	$= 1/T_{C,X-Y}$ code chip rate	Hz
$R_{S,X}$	$= 1/T_{S,X}$ sub-carrier frequency	Hz
$R_{S,X-Y}$	$= 1/T_{S,X-Y}$ sub-carrier frequency	Hz
$R_{D,X-Y}$	$= 1/T_{D,X-Y}$ navigation message symbol rate	Hz
$S_X(t)$	Signal band-pass representation	N/A
$C_{X-Y}(t)$	Binary (NRZ modulated) ranging code	N/A
$D_{X-Y}(t)$	Binary (NRZ modulated) navigation message signal	N/A
$sc_{X-Y}(t)$	Binary (NRZ modulated) sub-carrier	N/A
$e_{X-Y}(t)$	Binary NRZ modulated navigation signal component including code, sub-carrier (if available) and navigation message data (if available); $(= c_{X-Y}(t)\, sc_{X-Y}(t)\, D_{X-Y}(t))$	N/A

Parameter	Explanation	Unit
$sX(t)$	Normalised (unit mean power) baseband signal $= s_{X-I}(t) + j\, s_{X-Q}(t)$	N/A
$c_{X-Y,k}$	kth chip of the ranging code	N/A
$d_{X-Y,k}$	kth symbol of the navigation message	N/A
DC_{X-Y}	$= T_{D,X-Y}/T_{C,X-Y}$ number of code chips per symbol	N/A
$|i|_L$	i modulo L	N/A
$[i]_{DC}$	Integer part of i/DC	N/A
$\text{rect}_T(t)$	Function "rectangle" which is equal to 1 for $0 \leq t < T$ and equal to 0 elsewhere	N/A

Table 4.   Signal Description Parameters

2.3.1.   E5 Signal

2.3.1.1.   Modulation Scheme

The diagram in Figure 3 provides a generic view of the E5 signal AltBOC modulation generation.
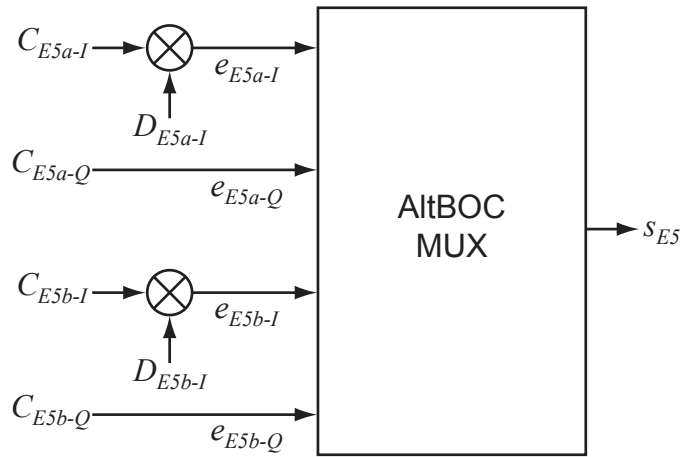
Figure 3.   Modulation Scheme for the E5 Signal

The E5 signal components are generated according to the following:

- e_{E5a-I} from the F/NAV navigation data stream D_{E5a-I} modulated with the ranging code C_{E5a-I}

- e_{E5a-Q} (pilot component) from the ranging code C_{E5a-Q}

- e_{E5b-I} from the I/NAV navigation data stream D_{E5b-I} modulated with the ranging code C_{E5b-I}

- e_{E5b-Q} (pilot component) from the ranging code C_{E5b-Q}

The respective definitions are following (Eq. 2):

$$e_{E5a-I}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{E5a-I,|i|_{L_{E5a-I}}}\, d_{E5a-I,[i]_{DC_{E5a-I}}}\, \text{rect}_{T_{C,E5a-I}}\left(t - iT_{C,E5a-I}\right) \right]$$

$$e_{E5a-Q}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{E5a-Q,|i|_{L_{E5a-Q}}}\, \text{rect}_{T_{C,E5a-Q}}\left(t - iT_{C,E5a-Q}\right) \right]$$

Eq. 2

$$e_{E5b-I}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{E5b-I,|i|_{L_{E5b-I}}}\, d_{E5b-I,[i]_{DC_{E5b-I}}}\, \text{rect}_{T_{C,E5b-I}}\left(t - iT_{C,E5b-I}\right) \right]$$

$$e_{E5b-Q}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{E5b-Q,|i|_{L_{E5b-Q}}}\, \text{rect}_{T_{C,E5b-Q}}\left(t - iT_{C,E5b-Q}\right) \right]$$

The Galileo satellites transmit the E5 signal components with the ranging codes chip rates and symbol rates stated in Table 5.

Signal (Parameter X)	Component (Parameter Y)	Ranging Code Chip-Rate $R_{C,X\text{-}Y}$ (Mchip/s)	Symbol-Rate $R_{D,X\text{-}Y}$ (symbols/s)
E5a	I	10.230	50
E5a	Q	10.230	No data ('pilot component')
E5b	I	10.230	250
E5b	Q	10.230	No data ('pilot component')

Table 5.   E5 Chip Rates and Symbol Rates

2.3.1.2.   Modulation Type

The wideband E5 signal is generated with the AltBOC modulation of side-band sub-carrier rate $R_{S,E5} = 1/T_{S,E5}$=15.345 MHz (15 x 1.023 MHz) according to the expression in Eq. 3 with the binary signal components $e_{E5a\text{-}I}$, $e_{E5a\text{-}Q}$, $e_{E5b\text{-}I}$ and $e_{E5b\text{-}Q}$ as defined in Eq. 2. Note that E5a and E5b signals can be processed independently by the user receiver as though they were two separate QPSK signals with a carrier frequency of 1176.45 MHz and 1207.14 MHz respectively.

$$s_{E5}(t) = \frac{1}{2\sqrt{2}}\Big(e_{E5a-I}(t) + j\,e_{E5a-Q}(t)\Big)\big[sc_{E5-S}(t) - j\,sc_{E5-S}(t - T_{s,E5}/4)\big] +$$

$$\frac{1}{2\sqrt{2}}\Big(e_{E5b-I}(t) + j\,e_{E5b-Q}(t)\Big)\big[sc_{E5-S}(t) + j\,sc_{E5-S}(t - T_{s,E5}/4)\big] +$$

$$\frac{1}{2\sqrt{2}}\Big(\overline{e}_{E5a-I}(t) + j\,\overline{e}_{E5a-Q}(t)\Big)\big[sc_{E5-P}(t) - j\,sc_{E5-P}(t - T_{s,E5}/4)\big] +$$

$$\frac{1}{2\sqrt{2}}\Big(\overline{e}_{E5b-I}(t) + j\,\overline{e}_{E5b-Q}(t)\Big)\big[sc_{E5-P}(t) + j\,sc_{E5-P}(t - T_{s,E5}/4)\big]$$

Eq. 3

The respective dashed signal components $\bar{e}_{E5a\text{-}I}$, $\bar{e}_{E5a\text{-}Q}$, $\bar{e}_{E5b\text{-}I}$ and $\bar{e}_{E5b\text{-}Q}$ represent product signals according to Eq. 4:

$$\overline{e}_{E5a\text{-}I} = e_{E5a\text{-}Q}\,e_{E5b\text{-}I}\,e_{E5b\text{-}Q} \qquad \overline{e}_{E5b\text{-}I} = e_{E5b\text{-}Q}\,e_{E5a\text{-}I}\,e_{E5a\text{-}Q}$$

$$\overline{e}_{E5a\text{-}Q} = e_{E5a\text{-}I}\,e_{E5b\text{-}I}\,e_{E5b\text{-}Q} \qquad \overline{e}_{E5b\text{-}Q} = e_{E5b\text{-}I}\,e_{E5a\text{-}I}\,e_{E5a\text{-}Q}$$

Eq. 4

The parameters $sc_{E5\text{-}S}$ and $sc_{E5\text{-}P}$ represent the four-valued sub-carrier functions for the single signals and the product signals respectively:

$$sc_{E5-S}(t) = \sum_{i=-\infty}^{\infty} AS_{|i|_8}\,\text{rect}_{T_{S,E5}/8}\big(t - iT_{s,E5}/8\big)$$

$$sc_{E5-P}(t) = \sum_{i=-\infty}^{\infty} AP_{|i|_8}\,\text{rect}_{T_{S,E5}/8}\big(t - iT_{s,E5}/8\big)$$

Eq. 5

The coefficients AS_i and AP_i are according to Table 6.

i	0	1	2	3	4	5	6	7
$2\cdot AS_i$	$\sqrt{2}+1$	1	-1	$-\sqrt{2}-1$	$-\sqrt{2}-1$	-1	1	$\sqrt{2}+1$
$2\cdot AP_i$	$-\sqrt{2}+1$	1	-1	$\sqrt{2}-1$	$\sqrt{2}-1$	-1	1	$-\sqrt{2}+1$

Table 6.   AltBOC Sub-carrier Coefficients

One period of the sub-carrier functions sc_{E5-S} and sc_{E5-P} is shown in Figure 4.
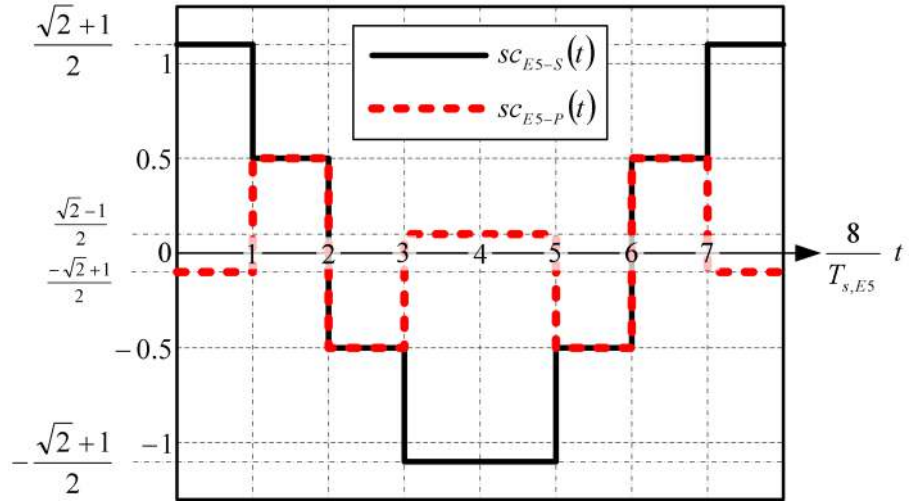
Figure 4.   One Period of the Two Sub-carrier Functions Involved in AltBOC Modulation

2.3.1.3.   Equivalent Modulation Type

Equivalently, the AltBOC complex baseband signal $s_{E5}(t)$ can be described as an 8-PSK signal according to Eq. 6. The corresponding phase states are illustrated in Figure 5.

$$s_{E5}(t) = \exp\left(j\frac{\pi}{4}k(t)\right) \quad \text{with} \quad k(t) \in \{1,2,3,4,5,6,7,8\}, \qquad \text{Eq. 6}$$
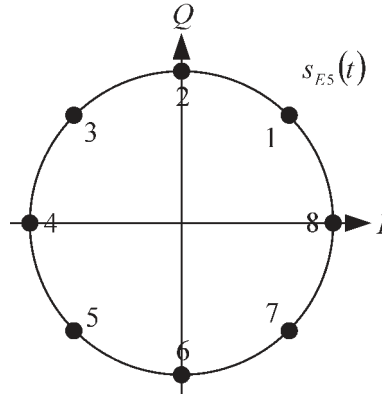
Figure 5.   8-PSK Phase-State Diagram of E5 AltBOC Signal

The relation of the 8 phase states to the 16 different possible states of the quadruple $e_{E5a-I}(t)$, $e_{E5a-Q}(t)$, $e_{E5b-I}(t)$, and $e_{E5b-Q}(t)$ depends also on time. Therefore, time is partitioned first in sub-carrier intervals $T_{s,E5}$ and further sub-divided in 8 equal sub-periods. The index i_{T_s} of the actual sub-period is given by Eq. 7 and determines which relation between input quadruple and phase states has to be used.

$$i_{T_s} = \text{integer part}\left[\frac{8}{T_{s,E5}}(t \bmod T_{s,E5})\right] \quad \text{with} \quad i_{T_s} \in \{0,1,2,3,4,5,6,7\} \qquad \text{Eq. 7}$$

The dependency of phase-states from input-quadruples and time is given in Table 7.

	Input Quadruples															
eE5a-I	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1
eE5b-I	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1
eE5a-Q	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1
eE5b-Q	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1

$t' = t$ modulo $T_{s,E5}$		k according to $s_{E5}(t)=\exp(jk\pi/4)$															
i_{T_s}	t'																
0	$[0, T_{s,E5}/8[$	5	4	4	3	6	3	1	2	6	5	7	2	7	8	8	1
1	$[T_{s,E5}/8, 2\ T_{s,E5}/8[$	5	4	8	3	2	3	1	2	6	5	7	6	7	4	8	1
2	$[2\ T_{s,E5}/8, 3\ T_{s,E5}/8[$	1	4	8	7	2	3	1	2	6	5	7	6	3	4	8	5
3	$[3\ T_{s,E5}/8, 4\ T_{s,E5}/8[$	1	8	8	7	2	3	1	6	2	5	7	6	3	4	4	5
4	$[4\ T_{s,E5}/8, 5\ T_{s,E5}/8[$	1	8	8	7	2	7	5	6	2	1	3	6	3	4	4	5
5	$[5\ T_{s,E5}/8, 6\ T_{s,E5}/8[$	1	8	4	7	6	7	5	6	2	1	3	2	3	8	4	5
6	$[6\ T_{s,E5}/8, 7\ T_{s,E5}/8[$	5	8	4	3	6	7	5	6	2	1	3	2	7	8	4	1
7	$[7\ T_{s,E5}/8, T_{s,E5}[$	5	4	4	3	6	7	5	2	6	1	3	2	7	8	8	1

Table 7.   Look-up Table for AltBOC Phase States

2.3.2.   E6 Signal

Figure 6 provides a generic view of the E6 signal generation.
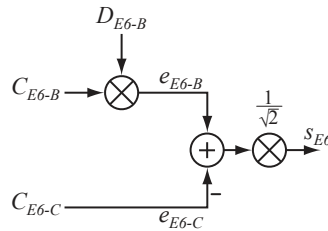
Figure 6.   Modulation Scheme for the E6 Signal

The E6 signal B and C components are generated according to the following

- e_{E6-B} from the C/NAV navigation data stream D_{E6-B} modulated with the ranging code C_{E6-B}

- e_{E6-C} (pilot component) from the ranging code C_{E6-C}

Equation 8 provides their mathematical description.

$$e_{E6-B}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{E6-B,|i|_{L_{E6-B}}} d_{E6-B,[i]_{DC_{E6-B}}} \mathrm{rect}_{T_{C,E6-B}}\left(t - iT_{C,E6-B}\right) \right]$$

$$e_{E6-C}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{E6-C,|i|_{L_{E6-C}}} \mathrm{rect}_{T_{C,E6-C}}\left(t - iT_{C,E6-C}\right) \right]$$

Eq. 8

Ranging code C_{E6-C} may be encrypted in the future. The Galileo satellites transmit the E6 signal components with the ranging codes chip rates and symbol rates stated in Table 8.

Component (Parameter Y)	Ranging Code Chip-Rate $R_{C,E6-Y}$ (MChip/s)	Symbol-Rate $R_{D,E6-Y}$ (symbols/s)
B	5.115	1000
C	5.115	No data ('pilot component')

Table 8.   E6 Chip Rates and Symbol Rates

The E6 signal is generated according to Eq. 9, with the binary signal components $e_{E6-B}(t)$ and $e_{E6-C}(t)$.

$$s_{E6}(t) = \frac{1}{\sqrt{2}}\left[e_{E6-B}(t) - e_{E6-C}(t)\right]$$

Eq. 9

Note: both pilot and data components are combined on the same carrier component, with a power sharing of 50 percent.

2.3.3. E1 Signal

Figure 7 provides a generic view of the E1 CBOC signal generation.
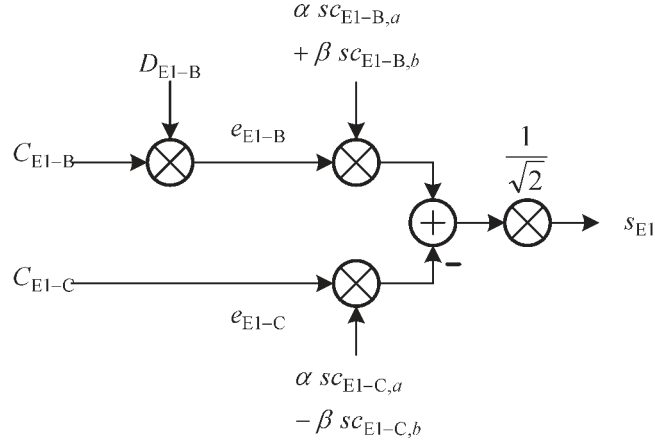
Figure 7. Modulation Scheme for the E1 CBOC Signal

The E1 CBOC signal components are generated as follows:

- e_{E1-B} from the I/NAV navigation data stream D_{E1-B} and the ranging code C_{E1-B}, then modulated with the sub-carriers $sc_{E1-B,a}$ and $sc_{E1-B,b}$

- e_{E1-C} (pilot component) from the ranging code C_{E1-C} including its secondary code, then modulated with the sub-carriers $sc_{E1-C,a}$ and $sc_{E1-C,b}$

Equation 10 provides the mathematical description of these components.

$$e_{E1-B}(t) = \sum_{i=-\infty}^{\infty}\left[c_{E1-B,|i|_{L_{E1-B}}}D_{E1-B,|i|_{DC_{E1-B}}}\mathrm{rect}_{T_{c,E1-B}}\left(t - iT_{c,E1-B}\right)\right]$$

Eq.10

$$e_{E1-C}(t) = \sum_{i=-\infty}^{\infty}\left[c_{E1-C,|i|_{L_{E1-C}}}\mathrm{rect}_{T_{c,E1-C}}\left(t - iT_{c,E1-C}\right)\right]$$

Galileo satellites transmit ranging signals for the E1 signal with the chip rates and sub-carrier rates defined in the following Table 9.

Component (Parameter Y)	Sub-carrier Type	Sub-carrier Rate		Ranging Code Chip-Rate $R_{C,E1-Y}$ (Mcps)
		$R_{S,E1-Y,a}$ (MHz)	$R_{S,E1-Y,b}$ (MHz)	
B	CBOC, in-phase	1.023	6.138	1.023
C	CBOC, anti-phase	1.023	6.138	1.023

Table 9. E1 CBOC Chip Rates and Sub-carrier Rates

The navigation data message stream, after channel encoding, is transmitted with the symbol rate as stated in Table 10.

Component (Parameter Y)	Symbol Rate $R_{D,E1-Y}$ (symbols/s)
B	250
C	No data ('pilot component')

Table 10. E1-B/C Symbol Rates

The E1–B/C composite signal is then generated according to equation Eq. 11 below, with the binary signal components e_{E1-B}(t) and e_{E1-C}(t). Note that as for E6, both pilot and data components are modulated onto the same carrier component, with a power sharing of 50 percent.

$$s_{E1}(t) = \frac{1}{\sqrt{2}}\left(e_{E1-B}(t)\left(\alpha\, sc_{E1-B,a}(t) + \beta\, sc_{E1-B,b}(t)\right) - e_{E1-C}(t)\left(\alpha\, sc_{Ei-C,a}(t) - \beta\, sc_{Ei-C,b}(t)\right)\right)$$

Eq. 11

$$\text{with } sc_X(t) = \text{sgn}(\sin\left(2\pi R_{s,X}t\right))$$

The parameters α and β are chosen such that the combined power of the $sc_{E1-B,b}$ and the $sc_{E1-C,b}$ sub carrier components equals 1/11 of the total power of e_{E1-B} plus e_{E1-C}, before application of any bandwidth limitation. This yields:

$$a = \sqrt{\frac{10}{11}} \quad \text{and} \quad b = \sqrt{\frac{1}{11}}$$

One period of the sub-carrier function $\alpha\, sc_{E1-B,a}$ (t) + $\beta\, sc_{E1-B,b}$ (t) for the E1-B signal component and one period of the sub-carrier function $\alpha\, sc_{E1-C,a}$ (t) − $\beta\, sc_{E1-C,b}$ (t) for the E1-C signal component are shown in the following figure
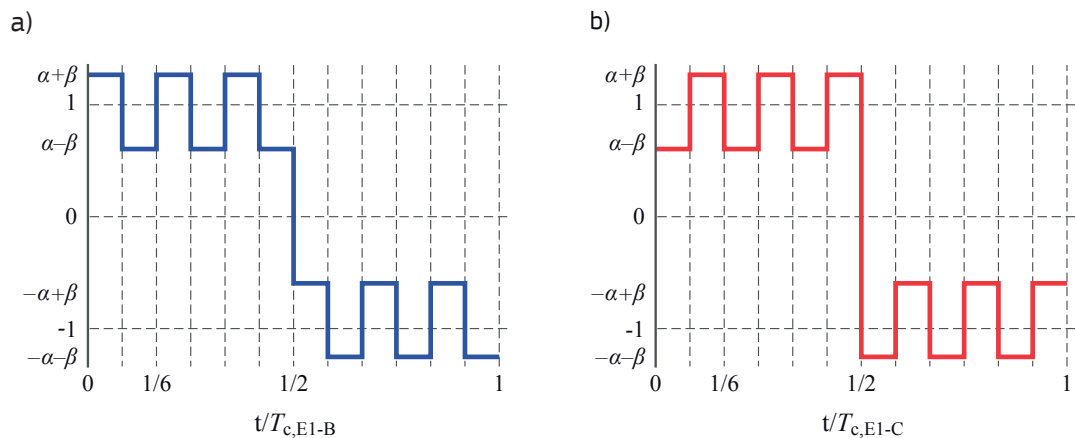
Figure 8.   One period of the CBOC sub-carrier for a) the E1-B signal component, and b) the E1-C signal component

2.4. Logic Levels

The correspondence between the logic level code bits used to modulate the signal and the signal level is according to the values stated in Table 11.

Logic Level	Signal Level
1	-1.0
0	+1.0

Table 11. Logic to Signal Level Assignment

2.5. Transmitted Signal Phase Noise

The phase noise spectral density of the un-modulated carrier will allow a second-order phase locked loop with 10 Hz one-sided noise bandwidth to track the carrier to an accuracy of 0.04 radians RMS.

2.6. Transmitted Signals Code/Data Coherency

The edge of each data symbol coincides with the edge of a code chip. Periodic spreading codes start coincides with the start of a data symbol.

The edge of each secondary code chip coincides with the edge of a primary code chip. Primary code start coincides with the start of a secondary code chip.

2.7. Received Power Levels on Ground

The Galileo satellites provide Galileo E5, E6 and E1 signal strengths that meet the minimum levels of received power on ground as specified in Table 12, for user elevation angles above 5 degrees. The minimum received power on ground is measured at the output of an ideally matched RHCP 0 dBi user receiving antenna.

Assuming the same receiving antenna, the Galileo terrestrial user's received signal power is not expected to exceed the maximum levels specified in Table 12.

Signal	Signal Component	Total Received Minimum Power (dBW)	Total Received Maximum Power (dBW)
E5	E5a (total I+Q) (50/50% I/Q power sharing)	-155.25	-150
	E5b (total I+Q) (50/50% I/Q power sharing)	-155.25	-150
E6	E6-B/C (total B+C) (50/50% E6-B/E6-C power sharing)	-155.25	-150
E1	E1-B/C (total B+C) (50/50% E1-B/E1-C power sharing)	-157.25	-152

Table 12. Minimum and Maximum Received Power Levels on Ground

For the purpose of user receiver design and test, a dynamic range of up to 7 dB above the corresponding minimum power levels should be considered.

2.8. Payload and Component Reception Losses

For each signal component, the correlation loss due to payload distortions will be below 0.6 dB.

For the reference receiver bandwidths defined in section 2.1.3, additional losses due to receiver filtering are to be considered, as shown in Table 13.

Signal	Loss (dB)
E1	0.1
E6	0.0
E5	0.4
E5a	0.6
E5b	0.6

Table 13. Additional Losses due to Receiver Filtering

3. Galileo Spreading Codes Characteristics

3.1. Code Lengths

The ranging codes are built from so-called primary and secondary codes by using a tiered codes construction described in paragraph 3.2. The code lengths to be used for each signal component are stated in Table 14. Note that the E6 ranging codes are not subject of this SIS ICD.

Signal Component	Tiered Code Period (ms)	Code Length (chips)	
		Primary	Secondary
E5a-I	20	10230	20
E5a-Q	100	10230	100
E5b-I	4	10230	4
E5b-Q	100	10230	100
E1-B	4	4092	N/A
E1-C	100	4092	25

Table 14. Code Lengths

3.2. Tiered Codes Generation

Long spreading codes are generated by a tiered code construction, whereby a secondary code sequence is used to modify successive repetitions of a primary code, as shown in Figure 9 for a primary code of length N and chip rate f_c, and a secondary code of length N_S and chip rate $f_{cs} = f_c/N$. The duration of N chips is also called a primary code epoch in Figure 9. In logical representation, the secondary code chips are sequentially exclusive-ored with the primary code, always one chip of the secondary code per period of the primary code.
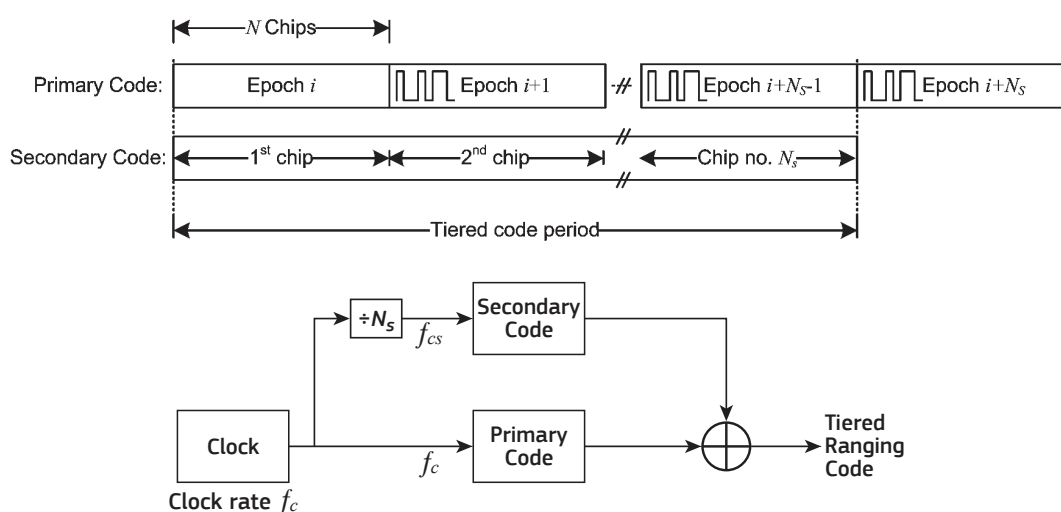
Figure 9. Tiered Codes Generation

3.3. Primary Codes Generation

The primary spreading codes can be either

- Linear feedback shift register-based pseudo-noise sequences, or

- Optimised pseudo-noise sequences

Optimised codes need to be stored in memory and therefore are often called 'memory codes'. Register based codes used in Galileo are generated as combinations of two M-sequences, being truncated to the appropriate length. These codes can be generated either with pairs of LFSR or might be also stored in memory.

Figure 10 shows an example standard implementation of the LFSR method for the generation of truncated and combined M sequences. Two parallel shift registers are used: base register 1 and base register 2. The primary code output sequence is the exclusive OR of base register 1 and 2 output sequences, the shift between these two sequences is zero. Each shift register i ($i=1$ for base register 1 and $i = 2$ base register 2) of length R is fed back with a particular set of feedback taps $\{a_{i,j}\}_{j=1...R} = [a_{i,1}, a_{i,2}, ..., a_{i,R}]$ and its content is represented by a vector $\{c_{i,j}\}_{j=1...R} = [c_{i,1}, c_{i,2}, ..., c_{i,R}]$. For truncation to primary code length N, the content of the two shift registers is reinitialised (reset) after N cycles with the so-called start-values $\{s_{i,j}\}_{j=1...R} = [s_{i,1}, s_{i,2}, ..., s_{i,R}]$.
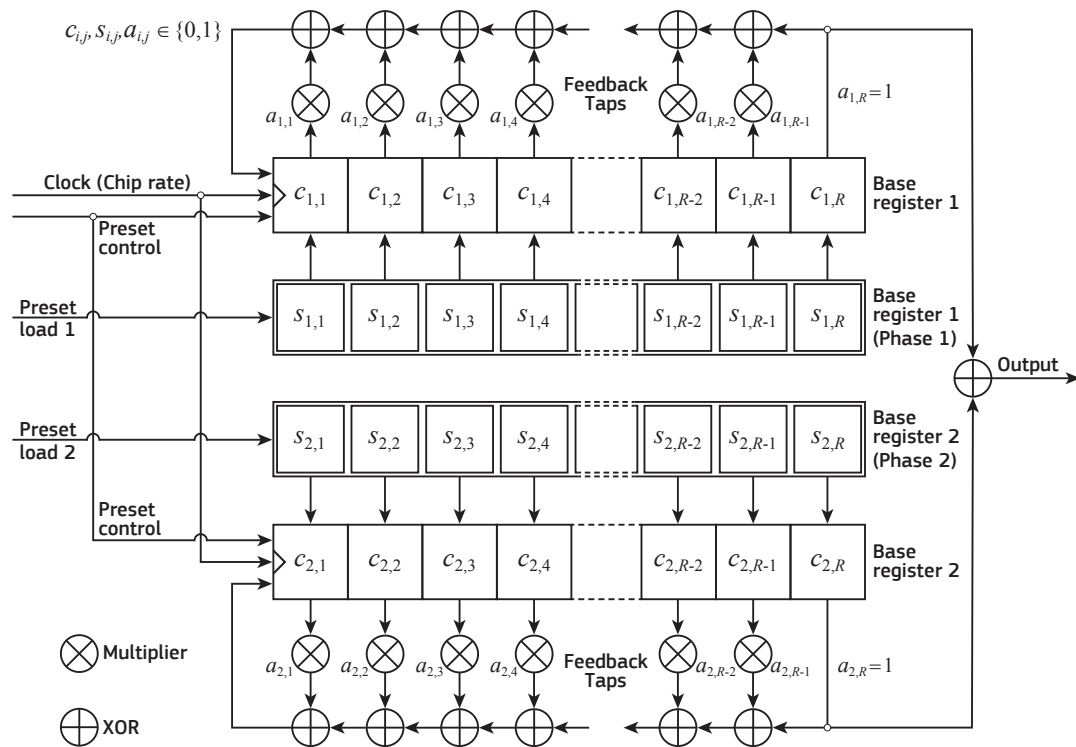
Figure 10. LFSR Based Code Generator for Truncated and Combined M-sequences

3.4. Primary Codes Definition

3.4.1. E5 Primary Codes

The E5a-I, E5a-Q, E5b-I and E5b-Q primary codes are generated via LFSR, using the principle defined in paragraph 3.3, and the parameters defined in Table 15. Note that each set of codes for each signal component comprises 50 members.

Component	Shift Register Length (polynomial order)	Feedback Taps (octal)	
		Register 1	Register 2
E5a-I	14	40503	50661
E5a-Q	14	40503	50661
E5b-I	14	64021	51445
E5b-Q	14	64021	43143

Table 15. E5 Primary Codes Specifications

The transformation between the octal notation and the vector description $\{a_{i,j}\}$ for the feedback tap positions is defined as follows and is illustrated with an example (Register 1 for E5a-I in Table 15) in Figure 11. After transferring the octal vector notation into binary notation, the bits are counted right to left starting with $j = 0$ from the LSB and ending with $j = R$ at the MSB, where R is the code register length. Then the jth bit applies for the feedback tap $a_{i,j}$ for $j = 1, ..., R$, as shown in Figure 10. Note: $a_{i,R}$ is always one and $a_{i,0}$ is not considered in the register feedback tap.
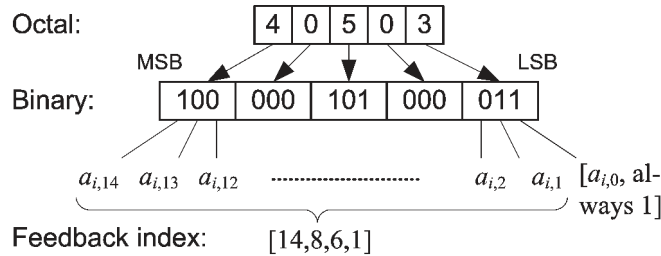
Figure 11. Code Register Feedback Taps Representation (example for E5a-I)

The start values for all base register 1 cells, in logic level notation, are '1' for all codes of E5a-I, E5a-Q, E5b-I and E5b-Q. The start values of base register 2 are provided in the subsequent sections. The transformation between the octal notation and the vector description $\{s_{i,j}\}$ for the register start values is defined as follows and is illustrated with an example in Figure 12 (code number 1 of E5a-I in Table 16). After transferring the octal notation in binary notation, the bits are counted right to left starting with $j=1$ (Note: the different start value compared to the feedback taps definition) from the LSB and ending with $j=R$ at the MSB, where R is the code register length. Then the jth bit applies to the start value $s_{i,j}$ for $j = 1, ..., R$, as shown in Figure 10. Note: in this example the MSB is zero in order to complete the 14-bits binary value sequence to fit into a sequence of octal symbols.
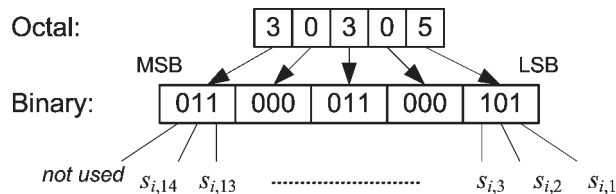
Figure 12. Start Value Representation for Base Register 2 (first code of E5a-I)

3.4.1.1. Base Register 2 Start Value for E5a-I

The octal format base register 2 start value with the convention defined in paragraph 3.4.1 is as defined in Table 16 for each primary E5a-I code. In addition, the conventional hexadecimal format of the first 24 code chips of the E5a-I primary codes is given in the table. For example, the first 24 chips of the E5a-I primary code N°1 in Table 16 are 0 0 1 1 1 1 0 0 1 1 1 0 1 0 1 0 1 0 0 1 1 1 0 1, the first binary value corresponding to the first primary code chip in time.

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
1	30305	3CEA9D	26	14401	9BFAC7
2	14234	9D8CF1	27	34727	18A25B
3	27213	45D1C8	28	22627	69A39F
4	20577	7A0133	29	30623	39B27D
5	23312	64D423	30	27256	454598
6	33463	23300D	31	01520	F2BC62
7	15614	91CEF2	32	14211	9DDBC6
8	12537	AA82DC	33	31465	332827
9	01527	F2A17D	34	22164	6E2FCA
10	30236	3D84AE	35	33516	22C6D5
11	27344	446D38	36	02737	E881D9
12	07272	C514F2	37	21316	74C4DB
13	36377	0C0184	38	35425	13AB03
14	17046	8767E0	39	35633	119323
15	06434	CB8EFF	40	24655	594886
16	15405	93EBCD	41	14054	9F4D89
17	24252	5D55CE	42	27027	47A3C0
18	11631	B19B7C	43	06604	C9ED53
19	24776	5805FC	44	31455	334994
20	00630	F99EA1	45	34465	1B2A30
21	11560	B23CE5	46	25273	5513F3
22	17272	8515E8	47	20763	7831C1
23	27445	436822	48	31721	30B93A
24	31702	30F77B	49	17312	84D5B4
25	13012	A7D629	50	13277	A5029C

Table 16. Base Register 2 Start Values and First Code Chip for E5a-I

3.4.1.2. Base Register 2 Start Value for E5a-Q

The octal format base register 2 start value with the convention defined in paragraph 3.4.1 is as defined in Table 17 for each E5a-Q primary code. The hexadecimal format of the first 24 code chips with the convention defined in paragraph 3.4.1.1 is also given.

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
1	25652	515537	26	20606	79E450
2	05142	D67539	27	11162	B63460
3	24723	58B2E5	28	22252	6D562B
4	31751	305914	29	30533	3A9010
5	27366	442710	30	24614	59CD72
6	24660	593CF8	31	07767	C0211A

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
7	33655	214AD7	32	32705	28EB96
8	27450	435EA6	33	05052	D7554B
9	07626	C1A7D5	34	27553	425126
10	01705	F0E94A	35	03711	E0DAFB
11	12717	A8C239	36	02041	EF79F2
12	32122	2EB63B	37	34775	18085D
13	16075	8F0A46	38	05274	D50CD8
14	16644	896DD4	39	37356	0447B9
15	37556	0245F1	40	16205	8DE877
16	02477	EB0160	41	36270	0D1FA0
17	02265	ED28B3	42	06600	C9FCF7
18	06430	CB9F5B	43	26773	48116D
19	25046	576592	44	17375	840BCC
20	12735	A88811	45	35267	152004
21	04262	DD3649	46	36255	0D4897
22	11230	B59F42	47	12044	AF6D25
23	00037	FF81F6	48	26442	4B7593
24	06137	CE8128	49	21621	71BB1B
25	04312	DCD55C	50	25411	53DA0E

Table 17. Base Register 2 start Values and First Code Chip for E5a-Q

3.4.1.3. Base Register 2 Start Value for E5b-I

The octal format base register 2 start value with the conventions defined in paragraph 3.4.1 is as defined in Table 18 for each E5b-I primary code. The hexadecimal format of the first 24 code chips with the conventions defined in paragraph 3.4.1.1 is also given.

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
1	07220	C5BEA1	26	25664	512FA9
2	26047	4F6248	27	21403	73F36B
3	00252	FD5488	28	32253	2D5317
4	17166	86277B	29	02337	EC8390
5	14161	9E39D5	30	30777	380374
6	02540	EA7EDE	31	27122	46B4DE
7	01537	F28321	32	22377	6C01D9
8	26023	4FB0C9	33	36175	0E0BB6
9	01725	F0AB64	34	33075	2708C7
10	20637	79833B	35	33151	265B55
11	02364	EC2D91	36	13134	A68E1C

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
12	27731	409B11	37	07433	C3916E
13	30640	397E16	38	10216	BDC595
14	34174	1E0FCD	39	35466	1327D0
15	06464	CB2F5A	40	02533	EA921F
16	07676	C1079A	41	05351	D45869
17	32231	2D9BC6	42	30121	3EB98A
18	10353	BC5146	43	14010	9FDE16
19	00755	F848B0	44	32576	2A04CA
20	26077	4F01E8	45	30326	3CA56F
21	11644	B16C9B	46	37433	03928A
22	11537	B2827D	47	26022	4FB5B9
23	35115	16C809	48	35770	101EC7
24	20452	7B570F	49	06670	C91D4F
25	34645	1969C0	50	12017	AFC22B

Table 18. Base Register 2 Start Values and First Code Chip for E5b-I

3.4.1.4. Base Register 2 Start Value for E5b-Q

The octal format base register 2 start value with the conventions defined in paragraph 3.4.1 is as defined in Table 19 for each E5b-Q primary code. The hexadecimal format of the first 24 code chips with the conventions defined in paragraph 3.4.1.1 is also given.

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
1	03331	E49AF0	26	20134	7E8CFB
2	06143	CE701F	27	11262	B536C3
3	25322	54B709	28	10706	B8E68C
4	23371	641AB1	29	34143	1E7272
5	00413	FBD0AE	30	11051	B75B69
6	36235	0D8BC9	31	25460	533F65
7	17750	805FA5	32	17665	812B41
8	04745	D86BA0	33	32354	2C4DE1
9	13005	A7E921	34	21230	759E2C
10	37140	067E55	35	20146	7E6434
11	30155	3E4B58	36	11362	B43640
12	20237	7D82FB	37	37246	05671B
13	03461	E33BC2	38	16344	8C6FE0
14	31662	31372C	39	15034	978D4E
15	27146	46676F	40	25471	5319BF
16	05547	D2613E	41	25646	516499
17	02456	EB443C	42	22157	6E4292

Code No	Start Value	Initial Sequence	Code No	Start Value	Initial Sequence
18	30013	3FD0B1	43	04336	DC86A3
19	00322	FCB7CF	44	16356	8C46BE
20	10761	B83815	45	04075	DF0B03
21	26767	48224A	46	02626	E9A5B2
22	36004	0FEE25	47	11706	B0E553
23	30713	38D33B	48	37011	07DBAC
24	07662	C135B9	49	27041	4778E4
25	21610	71DE13	50	31024	37AF4F

Table 19. Base Register 2 Start Values and First Code Chip for E5b-Q

3.4.2. E1-B and E1-C Primary Codes

The E1-B and E1-C primary codes are pseudo-random memory code sequences according to the hexadecimal representation provided in Annex C (provided only in the electronic version of this ICD). Note that each set of codes for each signal component comprises 50 members.

3.5. Secondary Codes

3.5.1. Definition of Secondary Codes

The secondary codes are fixed sequences as defined in hexadecimal notation in Table 20 and Table 21, following again the convention used in paragraph 3.4.1.1. For secondary codes whose length is not divisible by four (case of $CS25_1$ only), the last (most right-hand) hexadecimal symbol is obtained by filling up the last group of code chips with zeros at the end in time (to the right), to reach a final length of 4 binary symbols. Those two tables provide as well the code identifiers together with the code lengths, the number of hexadecimal symbols and the number of filled zeros.

For example, the $CS25_1$ secondary code in Table 20 corresponds to the binary sequence '0 0 1 1 1 0 0 0 0 0 0 1 0 1 0 1 1 0 1 1 0 0 1 0', the first binary value corresponding to the first secondary code chip in time.

Code Identifier	Code Length	No. of Hexadec. Symbols	Number of Filled up Zeros	Code Sequence
$CS4_1$	4	1	0	E
$CS20_1$	20	5	0	842E9
$CS25_1$	25	7	3	380AD90
$CS100_1$	100	25	0	83F6F69D8F6E15411FB8C9B1C
$CS100_2$	100	25	0	66558BD3CE0C7792E83350525
$CS100_3$	100	25	0	59A025A9C1AF0651B779A8381
$CS100_4$	100	25	0	D3A32640782F7B18E4DF754B7
$CS100_5$	100	25	0	B91FCAD7760C218FA59348A93
$CS100_6$	100	25	0	BAC77E933A779140F094FBF98

Code Identifier	Code Length	No. of Hexadec. Symbols	Number of Filled up Zeros	Code Sequence
CS100$_7$	100	25	0	537785DE280927C6B58BA6776
CS100$_8$	100	25	0	EFCAB4B65F38531ECA22257E2
CS100$_9$	100	25	0	79F8CAE838475EA5584BEFC9B
CS100$_{10}$	100	25	0	CA5170FEA3A810EC606B66494
CS100$_{11}$	100	25	0	1FC32410652A2C49BD845E567
CS100$_{12}$	100	25	0	FE0A9A7AFDAC44E42CB95D261
CS100$_{13}$	100	25	0	B03062DC2B71995D5AD8B7DBE
CS100$_{14}$	100	25	0	F6C398993F598E2DF4235D3D5
CS100$_{15}$	100	25	0	1BB2FB8B5BF24395C2EF3C5A1
CS100$_{16}$	100	25	0	2F920687D238CC7046EF6AFC9
CS100$_{17}$	100	25	0	34163886FC4ED7F2A92EFDBB8
CS100$_{18}$	100	25	0	66A872CE47833FB2DFD5625AD
CS100$_{19}$	100	25	0	99D5A70162C920A4BB9DE1CA8
CS100$_{20}$	100	25	0	81D71BD6E069A7ACCBEDC66CA
CS100$_{21}$	100	25	0	A654524074A9E6780DB9D3EC6
CS100$_{22}$	100	25	0	C3396A101BEDAF623CFC5BB37
CS100$_{23}$	100	25	0	C3D4AB211DF36F2111F2141CD
CS100$_{24}$	100	25	0	3DFF25EAE761739265AF145C1
CS100$_{25}$	100	25	0	994909E0757D70CDE389102B5
CS100$_{26}$	100	25	0	B938535522D119F40C25FDAEC
CS100$_{27}$	100	25	0	C71AB549C0491537026B390B7
CS100$_{28}$	100	25	0	0CDB8C9E7B53F55F5B0A0597B
CS100$_{29}$	100	25	0	61C5FA252F1AF81144766494F
CS100$_{30}$	100	25	0	626027778FD3C6BB4BAA7A59D
CS100$_{31}$	100	25	0	E745412FF53DEBD03F1C9A633
CS100$_{32}$	100	25	0	3592AC083F3175FA724639098
CS100$_{33}$	100	25	0	52284D941C3DCAF2721DDB1FD
CS100$_{34}$	100	25	0	73B3D8F0AD55DF4FE814ED890
CS100$_{35}$	100	25	0	94BF16C83BD7462F6498E0282
CS100$_{36}$	100	25	0	A8C3DE1AC668089B0B45B3579
CS100$_{37}$	100	25	0	E23FFC2DD2C14388AD8D6BEC8
CS100$_{38}$	100	25	0	F2AC871CDF89DDC06B5960D2B
CS100$_{39}$	100	25	0	06191EC1F622A77A526868BA1
CS100$_{40}$	100	25	0	22D6E2A768E5F35FFC8E01796
CS100$_{41}$	100	25	0	25310A06675EB271F2A09EA1D
CS100$_{42}$	100	25	0	9F7993C621D4BEC81A0535703
CS100$_{43}$	100	25	0	D62999EACF1C99083C0B4A417

Code Identifier	Code Length	No. of Hexadec. Symbols	Number of Filled up Zeros	Code Sequence
CS100₄₄	100	25	0	F665A7EA441BAA4EA0D01078C
CS100₄₅	100	25	0	46F3D3043F24CDEABD6F79543
CS100₄₆	100	25	0	E2E3E8254616BD96CEFCA651A
CS100₄₇	100	25	0	E548231A82F9A01A19DB5E1B2
CS100₄₈	100	25	0	265C7F90A16F49EDE2AA706C8
CS100₄₉	100	25	0	364A3A9EB0F0481DA0199D7EA
CS100₅₀	100	25	0	9810A7A898961263A0F749F56

Table 20. Secondary Code Sequences (Part 1)

Code Identifier	Code Length	No. of Hexadec. Symbols	Number of Filled up Zeros	Code Sequence
CS100₅₁	100	25	0	CFF914EE3C6126A49FD5E5C94
CS100₅₂	100	25	0	FC317C9A9BF8C6038B5CADAB3
CS100₅₃	100	25	0	A2EAD74B6F9866E414393F239
CS100₅₄	100	25	0	72F2B1180FA6B802CB84DF997
CS100₅₅	100	25	0	13E3AE93BC52391D09E84A982
CS100₅₆	100	25	0	77C04202B91B22C6D3469768E
CS100₅₇	100	25	0	FEBC592DD7C69AB103D0BB29C
CS100₅₈	100	25	0	0B494077E7C66FB6C51942A77
CS100₅₉	100	25	0	DD0E321837A3D52169B7B577C
CS100₆₀	100	25	0	43DEA90EA6C483E7990C3223F
CS100₆₁	100	25	0	0366AB33F0167B6FA979DAE18
CS100₆₂	100	25	0	99CCBBFAB1242CBE31E1BD52D
CS100₆₃	100	25	0	A3466923CEFDF451EC0FCED22
CS100₆₄	100	25	0	1A5271F22A6F9A8D76E79B7F0
CS100₆₅	100	25	0	3204A6BB91B49D1A2D3857960
CS100₆₆	100	25	0	32F83ADD43B599CBFB8628E5B
CS100₆₇	100	25	0	3871FB0D89DB77553EB613CC1
CS100₆₈	100	25	0	6A3CBDFF2D64D17E02773C645
CS100₆₉	100	25	0	2BCD09889A1D7FC219F2EDE3B
CS100₇₀	100	25	0	3E49467F4D4280B9942CD6F8C
CS100₇₁	100	25	0	658E336DCFD9809F86D54A501
CS100₇₂	100	25	0	ED4284F345170CF77268C8584
CS100₇₃	100	25	0	29ECCE910D832CAF15E3DF5D1
CS100₇₄	100	25	0	456CCF7FE9353D50E87A708FA
CS100₇₅	100	25	0	FB757CC9E18CBC02BF1B84B9A
CS100₇₆	100	25	0	5686229A8D98224BC426BC7FC

Code Identifier	Code Length	No. of Hexadec. Symbols	Number of Filled up Zeros	Code Sequence
$CS100_{77}$	100	25	0	700A2D325EA14C4B7B7AA8338
$CS100_{78}$	100	25	0	1210A330B4D3B507D854CBA3F
$CS100_{79}$	100	25	0	438EE410BD2F7DBCDD85565BA
$CS100_{80}$	100	25	0	4B9764CC455AE1F61F7DA432B
$CS100_{81}$	100	25	0	BF1F45FDDA3594ACF3C4CC806
$CS100_{82}$	100	25	0	DA425440FE8F6E2C11B8EC1A4
$CS100_{83}$	100	25	0	EE2C8057A7C16999AFA33FED1
$CS100_{84}$	100	25	0	2C8BD7D8395C61DFA96243491
$CS100_{85}$	100	25	0	391E4BB6BC43E98150CDDCADA
$CS100_{86}$	100	25	0	399F72A9EADB42C90C3ECF7F0
$CS100_{87}$	100	25	0	93031FDEA588F88E83951270C
$CS100_{88}$	100	25	0	BA8061462D873705E95D5CB37
$CS100_{89}$	100	25	0	D24188F88544EB121E963FD34
$CS100_{90}$	100	25	0	D5F6A8BB081D8F383825A4DCA
$CS100_{91}$	100	25	0	0FA4A205F0D76088D08EAF267
$CS100_{92}$	100	25	0	272E909FAEBC65215E263E258
$CS100_{93}$	100	25	0	3370F35A674922828465FC816
$CS100_{94}$	100	25	0	54EF96116D4A0C8DB0E07101F
$CS100_{95}$	100	25	0	DE347C7B27FADC48EF1826A2B
$CS100_{96}$	100	25	0	01B16ECA6FC343AE08C5B8944
$CS100_{97}$	100	25	0	1854DB743500EE94D8FC768ED
$CS100_{98}$	100	25	0	28E40C684C87370CD0597FAB4
$CS100_{99}$	100	25	0	5E42C19717093353BCAAF4033
$CS100_{100}$	100	25	0	64310BAD8EB5B36E38646AF01

Table 21. Secondary Code Sequences (Part 2)

3.5.2.   Secondary Codes Assignment

The assignment of the secondary codes of paragraph 3.5.1 to the signal components is according to Table 22. For the 4, 20 and 25 bit secondary codes the same code is used for all associated primary codes. For the 100 bit codes, an independent secondary code is assigned for each primary code.

Component	Secondary Code Assignment
E5a-I	$CS20_1$
E5a-Q	$CS100_{1-50}$
E5b-I	$CS4_1$
E5b-Q	$CS100_{51-100}$
E6-B	N/A

Component	Secondary Code Assignment
E6-C	$CS100_{1-50}$
E1-B	N/A
E1-C	$CS25_1$

Table 22. Secondary Code Assignment

3.6. Code Assignments to Satellites

3.6.1. Primary code assignment to satellites

The E5a-I, E5a-Q, E5b-I, E5b-Q primary codes (defined in Section 3.4.1) and E1-B, E1-C primary codes (defined in Annex C of the electronic version of this ICD) will be allocated to the space vehicle IDs (SVID) as follows:

- To SVID n (with $n = 1$ to 36) are assigned the corresponding E5a-I, E5a-Q, E5b-I, E5b-Q, E1-B and E1-C primary code number n.

3.6.2. Secondary code assignment to satellites

The E5a-I, E5a-Q, E5b-I, E5b-Q and E1-C secondary codes (defined in Section 3.5.1) are allocated to the space vehicle IDs (SVID) as follows:

- The following secondary codes are assigned according to SVID n (with $n = 1$ to 36):
  - secondary code $CS100_n$ for the signal component E5a-Q (i.e. $CS100_1$ to SVID 1)
  - secondary code $CS100_{(n+50)}$ for the signal component E5b-Q (i.e. $CS100_{51}$ to SVID 1)
- The following secondary codes are assigned to all SVIDs (1 to 36):
  - secondary code $CS20_1$ for the signal component E5a-I (same for all SVIDs)
  - secondary code $CS4_1$ for the signal component E5b-I (same for all SVIDs)
  - secondary code $CS25_1$ for the signal component E1-C (same for all SVIDs)

4. Galileo Message Structure

4.1. General Message Format Specification

4.1.1. General Navigation Message Content

The Galileo Signal-In-Space data channels transmit different message types according to the general contents identified in Table 23 below. The F/NAV types of message correspond to the OS and the I/NAV types of message correspond to both OS and CS.

Message Type	Services	Component
F/NAV	OS	E5a-I
I/NAV	OS/CS	E5b-I and E1-B
C/NAV	CS	E6-B

Table 23. Message Allocation and General Data Content

Note: The C/NAV message format is not the subject of this SIS ICD.

4.1.2. General Navigation Message Structure

The complete navigation message data are transmitted on each data component as a sequence of frames. A frame is composed of several sub-frames, and a sub-frame in turn is composed of several pages. The page is the basic structure for building the navigation message.

For all message types, only the message pages include a 'type' marker to identify the content of each page received by the user. There is no management data transmitted within the navigation message to indicate subframe and frame structures, and indeed these higher level structures should be considered as the typical flow of pages reflecting the current Galileo navigation message design, which may evolve together with future evolutions of Galileo. This evolution may also involve the inclusion of additional new page types beyond the types defined in this version of the Galileo OS SIS ICD. A user receiver is expected to be able to recognise page types and to react properly and in a well controlled manner to page types unknown to its software as well as to variations in the order of received pages.

4.1.3. 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

4.1.4. FEC Coding and Interleaving Parameters

4.1.4.1. FEC Encoding

The convolutional encoding for all data pages on all signal components is performed according to the parameters given in Table 24.

Code Parameter	Value
Coding Rate	½
Coding Scheme	Convolutional
Constraint Length	7
Generator Polynomials	$G1$=171o $G2$=133o
Encoding Sequence	$G1$ then $G2$

Table 24. Data Coding Parameters

Figure 13 depicts this convolutional coding scheme. Decoding can be implemented using a standard Viterbi decoder.
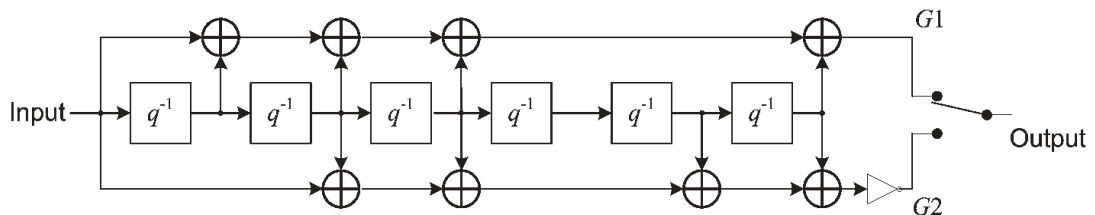
Figure 13.   Convolutional Coding Scheme

Note: Figure 13 describes an encoder where the second branch is inverted at the end.

4.1.4.2.   Interleaving

For each message type, the FEC encoded page is interleaved using a block interleaver with n columns (where data is written) and k rows (where data is read), as shown in Table 25.

Parameters	Message Type	
	F/NAV	I/NAV
Block interleaver size (Symbols)	488	240
Block interleaver dimensions (n columns x k rows)	61 x 8	30 x 8

Table 25. Interleaving Parameters

4.1.4.3.   FEC Coding and Interleaving Numerical Examples

Numerical examples for the convolutional encoding described in Section 4.1.4.1 and for the subsequent interleaving described in Section 4.1.4.2 are provided in Annex D.

4.1.5.   Frame and Page Timing

Time stamps are inserted in the navigation message at regular intervals by the broadcasting satellite to identify absolute Galileo System Time (GST). The exact timing of the page frame boundaries is used to identify fractional GST timing (less than one frame period). This is measured relative to the leading edge of the first chip of the first code sequence of the first page symbol of the page containing the TOW. The transmission timing of the navigation message provided through the TOW is synchronised to each satellite's version of GST.

4.1.6.   Reserved and Spare Bits

Reserved and spare bits may be used for evolution, and defined in future updates of this ICD.

4.2. F/NAV Message Description

4.2.1. General Description of the F/NAV Message

The F/NAV message structure is presented in Figure 14, where the duration of each entity is indicated.
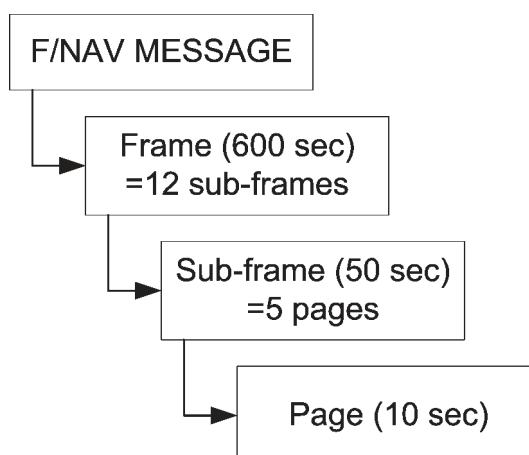
Figure 14. F/NAV Message Structure

4.2.2. F/NAV Page Layout

The page layout for the F/NAV message type is according to Table 26 where the symbols allocation and bits allocation are shown separately. The different fields composing this layout are defined in the sections below.

Sync.	F/NAV Symbols	Total (symb)
12	488	500

F/NAV Word			Tail	Total (bits)
Page type	Navigation Data	CRC		
6	208	24	6	244

Table 26. F/NAV Page Layout

Note: Transmission of a page starts with the first bit of the synchronisation pattern.

4.2.2.1. Synchronisation Pattern

The synchronisation pattern allows the receiver to achieve synchronisation to the page boundary.

Note: The synchronisation pattern is not encoded. The F/NAV synchronisation pattern is 101101110000

4.2.2.2. Tail Bits

The tail bits field consists of 6 zero-value bits enabling completion of the FEC decoding of each page's information content in the user receiver.

4.2.2.3. F/NAV Word

The useful data are contained in the F/NAV word composed of

- A page type field (6 bits) enabling to identify the page content as defined in paragraph 4.2.4

- A navigation data field (208 bits) whose structure is presented in paragraph 4.2.4

- A CRC (24 bits) to detect potential bit errors, according to paragraph 5.1.9.4. The CRC is computed on the Page Type and Navigation Data fields.

4.2.3. F/NAV Frame Layout

The F/NAV E5a-I message data packet transmission sequence is according to Table 27 where a whole frame is shown. Note that the odd numbered sub-frames contain the page type 5 and the even numbered sub-frames contain the page type 6. This allows the transmission of the almanacs for three satellites within two successive sub-frames (100 seconds). The parameter k is transparent for the user. It is set by the Galileo system for each of the active satellites, such as to improve almanac transport time by exploiting source diversity.

	Page Type	Page Content
Subframe 1	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite k and almanac for satellite (k+1) part 1
Subframe 2	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+1) part 2 and almanac for satellite (k+2)
Subframe 3	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+3) and almanac for satellite (k+4) part 1
Subframe 4	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+4) part 2 and almanac for satellite (k+5)
Subframe 5	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+6) and almanac for satellite (k+7) part 1

	Page Type	Page Content
Subframe 6	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+7) part 2 and almanac for satellite (k+8)
Subframe 7	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+9) and almanac for satellite (k+10) part 1
Subframe 8	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+10) part 2 and almanac for satellite (k+11)
Subframe 9	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+12) and almanac for satellite (k+13) part 1
Subframe 10	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+13) part 2 and almanac for satellite (k+14)
Subframe 11	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+15) and almanac for satellite (k+16) part 1

	Page Type	Page Content
Subframe 12	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+16) part 2 and almanac for satellite (k+17)

Table 27. F/NAV Frame Layout

4.2.4. F/NAV Page Contents

The following tables specify the contents of the F/NAV pages above allocated (see Chapter 5 for a description of the F/NAV pages contents).

Page Type 1: SVID, Clock correction, SISA, Ionospheric correction, BGD, GST, Signal health and Data validity status

Type=1	SVID	IOD_{nav}	Clock correction				SISA(E1,E5a)	Ionospheric correction								$BGD(E1,E5a)$	$E5a_{HS}$	GST		$E5a_{DVS}$	Spare	CRC	Tail	Total (bits)
								Az			Ionospheric disturbance flag													
			t_{0c}	a_{f0}	a_{f1}	a_{f2}		a_{i0}	a_{i1}	a_{i2}	Region 1	Region 2	Region 3	Region 4	Region 5			WN	TOW					
6	6	10	14	31	21	6	8	11	11	14	1	1	1	1	1	10	2	12	20	1	26	24	6	244

Table 28. Bits Allocation for F/NAV Page Type 1

Page Type 2: Ephemeris (1/3) and GST

Type=2	IOD_{nav}	Ephemeris (1/3)						GST		CRC	Tail	Total (bits)
		M_0	$\bullet\Omega$	e	$A^{1/2}$	Ω_0	$\bullet i$	WN	TOW			
6	10	32	24	32	32	32	14	12	20	24	6	244

Table 29. Bits Allocation for F/NAV Page Type 2

Page Type 3: Ephemeris (2/3) and GST

Type=3	IOD_{nav}	Ephemeris (2/3)								GST		Spare	CRC	Tail	Total (bits)
		i_0	ω	Δn	C_{uc}	C_{us}	C_{rc}	C_{rs}	t_{0e}	WN	TOW				
6	10	32	32	16	16	16	16	16	14	12	20	8	24	6	244

Table 30. Bits Allocation for F/NAV Page Type 3

Page Type 4: Ephemeris (3/3), GST-UTC conversion, GST-GPS conversion and TOW.

Type=4	IOD_{nav}	Ephemeris (3/3)		GST-UTC Conversion								GST-GPS Conversion				TOW	Spare	CRC	Tail	Total (bits)
		C_{ic}	C_{is}	A_0	A_1	Δt_{Ls}	t_{0t}	WN_{0t}	WN_{LSF}	DN	Δt_{LSF}	t_{0G}	A_{0G}	A_{1G}	WN_{0G}					
6	10	16	16	32	24	8	8	8	8	3	8	8	16	12	6	20	5	24	6	244

Table 31. Bits Allocation for F/NAV Page Type 4

Page Type 5: Almanac (SVID1 and SVID2(1/2)), Week Number and almanac reference time

Type=5	IOD_a	WN_a	t_{0a}	SV_{SVID1}											$SV_{SVID2}(1/2)$						CRC	Tail	Total (bits)
				$SVID1$	$\Delta(A^{1/2})$	e	ω	δi	Ω_0	$\dot{\Omega}$	M_0	a_{f0}	a_{f1}	$E5a_{HS}$	$SVID2$	$\Delta(A^{1/2})$	e	ω	δi	$\Omega_{0(1/2)}$			
6	4	2	10	6	13	11	16	11	16	11	16	16	13	2	6	13	11	16	11	4	24	6	244

Table 32. Bits Allocation for F/NAV Page Type 5

Page Type 6: Almanac (SVID2(2/2) and SVID3)

Type=6	IOD_a	$SV_{SVID2}(2/2)$						SV_{SVID3}												Spare	CRC	Tail	Total (bits)
		$\Omega_{0(2/2)}$	$\dot{\Omega}$	M_0	a_{f0}	a_{f1}	$E5a_{HS}$	$SVID3$	$\Delta(A^{1/2})$	e	ω	δ_i	Ω_0	$\dot{\Omega}$	M_0	a_{f0}	a_{f1}	$E5a_{HS}$					
6	4	12	11	16	16	13	2	6	13	11	16	11	16	11	16	16	13	2	3	24	6	244

Table 33. Bits Allocation for F/NAV Page Type 6

4.2.5. F/NAV Dummy Page Definition

In case no valid F/NAV data is to be transmitted, the satellite generates and downlinks the dummy pages (Page Type 63) replacing the pages in the nominal sequencing, according to the format in Table 34. CRC is computed on the Page Type and Dummy sequence fields.

Type=63	Dummy sequence	CRC	Tail	Total (bits)
6	208	24	6	244

Table 34. Bits Allocation for F/NAV Dummy Page

4.3. I/NAV Message Description

4.3.1. General Description of the I/NAV Message

The I/NAV message structure is presented in Figure 15, where the duration of each entity is indicated.
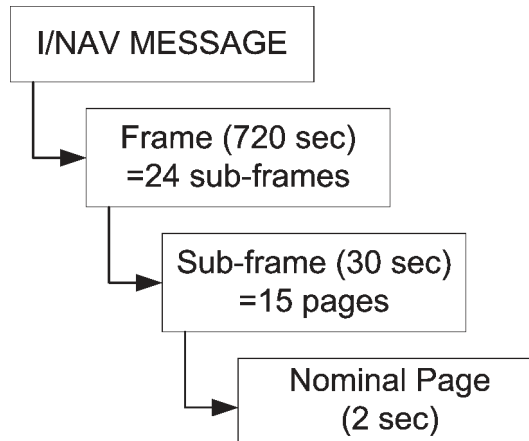
Figure 15. I/NAV Message Structure in the Nominal Mode

The I/NAV message structures for the E5b-I and E1-B signals use the same page layout since the service provided on these frequencies is a dual frequency service, using frequency diversity. Only page sequencing is different, with page swapping between both components in order to allow a fast reception of data by a dual frequency receiver. Nevertheless, the frame is designed to allow receivers to work also with a single frequency.

4.3.2. I/NAV Page Layout

Two types of I/NAV pages are defined:

- Nominal pages having a duration of 2 seconds transmitted sequentially in time in two parts of duration 1 second each on each of the E5b-I and E1-B components according to Table 36. The first part of a page is denoted 'even' and the second one is denoted 'odd'.

- Alert pages having a duration of 1 second transmitted in two parts of duration 1 second each at the same epoch over the E5b-I and E1-B components according to Table 37. Again, the first part of a page is denoted 'even' and the second one is denoted 'odd'. This transmission is repeated at the next epoch but switching the two parts between the components.

The I/NAV page part (even or odd) layout is defined in Table 35 for both nominal and alert page types. This table shows the symbols allocation and bits allocation separately. The different fields composing this layout are defined in the sections below.

Sync.	I/NAV Page Part (even or odd) Symbols	Total (symb)
10	240	250

I/NAV Page Part (even or odd) Bits	Tail	Total (bits)
114	6	120

Table 35. I/NAV Page Part Layout

Note: Transmission of a page starts with the first bit of the synchronisation pattern.

4.3.2.1. Synchronisation Pattern

The synchronisation pattern allows the receiver to achieve synchronisation to the page boundary.

Note: The synchronisation pattern is not encoded. The I/NAV synchronisation pattern is 0101100000

The tail bits field consists of 6 zero-value bits enabling completion of the FEC decoding of each page's information content in the user receiver.

4.3.2.3. *I/NAV Page Part*

The structure of the nominal I/NAV even and odd page parts on E5b-I and E1-B are defined in Table 36. A nominal page is composed by the two page parts (even and odd) transmitted sequentially over the same frequency ("vertical page").

E5b-I

Even/odd=0	Page Type	Data i (1/2)	Tail	Total (bits)
1	1	112	6	120

Even/odd=1	Page Type	Data i (2/2)	Reserved 1	CRC$_i$	Reserved 2	Tail	Total (bits)
1	1	16	64	24	8	6	120

E1-B

Even/odd=1	Page Type	Data j (2/2)	Reserved 1	SAR	Spare	CRC$_j$	SSP	Tail	Total (bits)
1	1	16	40	22	2	24	8	6	120

Even/odd=0	Page Type	Data k (1/2)	Tail	Total (bits)
1	1	112	6	120

Table 36. I/NAV Nominal Page with Bits Allocation

The parameters for the nominal page have the following meaning and related values:

- Even/Odd field (1 bit) to indicate the part of the page (0=even/1=odd) that is broadcast

- Page Type (1 bit) equal to 0 to indicate the nominal page type

- Data field composed of a nominal word (described in 4.3.5) of 128 bits (comprising 112 bits of data (1/2) and 16 bits of data (2/2))

- SAR data (22 bits) composed of SAR RLM data on E1-B only as defined in 4.3.7

- CRC (24 bits) computed on the Even/Odd fields, Page Type fields, Data fields (1/2 and 2/2), Spare field, SAR (on E1-B only) and reserved fields (Reserved 1 for E5b-I and Reserved 1 for E1-B). In nominal mode the CRC is computed for the Even and Odd parts of a page of the same frequency ("vertical CRC") and is always broadcast on the second part of the "vertical page".

  Note: The Reserved 2 field on E5b-I and the SSP field on E1-B are not protected by the CRC.

- SSP (8 bits) containing one of the three secondary synchronisation pattern configurations as defined in 5.1.9.5

- Tail bits (2*6 bits) as defined in 4.3.2.2. These fields are not protected by the CRC.

The structure of the alert I/NAV even and odd page parts on E5b-I and E1-B are defined in Table 37. An alert page is composed by the two page parts (even and odd) transmitted at the same epoch over E5b-I and E1-B ("horizontal page").

Table 37. I/NAV Alert Page with Bits Allocation

E5b-I

Even/odd=0	Page Type	Reserved 1 (1/2)	Tail	Total (bits)
1	1	112	6	120

E1-B

Even/odd=1	Page Type	Reserved 1 (2/2)	CRC	SSP	Tail	Total (bits)
1	1	80	24	8	6	120

E5b-I

Even/odd=1	Page Type	Reserved 1 (2/2)	CRC	Reserved 2	Tail	Total (bits)
1	1	80	24	8	6	120

E1-B

Even/odd=0	Page Type	Reserved 1 (1/2)	Tail	Total (bits)
1	1	112	6	120

The parameters for the alert page have the following meaning and related values:

- Even/Odd field to indicate the part of the page (0=even/1=odd) that is broadcast

- Page Type (1 bit) equal to 1 to indicate the alert page type

- CRC (24 bits) computed on the Even/Odd fields, Page Type fields and on Reserved 1 (1/2 and 2/2). In alert mode the CRC is computed for the Even/ Odd pages of both frequencies E5b and E1-B ("horizontal CRC").

- The Reserved 1 and Reserved 2 fields will be published in a future update of this ICD. Note that the Reserved 2 field on E5b-I and the SSP field on E1-B are not protected by CRC.

- SSP (8 bits) containing one of the three secondary synchronisation pattern configurations as defined in 5.1.9.5.

- Tail bits (2*6 bits) as defined in 4.3.2.2.

4.3.3. I/NAV Nominal Sub-Frame Layout

In the nominal mode, the page sequence for I/NAV E5b-I and I/NAV E1-B components in every sub-frame is according to Table 38, where T_0 is synchronised with GST origin modulo 30 seconds.

T_0 (GST$_0$ sync.) (s)	E5b-I Sub frame ID	E5b-I Page	E5b-I Content				E1-B Content						E1-B Page	E1-B Sub frame ID
0	N	Even	Word 1 (1/2)				Word 16 (2/2)	Res	SAR	Spare	CRC	SSP3	Odd	N-1
1	N	Odd	Word 1 (2/2)	Res	CRC	Res	Word 2 (1/2)						Even	N
2	N	Even	Word 3 (1/2)				Word 2 (2/2)	Res	SAR	Spare	CRC	SSP1	Odd	N
3	N	Odd	Word 3 (2/2)	Res	CRC	Res	Word 4 (1/2)						Even	N
4	N	Even	Word 5 (1/2)				Word 4 (2/2)	Res	SAR	Spare	CRC	SSP2	Odd	N
5	N	Odd	Word 5 (2/2)	Res	CRC	Res	Word 6 (1/2)						Even	N

T0 (GST0 sync.) (s)	E5b-I Sub frame ID	E5b-I Page	E5b-I Content				E1-B Content						E1-B Page	E1-B Sub frame ID
6	N	Even	Word 7 or 9 (1/2)*				Word 6 (2/2)	Res	SAR	Spare	CRC	SSP3	Odd	N
7	N	Odd	Word 7 or 9 (2/2)*	Res	CRC	Res	Word 7 or 9 (1/2)*						Even	N
8	N	Even	Word 8 or 10 (1/2)*				Word 7 or 9 (2/2)*	Res	SAR	Spare	CRC	SSP1	Odd	N
9	N	Odd	Word 8 or 10 (2/2)*	Res	CRC	Res	Word 8 or 10 (1/2)*						Even	N
10	N	Even	Word 0 (1/2)				Word 8 or 10 (2/2)*	Res	SAR	Spare	CRC	SSP2	Odd	N
11	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 17 or 18 (1/2)**						Even	N
12	N	Even	Word 0 (1/2)				Word 17 or 18 (2/2)**	Res	SAR	Spare	CRC	SSP3	Odd	N
13	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 19 or 20 (1/2)**						Even	N
14	N	Even	Word 0 (1/2)				Word 19 or 20 (2/2)**	Res	SAR	Spare	CRC	SSP1	Odd	N
15	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 16 (1/2)						Even	N
16	N	Even	Word 0 (1/2)				Word 16 (2/2)	Res	SAR	Spare	CRC	SSP2	Odd	N
17	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 0 (1/2)						Even	N
18	N	Even	Word 0 (1/2)				Word 0 (2/2)	Res	SAR	Spare	CRC	SSP3	Odd	N
19	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 0 (1/2)						Even	N
20	N	Even	Word 2 (1/2)				Word 0 (2/2)	Res	SAR	Spare	CRC	SSP1	Odd	N
21	N	Odd	Word 2 (2/2)	Res	CRC	Res	Word 1 (1/2)						Even	N
22	N	Even	Word 4 (1/2)				Word 1 (2/2)	Res	SAR	Spare	CRC	SSP2	Odd	N
23	N	Odd	Word 4 (2/2)	Res	CRC	Res	Word 3 (1/2)						Even	N
24	N	Even	Word 6 (1/2)				Word 3 (2/2)	Res	SAR	Spare	CRC	SSP3	Odd	N
25	N	Odd	Word 6 (2/2)	Res	CRC	Res	Word 5 (1/2)						Even	N
26	N	Even	Word 0 (1/2)				Word 5 (2/2)	Res	SAR	Spare	CRC	SSP1	Odd	N
27	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 0 (1/2)						Even	N
28	N	Even	Word 0 (1/2)				Word 0 (2/2)	Res	SAR	Spare	CRC	SSP2	Odd	N
29	N	Odd	Word 0 (2/2)	Res	CRC	Res	Word 16 (1/2)						Even	N
30	N+1	Even	Word 1 (1/2)				Word 16 (2/2)	Res	SAR	Spare	CRC	SSP3	Odd	N

Table 38. I/NAV Nominal Sub-Frame Structure

* The dissemination sequence of Word Types 7, 8, 9 and 10 within a frame is detailed in Table 39.
** FEC2 RS CED broadcast cycles through all four FEC2 RS CED Words.

The sub-frame structure shown in Table 38 is indicative: Deviations from the I/NAV word dissemination sequence as shown may appear, individually per satellite and precautions as per Section 4.1.2 are expected to be foreseen within the user receiver.

The indication of Word Type 0 in Table 38 reflects spare capacities in the I/NAV word dissemination sequence reserved for future use.

4.3.4. I/NAV Nominal Frame Layout

The I/NAV sub-frames containing almanac data are sequenced in a nominal frame according to Table 39.

T_0 (s)	Sub-frame ID	E5b	E1B
0	1	Word 7: Almanac SV 1 (1/2)	Word 7: Almanac SV 19 (1/2)
		Word 8: Almanac SV 1 (2/2) + almanac SV 2 (1/2)	Word 8: Almanac SV 19 (2/2) + almanac SV 20 (1/2)
30	2	Word 9: Almanac SV 2 (2/2) + almanac SV 3 (1/2)	Word 9: Almanac SV 20 (2/2) + almanac SV 21 (1/2)
		Word 10: Almanac SV 3 (2/2)	Word 10: Almanac SV 21 (2/2)
60	3	Word 7: Almanac SV 4 (1/2)	Word 7: Almanac SV 22 (1/2)
		Word 8: Almanac SV 4 (2/2) + almanac SV 5 (1/2)	Word 8: Almanac SV 22 (2/2) + almanac SV 23 (1/2)
90	4	Word 9: Almanac SV 5 (2/2) + almanac SV 6 (1/2)	Word 9: Almanac SV 23 (2/2) + almanac SV 24 (1/2)
		Word 10: Almanac SV 6 (2/2)	Word 10: Almanac SV 24 (2/2)
120	5	Word 7: Almanac SV 7 (1/2)	Word 7: Almanac SV 25 (1/2)
		Word 8: Almanac SV 7 (2/2) + almanac SV 8 (1/2)	Word 8: Almanac SV 25 (2/2) + almanac SV 26 (1/2)
150	6	Word 9: Almanac SV 8 (2/2) + almanac SV 9 (1/2)	Word 9: Almanac SV 26 (2/2) + almanac SV 27 (1/2)
		Word 10: Almanac SV 9 (2/2)	Word 10: Almanac SV 27 (2/2)
180	7	Word 7: Almanac SV 10 (1/2)	Word 7: Almanac SV 28 (1/2)
		Word 8: Almanac SV 10 (2/2) + almanac SV 11 (1/2)	Word 8: Almanac SV 28 (2/2) + almanac SV 29 (1/2)
210	8	Word 9: Almanac SV 11 (2/2) + almanac SV 12 (1/2)	Word 9: Almanac SV 29 (2/2) + almanac SV 30 (1/2)
		Word 10: Almanac SV 12 (2/2)	Word 10: Almanac SV 30 (2/2)
240	9	Word 7: Almanac SV 13 (1/2)	Word 7: Almanac SV 31 (1/2)
		Word 8: Almanac SV 13 (2/2) + almanac SV 14 (1/2)	Word 8: Almanac SV 31 (2/2) + almanac SV 32 (1/2)
270	10	Word 9: Almanac SV 14 (2/2) + almanac SV 15 (1/2)	Word 9: Almanac SV 32 (2/2) + almanac SV 33 (1/2)
		Word 10: Almanac SV 15 (2/2)	Word 10: Almanac SV 33 (2/2)
300	11	Word 7: Almanac SV 16 (1/2)	Word 7: Almanac SV 34 (1/2)
		Word 8: Almanac SV 16 (2/2) + almanac SV 17 (1/2)	Word 8: Almanac SV 34 (2/2) + almanac SV 35 (1/2)
330	12	Word 9: Almanac SV 17 (2/2) + almanac SV 18 (1/2)	Word 9: Almanac SV 35 (2/2) + almanac SV 36 (1/2)
		Word 10: Almanac SV 18 (2/2)	Word 10: Almanac SV 36 (2/2)
360	13	Word 7: Almanac SV 19 (1/2)	Word 7: Almanac SV 1 (1/2)
		Word 8: Almanac SV 19 (2/2) + almanac SV 20 (1/2)	Word 8: Almanac SV 1 (2/2) + almanac SV 2 (1/2)
390	14	Word 9: Almanac SV 20 (2/2) + almanac SV 21 (1/2)	Word 9: Almanac SV 2 (2/2) + almanac SV 3 (1/2)
		Word 10: Almanac SV 21 (2/2)	Word 10: Almanac SV 3 (2/2)

T_0 (s)	Sub-frame ID	E5b	E1B
420	15	Word 7: Almanac SV 22 (1/2)	Word 7: Almanac SV 4 (1/2)
		Word 8: Almanac SV 22 (2/2) + almanac SV 23 (1/2)	Word 8: Almanac SV 4 (2/2) + almanac SV 5 (1/2)
450	16	Word 9: Almanac SV 23 (2/2) + almanac SV 24 (1/2)	Word 9: Almanac SV 5 (2/2) + almanac SV 6 (1/2)
		Word 10: Almanac SV 24 (2/2)	Word 10: Almanac SV 6 (2/2)
480	17	Word 7: Almanac SV 25 (1/2)	Word 7: Almanac SV 7 (1/2)
		Word 8: Almanac SV 25 (2/2) + almanac SV 26 (1/2)	Word 8: Almanac SV 7 (2/2) + almanac SV 8 (1/2)
510	18	Word 9: Almanac SV 26 (2/2) + almanac SV 27 (1/2)	Word 9: Almanac SV 8 (2/2) + almanac SV 9 (1/2)
		Word 10: Almanac SV 27 (2/2)	Word 10: Almanac SV 9 (2/2)
540	19	Word 7: Almanac SV 28 (1/2)	Word 7: Almanac SV 10 (1/2)
		Word 8: Almanac SV 28 (2/2) + almanac SV 29 (1/2)	Word 8: Almanac SV 10 (2/2) + almanac SV 11 (1/2)
570	20	Word 9: Almanac SV 29 (2/2) + almanac SV 30 (1/2)	Word 9: Almanac SV 11 (2/2) + almanac SV 12 (1/2)
		Word 10: Almanac SV 30 (2/2)	Word 10: Almanac SV 12 (2/2)
600	21	Word 7: Almanac SV 31 (1/2)	Word 7: Almanac SV 13 (1/2)
		Word 8: Almanac SV 31 (2/2) + almanac SV 32 (1/2)	Word 8: Almanac SV 13 (2/2) + almanac SV 14 (1/2)
630	22	Word 9: Almanac SV 32 (2/2) + almanac SV 33 (1/2)	Word 9: Almanac SV 14 (2/2) + almanac SV 15 (1/2)
		Word 10: Almanac SV 33 (2/2)	Word 10: Almanac SV 15 (2/2)
660	23	Word 7: Almanac SV 34 (1/2)	Word 7: Almanac SV 16 (1/2)
		Word 8: Almanac SV 34 (2/2) + almanac SV 35 (1/2)	Word 8: Almanac SV 16 (2/2) + almanac SV 17 (1/2)
690	24	Word 9: Almanac SV 35 (2/2) + almanac SV 36 (1/2)	Word 9: Almanac SV 17 (2/2) + almanac SV 18 (1/2)
		Word 10: Almanac SV 36 (2/2)	Word 10: Almanac SV 18 (2/2)

Table 39. I/NAV Sub-Frame Sequencing

4.3.5. I/NAV Word Types

The content of the I/NAV word types is stated in the following tables (see Chapter 5 for a description of the I/NAV word types contents).

Word Type 1: Ephemeris (1/4)

Type=1	IOD_{nav}	Ephemeris (1/4)				Reserved	Total (bits)
		t_{0e}	M_0	e	$A^{1/2}$		
6	10	14	32	32	32	2	128

Table 40. Bits Allocation for I/NAV Word Type 1

Word Type 2: Ephemeris (2/4)

Type=2	IOD_{nav}	Ephemeris (2/4)				Reserved	Total (bits)
		Ω_0	i_0	ω	$\dot{i}$		
6	10	32	32	32	14	2	128

Table 41. Bits Allocation for I/NAV Word Type 2

Word Type 3: Ephemeris (3/4) and SISA

Type=3	IOD_{nav}	$\dot{\Omega}$	Δn	C_{UC}	C_{US}	C_{RC}	C_{RS}	SISA(E1,E5b)	Total (bits)
		Ephemeris (3/4)							
6	10	24	16	16	16	16	16	8	128

Table 42. Bits Allocation for I/NAV Word Type 3

Word Type 4: SVID, Ephemeris (4/4), and Clock correction parameters

Type=4	IOD_{nav}	SVID	C_{ic}	C_{is}	t_{0c}	a_{f0}	a_{f1}	a_{f2}	Spare	Total (bits)
			Ephemeris (4/4)		Clock correction					
6	10	6	16	16	14	31	21	6	2	128

Table 43. Bits Allocation for I/NAV Word Type 4

Word Type 5: Ionospheric correction, BGD, signal health and data validity status and GST

Type=5	a_{i0}	a_{i1}	a_{i2}	Region 1	Region 2	Region 3	Region 4	Region 5	$BGD(E1,E5a)$	$BGD(E1,E5b)$	$E5b_{HS}$	$E1B_{HS}$	$E5b_{DVS}$	$E1B_{DVS}$	WN	TOW	Spare	Total (bits)
	Ionospheric correction														GST			
	Az			Ionospheric disturbance flag														
6	11	11	14	1	1	1	1	1	10	10	2	2	1	1	12	20	23	128

Table 44. Bits Allocation for I/NAV Word Type 5

Word Type 6: GST-UTC conversion parameters

Type=6	A_0	A_1	Δt_{LS}	t_{ot}	WN_{0t}	WN_{LSF}	DN	Δt_{LSF}	TOW	Spare	Total (bits)
	GST-UTC conversion parameters										
6	32	24	8	8	8	8	3	8	20	3	128

Table 45. Bits Allocation for I/NAV Word Type 6

Word Type 7: Almanac for SVID1 (1/2), almanac reference time and almanac reference week number

Type=7	IOD_a	WN_a	t_{0a}	SVID1	$\Delta(A^{1/2})$	e	ω	δ_i	Ω_0	$\dot{\Omega}$	M_0	Reserved	Total (bits)
				SV_{SVID1} (1/2)									
6	4	2	10	6	13	11	16	11	16	11	16	6	128

Table 46. Bits Allocation for I/NAV Word Type 7

Word Type 8: Almanac for SVID1 (2/2) and SVID2 (1/2))

Type=8	IOD_a	SV$_{SVID1}$(2/2)				SV$_{SVID2}$(1/2)							Spare	Total (bits)
		a_{f0}	a_{f1}	E5b$_{HS}$	E1B$_{HS}$	SVID2	$\Delta(A^{1/2})$	e	ω	δ_i	Ω_0	$\bullet\Omega$		
6	4	16	13	2	2	6	13	11	16	11	16	11	1	128

Table 47. Bits Allocation for I/NAV Word Type 8

Word Type 9: Almanac for SVID2 (2/2) and SVID3 (1/2))

Type=9	IOD_a	WN_a	t_{0a}	SV$_{SVID2}$(2/2)					SV$_{SVID3}$(1/2)					Total (bits)
				M_0	a_{f0}	a_{f1}	E5b$_{HS}$	E1B$_{HS}$	SVID3	$\Delta(A^{1/2})$	e	ω	δ_i	
6	4	2	10	16	16	13	2	2	6	13	11	16	11	128

Table 48. Bits Allocation for I/NAV Word Type 9

Word Type 10: Almanac for SVID3 (2/2) and GST-GPS conversion parameters

Type=10	IOD_a	SV$_{SVID3}$(2/2)							GST-GPS conversion parameters				Total (bits)
		Ω_0	$\bullet\Omega$	M_0	a_{f0}	a_{f1}	E5b$_{HS}$	E1B$_{HS}$	A_{0G}	A_{1G}	t_{0G}	WN_{0G}	
6	4	16	11	16	16	13	2	2	16	12	8	6	128

Table 49. Bits Allocation for I/NAV Word Type 10

Word Type 16: Reduced Clock and Ephemeris Data (CED) parameters

Type=16	Reduced CED parameters								Total (bits)
	ΔA_{red}	e_{xred}	e_{yred}	Δi_{0red}	Ω_{0red}	λ_{0red}	a_{f0red}	a_{f1red}	
6	5	13	13	17	23	23	22	6	128

Table 50. Bits Allocation for I/NAV Word Type 16

Word types 17, 18, 19, 20: FEC2 Reed-Solomon for Clock and Ephemeris Data (CED)

Type= 17, 18, 19, 20	FEC2 Reed-Solomon for CED (1/2)	LSB(IOD$_{nav}$)	FEC2 Reed-Solomon for CED (2/2)	Total (bits)
6	8	2	112	128

Table 51. Bits Allocation for I/NAV Word Types 17, 18, 19, and 20

FEC2 Reed-Solomon (RS) words consist of 15 RS parity octets that can be used

- to recover missing RS octets from the RS information vector
- and/or to correct errors contained in received octets of the RS information vector.

The RS information and parity vectors are described in section 5.1.13.

Word Type 0: I/NAV Spare Word

Type=0	Time	Spare	GST		Total (bits)
			WN	TOW	
6	2	88	12	20	128

Table 52. Bits Allocation for Spare Word

When the field 'Time' is not set to '10', the fields WN and TOW do not contain valid data.

4.3.6. I/NAV Dummy Message Layout

In case no valid I/NAV data is to be transmitted, the satellite generates and downlinks the dummy message on E5b-I and E1-B components replacing the pages in the nominal sequencing, according to the Dummy pages layout defined in Table 53.

E5b-I						E1-B						
Even/odd=0	Page Type	Dummy data (1/2)	Tail		Total (bits)	Even/odd=1	Page Type	Dummy data (2/2)	CRC	Spare	Tail	Total (bits)
1	1	112	6		120	1	1	80	24	8	6	120
Even/odd=1	Page Type	Dummy data (2/2)	CRC	Spare	Tail	Total (bits)	Even/odd=0	Page Type	Dummy data (1/2)		Tail	Total (bits)
1	1	80	24	8	6	120	1	1	112		6	120

Table 53. I/NAV Dummy Page with Bits Allocation

The parameters for the dummy page have the following meaning and related values:

- Even/Odd (1 bit) to indicate the part of the page (0=even/1=odd) that is broadcast

- Page Type (1 bit) equal to 0 to indicate the nominal page type

- Dummy Data (192 bits = 80 bits + 112 bits)

- CRC (24 bits): computed on the Even/odd fields, Type fields and Dummy data fields (1/2 and 2/2) for the Even/Odd page of the same frequency ("vertical CRC"), and the CRC is always broadcast on the second part of the "vertical page"

- Spare (8 bits). This field is not protected by the CRC

- Tail bits (2*6 bits) as defined in 4.3.2.2. These fields are not protected by the CRC

The dummy data word is formatted according to Table 54, with

- Word Type (6 bits) to indicate the word type dummy message, which is defined as type 63

- The dummy sequence (186 bits) is an arbitrary sequence

Type = 63	Dummy Sequence	Total (bits)
6	186	192
	Dummy Data (1/2) (112 bits)	Dummy Data (2/2) (80 bits)	

Table 54. Dummy Word with Bits Allocation

4.3.7. SAR Field Structure

In the nominal mode the SAR RLM is transmitted only in the E1-B component. The SAR field structure for the E1-B component in nominal mode is formatted according to the values stated in Table 55. When an alert is present, the SAR data will not be transmitted

SAR Data			Total (bits)
Start Bit	Short/Long RLM Identifier	SAR RLM Data	
1	1	20	22

Table 55. SAR Field Bit Structure

The RLM identifier bit is described in the following table.

RLM Identifier Value	Description
0	Short RLM
1	Long RLM

Table 56. RLM Identifier Description

SAR data in Nominal Mode

In nominal mode, 22 bits are allocated to SAR data in one E1-B I/NAV page. The SAR messages are formatted according to the values and structure stated in Table 57 and Table 58 respectively for the short RLM and the long RLM. This structure allows the downlink of a short RLM within 8 seconds and of a long RLM within 16 seconds. The content of the SAR data is provided in paragraph 5.2.

● Short RLM

Part (1/4)			Part (2/4)			Part (3/4)			Part (4/4)			
Start bit = 1	Short RLM	SAR RLM data — Beacon ID (1/3)	Start bit = 0	Short RLM	SAR RLM data — Beacon ID (2/3)	Start bit = 0	Short RLM	SAR RLM data — Beacon ID (3/3)	Start bit = 0	Short RLM	SAR RLM data — Message code	Parameters
1	1	20	1	1	20	1	1	20	1	1	4	16
22			22			22			22			

Table 57. SAR Short RLM

- Long RLM

Part (1/8)			Part (2/8)			Part (3/8)			Part (4/8)			
		SAR RLM data			SAR RLM data			SAR RLM data			SAR RLM data	
Start bit = 1	Long RLM	Beacon ID (1/3)	Start bit = 0	Long RLM	Beacon ID (2/3)	Start bit = 0	Long RLM	Beacon ID (3/3)	Start bit = 0	Long RLM	Message code	Parameters (1/5)
1	1	20	1	1	20	1	1	20	1	1	4	16
22			22			22			22			

Part (5/8)			Part (6/8)			Part (7/8)			Part (8/8)		
		SAR RLM data			SAR RLM data			SAR RLM data			SAR RLM data
Start bit = 0	Long RLM	Parameters (2/5)	Start bit = 0	Long RLM	Parameters (3/5)	Start bit = 0	Long RLM	Parameters (4/5)	Start bit = 0	Long RLM	Parameters (5/5)
1	1	20	1	1	20	1	1	20	1	1	20
22			22			22			22		

Table 58. SAR Long RLM

Spare SAR Data

In case no valid SAR data is to be transmitted, the satellite generates the spare SAR data field according to Table 59.

SAR Data		Total
Start Bit = 1	Spare	(bits)
1	21	22

Table 59. Spare SAR Data

A SAR receiver will use the sequence of start bits (and only these) to identify SAR data parts belonging to SAR RLMs. If the start bit of the current data part is equal to zero, then the data part contains SAR relevant data. If the start bit of the current data part is equal to one, the data part contains SAR relevant data only if the start bit of the next (immediately subsequent) data part is equal to zero.

5. Message Data Contents

This section describes the data items above mentioned. Semantics, formats and other characteristics are provided for all items to be transmitted inside frames.

5.1. Navigation Data

The navigation data contain all the parameters required for the user to compute a complete position, velocity and time (PVT) solution. They are stored on board each satellite with a validity duration and broadcast world-wide by all the satellites of the Galileo constellation. The 4 types of data needed to perform positioning are:

- Ephemeris parameters, which are needed to indicate the position of the satellite to the user receiver

- Time and clock correction parameters which are needed to compute pseudo-range

- Service parameters which are needed to identify the set of navigation data, satellites, and indicators of the signal health

- Almanac parameters, which are needed to indicate the position of all the satellites in the constellation with a reduced accuracy

5.1.1. Ephemeris

The ephemeris for each Galileo satellite is composed of 16 parameters, which are:

- 6 Keplerian parameters

- 6 harmonic coefficients

- 1 orbit inclination rate parameter

- 1 RAAN rate parameter

- 1 mean motion correction parameter, and

- 1 reference time parameter t_{0e} for the ephemeris data set

The ephemeris for each Galileo satellite is according to the characteristics stated in Table 60.

Parameter	Definition	Bits	Scale factor	Unit
M_0	Mean anomaly at reference time	32*	2^{-31}	semi-circles**
Δn	Mean motion difference from computed value	16*	2^{-43}	semi-circles/s**
e	Eccentricity	32	2^{-33}	N/A
$A^{1/2}$	Square root of the semi-major axis	32	2^{-19}	meter$^{1/2}$
Ω_0	Longitude of ascending node of orbital plane at weekly epoch***	32*	2^{-31}	semi-circles**
i_0	Inclination angle at reference time	32*	2^{-31}	semi-circles**
ω	Argument of perigee	32*	2^{-31}	semi-circles**

Parameter	Definition	Bits	Scale factor	Unit
$\dot{\Omega}$	Rate of change of right ascension	24*	2^{-43}	semi-circles/s**
$\dot{i}$	Rate of change of inclination angle	14*	2^{-43}	semi-circles/s**
C_{uc}	Amplitude of the cosine harmonic correction term to the argument of latitude	16*	2^{-29}	radians
C_{us}	Amplitude of the sine harmonic correction term to the argument of latitude	16*	2^{-29}	radians
C_{rc}	Amplitude of the cosine harmonic correction term to the orbit radius	16*	2^{-5}	meters
C_{rs}	Amplitude of the sine harmonic correction term to the orbit radius	16*	2^{-5}	meters
C_{ic}	Amplitude of the cosine harmonic correction term to the angle of inclination	16*	2^{-29}	radians
C_{is}	Amplitude of the sine harmonic correction term to the angle of inclination	16*	2^{-29}	radians
t_{0e}	Ephemeris reference time	14	60	seconds
Total Ephemeris Size		**356**		

Table 60. Ephemeris Parameters

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

**   Note that the 'semi-circle' is not a SI unit but can be converted as: 1 semi-circle = π rad.

***   More precisely, Ω_0 is the longitude of ascending node of orbital plane at the weekly epoch propagated to the reference time t_{0e} at the rate of change of right ascension.

A single ephemeris is applicable to all signals of a specific satellite. The ephemeris is computed with respect to the apparent CoP common to every frequency.

The user can compute the ECEF coordinates of the SV's antenna phase centre position at GST time t utilising the equations shown in Table 61.

Constant	Description
π = 3.1415926535898	Ratio of a circle's circumference to its diameter
μ = 3.986004418 × 10^{14} m³/s²	Geocentric gravitational constant
ω_E = 7.2921151467 × 10^{-5} rad/s	Mean angular velocity of the Earth
c = 299792458 m/s	Speed of light

Computation	Description
$A = (A^{1/2})^2$	Semi-major axis
$n_0 = \sqrt{\dfrac{\mu}{A^3}}$	Computed mean motion (rad/s)
$t_k = t - t_{0e}$*	Time from ephemeris reference epoch
$n = n_0 + \Delta n$	Corrected mean motion
$M = M_0 + n t_k$	Mean anomaly
$M = E - e\,\sin(E)$	Kepler's Equation for Eccentric Anomaly E (may be solved by iteration)

Computation	Description
$v = \tan^{-1}\left\{\dfrac{\sin v}{\cos v}\right\}$ $= \tan^{-1}\left\{\dfrac{\sqrt{1-e^2}\,\sin E/(1-e\cos E)}{(\cos E - e)/(1-e\cos E)}\right\}$	True Anomaly
$\Phi = v + \omega$	Argument of Latitude
$\delta u = C_{us}\sin 2\Phi + C_{uc}\cos 2\Phi$	Argument of Latitude Correction
$\delta r = C_{rs}\sin 2\Phi + C_{rc}\cos 2\Phi$	Radius Correction
$\delta i = C_{is}\sin 2\Phi + C_{ic}\cos 2\Phi$	Inclination Correction
$u = \Phi + \delta u$	Corrected Argument of Latitude
$r = A(1 - e\cos E) + \delta r$	Corrected Radius
$i = i_0 + \delta i + [\dot{i}]t_k$	Corrected Inclination
$x' = r\cos u$ $y' = r\sin u$	Position in orbital plane
$\Omega = \Omega_0 + [\dot{\Omega} - \omega_E]t_k - \omega_E t_{0e}$	Corrected longitude of ascending node
$x = x'\cos(\Omega) - y'\cos(i)\sin(\Omega)$ $y = x'\sin(\Omega) + y'\cos(i)\cos(\Omega)$ $z = y'\sin(i)$	GTRF coordinates of the SV antenna phase center position at time t

Table 61. User Algorithm for Ephemeris Determination

* t is Galileo System Time (see e.g. paragraph 5.1.2). Furthermore, t_k is the actual total time difference between the time t and the epoch time t_{0e} (t_{0a} for the almanacs) and it accounts for beginning or end of week crossovers.

5.1.2. Galileo System Time (GST)

The GST is given as 32-bit binary number composed of two parameters as follows:

- The Week Number is an integer counter that gives the sequential week number from the GST start epoch. This parameter is represented with 12 bits, which covers 4096 weeks (about 78 years). Then the counter is reset to zero to cover an additional period modulo 4096.

- The Time of Week is defined as the number of seconds that have occurred since the transition from the previous week. The TOW covers an entire week from 0 to 604799 seconds and is reset to zero at the end of each week.

The GST parameters are transmitted according to the characteristics stated in Table 62.

Parameter	Definition	Bits	Scale factor	Unit
WN	Week Number	12	1	week
TOW	Time of Week	20	1	s
Total Galileo System Time Size		**32**		

Table 62. GST Parameters

The GST start epoch is defined as 13 seconds before midnight between 21st August and 22nd August 1999, i.e. GST was equal to 13 seconds at 22nd August 1999 00:00:00 UTC.

As GST is a continuous time scale, and UTC is corrected periodically with an integer number of leap seconds, the Galileo navigation message contains all necessary parameters to convert between GST and UTC.

The epoch denoted in the navigation messages by *TOW* and *WN* will be measured relative to the leading edge of the first chip of the first code sequence of the first page symbol. The transmission timing of the navigation message provided through the *TOW* is synchronised to each satellite's version of Galileo System Time (GST).

5.1.3. Clock Correction Parameters

The clock correction parameters are transmitted according to the values stated in Table 63.

Parameter	Definition	Bits	Scale factor	Unit
t_{0c}	Clock correction data reference Time of Week	14	60	s
a_{f0}	SV clock bias correction coefficient	31*	2^{-34}	s
a_{f1}	SV clock drift correction coefficient	21*	2^{-46}	s/s
a_{f2}	SV clock drift rate correction coefficient	6*	2^{-59}	s/s^2
Total Clock Correction Size		**72**		

Table 63. Galileo Clock Correction Parameters

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

Each Galileo satellite broadcasts its own clock correction data for all signals through the relevant signal, according to Table 64.

Message Type	Clock Model X=(f1,f2)	Satellite Time Correction Model Parameters	Services
F/Nav	(E1,E5a)	a_{f0} (E1,E5a) a_{f1} (E1,E5a) a_{f2} (E1,E5a) t_{0C} (E1,E5a)	Dual-Frequency (E1,E5a) Single-frequency E5a
I/NAV	(E1,E5b)	a_{f0} (E1,E5b) a_{f1} (E1,E5b) a_{f2} (E1,E5b) t_{0C} (E1,E5b)	Dual-Frequency (E1,E5b) Single-frequency E5b Single-frequency E1

Table 64. Galileo Clock Correction Data

5.1.4. Satellite Time Correction Algorithm

Each satellite transmits time correction data. The predicted offset of the physical satellite signal TOT relative to the satellite signal TOT in GST can be computed for the dual frequency signal combination using the following formula:

$$TOT_c(X) = TOT_m(X) - \Delta t_{SV}(X) \qquad \text{Eq. 12}$$

where

- $(X)=(f_1,f_2)$ is the dual frequency combination f_1 and f_2 used for the clock model

- $TOT_C(X)$ is the corrected satellite TOT in GST for the signal combination X

- $TOT_m(X)$ is the physical satellite TOT for the signal combination X retrieved through pseudo-range measurements

- $\Delta t_{SV}(X)$ is the satellite time correction for the signal combination X computed by means of the time correction data retrieved from the navigation message

This satellite time correction (in seconds) is modelled through the following second order polynomial:

$$\Delta t_{SV}(X) = a_{f0}(X) + a_{f1}(X)[t - t_{0C}(X)] + a_{f2}(X)[t - t_{0C}(X)]^2 + \Delta t_r \qquad \text{Eq. 13}$$

where

- $a_{f0}(X)$, $a_{f1}(X)$, and $a_{f2}(X)$ are defined in 5.1.3

- $t_{0c}(X)$ is the reference time for the clock correction as defined in 5.1.3

- t is the GST time in seconds

- Δt_r, expressed in seconds, is a relativistic correction term, given by

$$\Delta t_r = F\, e\, A^{1/2} \sin(E)$$

with the orbital parameters (e, $A^{1/2}$, E) as described in paragraph 5.1.1 and

$$F = -2\mu^{1/2}/c^2 = -4.442807309 \times 10^{-10} \text{ s/m}^{1/2}$$

5.1.5. Broadcast Group Delay

The Broadcast Group Delay $BGD(f_1,f_2)$ broadcast through the Galileo navigation message is defined as follows:

$$BGD(f_1, f_2) = \frac{TR_1 - TR_2}{1 - \left(\dfrac{f_1}{f_2}\right)^2} \qquad \text{Eq. 14}$$

where

- f_1 and f_2 denote the carrier frequencies of two Galileo signals

- TR_1 and TR_2 are the group delays of the signals whose carrier frequencies are respectively f_1 and f_2.

A single frequency user receiver processing pseudo-ranges from the frequency f_1 applies the following correction to the SV clock correction Δt_{SV} which is defined in paragraph 5.1.4

$$\Delta t_{SV}(f_1) = \Delta t_{SV}(f_1, f_2) - BGD(f_1, f_2) \qquad \text{Eq. 15}$$

A single frequency user receiver processing pseudo-ranges from the frequency $f2$ applies the following correction to the SV clock correction Δt_{SV} which is defined in paragraph 5.1.4

$$\Delta t_{SV}(f_2) = \Delta t_{SV}(f_1, f_2) - \left(\frac{f_1}{f_2}\right)^2 BGD(f_1, f_2) \qquad \text{Eq. 16}$$

A dual frequency user receiver processing pseudo-ranges from the two frequencies f_1 and f_2 does not apply any additional correction for group delay. The Broadcast Group Delay is coded according to the values stated in Table 65.

Parameter	Definition	Bits	Scale factor	Unit
$BGD(E1,E5a)$	E1-E5a Broadcast Group Delay	10*	2^{-32}	s
$BGD(E1,E5b)$	E1-E5b Broadcast Group Delay	10*	2^{-32}	s

Table 65. BGD Parameters

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

Each Galileo satellite broadcasts its own BGD data for all signals, through the relevant signal according to Table 66.

Message Type	Type of Satellite Clocks	BGD(f_1,f_2)	Services
F/NAV	(E1,E5a)	$BGD(E1,E5a)$	Single-frequency E5a
I/NAV	(E1,E5b)	$BGD(E1,E5b)$	Single-frequency E1 Single-frequency E5b

Table 66. BGD Values Mapping on Messages and Services

5.1.6. Ionospheric Correction

The ionospheric model parameters provided in Table 67 are foreseen to be used with the ionospheric correction algorithm described in RD1.

The ionospheric model parameters include:

● the broadcast coefficients a_{i0}, a_{i1} and a_{i2} used to compute the Effective Ionisation Level Az

● the "Ionospheric Disturbance Flag" (also referred as "storm flag"), given for five different regions

These parameters are transmitted according to the characteristics stated in Table 67.

Parameter	Definition	Bits	Scale factor	Unit
a_{i0}	Effective Ionisation Level 1st order parameter	11	2^{-2}	sfu**
a_{i1}	Effective Ionisation Level 2nd order parameter	11*	2^{-8}	sfu**/degree
a_{i2}	Effective Ionisation Level 3rd order parameter	14*	2^{-15}	sfu**/degree^2
SF_1	Ionospheric Disturbance Flag for region 1	1	N/A	dimensionless
SF_2	Ionospheric Disturbance Flag for region 2	1	N/A	dimensionless
SF_3	Ionospheric Disturbance Flag for region 3	1	N/A	dimensionless
SF_4	Ionospheric Disturbance Flag for region 4	1	N/A	dimensionless
SF_5	Ionospheric Disturbance Flag for region 5	1	N/A	dimensionless
Total Ionosphere Correction Size		**41**		

Table 67. Ionospheric Correction Parameters

*   Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.
**   Note that 'sfu' (solar flux unit) is not a SI unit but can be converted as: 1 sfu = 10^{-22} W/(m²*Hz)

The Effective Ionisation Level, Az, is computed from the three ionospheric coefficients broadcast within the navigation message as follows:

$$Az = a_{i0} + a_{i1} \times MODIP + a_{i2} \times (MODIP)^2 \qquad \text{Eq. 17}$$

where (a_{i0}, a_{i1}, a_{i2}) are the three broadcast coefficients described in Table 67 and MODIP is Modified Dip Latitude at the location of the user receiver, expressed in degrees. A table grid of MODIP values versus geographical location is provided in RD1.

The Ionospheric Disturbance Flags SF_1 to SF_5 are reserved for future use.

The five regions mentioned in Table 67 are defined as follows:

- region 1: for the northern region   (60°<MODIP≤90°)

- region 2: for the northern middle region   (30°<MODIP≤60°)

- region 3: for the equatorial region   (−30°≤MODIP≤30°)

- region 4: for the southern middle region   (−60°≤MODIP<−30°)

- region 5: for the southern region   (−90°≤MODIP<−60°)

5.1.7. GST–UTC Conversion Algorithm and Parameters

The UTC time t_{UTC} is computed through 3 different cases depending on the epoch of a possible leap second adjustment (scheduled future or recent past) given by DN, the day at the end of which the leap second becomes effective, and week number WN_{LSF} to which DN is referenced. "Day one" of DN is the first day relative to the end/start of week and the WNLSF value consists of eight bits which are a modulo 256 binary representation of the Galileo week number to which the DN is referenced.

The parameters for GST to UTC conversion are defined in Table 68.

Parameter	Definition	Bits	Scale factor	Unit
A_0	Constant term of polynomial	32*	2^{-30}	s
A_1	1st order term of polynomial	24*	2^{-50}	s/s
Δt_{LS}	Leap Second count before leap second adjustment	8*	1	s
t_{0t}	UTC data reference Time of Week	8	3600	s
WN_{0t}	UTC data reference Week Number	8	1	week
WN_{LSF}	Week Number of leap second adjustment	8	1	week
DN	Day Number at the end of which a leap second adjustment becomes effective	3**	1	day
Δt_{LSF}	Leap Second count after leap second adjustment	8*	1	s
Total GST–UTC Conversion Size		**99**		

Table 68. Parameters for the GST–UTC Conversion

*   Parameters so indicated are two's complement, with the sign bit (+ or −) occupying the MSB.
**   The value range of DN is from 1 (= Sunday) to 7 (= Saturday).

In all computations the user must account for the truncated nature (roll-over) of the parameters (DN, WN, WN_{0t}, and WN_{LSF}), considering the following properties:

At the time of broadcast of the GST – UTC parameters,

- the absolute value of the difference between untruncated WN and WN_{0t} values does not exceed 127

- when Δt_{LS} and Δt_{LSF} differ, the absolute value of the difference between the untruncated WN and WN_{LSF} values received within the same subframe does not exceed 127.

In addition to the parameters listed in Table 68, the following parameters are used in the GST – UTC conversion algorithm:

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

WN is the week number to which t_E is referenced.

Case a

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

$$t_{UTC} = (t_E - \Delta t_{UTC})[\text{Modulo } 86400]$$

$$\text{where: } \Delta t_{UTC} = \Delta t_{LS} + A_0 + A_1(t_E - t_{0t} + 604800(WN - WN_{0t}))$$

Eq. 18

Case b

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

$$t_{UTC} = W[\text{Modulo}(86400 + \Delta t_{LSF} - \Delta t_{LS})]$$

$$\text{where: } W = (t_E - \Delta t_{UTC} - 43200)[\text{Modulo } 86400] + 43200$$

Eq. 19

Case c

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

$$t_{UTC} = (t_E - \Delta t_{UTC})[\text{Modulo } 86400]$$

$$\text{where: } \Delta t_{UTC} = \Delta t_{LSF} + A_0 + A_1(t_E - t_{0t} + 604800(WN - WN_{0t}))$$

Eq. 20

5.1.8. GPS to Galileo System Time Conversion and Parameters

The difference between the Galileo and the GPS time scales, expressed in seconds, is given by the equation below.

$$\Delta t_{Systems} = t_{Galileo} - t_{GPS} = A_{0G} + A_{1G}[TOW - t_{0G} + 604800 \cdot (WN - WN_{0G})] \quad \text{Eq. 21}$$

with

- A_{0G} constant term of the offset $\Delta t_{systems}$
- A_{1G} rate of change of the offset $\Delta t_{systems}$
- t_{0G} reference time for GGTO data
- $t_{Galileo}$ GST time (s)
- t_{GPS} GPS time(s)
- WN GST Week Number
- WN_{0G} Week Number of the GPS/Galileo Time Offset reference

The user must account in the above formula for the truncated nature (roll-over) of the weekly parameters (WN, WN_{0G}), considering that at the time of broadcast of the GGTO parameters, the absolute value of the difference between untruncated WN and WN_{0G} values does not exceed 31.

The GGTO parameters are formatted according to the values in Table 69.

When the GGTO is not available the GGTO parameters disseminated are: A_{0G} (all ones -16 bits), A_{1G} (all ones - 12 bits), t_{0G} (all ones - 8 bits), WN_{0G} (all ones - 6 bits). When a user receives all four parameters set to all ones the GGTO is considered as not valid.

Parameter	Definition	Bits	Scale factor	Unit
A_{0G}	Constant term of the polynomial describing the offset $\Delta t_{systems}$	16*	2^{-35}	s
A_{1G}	Rate of change of the offset $\Delta t_{systems}$	12*	2^{-51}	s/s
t_{0G}	Reference time for GGTO data	8	3600	s
WN_{0G}	Week Number of GGTO reference	6	1	week
Total GST-GPS Conversion Size		**42**		

Table 69. Parameters for the GPS Time to GST Offset Computation

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

5.1.9. Service Parameters

5.1.9.1. Satellite ID

The satellite Identification is coded with 6 bits and has the characteristics given in Table 70.

Parameter	Definition	Bits	Scale Factor	Unit	Values
SVID	Satellite Identification	6	N/A	dimensionless	0…63

Table 70. Satellite ID

Note: SVID = 0 is used in the broadcast almanac data to indicate unused almanac entries. SVID values 1 to 36 are defined in this OS SIS ICD. Higher values are reserved for future use.

5.1.9.2. Issue Of Data

The navigation data is disseminated in data batches each one identified by an Issue of Data. In nominal operation the navigation data (ephemeris, satellite clock correction and SISA) have limited validity duration depending on the data type. The identification of each batch by an Issue of Data (IOD) value enables:

- the users to distinguish the data in different batches received from each satellite

- to indicate to the user receiver the validity of the data (which have to be updated using new issue of navigation data)

- the user receiver to compute the full batch of data even if it misses some pages or start receiving the data somewhere during the transmission

Two IODs are defined for (Table 71):

- the ephemeris, satellite clock correction parameters and SISA

- the almanacs

Data Type	Bits	Unit
Ephemeris, Clock correction and SISA IOD_{nav}	10	dimensionless
Almanacs IOD_a	4	dimensionless

Table 71. IOD Values Mapping on Data Type

Each IOD has an associated reference time parameter disseminated within the batch.

Note: the broadcast group delay, ionospheric corrections, GST-UTC and GST-GPS conversion parameters, navigation data validity status and signal health status are not identified by any Issue of Data value.

5.1.9.3. Navigation Data Validity and Signal Health Status

The signal health status and data validity status refer to the transmitting satellite. These status flags are used as service performance level notification (e.g. notification of satellite non availability). The navigation data validity status transmitted on E5a, E5b and E1, is coded on 1 bit, according to Table 72 and Table 73.

Parameter	Definition	Bits	Scale factor	Unit
E5a$_{DVS}$	E5a Data Validity Status	1	N/A	dimensionless

Table 72. Data Validity Satellite Status (transmitted on E5a)

Parameter	Definition	Bits	Scale factor	Unit
E5b$_{DVS}$	E5b Data Validity Status	1	N/A	dimensionless
E1-B$_{DVS}$	E1-B Data Validity Status	1	N/A	dimensionless

Table 73. Data Validity Satellite Status (transmitted on E5b and E1-B)

The data validity status bit has the values shown in Table 74:

Data Validity Status	Definition
0	Navigation data valid
1	Working without guarantee

Table 74. Data validity Status Bit Values

The E5a signal health status transmitted on E5a-I is coded on 2 bits according to Table 75

Parameter	Definition	Bits	Scale factor	Unit
E5a$_{HS}$	E5a Signal Health Status	2	N/A	dimensionless

Table 75. Signal Health Status for E5a (transmitted on E5a)

The E5b and E1-B/C signal health status transmitted on E5b and E1-B are coded on 2 bits according to Table 76.

Parameter	Definition	Bits	Scale factor	Unit
E5b$_{HS}$	E5b Signal Health Status	2	N/A	dimensionless
E1-B$_{HS}$	E1-B/C Signal Health Status	2	N/A	dimensionless

Table 76. Signal Health Status for E5b and E1-B/C (transmitted on E5b and E1-B)

The signal status bits have the values shown in Table 77.

Signal Health Status	Definition
0	Signal OK
1	Signal out of service
2	Signal will be out of service
3	Signal Component currently in Test

Table 77. Signal Health Status Bit Values

5.1.9.4. Checksum

The checksum, which employs a CRC technique, is used to detect the reception of corrupted data. The checksum does not include the frame synchronisation pattern or the tail bit fields since these do not form part of the required message information. For the F/NAV and I/NAV data, a CRC of 24 bits is generated from the generator polynomial $G(X)$ described below.

$$G(X) = (1 + X)\, P(X) \qquad \text{Eq. 22}$$

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

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

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 $m(X)\, X^{24}$ 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.

5.1.9.5. Secondary Synchronisation Pattern

The Secondary Synchronisation Pattern (SSP) is a pre-defined data bit sequence of 8 bits located at the end of the I/NAV pages. The SSP can assume three different configurations, named SSP1, SSP2 and SSP3.

Before FEC encoding, the SSP is inserted between the CRC and the tail bits in the I/NAV pages on E1, cycling among the three configurations as shown in Table 38, thus maintaining synchronisation to $(GST_0 + 1\ s)$ modulo 6 seconds.

After FEC encoding, the last 16 symbols of E1 I/NAV pages provide three pre-defined sequences with well-defined cross-correlation properties. These are shown in Table 78.

	SSP1	SSP2	SSP3
Plain SSP configurations	00000100	00101011	00101111
Encoded SSP configurations (last 16 symbols of the I/NAV E1 pages, after FEC encoding of the 8 plain SSP bits + 6 tail bits)	1110100100100101	0110110001001110	1101000000111110

Table 78. Bit and symbol sequences of the three SSP configurations.

The Secondary Synchronisation Pattern allows a receiver to correlate a local replica of the encoded pattern configurations with the received data symbols, after de-interleaving. As soon as any occurrence of the three SSP configurations is detected in the incoming symbol stream, the receiver has the knowledge of the GST (modulo 6 seconds) without the need for successful data decoding.

Note: SSP configurations are an evolution of the Galileo navigation message and as such will be gradually deployed to all Galileo satellites, including those already in orbit. During this deployment phase the not-yet upgraded satellites will be downlinking a legacy reserved sequence.

SSP configurations will not be downlinked while I/NAV dummy messages are transmitted on E1-B (see Table 53).

In both cases above, the contents transmitted instead of the SSP configurations are not intended for time synchronisation and have low cross-correlation with the SSP configurations provided in Table 78.

5.1.10. Almanac

The almanac data is a reduced-precision subset of the clock and ephemeris parameters of the active satellites in orbit. The user receiver utilises the algorithm described in section 5.1.1 to compute the positions of the Galileo satellites. All parameters appearing in the equations of Table 61, but not included in the content of the almanac, are set to zero for satellite position determination.

The Galileo almanac orbital parameters consist of

- Semi-major axis
- Eccentricity
- Inclination
- Longitude of the ascending node
- Argument of perigee
- Mean anomaly

The almanac time correction is provided by the coefficients a_{f0} and a_{f1} of a first order polynomial, and is evaluated as per section 5.1.4 assuming the clock drift rate is set to zero.

Predicted signal health status is provided as well, which can be used to determine which Galileo satellites should be tracked by the receiver.

The IOD_a disseminated with the almanac data allows detection of almanac batch changes. The almanac reference time t_{0a} and reference week number WN_a apply to the orbital parameters and to the clock correction parameters from the associated almanac batch. The two-bit WN_a provides the two least significant bits of the associated GST week number.

The almanac parameters are transmitted according to the characteristics stated in Table 79 .

Parameter	Definition	Bits	Scale factor	Unit
SVID	Satellite ID (1 constellation of 36 satellites)	6	1	dimensionless
$\Delta(A^{1/2})$	Difference between the square root of the semi-major axis and the square root of the nominal semi-major axis ($A_{nominal}$ according to Table 1): $\Delta(A^{1/2}) = A^{1/2} - A^{1/2}_{nominal}$	13*	2^{-9}	meters$^{1/2}$
e	Eccentricity	11	2^{-16}	dimensionless
δ_i	Difference between the inclination angle at reference time and the nominal inclination ($i_{nominal}$ according to Table 1): $\delta_i = i_0 - \frac{i_{nominal}}{180°}$	11*	2^{-14}	semi-circles***
Ω_0	Longitude of ascending node of orbital plane at weekly epoch****	16*	2^{-15}	semi-circles***
$\dot{\Omega}$	Rate of change of right ascension	11*	2^{-33}	semi-circles/s***
ω	Argument of perigee	16*	2^{-15}	semi-circles***

Parameter	Definition	Bits	Scale factor	Unit
M_0	Satellite mean anomaly at reference time	16*	2^{-15}	semi-circles***
a_{f0}	Satellite clock correction bias "truncated"	16*	2^{-19}	s
a_{f1}	Satellite clock correction linear "truncated"	13*	2^{-38}	s/s
$E5a_{HS}$**	Satellite E5a signal health status	2	N/A	dimensionless
$E5b_{HS}$**	Satellite E5b signal health status	2	N/A	dimensionless
$E1\text{-}B_{HS}$**	Satellite E1-B/C signal health status	2	N/A	dimensionless
Total Satellite Almanac Size		**131(F/NAV) 133(I/NAV)**		
IOD_a	Almanac Issue Of Data	4	N/A	dimensionless
t_{0a}	Almanac reference time	10	600	s
WN_a	Almanac reference Week Number	2	1	week
Total Almanac References Size		**16**		

Table 79. Almanac Parameters

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

**   The F/NAV almanac transmitted on the E5a-I component contains the signal health status $E5a_{HS}$. The I/NAV almanac transmitted on the E5b-I and E1-B components contains both signal health status $E5b_{HS}$ and $E1\text{-}B_{HS}$. The two-bit health status is encoded as per Table 77.

***   Note that the 'semi-circle' is not a SI unit but can be converted as: 1 semi-circle = π radian.

****   More precisely, Ω_0 is the longitude of ascending node of orbital plane at the weekly epoch propagated to the reference time t_{0a} at the rate of change of right ascension.

5.1.11. Reduced Clock and Ephemeris Data

The Reduced Clock and Ephemeris Data (Reduced CED) is a compact set of ephemeris and clock minus radial error correction information, transmitted within one single I/NAV word and with a reduced accuracy with respect to the ephemeris of section 5.1.1. Receivers can use these reduced-precision parameters to compute an initial position fix in case a full ephemeris and clock correction set (I/NAV words 1 to 4) has not yet been received.

The Reduced CED for each Galileo satellite is composed of 8 parameters:

- 6 orbital parameters
- 2 clock minus radial error correction coefficients.

The Reduced CED for each Galileo satellite is according to the characteristics stated in Table 80.

Parameter	Definition	Bits	Scale factor	Unit
ΔA_{red}	Difference between the Reduced CED semi-major axis and the nominal semi-major axis ($A_{nominal}$ according to Table 1): $$\Delta A_{red} = A_{red} - A_{nominal}$$	5*	2^8	meters
e_{xred}	Reduced CED eccentricity vector component x***	13*	2^{-22}	dimensionless
e_{yred}	Reduced CED eccentricity vector component y***	13*	2^{-22}	dimensionless

Parameter	Definition	Bits	Scale factor	Unit
Δi_{0red}	Difference between the Reduced CED inclination angle at reference time and the nominal inclination ($i_{nominal}$ according to Table 1): $\Delta i_{0red} = i_{0red} - \dfrac{i_{nominal}}{180°}$	17*	2^{-22}	semi-circles**
Ω_{0red}	Reduced CED longitude of ascending node at weekly epoch	23*	2^{-22}	semi-circles**
λ_{0red}	Reduced CED mean argument of latitude***	23*	2^{-22}	semi-circles**
a_{f0red}	Reduced CED satellite clock bias correction coefficient	22*	2^{-26}	s
a_{f1red}	Reduced CED satellite clock drift correction coefficient	6*	2^{-35}	s/s
Total Reduced CED size		**122**		

Table 80. Reduced Clock and Ephemeris Data parameters

*   Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB.
**   Note that the 'semi-circle' is not a SI unit but can be converted as: 1 semi-circle = π rad, with π as per Table 61.

Table 81. ***   Definition of orbital elements: $e_x = e \cdot cos(\omega)$, $e_y = e \cdot sin(\omega)$, $\gamma_0 = M_0 + \omega$

The user can compute the ECEF coordinates of the SV's antenna phase centre position and the satellite time minus radial error correction at GST time t utilising the user algorithm for ephemeris determination listed in Table 61 and the satellite time correction algorithm defined in section 5.1.4. Additional computation steps, which are required when working with Reduced CED parameters instead of full-precision CED parameters, are listed in Tables 81-83.

Notes:

● The Reduced CED parameters introduced in this section cannot be combined with the full-precision CED parameters of section 5.1.1-5.1.3 when calling the user algorithms for ephemeris determination and/or satellite time correction, since the two sets are not cross-compatible.

● Computation of satellite position and clock correction from Reduced CED must use the parameters from a single Reduced CED word (i.e. parameters or intermediate results derived from different Reduced CED words cannot be combined).

The user can compute the Reduced CED reference time as described in Table 81. A set of Reduced CED parameters is usable for 10 minutes starting from its reference time.

Reference Time Computation	Description
$t_{0r} = modulo\left(30 * \left\lfloor \dfrac{TOT_{RedCED}}{30} \right\rfloor + 1s, 604800s\right)$ *	Reduced CED reference time (TOT_{RedCED} is the start time of transmission of the Reduced CED word in GST and $\lfloor . \rfloor$ indicates the integer part)

Table 82. Reduced CED parameters Reference Time Computation

*   Note: Since both t_{0e} and t_{0c} are reference times of week (GST modulo 604800 seconds), t_{0r} has to be expressed as modulo 604800 seconds value when replacing the reference times t_{0e} and t_{0c}. The Reduced CED reference time is aligned with the E1-B sub-frame boundary (see section 4.3.3.)

As previously described, in the following Tables 82 and 83 the additional computation steps required when working with Reduced CED parameters are described for the ephemeris and the clock correction computation, respectively.

Usage of Reduced CED Orbital Parameters	Description
$A^{1/2} = A^{1/2}_{red}$	Square root of the semi-major axis
$i_0 = i_{0red}$	Inclination angle at reference time *
$e = \sqrt{e^2_{xred} + e^2_{yred}}$	Eccentricity
$\omega = tan^{-1}\left(\frac{e_{yred}}{e_{xred}}\right)$	Argument of perigee *
$M_0 = \lambda_{0red} - \omega$	Mean anomaly at reference time *
$\Omega_0 = \Omega_{0red}$	Longitude of ascending node of orbital plane at weekly epoch *
$\Delta n = 0, \dot{\Omega} = 0, \dot{i} = 0, C_{uc} = 0, C_{us} = 0, C_{rc} = 0, C_{rs} = 0, C_{ic} = 0, C_{is} = 0$	Correction terms
$t_{0e} = t_{0r}$	Ephemeris reference time

Table 83. Introduction of Reduced CED Orbital Parameters into Computation of Satellite Position

* Angular parameters are in radians for further processing according to Table 61, i.e. insertion of i_{0red}, λ_{0red} and Ω_{0red} in units of radians.

After having applied the steps described in Table 82, GTRF coordinates of the SV antenna phase centre position at time t can be computed utilising the user algorithm for ephemeris determination defined in Table 61.

The combined correction for clock minus radial error is computed using the satellite time correction algorithm for Δt_{SV} as defined in section 5.1.4 with input parameters from Reduced CED applied as specified in table 83.

Usage of Reduced CED Clock minus Radial Error Correction Coefficients	Description
$a_{f0} = a_{f0red}$	SV clock bias correction coefficient
$a_{f1} = a_{f1red}$	SV clock drift correction coefficient
$a_{f2} = 0$	SV clock drift rate correction coefficient
$t_{0c} = t_{0r}$	Clock correction data reference Time of Week

Table 84. Introduction of Reduced CED Clock minus Radial Error Correction Coefficients into Computation of Δt_{SV}

The subsequent PVT computation can use Δt_{SV} calculated from Reduced CED as clock correction, but must then combine this clock correction with the satellite position computation using orbital parameters from the same Reduced CED word. This is important because the Reduced CED clock correction coefficients incorporate a fraction of the radial satellite position, in order to minimise ranging errors due to numerical quantisation of Reduced CED parameters.

Note that Δt_{SV} from Reduced CED is optimised for the dual-frequency signal combination (E1/E5b). Single-frequency OS (E1) users may use BGD(E1,E5b) introduced in section 5.1.5 in order to improve the Reduced CED ranging accuracy.

The Galileo satellites transmit Reduced CED only if the E5b and E1-B Data Validity Status and Signal Health Status flags defined in section 5.1.9.3 are set to "0", and if SISA(E1,E5b)≠NAPA as per section 5.1.12. Note that an absence of Reduced CED in the broadcast may also be due to operational reasons unrelated to the aforementioned SIS flags.

5.1.12. Signal–In–Space Accuracy (SISA)

Signal–In–Space Accuracy (SISA) is a prediction of the minimum standard deviation (1-sigma) of the unbiased Gaussian distribution which overbounds the Signal–In–Space Error (SISE) predictable distribution for all possible user locations within the satellite coverage area. When no accurate prediction is available (SISA = NAPA), this is an indicator of a potential anomalous SIS.

The SISA Index shall be encoded according to the values stated in the following table.

SISA Index	SISA Value
0........49	0cm to 49cm with 1cm resolution
50........74	50cm to 0.98m with 2cm resolution
75........99	1m to 1.96m with 4cm resolution
100......125	2m to 6m with 16cm resolution
126......254	Spare
255	No Accuracy Prediction Available (NAPA)

Table 85. SISA Index Values

The Signal–In–Space Accuracy (SISA) shall be coded according to the values stated in the following table.

Parameter	Definition	Bits	Scale factor	Units
SISA(E1,E5a)	SISA index for dual frequency E1-E5a	8	N/A	dimensionless
SISA(E1,E5b)	SISA index for dual frequency E1-E5b	8	N/A	dimensionless

Table 86. SISA Parameters

5.1.13. Protection of I/NAV Clock and Ephemeris Data by means of Reed-Solomon Outer Forward Error Correction

In order to provide the user with an option for a more robust decoding of I/NAV Clock and Ephemeris Data (CED), an Outer Forward Error Correction (FEC2) based on Reed Solomon (RS) encoding is provided within the E1-B I/NAV message. The FEC2 RS encoding is applied to the data bits of I/NAV word types 1-4.
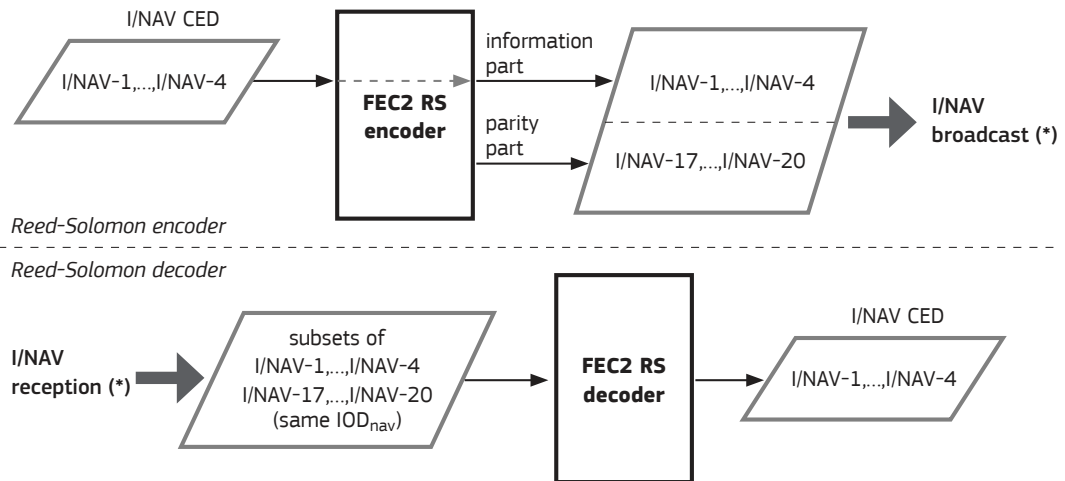

Figure 16.   Protection of I/NAV CED by Outer Forward Error Correction (FEC2 RS)

* Like all other I/NAV words, the I/NAV words 1-4 and 17-20 are also subject to convolutional encoding (FEC Viterbi) and interleaving before broadcast (see Chapter 4.1.4.). Users must perform de-interleaving and Viterbi decoding after symbol demodulation and before optional application of the FEC2 RS decoding.

The FEC2 RS is a systematic coding scheme, meaning that the CED is provided as unaltered information within I/NAV words 1-4 in every subframe. The FEC2 RS CED parity words are provided in words 17-20 and may differ in subsequent subframes. As depicted in Figure 16, users can either process just the CED words performing the standard Viterbi decoding or, alternatively, process also the FEC2 RS CED parity words in order to benefit from RS erasure and error correction capabilities.

Annex E provides a reference algorithm for the FEC2 RS decoder, which shows how the FEC2 RS CED parity words can be exploited by the user.

The encoding is constructed based upon a Galois Field of order 256, GF(256), using code symbols ('octets') consisting of 8 data or parity bits. The shortened Reed-Solomon code vector (or alternatively, shortened RS code word) comprises 118 octets and is subdivided into RS information vector C_{RS} (58 octets) and RS parity vector γ_{RS} (60 octets).

Annex F provides detailed FEC2 Reed-Solomon encoder parameters, implementation details, and one encoding example.

5.1.13.1. RS information vector

The FEC2 RS information vector C_{RS} (58 octets) represented in Figure 17, is constructed from the concatenation of the octet vectors $C_{RS,0}$, $C_{RS,1}$, $C_{RS,2}$ and $C_{RS,3}$, which are derived from I/NAV word types 1 to 4 (all words with the same IODnav).
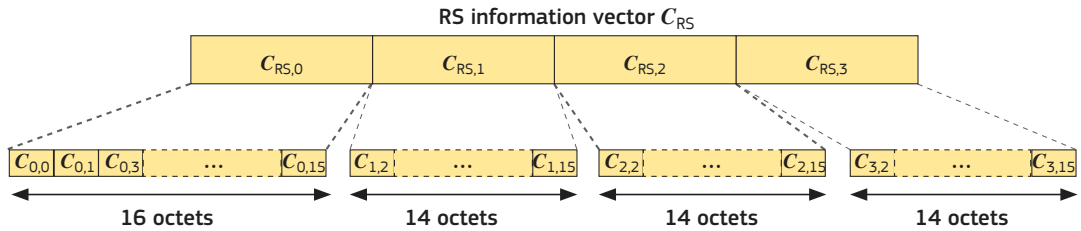
Figure 17. FEC2 RS information vector C_{RS}

The FEC2 RS information vector is built as follows:

a. The octet vector $C_{RS,0}=[C_{0,0} \quad ... \quad C_{0,15}]$ (16 octets) is derived from I/NAV word type 1 as per figure 18:
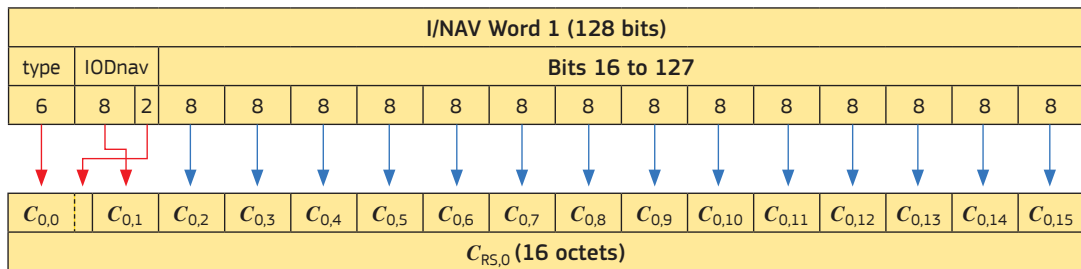

Figure 18. Derivation of the octet vector $C_{RS,0}$

- The octet $C_{0,0}$ consists of a concatenation of the word type field (bit pattern '000001' for word type 1) and of the 2 LSBs of the IODnav derived from word type 1.

- The octet $C_{0,1}$ consists of the 8 MSBs of IODnav derived from word type 1.

- The octets $C_{0,2}$ to $C_{0,15}$ are built by partitioning I/NAV word type 1 bits 16 to 127 into octets while maintaining the order of MSB to LSB.

b. The octet vectors $C_{RS,1}=[C_{1,2} \quad ... \quad C_{1,15}]$, $C_{RS2}=[C_{2,2} \quad ... \quad C_{2,15}]$ and $C_{RS,3}=[C_{3,2} \quad ... \quad C_{3,15}]$ (14 octets each) are derived from I/NAV word types 2, 3 and 4 respectively:
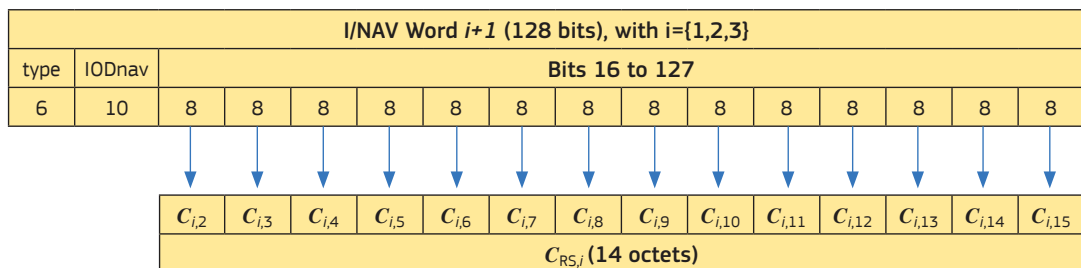
Figure 19. Derivation of the octet vectors $C_{RS,1}$, $C_{RS,2}$ and $C_{RS,3}$

- The octets $C_{i,0}$ and $C_{i,1}$ (i = 1,2,3) corresponding to bits 0...15 (word type and IODnav) of I/NAV word types 2...4 are not included in the RS information vector, as this information is already provided through $C_{0,0}$ and $C_{0,1}$.

- The octets $C_{i,2}$ to $C_{i,15}$ are built by partitioning I/NAV word type 2...4 bits 16 to 127 into octets while keeping the order of MSB to LSB.

c. The FEC2 RS information vector C_{RS} is obtained by concatenating the octet vectors $C_{RS,0}$, $C_{RS,1}$, $C_{RS,2}$, and $C_{RS,3}$ as per figure 17.

5.1.13.2. RS parity vector

The FEC2 RS parity vector γ_{RS} (60 octets) consists of the concatenation of the octet vectors $\gamma_{RS,0}$, $\gamma_{RS,1}$, $\gamma_{RS,2}$ and $\gamma_{RS,3}$ according to the following figure.
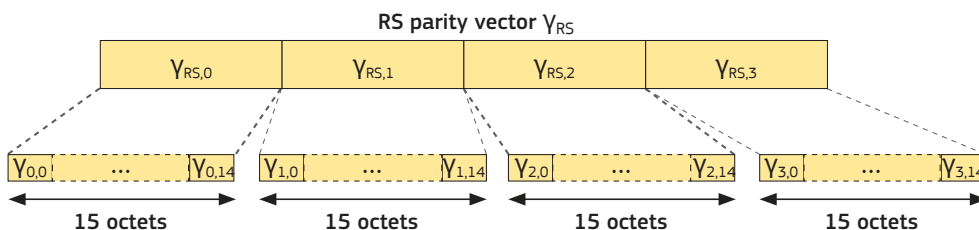
Figure 20. FEC2 RS parity vector γ_{RS}

The octet vectors $\gamma_{RS,0}$, $\gamma_{RS,1}$, $\gamma_{RS,2}$ and $\gamma_{RS,3}$ (15 octets each) are broadcast in I/NAV word types 17, 18, 19 and 20 (FEC2 RS CED words), where

- the field 'type' contains the binary FEC2 Reed–Solomon word type number,

- the field 'L' contains the 2 LSBs of IODnav,

- the remaining bits 6 to 13 and bits 16 to 127 provide the 15 octets $\gamma_{i,0}$ to $\gamma_{i,14}$
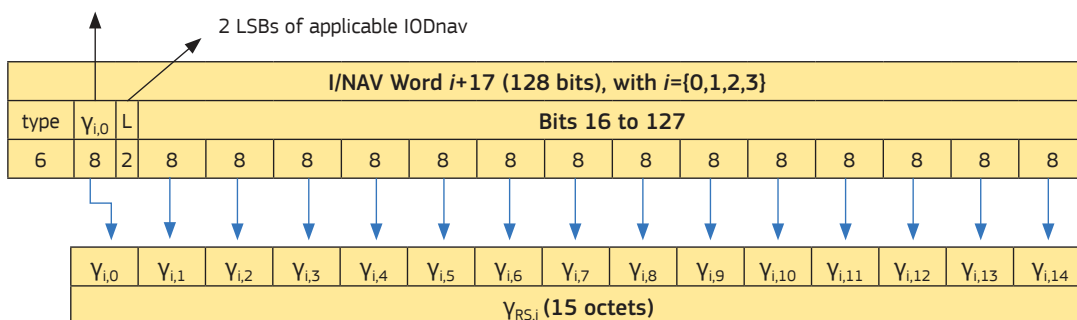
Figure 21. Derivation of the octet vectors $\gamma_{RS,0}$, $\gamma_{RS,1}$, $\gamma_{RS,2}$ and $\gamma_{RS,3}$

Note: The 2 LSBs of IODnav are provided to support detection of changes to IODnav after Viterbi decoding and prior to an RS decoding attempt.

A user may attempt to recover the 58 octets of the shortened RS information vector, containing the I/NAV clock and ephemeris data, with any combination of four or more received words with different types within the range 1 to 4 and 17 to 20. All words must have the same IODnav.

The RS erasure and error correction capability can be used

- to recover missing RS octets from the RS information vector and/or

- to correct errors contained in received octets of the RS information vector.

5.2. SAR RLM Data

Each Return Link Message encapsulated in a SAR data page contains the following data:

- Beacon ID (60 bits):
The Beacon ID is identical to the 60 bits (15 Hexadecimal characters) of the standard beacon identification defined in the COSPAS – SARSAT T.001 document (RD2). It uniquely identifies the beacon to which the RLM is addressed.

- Message code (4 bits):
The Message Code defines the Return Link Service according to Table 86.

RLM	Message Code (4 bits)	Return Link Service
Short-RLM	0 0 0 1	Acknowledgement Service
Short-RLM	1 1 1 1	Test Service
Short-RLM	Other codes	Spare
Long-RLM	All codes to be defined	Spare

Table 87. SAR RLM Message Code Values

- Parameters field (16 bits for the short RLM, 96 bits for the long RLM):
The Parameters field provides the information related to the specific Return Link Service identified by the "Message Code".
The last bit of the Parameters field, i.e. bit 16 of the Short-RLM Parameters field and bit 96 of the Long-RLM Parameters field, is a SAR RLM data parity bit. This parity bit shall ensure that the total number of ones (1) in the fields "Beacon ID", "Message Code" and "Parameters", (including spare bits), is even.
The Parameters field values for Return Link Services based on Short-RLM are defined in Table 87:

Return Link Service	Beacon Id			Message Code				Short-RLM Parameters Field															
	60			4				16															
	Bit 1**	to	Bit 60	Bit 61	Bit 62	Bit 63	Bit 64	Bit 65	Bit 66	Bit 67	Bit 68	Bit 69	Bit 70	Bit 71	Bit 72	Bit 73	Bit 74	Bit 75	Bit 76	Bit 77	Bit 78	Bit 79	Bit 80
Acknowledgement Service – Type 1*	15 Hex Id			0	0	0	1	1	0	Spare													Parity
Test Service	15 Hex Id			1	1	1	1	Reserved															Parity

Table 88. SAR Short-RLM Data Values

* Combinations of Message Code [0001] (Acknowledgement Service) with other values of bits 65 – 66 are spare. Refer to COSPAS – SARSAT T.001 document (RD2) for the service description of the acknowledgement Type 1.

** Bit numbers are counted after concatenating the four parts of Short-RLM data described in section 4.3.7 "SAR Field Structure". Bit 1 is received first, Bit 80 is received last.

The Parameters field values for Long-RLM are currently not defined.

Annex A - List of Acronyms

AltBOC	Constant envelope modulation scheme for combining two sidebands each consisting itself of two binary signals (in I- and Q-component).
ARNS	Aeronautical Radionavigation Services
BGD	Broadcast Group Delay
BOC	Binary Offset Carrier
CBOC	Composite Binary Offset Carrier modulation
CDMA	Code Division Multiple Access
CED	Clock and Ephemeris Data
CoP	Centre of Phase
COSPAS – SARSAT	Cosmicheskaya Systyema Poiska Avariynich Sudov – Search and Rescue Satellite Aided Tracking
CRC	Cyclic Redundancy Check
CS	Commercial Service
DME	Distance Measuring Equipment
DN	Day Number
ECEF	Earth-Centred, Earth-Fixed
EGNOS	European Geostationary Navigation Overlay Service
FEC	Forward Error Correction
FEC2	Outer Forward Error Correction
GF	Galois Field
GGTO	Galileo/GPS Time Offset
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GST	Galileo System Time
GTRF	Galileo Terrestrial Reference Frame
I	In-phase signal component
ICD	Interface Control Document
ID	Identifier
IOD	Issue Of Data
ITU	International Telecommunication Union
ITU-R	ITU – Radiocommunication Sector
JTIDS	Joint Tactical Information Distribution System
LAN	Longitude of the Ascending Node
LFSR	Linear Feedback Shift Register
LSB	Least Significant Bit
Mcps	Mega chips per second
MHz	Megahertz
MIDS	Multifunctional Information Distribution System
MODIP	MOdified DIP latitude
MSB	Most Significant Bit
MUX	Multiplexer
N/A	Not Applicable
NAPA	No Accuracy Prediction Available
NIB	Non-Interference Basis
NRZ	Non-Return-to-Zero
OS	Open Service
PSK	Phase-Shift Keying

PVT	Position, Velocity and Time
Q	Quadrature Signal Component
QPSK	Quadrature Phase-Shift Keying
RAAN	Right Ascension of the Ascending Node
RF	Radio Frequency
RHCP	Right-Hand Circular Polarisation
RLM	Return Link Message
RNSS	Radionavigation-Satellite Services
RS	Reed-Solomon
SAR	Search-and-Rescue Service/Signal
SI	International System of Units (Le Système international d'unités)
SIS	Signal-In-Space
SISA	Signal-In-Space Accuracy
sfu	Solar flux unit
SNF	Satellite Navigation Frame
SSP	Secondary Synchronisation Pattern
SV	Space Vehicle
SVID	Space Vehicle IDentifier
TACAN	TACtical Air Navigation (system) equipment
TOT	Time Of Transmission
TOW	Time Of Week
TTF	Time To Fix
UTC	Coordinated Universal Time
WN	Week Number

Annex B - Definitions and Nomenclature

E5-Signal	The Galileo E5-signal consists of the signals E5a, E5b (and modulation product signals) and is transmitted in the frequency band 1164 – 1215 MHz allocated to RNSS with a worldwide co-primary status. The E5-signal shares the band with the co-primary Aeronautical Radionavigation Service (ARNS) (ITU-R Radio Regulations). Moreover, it shares the band with other RNSS-signals provided by EGNOS, GPS-L5, GLONASS etc. as well as signals of the ARNS (DME, TACAN). Also found in the band is the JTIDS-MIDS signal which is permitted on an NIB.
E5a-Signal	The Galileo E5a-signal is an inherent element of the E5-signal and consists of a data-component transmitted in the in-phase component and a pilot-component transmitted in the quadrature component. The E5a-signal provides the F/NAV message supporting Galileo Open Service and overlaps (in the spectrum) with the GPS-L5-signal.
E5b-Signal	The Galileo E5b-signal is an inherent element of the E5-signal and consists of a data-component transmitted in the in-phase component and a pilot-component transmitted in the quadrature component. The E5b-signal provides the I/NAV message and supports the Open Service and the Commercial Service.
E6-Signal	The Galileo E6-signal consists of the signal components E6-B and E6-C and is transmitted in the frequency band 1260 – 1300 MHz allocated on a worldwide co-primary basis (ITU-R Radio Regulations), sharing with radar systems of the radio navigation and radiolocation service. The signal components E6-B and E6-C are data-component and pilot-component respectively. The E6-signal provides the C-NAV message and supports Commercial Service.
E1- Signal	The Galileo E1-signal comprises the signal components E1-B and E1-C and is transmitted in the frequency band 1559 – 1591 MHz allocated to RNSS and ARNS on a worldwide co-primary basis (ITU-R Radio Regulations).
	The signal components E1-B and E1-C are data-component and pilot-component respectively. The E1-signal provides the I/NAV message and supports the Open Service and the Commercial Service.
Navigation Data Stream	Sequence of bits carrying the navigation data information by using a frame structured transmission protocol.
F/NAV Message	Navigation message provided by the E5a signal for Open Service.
I/NAV Message	Navigation message provided by E5b and E1-B signals, supporting the Open Service and the Commercial Service.
C/NAV Message	Commercial navigation message type provided by the E6-B signal supporting Commercial Service.
Data component	A data component is the result of modulating ranging code, sub-carrier (if present) and secondary code with a navigation data stream.
Pilot component	A pilot component (or dataless component) is made of ranging code, sub-carrier (if present) and secondary code only, not modulated by a navigation data stream.
Receiver reference bandwidth	The bandwidth of a hypothetical receiver with ideal (rectangular frequency response) input filters

Annex C – Galileo E1 and E5 Primary Codes

C.1. Introduction

This annex provides the primary codes (expressed in hexadecimal format) for the Galileo Open Signal components E5a-I, E5a-Q, E5b-I, E5b-Q, E1-B and E1-C in sections C.3 to C.8, respectively. The E5 codes are derived from LFSR sequences as described in Section 3.4.1 and provided here for convenience and completeness.

C.2. Hexadecimal Coding Convention

Generally, one hexadecimal symbol (0,..,9, A,..,F) corresponds to four succeeding code-chips. The leftmost code-chip corresponds to the first code-chip in time, and the rightmost code-chip corresponds to the last code-chip in time. The first group is built with the first four code-chips, the second group with the fifth to eighth code-chip etc.

For primary codes whose length is not divisible by four, the last hexadecimal symbol is built from the last group of code-chips, filled up with zeros at the end in time (to the right) to reach a final length of 4 binary symbols. The translation from the chip-stream to hexadecimal symbol stream is illustrated with an example code of length 10 in Table 88.

Time (in Chip)	1	2	3	4	5	6	7	8	9	10	11	12
Logic Representation of Chip-Values	1	1	1	0	1	1	0	0	0	1	-	-
Logic Representation Filled up with Zeros at the End	1	1	1	0	1	1	0	0	0	1	0	0
Logic to Decimal Translation												
Decimal Representation	14				12				4			
Hexadecimal Representation	E				C				4			

Table 89. Example for the Translation of Logical (binary) Spreading Code into Hexadecimal Representation

Component	Primary Code Length (chips)	Number of Hexadecimal Symbols	Number of Filled up Zeros	Number of Defined Codes
E5a-I	10230	2558	2	50
E5a-Q	10230	2558	2	50
E5b-I	10230	2558	2	50
E5b-Q	10230	2558	2	50
E1-B	4092	1023	0	50
E1-C	4092	1023	0	50

Table 90. Primary Code-Length and Hexadecimal Representation Characteristics for the Galileo Signal Components.

C.3. to C.8. Primary Codes

The primary codes can be accessed/saved from the attachments panel of the pdf file reader.

Annex D – FEC Coding and Interleaving Numerical Examples

This appendix provides input and output numerical examples for the convolutional encoding described in Section 4.1.4.1 and for the subsequent interleaving described in Section 4.1.4.2. The same examples can be applied to a decoder and a de-interleaver, by simply using them in the reverse order.

In this annex two examples are provided, namely one for F/NAV and one for I/NAV. The only difference between the two is the size of the block interleaver, as the same convolutional coding is employed for both messages.

D.1. F/NAV FEC Coding and Interleaving Numerical Example

Let the input to the convolutional encoder, M_{input}^{FNAV}, be the following 244 – bit binary string:

```
11111111  11110000  11001100  10101010  00000000  00001111  00110011  01010101
11100011  11101100  11011111  10001010  00011100  00010011  00100000  01110101
01010101  01100001  01100010  01100011  10101010  10011110  10011101  10011100
00011100  00100011  00001101  00111001  11011100  11101100  0000
```

Note that the last six bits of the string M_{input}^{FNAV} are 6 zeros, corresponding to the tail bits described in Section 4.2.2.2.

The output of the convolutional encoder (described in Table 24 and Figure 13 within Section 4.1.4.1), $M_{encoded}^{FNAV}$, is the following 488 – symbol binary string:

```
10001100  00011010  10101010  01110011  00110001  01011010  01101111  01011001
01111000  10010101  01010101  10001100  11001110  10100101  10010000  10100110
10000100  00000010  00000010  00011011  10011001  11101011  01011100  00011000
10111011  11111101  11111101  11100100  01100110  00010100  10100011  11100111
10100110  01100110  01101011  00010000  00011100  00011101  01010001  10101110
00111001  11101001  10010100  11101111  11100011  11100010  10101110  01010001
11111101  00111101  11110000  10101001  11011000  00110010  00111111  10000100
10010010  10010110  00100100  10101011  01001110
```

The encoded symbols of the string $M_{encoded}^{FNAV}$ are given as input to the F/NAV block interleaver described in Table 25 within Section 4.1.4.2, characterised by 61 columns and 8 rows. The output of the interleaver, $M_{interleaved}^{FNAV}$, is the following 488 – symbol binary string:

```
10100000  01011111  10001100  11110011  10000001  01111110  10111001  11010000
10111101  01000000  00110011  11001011  00010010  11101101  01000000  01001110
10100001  01000001  00111110  11111000  01110111  10111101  10001100  10111011
11000100  00110111  11001000  00111101  01000011  11011101  10001110  01111001
10000001  11111110  00000010  11011101  00101101  10100001  11000001  00111110
11000001  00111110  11100110  10011001  01100001  10110101  11011000  00100101
11010010  00101111  10000100  01111000  00011011  01100011  01101100  10000011
10011100  01100100  11011011  00111010  01000010
```

D.2. I/NAV FEC Coding and Interleaving Numerical Example

Let the input to the convolutional encoder, M_{input}^{INAV}, be the following 120 – bit binary string:

```
11111111  11110000  11001100  10101010  00000000  00001111  00110011  01010101
11100011  11101100  11011111  10001010  00011100  00010011  01000000
```

Note that the last six bits of the string M_{input}^{INAV} are 6 zeros, corresponding to the tail bits described in Section 4.3.2.2.

The output of the convolutional encoder (described in Table 23 and Figure 13 within Section 4.1.4.1), $M_{encoded}^{INAV}$, is the following 240–symbol binary string:

```
10001100  00011010  10101010  01110011  00110001  01011010  01101111  01011001
01111000  10010101  01010101  10001100  11001110  10100101  10010000  10100110
10000100  00000010  00000010  00011011  10011001  11101011  01011100  00011000
10111011  11111101  11111101  11100100  01010011  00100010
```

The encoded symbols of the string $M_{encoded}^{INAV}$ are given as input to the I/NAV block interleaver described in Table 25 within Section 4.1.4.2, characterised by 30 columns and 8 rows. The output of the interleaver, $M_{interleaved}^{INAV}$, is the following 240–symbol binary string:

```
10100000  01011111  10001100  11110000  01011110  10100000  00011001  11100011
10101000  01010000  01001111  01010111  01111000  10000110  11111010  11100111
10011000  00011111  11100010  00001001  11110110  00001001  11000111  01100000
10010111  01001000  11000110  11011001  00000111  00111010
```

Annex E – Reference Algorithm for Exploitation of FEC2 Reed-Solomon Words

In order to recover the I/NAV clock and ephemeris data from unaltered CED words (I/NAV words 1-4) and/or FEC2 RS CED parity words (I/NAV words 17-20), the following simplified example algorithm may be used by the user receiver:
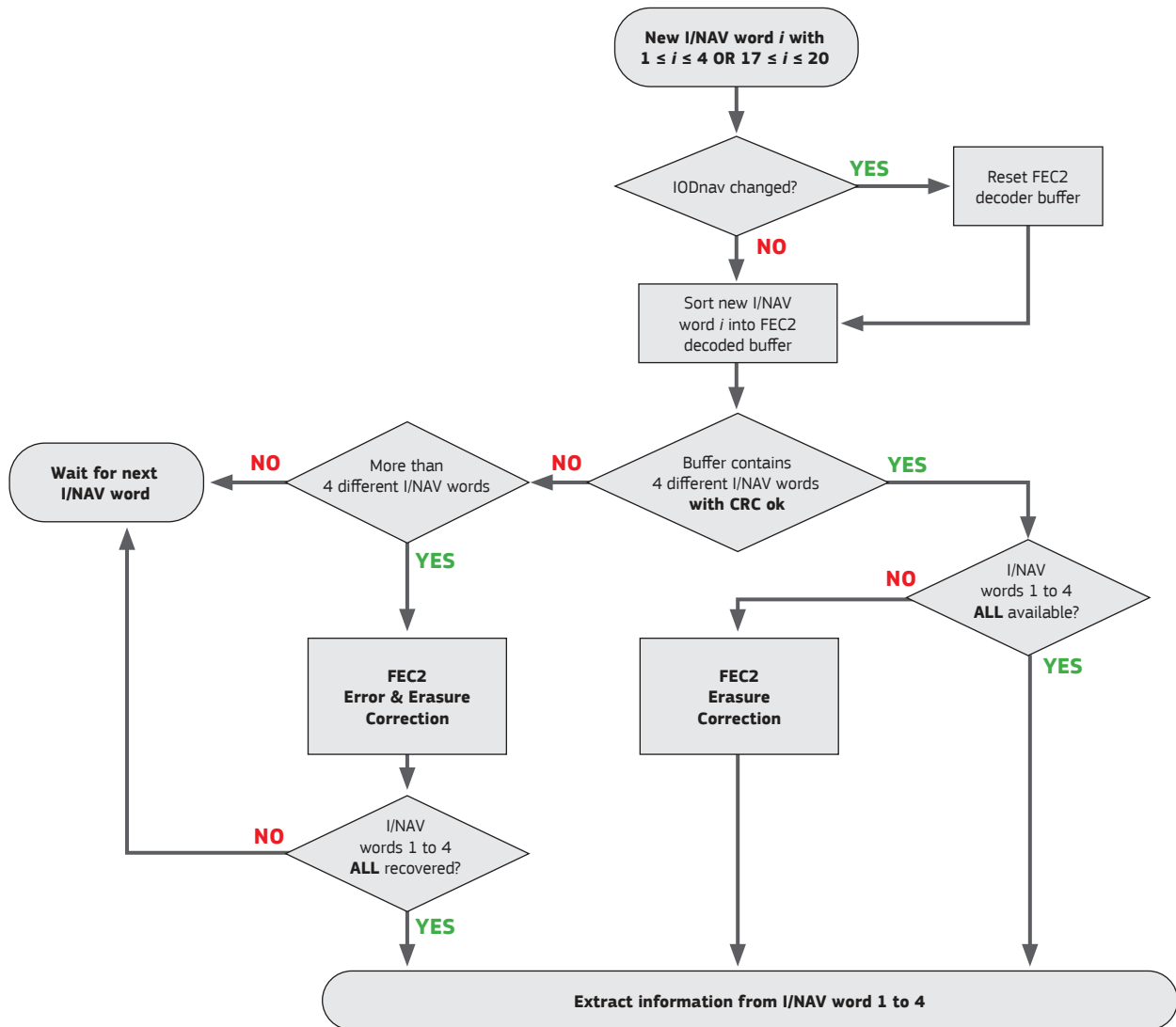
Figure 22.   Reference algorithm for exploitation of the FEC2 RS CED words

The octets $C_{0,0}$ and $C_{0,1}$ of the FEC2 RS information vector (see section 5.1.13) contain information that is either pre-defined (i.e. word type value for I/NAV word type 1) or known from repeated transmission in other CED or FEC2 RS CED words (i.e. IODnav value). This known or repeated information can be used to verify correctness of the FEC2 Reed-Solomon erasure and error correction (sanity check).

Annex F – Specification of the Outer FEC2 Reed-Solomon Encoding of CED in the Galileo E1 I/NAV Message

F.1. Introduction

This annex provides the definition of the Galois field, the generator polynomial and the generator matrix used for FEC2 Reed-Solomon coding of I/NAV clock and ephemeris data (CED), transmitted in the Galileo I/NAV words 17, 18, 19 and 20.

F.2. Galois Field

The FEC2 Reed-Solomon is based on a Galois field of order 256, GF(256), defined by the primitive polynomial

$$p(x)=x^8+x^4+x^3+x^2+1.$$

The resulting Galois field elements in polynomial representation, octet representation (binary and integer), and in α^n representation with primitive element α are provided in the following table:

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}
$\alpha^4+\alpha+1$	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 90: Polynomial, octet and power representation of GF(256) using $p(x)=x^8+x^4+x^3+x^2+1$.

F.3 FEC2 Reed-Solomon Generator Polynomial and Generator Matrix

F.3.1 The Shortened Reed-Solomon Code

The Reed-Solomon code used as outer code for Clock and Ephemeris Data in the Galileo E1 I/NAV message is a shortened version of an (n,k,d) linear code, where

• the unshortened code vector length is $n = 2^m - 1 = q - 1 = 255$,

• the unshortened information vector length is $k = 195$

• and the minimum Hamming distance is $d = n - k + 1 = 61$.

A code vector is shortened by setting s symbols of the information vector to the zero element of the underlying GF(256). The resulting shortened code is $(n_s,k_s,d)=(n-s,k-s,d)$. The message to be transmitted consists of k_s=58 octets $c_0,c_1,...,c_{57}$. Since the number of required parity octets is n_s-k_s=60, the shortened code vector has a length of $n_s=k_s+60=58+60=118$ and the shortening parameter is determined as $s=n-n_s$=255-118=137. The shortened code is (n_s,k_s,d)=(118,58,61).

F.3.2 Generator Polynomial

The foreseen Reed-Solomon code is a narrow sense code over GF(256) with primitive element α. The corresponding generator polynomial in the indeterminate x is

$$g(x) = \prod_{i=1}^{n_s-k_s} (x - \alpha^i) = \sum_{j=0}^{60} g_j \cdot x^j = \alpha^{45} + \alpha^{92}x + \alpha^{65}x^2 + \cdots + \alpha^{108}x^{59} + x^{60}.$$

The resulting coefficients g_j of the polynomial are tabularised below, using integer octet representation:

j	g_j		j	g_j		j	g_j		j	g_j
0	193		15	23		30	66		45	251
1	91		16	36		31	46		46	124
2	190		17	202		32	131		47	18
3	154		18	63		33	42		48	186
4	101		19	20		34	187		49	244
5	58		20	102		35	9		50	166
6	231		21	230		36	122		51	235
7	197		22	131		37	3		52	167
8	152		23	141		38	19		53	108
9	88		24	214		39	118		54	41
10	73		25	45		40	6		55	19
11	62		26	101		41	154		56	76
12	169		27	94		42	14		57	48
13	88		28	62		43	193		58	42
14	188		29	65		44	79		59	208
									60	1

Table 91: Integer octet representation of the coefficients of the generator polynomial

F.3.3 Systematic Encoding Using the Reed–Solomon Generator Polynomial

The zero-padded information vector $\tilde{\mathbf{c}}$

$$\tilde{\mathbf{c}}^{\mathrm{T}} = [\tilde{c}_0, \tilde{c}_1, \tilde{c}_2, \ldots, \tilde{c}_{194}] = [c_0, c_1, c_2, \ldots, c_{57}, \underbrace{0, \ldots, 0}_{137 \text{ zeros}}]$$

can be represented in polynomial form by

$$\tilde{c}(x) = \sum_{j=0}^{194} \tilde{c}_j \cdot x^j = \tilde{c}_0 + \tilde{c}_1 \cdot x + \tilde{c}_2 \cdot x^2 + \cdots + \tilde{c}_{194} \cdot x^{194},$$

where the coefficients $\tilde{c}_{58}$ to $\tilde{c}_{194}$ are set to zero. The coefficients $c_0, c_1, \ldots, c_{57}$ form the shortened RS information vector

$$\mathbf{c}^{\mathrm{T}} = [c_0, c_1, c_2, \ldots, c_{57}].$$

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

$$\tilde{\Gamma}(x) = \tilde{c}(x) \cdot x^{n-k} - R_{g(x)}[\tilde{c}(x) \cdot x^{n-k}]$$

$$= \sum_{j=0}^{254} \tilde{\Gamma}_j \cdot x^j = \tilde{\Gamma}_0 + \tilde{\Gamma}_1 \cdot x + \tilde{\Gamma}_2 \cdot x^2 + \cdots + \tilde{\Gamma}_{254} \cdot x^{254}$$

$$= \gamma_0 + \gamma_1 x + \cdots + \gamma_{59} x^{59} + c_0 x^{60} + c_1 x^{61} + \cdots + c_{57} x^{117}$$

where the coefficients $\tilde{\Gamma}_{118}$ to $\tilde{\Gamma}_{254}$ equal zero and are omitted during transmission. The function $R_{g(x)}[f(x)]$ denotes the remainder of the polynomial division $\frac{f(x)}{g(x)}$ and the coefficients γ and c denote parity symbols and information symbols, respectively.

The (shortened) RS code vector Γ therefore consists of the non-zero information part and the parity part of $\tilde{\Gamma}$ in exchanged order, i.e.: information part first and parity part second:

$$\Gamma^T = [\Gamma_0, \Gamma_1, \dots, \Gamma_{117}] = \left[\tilde{\Gamma}_{60}, \tilde{\Gamma}_{61}, \dots, \tilde{\Gamma}_{117}, \tilde{\Gamma}_0, \tilde{\Gamma}_1, \dots, \tilde{\Gamma}_{59}\right] = [c_0, c_1, c_2, \dots, c_{57}, \gamma_0, \gamma_1, \dots, \gamma_{59}].$$

Only the shortened RS code vector is broadcast.

F.3.4 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 shortened RS code vector in the required indexing order.

The unshortened RS code vector $\tilde{\Gamma}$ as per section F.3 consists of 255 octets, the first 60 octets being the parity part γ. The remaining 195 octets are the unshortened information vector $\tilde{c}$, whose first 58 octets then form the shortened RS information vector c (figure 23 a). Extracting the nonzero part of $\tilde{\Gamma}$, and swapping its components γ and c, then yields the desired form of the shortened RS code vector Γ (figure 23 b).
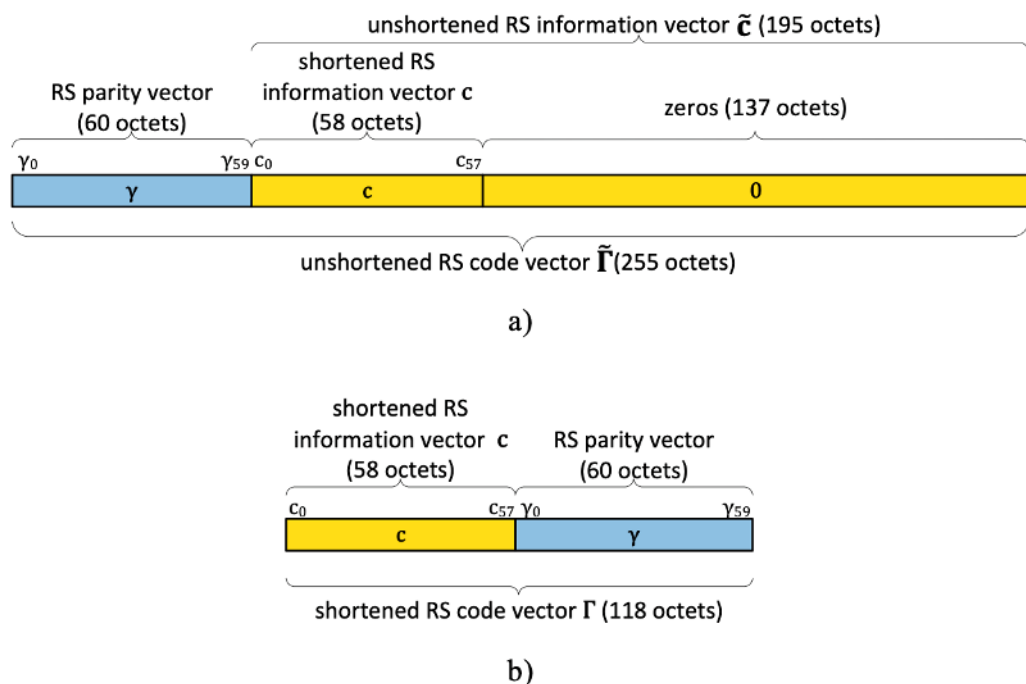

Figure 23. Shortening of the systematic RS code vector (symbol allocation for polynomial encoding)

The shortened code vector $\mathbf{\Gamma}$ as per figure 23 can be computed through a GF(256) matrix multiplication of the shortened RS information vector c with the systematic generator matrix $\mathbf{G}$:

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

or more explicitly

$$\mathbf{\Gamma} = \begin{pmatrix} \Gamma_0 \\ \Gamma_1 \\ \vdots \\ \Gamma_{117} \end{pmatrix} = \begin{pmatrix} c_0 \\ c_1 \\ \vdots \\ c_{57} \\ \gamma_0 \\ \gamma_1 \\ \vdots \\ \gamma_{59} \end{pmatrix} = \begin{pmatrix} \boldsymbol{c} \\ \boldsymbol{\gamma} \end{pmatrix} = \mathbf{G} \cdot c = \begin{pmatrix} \mathbf{I} \\ \mathbf{P} \end{pmatrix} \cdot \begin{pmatrix} c_0 \\ c_1 \\ \vdots \\ c_{57} \end{pmatrix}.$$

The systematic generator matrix $\mathbf{G}$ consists of 118 rows and 58 columns and can be split into two submatrices $\mathbf{I}$ and $\mathbf{P}$, where $\mathbf{I}$ is the identity matrix of size 58x58 and $\mathbf{P}$ is a dense submatrix of size 60x58 which produces the parity part of the code vector, i.e. the RS parity vector $\boldsymbol{\gamma}$:

$$\mathbf{G} = \begin{pmatrix} 1 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \\ g_{58,0} & g_{58,1} & g_{58,2} & \cdots & g_{58,57} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ g_{117,0} & g_{117,1} & g_{117,2} & \cdots & g_{117,57} \end{pmatrix}$$

The PDF version of this ICD provides the generator matrix $\mathbf{G}$ as a file attachment, as comma separated values in octet representation as per table 90.

F.4 Further Notes on FEC2 Reed Solomon Implementations

F.4.1 Encoding Example

This section provides an example FEC2 Reed Solomon encoding, to support implementers of the above algorithms in the verification of their implementation. The sample information vector (see attached csv file)

$$c^T = [147, \quad 109, \quad 66, \quad 23, \ldots, 162],$$

which contains randomly generated Galois field symbols is encoded via the encoding algorithms described in the previous sections F.3.3 or F.3.4 and yields the shortened RS code vector (see attached csv file)

$$\mathbf{\Gamma}^T = [147, \quad 109, \quad 66, \quad 23, \ldots, 162, \quad 238, \quad 77, \quad 12, \quad 72, \ldots, 242].$$

The PDF version of this ICD provides the complete encoding example as file attachments, comma separated values in octet representation.

F.4.2 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

$$[147, \quad 109, \quad 66, \quad 23, ..., 162, \quad 0, \quad 248, \quad 29, \quad 36, ..., 7]$$

instead of the correct coded sequence

$$[147, \quad 109, \quad 66, \quad 23, ..., 162, \quad 238, \quad 77, \quad 12, \quad 72, ..., 242]$$

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

$$[c_{57}, c_{56}, c_{55}, ..., c_0]^T$$

instead of

$$c^T = [c_0, c_1, c_2, ..., c_{57}].$$

Therefore, the input sequence needs to be reversed

$$[c_{57}, c_{56}, c_{55}, c_{54}, ..., c_0] = [162, \quad 215, \quad 199, \quad 67, ..., 147]$$

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

$$[c_{57}, c_{56}, c_{55}, c_{54}, ..., c_0, \gamma_{59}, \gamma_{58}, \gamma_{57}, \gamma_{56}, ..., \gamma_0]$$
$$= [162, \quad 215, \quad 199, \quad 67, ..., 147, \quad 242, \quad 137, \quad 76, \quad 212, ..., 238]$$

Nevertheless, the ordering of the information and parity octets as described and depicted above in figure 23 b) must be restored before further processing and embedding the octets into the (RS) CED words.

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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.

G.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 OS 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 OS SIS ICD IPRs, the Authorised Person shall collaborate with the EU and provide the EU with all the assistance necessary to such defence.

G.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.

G.10. Applicable Law and Dispute Resolution

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

Except for the right of the EU and/or the Authorised Person to apply to a court of competent jurisdiction for a temporary restraining order or a preliminary injunction to prevent irreparable harm, any dispute, controversy or claim arising under, out of or relating to the Authorisation and any subsequent amendments thereof, including, without limitation, its validity, binding effect, interpretation, performance, breach or termination shall be submitted to mediation in accordance with the WIPO Mediation Rules. The place of mediation shall be Brussels. The language to be used in the mediation shall be English.

If, and to the extent that, any such dispute, controversy or claim has not been settled pursuant to the mediation within sixty (60) days of the commencement of the mediation, it shall, upon filing of a Request for Arbitration by either the EU or the Authorised Person, be referred to and finally determined by arbitration in accordance with the WIPO Expedited Arbitration Rules. Alternatively, if, before the expiration of said period of sixty (60) days, either the EU or the Authorised Person fails to participate or to continue to participate in the mediation, the dispute, controversy or claim shall, upon the filing of a Request for Arbitration by the participating EU or Authorised Person, be referred to and finally determined by arbitration in accordance with the WIPO Expedited Arbitration Rules. The arbitral tribunal shall consist of three arbitrators. The place of arbitration shall be Brussels. The language used in the arbitration proceedings shall be English.

In any action to enforce the Authorisation, the prevailing entity shall be entitled to recover its reasonable attorney's fees, court costs and related expenses from the other entity.

G.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 OS 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 OS SIS ICD IPRs by the Authorised Person.

G.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 filing	Applicant	Owner	Designated Countries
1	Patent	Multi-band antenna for satellite positioning system	PCT/EP2006/064067	10/07/2006	GSA	EU	Australia Canada Norway USA S.Korea China India Japan Russia
2	Patent	Method for providing assistance data to a mobile station of a satellite positioning system	PCT/EP2006/068177	07/11/2006	GSA	EU	Australia Canada Europe designated countries: (AT, BE, CH, CZ, DEDK, ES, FI, FR, GB, GR, HU, IE, IT, LU, NL, PL, PT, RO, SE, TR) USA S.Korea China India Japan Russia
3	Patent	Method and generator for generating a spread-spectrum signal (initially referred to as Use of antiphase CBOC (6.1) modulation to improve ranging accuracy in satellite navigation signals)	11738006	20/04/2007	GSA	EU	USA
4	Patent	Method and generator for generating a spread-spectrum signal	12559874	15/09/2009	GSA	EU	USA
5	Patent	Chaotic spreading codes and their generation	PCT/EP2007/063080	30/11/2007	GSA	EU	Australia Brazil Canada China Europe designated countries: (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR) India Japan S.Korea Russia USA
6	Copyright	OS SIS ICD	NA	NA	NA	EU	Worldwide

	IPR	Name of IPR	Application Number	Date of filing	Applicant	Owner	Designated Countries
7	Patent	Spreading codes for a satellite navigation system (concerning memory codes)	PCT/EP2004/014488	17/12/2004	ESA	EU	Canada Europe designated countries: (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR) USA Brazil China Japan
8	Patent	Spreading codes for a satellite navigation system (concerning secondary Codes)	PCT/EP2005/007235	01/07/2005	ESA	EU	Canada Europe designated countries: (BE, CH, CZ, DE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, SE, TR) USA Brazil China Japan
9	Patent	Method and device for generating a constant envelope navigation signal with four independent codes	PCT/FR2003/003695	12/12/2003	CENTRE NAT ETD SPATIALES (CNES)	Control by the EU under licence from CNES	Europe designated countries (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LI, LU, MC, NL, PT, RO, SE, SI, SK, TR) USA
10	Patent	Spread spectrum signal	PCT/EP2006/050179	12/01/2006	CNES	Control by the EU under licence from CNES	Canada China Europe designated countries (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LI, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR) Japan Russia USA
11	Patent	GNSS radio signal with an improved navigation message	PCT/EP2013/064477	09/07/2013	CNES	Control by the EU under licence from CNES	China Europe designated countries (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LI, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR) Japan South Korea USA
12	Patent	GNSS radio signal for improved synchronisation	PCT/EP2013/064573	10/07/2013	CNES	Control by the EU under licence from CNES	China Europe designated countries (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LI, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR) Japan South Korea USA

IPR	Name of IPR	Application Number	Date of filing	Applicant	Owner	Designated Countries
13 Patent	Modulation signals for a satellite navigation system	PCT/GB2004/003745	01/09/2004	Secretary of State for Defence of the UK	Control by the EU under licence from the Secretary of State for Defence of the UK	Australia Canada China Europe designated countries (BE, DE, DK, ES, FI, FR, GB, IT, NL, SE) India Japan New Zealand Russia USA
14 Patent	Signals, system, method and apparatus	PCT/GB2007/002293	20/06/07	Secretary of State for Defence of the UK	Control by the EU under licence from the Secretary of State for Defence of the UK	Australia Brazil Canada China Europe designated countries (BE, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NL, PT, SE, SK) Israel India Japan Republic of Korea Malaysia Norway New Zealand Russia Singapore USA
15 Patent Application	Techniques for Transmitting and Receiving GNSS Navigation Messages	16174636.7	15/06/16	Airbus Defence and Space GmbH	Control by the EU under licence from Airbus Defence and Space GmbH	EU (Pending)
16 Patent Application	Techniques for Transmitting and Receiving GNSS Navigation Messages	PCT/EP2017/064120	09/06/17	Airbus Defence and Space GmbH	Control by the EU under licence from Airbus Defence and Space GmbH	USA, China, Japan (Pending)

Annex H—Authorisation Concerning use of the Galileo Trade Marks

By using the Galileo Trade Marks in the Field of Use, 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.

The European Union (hereinafter "the EU") is the owner of the Galileo Trade Marks.

In the interest of facilitating and encouraging the market uptake of satellite navigation, as required by the GNSS Regulation, the EU represented by the European Commission hereby issues the Authorisation concerning the use of the Galileo Trade Marks in the Field of Use, towards natural or legal persons worldwide, subject to the terms, conditions and limitations described herein. The Authorisation is non-exclusive and royalty-free.

H.1. Definitions

The under mentioned terms printed with an initial capital letter shall have the meanings stated below. Any reference to the plural shall include the singular and any reference to the singular shall include the plural.

"**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 Galileo Trade Marks against the use 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.

"**EU Stakeholders**" – shall mean the European Space Agency (ESA), the European GNSS Agency (GSA) and other international organisations with activities in GNSS, any of the EU, ESA or GSA contractors and subcontractors at any tier working in the Galileo programme, operator(s) of the Galileo satellite navigation system, EU Member States and their institutions and bodies, including national space agencies.

"**Field of Use**" – shall mean the use of one or more of the Galileo Trade Marks by the Authorised Person in order to signify that the respective Products make use of the GNSS Services provided by the EU and/or the EU Stakeholders. Reference to the Galileo Trade Marks may be made by any means associated with the marketing of the Products, including but not limited to packaging, instructional and promotional materials.

"**Galileo Trade Marks**" – shall mean any and all trade mark registrations and applications owned by EU and/or the EU Stakeholders, anywhere in the world consisting of or incorporating the word GALILEO, including without limitation the trade mark applications and registrations set out in section H.10.

"**GNSS**" – shall mean Global Navigation Satellite System.

"**GNSS Regulation**" – shall mean Regulation (EU) 1285/2013 of the European Parliament and of the Council of 11 December 2013 on the implementation and exploitation of European Satellite Navigation Systems and repealing Council Regulation (EC) No 876/2002 and Regulation (EC) No 683/2008 of the European Parliament and of the Council.

"GNSS Services" – shall mean the following activities contemplated by the GNSS Regulation:

a) open service (OS), which is free of charge to the user and provides positioning and synchronisation information intended mainly for high-volume satellite navigation applications;

b) contribution, by means of Galileo open service signals and/or in cooperation with other satellite navigation systems, to integrity-monitoring services aimed at users of safety-of-life applications in compliance with international standards;

c) commercial service (CS) for the development of applications for professional or commercial use by means of improved performance and data with greater added value than those obtained through the open service;

d) public regulated service (PRS) restricted to government-authorised users, for sensitive applications which require a high level of service continuity, free of charge for the Member States, the Council, the Commission, EEAS and, where appropriate, duly authorised Union agencies; this service uses strong, encrypted signals;

e) contribution to the search and rescue support service (SAR) of the COSPAS-SARSAT system by detecting distress signals transmitted by beacons and relaying messages to them.

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

"Value Added Services" shall mean any service delivering different or additional capabilities with respect to signals broadcasted by the infrastructure developed under the European GNSS Programmes.

H.2. Ownership of Rights

Ownership of the Galileo Trade Marks shall remain with the EU and therefore, no title of any intellectual property right on the Galileo Trade Marks under the Authorisation shall be acquired by the Authorised Person.

The Authorisation shall be withdrawn and shall not apply to any natural or legal person that challenges the validity or enforceability of any of the Galileo Trade Marks or participates in such a challenge, or encourages or supports any third parties in such a challenge.

H.3. Scope of the Authorisation

The scope of the Authorisation is limited to the 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 use the Galileo Trade Marks 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 in article 13 and article 17 of the GNSS Regulation.

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 the EU Stakeholders.

Pursuant to the Authorisation, the EU's covenant not to assert covers the use of the Galileo Trade Marks in the context of the development and marketing of any Products, including its use on the Products themselves and on their packaging, instructional and promotional materials, by the Authorised Person or by third party contractors used by the Authorised Person for manufacturing said Products, only in the Field of Use;

In addition to the limitations described above, the Authorised Person shall not:

a) Use the Galileo Trade Marks or any confusingly similar sign as, or as part of, the stand-alone brand name or sub-brand name of any of its Products, or as the stand-alone registered or trading name of any corporate entity or business. For the avoidance of doubt, this does not prevent the Authorised Person from affixing one or more Galileo Trade Marks to the packaging of their Products;

b) Apply for or obtain registration of any trade mark which consists of, comprises, or is confusingly similar to the Galileo Trade Marks;

c) Claim any interest or rights to the Galileo Trade Marks, other than the rights explicitly granted by the EU under the Authorisation;

By way of example, acceptable use of the Galileo Trade Marks under the Authorisation and in the Field of Use would include "the new [Product brand name] satnav powered by Galileo" or "the [Product brand name] Galileo receiver". "A Galileo receiver" or "Galileo receivers" shall also be considered acceptable as referential uses. Unacceptable uses would include "a new satna v by Galileo" and "the Galileo receiver".

The Authorised Person shall be solely responsible for exercising its activities hereunder strictly in compliance with all laws and regulations of each of the countries in which such activity takes place.

H.4. Additional Intellectual Property Rights and Maintenance of Rights

The EU reserves the right, in the course of the Authorisation term, to acquire ownership or control of additional trade marks related with the sign Galileo. In that case, the EU may update section H.10 accordingly. The EU however takes no obligation to communicate the acquisition of additional trade mark rights to the Authorised Person.

The Authorisation shall automatically cover any such additional trade mark rights included in the updated section H.10, without the need to amend the Authorisation. The EU shall have no obligation, duty or commitment whatsoever to:

a) maintain the Galileo Trade Marks in force nor shall it be obliged to communicate any decision thereto to the Authorised Person;

b) provide any assistance, technical information or know-how to the Authorised Person.

H.5. Duration and Termination

The Authorisation shall be valid as long as the Galileo Trade Marks remain valid and in force, 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.

The Authorisation and its validity shall not be influenced by the fact that one or more of the Galileo Trade Marks whose use is authorised hereunder should finally be declared not granted or invalid.

H.6. Warranties and Liability

The Authorisation is issued under the Galileo Trade Marks 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 Galileo Trade Marks, including as to the validity and enforceability of the Galileo Trade Marks;

To the full extent allowed by law, all warranties, whether expressed or implied, for any use of the Galileo Trade Marks are excluded. 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.

H.7. 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 use of the Galileo Trade Marks or marketing of the 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 Galileo Trade Marks, the Authorised Person shall collaborate with the EU and provide the EU with all the assistance necessary to such defence.

H.8. 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 Contract.

H.9. 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 Galileo Trade Marks.

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 use of the Galileo Trade Marks by the Authorised Person.

H.10. Galileo Trade Marks

The trade marks listed in the following tables are an integral part of the Authorisation.

APPLICATIONS

Mark	Territory	Application number
	EU	3710712
GALILEI	EU	4546561
GALILEO	EU	11517984

Mark	Territory	Registration number
	EU	2742237