PROGRAM: GALILEO

TITLE: L1 band part of Galileo Signal in Space ICD (SIS ICD)

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1 INTRODUCTION

1.1 DOCUMENT SCOPE

This document aims at describing the L1 band part of the Galileo Signal in Space. The signals conveyed in L1 band are the ones used by the Galileo Open Service. This document gathers the information about Galileo L1 signal information useful for 3GPP members such information shall be considered preliminary and not yet in its final state.

1.2 DOCUMENT OVERVIEW

The present document is organised as follows:

- Chapter 1 is an introduction
- Chapter 2 provides an overview of Galileo Signal In Space
- Chapter 3 describes the L1 SIS radio-frequency characteristics and transmissions characteristics of the signal
- Chapter 4 describes the message structure
- Chapter 5 describes the Message Data Contents

1.3 ACRONYMS AND DEFINITIONS

1.3.1 Acronyms

AltBOC	Constant envelope modulation scheme for combining two sidebands each consisting itself of two binary signals (in I- and Q-channel).
BOC	Binary Offset Coding with sine shaped subcarrier (see Definitions)
BOCc	Binary Offset Coding with cosine shaped subcarrier (see Definitions)
CASM	Coherent Adaptive Sub-carrier Modulation. Also called Interplex or Modified Tricode Hexaphase
RX	Receiver

1.3.2 Definitions

Galileo L1- signal	The Galileo L1-signal consists of the signal components (or channels) L1-A, L1-B and L1-C and is transmitted in the frequency band 1559 – 1610 MHz allocated to RNSS and ARNS on a worldwide co-primary basis (ITU-R Radio Regulations).
Navigation Signal	Consists of a data channel or a combination of a data channel and a pilot channel which are characterised by the type of navigation service they can support due to the contents of their navigation data stream.
Navigation Data Stream	Sequence of bits carrying the navigation data information by using a frame structured transmission protocol.
I/NAV - Signals	Signals mapped to the Safety of Life Service (L1-B/C channels).
G/NAV - Signals	Signals mapped to the Public Regulated Service (L1-A channel).
Data channel	A data channel is the result of modulating a ranging code with a navigation data stream.

Pilot channel	A pilot channel, or dataless channel, is made of a ranging code only, not modulated by a navigation data stream.
Transmitted bandwidth	The 3dB bandwidth of the overall signal transmission chain. It is referred also as the signal bandwidth, when a transmission signal is addressed.
BOC	Binary Offset Carrier – BOC type signals are usually expressed in the form BOC(fsub,fchip) where frequencies are indicated as multiples of 1.023 MHz. For example, a BOC(10,5) signal has actually a subcarrier frequency of 10x1.023 MHz=10.230 MHz and a code chip rate of 5x1.023MHz=5.115 MHz.
BOC	BOC-Sine: Subcarrier-function of code-chips according to sign(sin(2*pi*fsub*t)), with sub-carrier frequency fsub and code-chips starting at t=0.
BOCc	BOC-Cosine: Subcarrier-function of code-chips according to sign(cos(2*pi*fsub*t)), with sub-carrier frequency fsub and code-chips starting at t=0.

2 GALILEO SIGNAL IN SPACE OVERVIEW

2.1 GALILEO FREQUENCY PLAN

2.1.1 Frequency bands

The Galileo Navigation Signals are transmitted in the four frequency bands indicated in blue in Figure 1. These four frequency bands are: the E5a band, the E5b band, the E6 band and the E2-L1-E1 band. They provide a wide bandwidth for the transmission of the Galileo Signals.

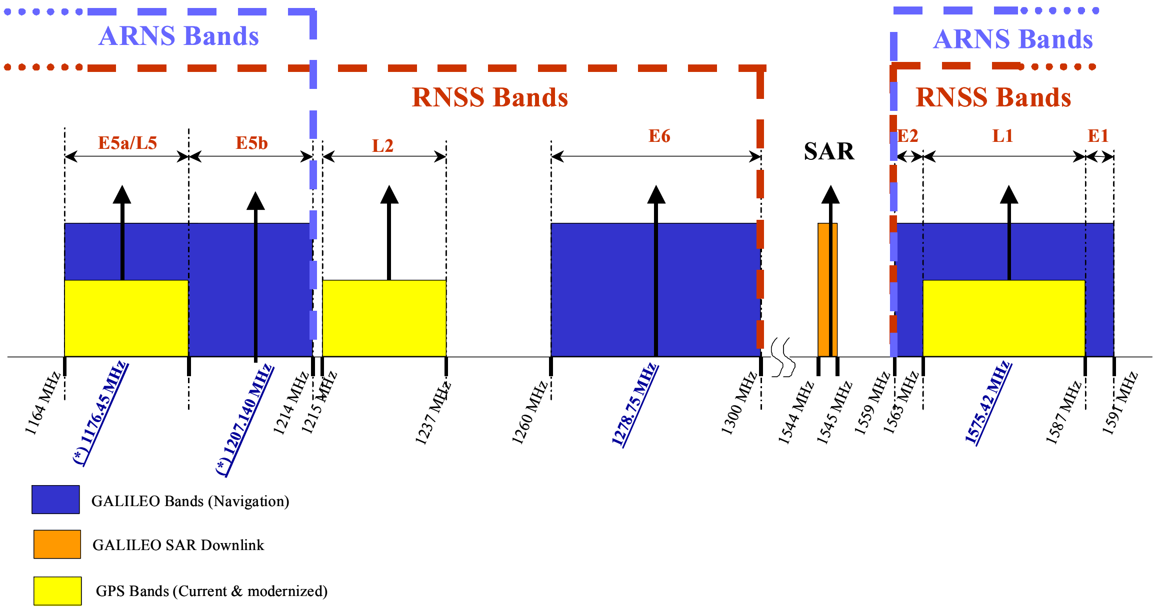

Figure 1: Galileo Frequency Plan

The frequency bands have been selected in the allocated spectrum for Radio Navigation Satellite Services (RNSS) and in addition to that, E5a, E5b and L1 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 and bandwidths

Galileo L1 transmitted bandwidth and center frequencies is specified in the next table.

Frequency Band	Carrier Frequency	Transmitted Bandwidth
E5a/L5 Band	1176.450 MHz	
E5b band	1207.140 MHz	
E5 band (E5a+E5b)	1191.795 MHz	90x1.023 MHz
E6 band	1278.75 MHz	40x1.023 MHz
E2-L1-E1 band	1575.42 MHz	40x1.023 MHz

Table 1: Transmitted bandwidth and center frequency for Galileo L1

2.1.3 Polarisation

All Galileo signals will be transmitted in right-hand circular polarization.

2.1.4 Multiple Access

All Galileo transmitting satellites will share the same frequency bands, making use of Code Division Multiple Access (CDMA) technique. Spread Spectrum signals will be transmitted including different Ranging Codes per signal, per frequency and per Galileo Satellites.

2.2 GALILEO NAVIGATION SIGNALS DESCRIPTION

Each Galileo Satellite transmits six Navigation Signals, which are named L1F, L1P, E6C, E6P, E5A, and E5B signals:

- **L1F Signal**: L1F is an open access signal transmitted in the L1 band comprising a data channel and a pilot channel (the L1-B and L1-C signal components respectively). It has unencrypted ranging codes and navigation data, which is accessible to all users. The L1F navigation data stream corresponds to a I/Nav message type and contains integrity messages as well as encrypted commercial data.
- **L1P Signal**: The L1P signal is a restricted access signal transmitted in L1-A signal channel. Its ranging codes and navigation data are encrypted using a governmental encryption algorithm. The L1P navigation data stream corresponds to a G/Nav message type
- **E6C Signal**: E6C is a commercial access signal transmitted in E6 that includes a data channel and a pilot channel (the E6-B and E6-C signal components respectively). Its ranging codes and navigation data are encrypted using a commercial algorithm. The E6C navigation data stream corresponds to a C/Nav message type.
- **E6P Signals**: The E6P signal is a restricted access signal transmitted in E6-A signal channel. Its ranging codes and navigation data are encrypted using a governmental encryption algorithm. The E6P navigation data stream corresponds to a G/Nav message type
- **E5a Signal**: The E5a signal is an open access signal transmitted in the E5 band that includes data and pilot channels (the E5a-I and E5a-Q signal components respectively). The E5a signal has unencrypted ranging codes and navigation data, which is accessible by all users. The E5a navigation data stream corresponds to a F/Nav message type and transmits the basic data to support navigation and timing functions.
- **E5b Signal**: E5b is an open access signal transmitted in E5 band comprising data and pilot channels (the E5b-I and E5b-Q signal components respectively). It has unencrypted ranging codes and navigation data accessible to all users. The E5b navigation data stream corresponds to a I/Nav message type and contains integrity messages as well as encrypted commercial data.

E5a and E5b signals are modulated on to a single E5 carrier using a technique known as AltBOC. This signal is known as **E5** and can be processed as a single signal by an appropriate user receiver. A summary of these characteristics is provided in Table 2

Galileo Signals	RF channels	Nav. Message type	Description	Ranging Code Encryption	Data Encryption
L1F Signal	L1-B L1-C	I/Nav	Open access code signal carrying integrity data.	No	Partial[1]
L1P Signal	L1-A	G/Nav	Restricted access code and data signal.	Governmenta l	Governmenta l
E6C Signal	E6-B E6-C	C/Nav	Controlled access code carrying encrypted commercial data.	Commercial	Commercial

Galileo Signals	RF channels	Nav. Message type	Description	Ranging Code Encryption	Data Encryption
E6P Signal	E6-A	G/Nav	Restricted access code and data signal.	Governmental	Governmental
E5a Signal	E5a-I E5a-Q	F/Nav	Open access code.	No	No
E5b Signal	E5b-I E5b-Q	I/Nav	Open access code signal carrying integrity data.	No	Partial[1]
E5 Signal	Combination of E5a and E5b signals				

Table 2: Summary Characteristics of the Galileo Navigation Signals

Figure 2 shows a global picture of the Galileo signals, the allocated frequencies and the relationship with Galileo services.

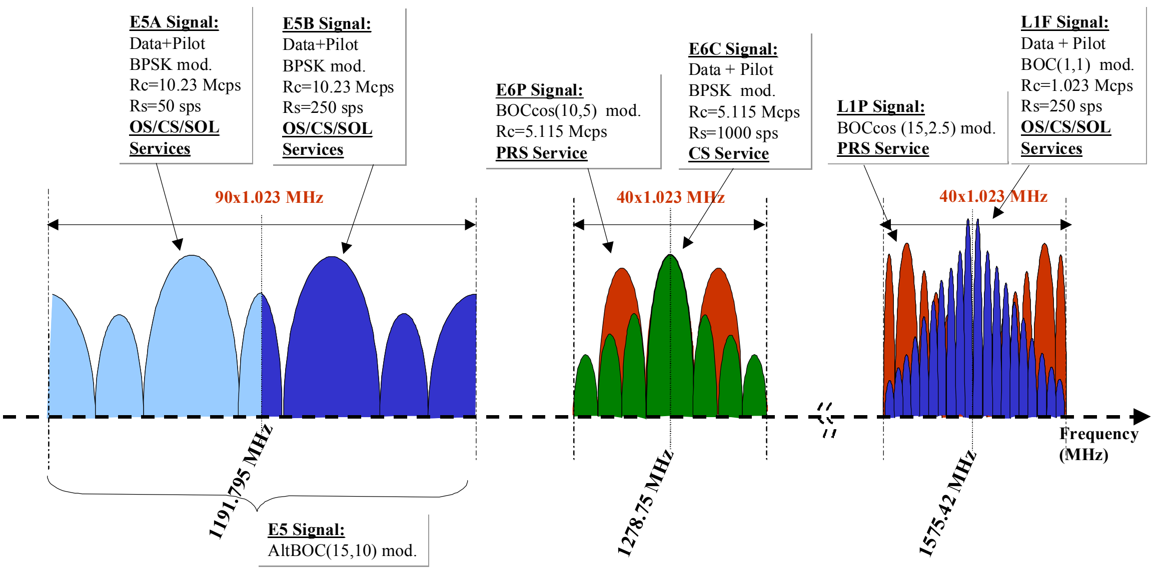

Figure 2 Galileo Navigation Signals Overview

2.3 GALILEO SERVICES DESCRIPTION AND MAPPING OF SIGNALS INTO SERVICES

The Galileo System provides five different services:

- **An Open Service (OS)**, providing positioning, navigation and timing services, free of charge, for mass market navigation applications and competitive to the GPS Standard Positioning Services and its evolutions;
- **A Safety-Of-Life Service (SOL),** compliant to standards in the aeronautical, maritime and rail domain. The SOL includes Integrity and Authentication capability, although the activation of these possibilities will depend on the user communities. The SOL service includes service guarantees;
- **A commercial Service (CS),** generates commercial revenue by providing added value over the Open Service, such as by dissemination of encrypted navigation related data (0.5 kbps), ranging and timing for professional use – with service guarantees;
- **A Public Regulated Service (PRS),** for applications devoted to European and Member States National Security, regulated or critical applications and activities of strategic importance. It makes use of a robust signal, and is controlled by Member States;

[1] Partial encryption of dedicated commercial data.

- **<u>A Search and Rescue Support Service (SAR),</u>** provides assistance to the COSPAS-SARSAT System by detecting Emergency Beacons and forwarding Return Link Messages to the Emergency Beacons.

The indicative mapping of the Galileo Services into the Galileo Navigation Signals is provided in Table 3

Signals	Open Service Users	Safety-Of-life Service Users	Commercial Service Users	Public Regulated Service Users
L1F	**x(*)**	**x(*)**	**x(*)**	
L1P				**x**
E6C			**x**	
E6P				**x**
E5a	**x**	**x**	**x**	
E5b	**x(*)**	**x(*)**	**x**	

(*) with no access to encrypted commercial data

Table 3 : Mapping of Galileo Navigation Signals onto Galileo Navigation Services

3 GALILEO L1 SIGNAL

3.1 L1 FREQUENCY PLAN

The Galileo satellites transmit the Navigation Signals on the L1 carrier frequency, polarisation and transmitted bandwidth stated in the following table.

Signal	**Carrier – Frequency Parameter**	**Carrier-Frequency**	**Polarisation**	**Transmitted bandwidth**
L1	f_{L1}	1575.420 MHz	Right-hand circular	40.92 MHz

Table 4: Frequency plan

3.2 L1 CHANNELS CONTENTS AND MODULATIONS

As stated in previous section, the Galileo L1 signal consists of the multiplexing of three components that are respectively:

- The L1-A channel corresponding to Public Regulated Signals (L1P navigation signal)
- The L1-B channel: it is the data channel of the L1F navigation signal. It results from the modulo-two addition of the L1-B navigation data stream with the L1-B channel PRN code sequence, both added modulo-two again to the L1B subcarrier.
- The L1-C channel: it is the pilot channel of the L1F navigation signal. It results from the modulo-two addition of the L1-C channel PRN code sequence with the L1-C subcarrier.

Note : An optimized version of the modulation, consisting in a slight variation of the modulation described above, is under evaluation.

The three components of the L1 signal are multiplexed using a CASM or modified Hexaphase modulation that ensures a constant envelope of the transmitted signal.

3.3 L1F RANGING CODES CHIP RATES AND SUB-CARRIER RATES

Galileo satellites transmit ranging codes for L1 signal with the chip- and sub-carrier-rates stated in the following table.

Channel (Parameter Y)	Subcarrier-Type	Subcarrier-Rate $R_{S,L1-Y}$ [MHz]	Ranging Code Chip-Rate $R_{C,L1-Y}$ [MChip/s]
B	BOC	1.023	1.023
C	BOC	1.023	1.023

Table 5: L1 chip- and sub-carrier-rates

3.4 L1F DATA RATES

The coded and interleaved navigation data streams are transmitted at the rates shown in the next table.

Channel	Data rate (symbols per second)
L1F-data	250
L1F-pilot	Pilot channel (*)

Table 6 : L1 channels data rates

(*) The pilot channel may be data less channel or may include very low rate synchronization data (TBC)

3.5 L1F POWER LEVELS

The minimum received signal power levels by a receiver with a 0dBi isotropic reception are listed in Table 7. The values are valid for elevations between 10 and 90 degrees

Signals	**L1F**
Min Power (dBW)	-157

Table 7: Minimum received power for Galileo L1F signal

The sharing of the power in L1F among the two signal channels has to be as shown in the next table.

Channel	Relative signal power
L1-B	50%
L1-C	50%

Table 8: Distribution of L1 total power among channels

3.6 L1F CODE LENGTHS

Codes in L1 have the characteristics shown in the next table.

Channel	**Primary code length (chips)**	**Secondary code length (chips)**
L1-B	**4092**	**--**
L1-C	**4092**	**25**

Table 9: Code lengths for L1 channels

3.7 L1 SIGNAL GENERATION

3.7.1 Notation

The following table defines the signal parameters used in this chapter, with the indices

'X' accounting for the respective signal (L1) and

'Y' accounting for the respective signal component or signal channel (A, B, C, I or Q) within the signal 'X'.

Parameter	**Explanation**	**Value**
f_X	Carrier Frequency [Hz]	See § 'Frequency Plan'
P_X	RF-Signal Power [W]	

$L_{X\text{-}Y}$	Ranging Code Repetition Period [Chips]	See § 'Code Length'
$T_{C,X\text{-}Y}$	Ranging Code-Chip-Length [Seconds]	
$T_{S,X\text{-}Y}$	Subcarrier-Period [Seconds]	
$T_{D,X\text{-}Y}$	Navigation Message Symbol Duration [Seconds]	
$R_{C,X\text{-}Y}$	= 1/ $T_{C,X\text{-}Y}$; Code-Chip-Rate [Hz]	See § 'Ranging Codes Chip & Subcarrier Rates'
$R_{S,X\text{-}Y}$	= 1/ $T_{S,X\text{-}Y}$; Subcarrier-Frequency [Hz]	See § 'Ranging Codes Chip & Subcarrier Rates'
$R_{D,X\text{-}Y}$	= 1/ $T_{D,X\text{-}Y}$; Navigation Message Symbol Rate [Hz]	See § 'Data Rates'
$C_{X\text{-}Y}(t)$	Binary (NRZ modulated) ranging code	
$D_{X\text{-}Y}(t)$	Binary (NRZ modulated) navigation message signal	
$sc_{X\text{-}Y}(t)$	Binary (NRZ modulated) subcarrier	
$e_{X\text{-}Y}(t)$	Binary NRZ modulated navigation signal component including code, sub-carrier (if available) and navigation message data (if available); (= $C_{X\text{-}Y}(t) \cdot sc_{X\text{-}Y}(t) \cdot D_{X\text{-}Y}(t)$);	
$s_X(t)$	Normalised Baseband Signal (=$s_{X\text{-}I}(t) + j \cdot s_{X\text{-}Q}(t)$) (Unit mean power)	
$c_{X\text{-}Y,k}$	'k^{th}' Chip of the Ranging Code	
$d_{X\text{-}Y,k}$	'k^{th}' Symbol of the Navigation Message	
$DC_{X\text{-}Y}$	= $T_{D,X}{}^{Y} / T_{C,X}{}^{Y}$; Number of Code-Chips per Symbol	
$\|i\|_L$	'i' modulo L	
$[i]_{DC}$	Integer part of i/DC	

Table 10: Signal description parameters of Galileo Signal In Space

Signal expressions are given for the power normalized complex envelope (i.e. base-band version) s(t) of a modulated (band-pass) signal S(t). Both are described in terms of its in-phase and quadrature components by the following generic expressions

$$S_{L1}(t) = \sqrt{2 \cdot P_{L1}} \cdot \left[s_{L1-I}(t) \cdot \cos(2\pi \cdot f_{L1} \cdot t) - s_{L1-Q}(t) \cdot \sin(2\pi \cdot f_{L1} \cdot t)\right]$$

$$s_{L1}(t) = s_{L1-I}(t) + j \cdot s_{L1-Q}(t)$$

with the parameters according to Table 10

3.7.2 L1 modulation Scheme

The diagram in the following figure provides a generic view of the L1 signal generation.

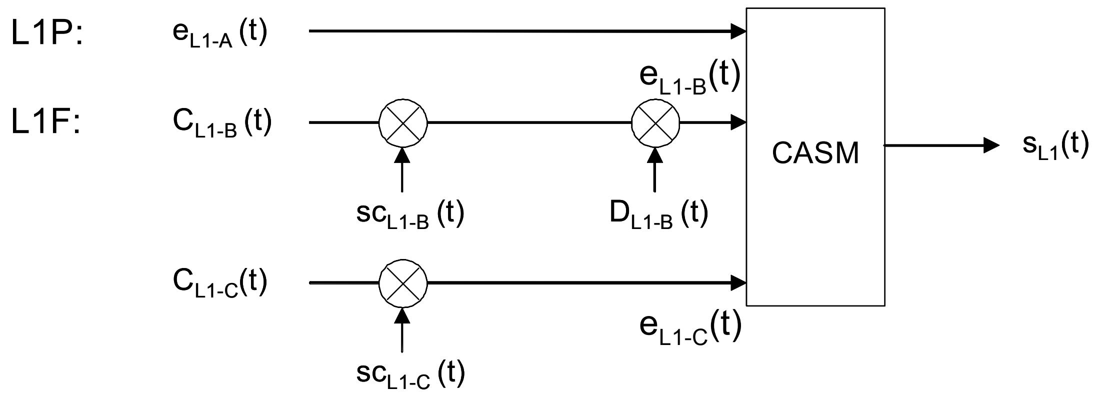

Figure 3: Modulation scheme for the L1 signal

3.7.3 L1 Signal Components Generation

The L1 signal components are generated according to the following.

- e_{L1-B} from the I/NAV navigation data stream D_{L1-B}, modulated with the ranging code C_{L1-B} and the sub-carrier sc_{L1-B}.
- e_{L1-C} (pilot channel) from the ranging code C_{L1-C} modulated with the sub-carrier sc_{L1-C}.

The B and C components are generated according to the following definitions:

$$e_{L1-B}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{L1-B,|i|_{L_{L1-B}}} \cdot d_{L1-B,|i|_{DC_{L1-B}}} \cdot rect_{T_{c,L1-B}} \left(t - i \cdot T_{c,L1-B} \right) \cdot sign\left[\sin\left(2\pi \cdot R_{s,L1-B} \cdot t \right) \right] \right]$$

$$e_{L1-C}(t) = \sum_{i=-\infty}^{+\infty} \left[c_{L1-C,|i|_{L_{L1-C}}} \cdot rect_{T_{c,L1-C}} \left(t - i \cdot T_{c,L1-C} \right) \cdot sign\left[\sin\left(2\pi \cdot R_{s,L1-C} \cdot t \right) \right] \right]$$

3.7.3.1 CASM modulation

The L1 composite signal is generated according to the CASM expression below, with the binary signal components $e_{L1-A}(t)$, $e_{L1-B}(t)$ and $e_{L1-C}(t)$.

$$s_{L1}(t) = \frac{1}{3} \left\{ \left[\sqrt{2} \cdot e_{L1-B}(t) - \sqrt{2} \cdot e_{L1-C}(t) \right] + j \cdot \left[2 \cdot e_{L1-A}(t) + e_{L1-A}(t) \cdot e_{L1-B}(t) \cdot e_{L1-C}(t) \right] \right\}$$

For the CASM multiplexing scheme the constant envelope is maintained by adding to the desired channels A, B and C an additional signal, which is the product of all desired binary signals (the last term in the above equation).

3.8 LOGIC LEVELS FOR THE CODE BITS

The correspondence between the logic level code bits used to modulate the signal and the signal level are defined in the following table:

Logic Level	Signal Level
1	-1.0
0	+1.0

Table 11: Logic to Signal Level Assignment

4 MESSAGE STRUCTURE

4.1 GALILEO MESSAGE FRAME STRUCTURE

Galileo
The complete navigation messages will be transmitted on each data channel as a sequence of frames. A frame is composed of several sub-frames, and a sub-frame is composed of several pages As shown in Figure 4.

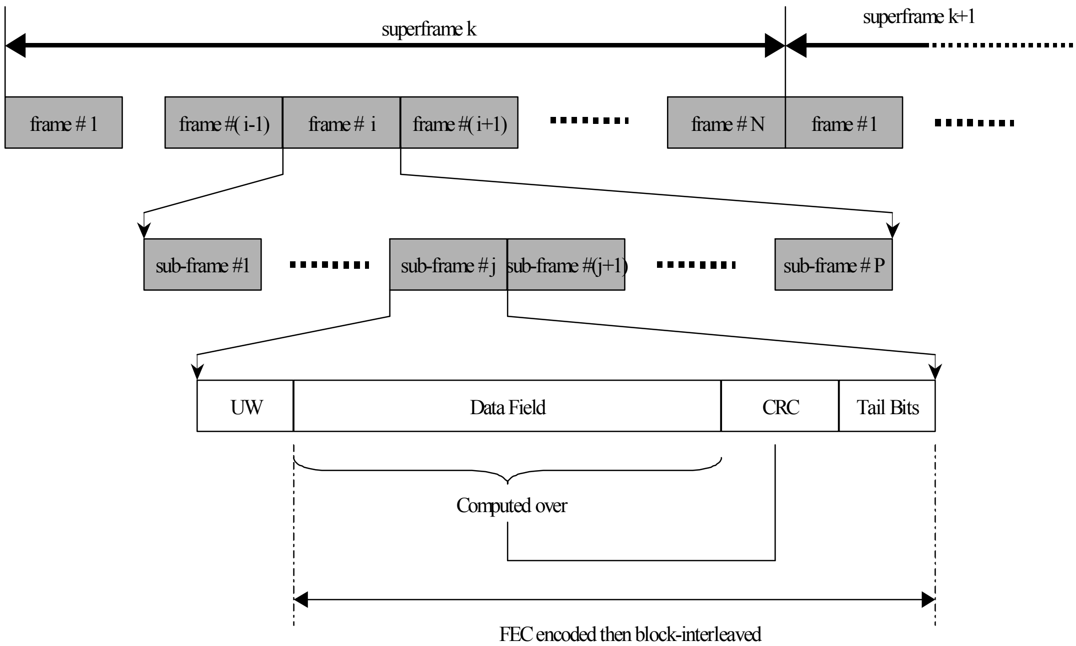

Figure 4 **Navigation message structure**

4.2 PAGE STRUCTURE AND FORMAT

The page is the basic structure for building the navigation message, and contains the following fields:

- A synchronization word (SW)
- A data field
- Cyclic redundancy check (CRC) bits for error detection
- Tail bits for the Forward Error Correction (FEC) encoder, in a defined fixed state, containing all zeros.

The page synchronization field is a fixed pattern (Unique Word) that allows the receiver to achieve synchronization to the data field boundaries. The synchronization pattern is applied as uncoded data symbols at the transmitter.

Each page contains a Cyclic Redundancy Check (CRC) parity block covering the page data field used to detect the reception of corrupted data (excluding then the synchronization pattern and the tail bits).

The page, excluding the synchronization word, is rate ½ convolutional encoded with a Forward Error Correction (FEC) code. Therefore, the symbol rate is twice the original data rate.

Finally, block interleaving is applied after convolutional encoding to all pages excluding the synchronization pattern. The block interleaver uses block sizes of $n \times k$ bits, where a $n \times k$ block interleaver takes $n \times k$ symbols and fills a matrix having *k* rows and *n* columns column-by-column; symbols are then transmitted row-by-row.

4.2.1 Page Synchronisation Field

All pages shall start with a Frame Synchronization. The synchronisation pattern is applied as uncoded data symbols at the transmitter.

For the I/NAV navigation message in L1 the synchronisation pattern that apply is stated in the following table:

Message Type	Number of Symbols	Frame Bit Allocation	Binary Pattern
I/Nav	10	5	TBD

Table 12: Synchronisation Pattern for I/Nav

4.2.2 Tail Bits Field

The Tail Bits Field includes a 6 zero-value tail bits.

4.2.3 Data Bit and byte ordering criteria

All data values are encoded using the following bit and byte ordering criteria [TBC]:

- 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.

For data diagrams and tables, the notation used in this document is according to the next figure. The most significant bit (MSB) is placed left, the less significant bit (LSB) is placed right, the most significant items top, and the less significant items bottom.

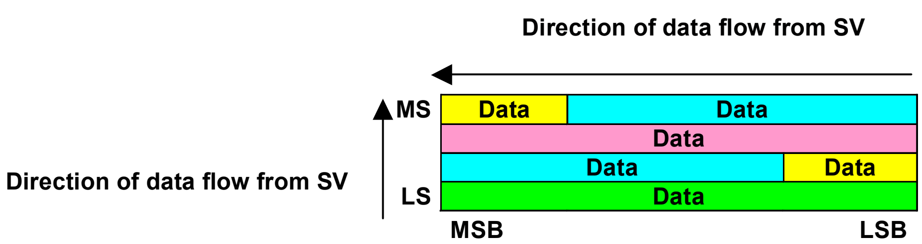

Figure 5: Notation for data

4.2.4 Cyclic Redundancy Check

The checksum, which employs a CRC technique, does not include the frame synchronization pattern or the tail bit fields since these do not form part of the required message information.

To compute the CRC, the page data field is written as a polynomial in x, where the coefficient on X^N is the first transmitted bit of the page data field and the coefficient of x^{24} is the last transmitted bit of the navigation data (N is the number of bits in the data field, including the CRC). This polynomial is divided by the generator polynomial G(x) using modulo-2 arithmetic. The remainder is a polynomial of degree <24 in X. The first bit of the CRC is the coefficient of X^{23} in this polynomial, and the last bit of the CRC is the coefficient of X^0.

For the all navigation messages, the common checksum stated in the table below is used:

Checksum (bits)	CRC Polynomial P(X)
24	TBD

Table 13: Checksum CRC Polynomials

4.2.5 FEC Coding Parameters

The Viterbi convolutional coding for all data channels are performed according to requirements stated in the following table.

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

Table 14: Data Coding Parameters

The following figure depicts the Viterbi convolutional coding scheme to be used.

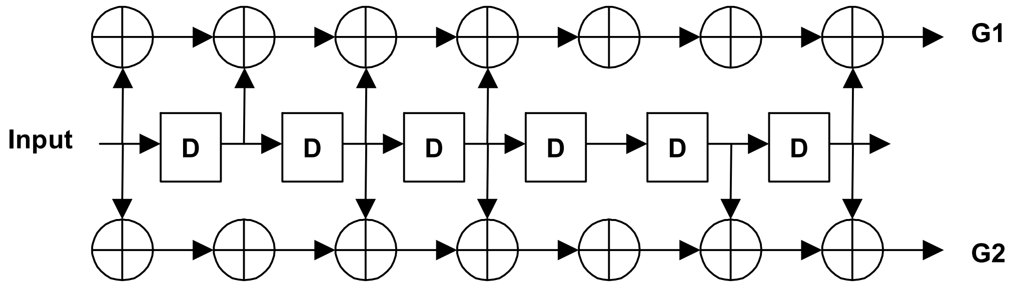

Figure 6: Viterbi Convolutional Coding Scheme

4.3 FRAME TIMING

Time stamps are inserted in the navigation message at regular intervals, by the broadcasting satellite, to identify absolute GST in multiples of the shortest page period of 1s. The exact timing of the message frame boundaries will be used to identify fractional GST timing (less than one frame period). This will be measured relative to the leading edge of the first chip of the first code sequence of the first frame symbol.

5 MESSAGE CONTENTS

The Galileo SIS data channels transmit four different message types according to the general contents identified in the table below.

- F/NAV is the acronym for Freely Accessible Navigation message type and related signal.
- I/NAV is the acronym for Integrity Navigation message type and related signals.
- C/NAV is the acronym for Commercial Navigation message type and related signal.
- G/NAV is the acronym for Governmental Access Navigation message type and related signals.

Message type	Services	Channel(s)	Message Data Content				
			Navigation	Integrity	Search & Rescue	Supplementary	Service Management
F/NAV	OS/CS/SOL	E5A-I	Yes	No	No	No	No
I/NAV	OS/CS/SOL	E5B-I & L1-B	Yes	Yes	Yes (On L1 only)	No	Yes
C	CS	E6-B	No	No	No	Yes	Yes
G/NAV	PRS	E6A & L1-A	Yes	Yes	No	No	Yes

Table 15: Message Allocation and General Data Content

The Galileo message contents listed In the following sections are applicable to all message types, however, some particularisations for L1 I/Nav messages are made.

5.1 NAVIGATION DATA

The navigation data contain all the parameters that enable the user to perform positioning service. They are stored on board all the satellite with a validity duration and broadcast world-wide by all the satellite of the constellation.

4 types of data needed to perform positioning are specified in the following section:

- Ephemeris: needed to indicate the position of the satellite to the user with a sufficient accuracy
- Time parameters and Clock correction parameters: needed to compute pseudo-range measurements
- Service parameters: needed to identify the set of navigation data, the satellites, some indicator of the health of the signal…
- Almanacs: to indicate the position of all the satellite in the constellation with a reduced accuracy needed for the acquisition of the signal by the receiver.

5.1.1 Ephemeris

The Galileo ephemeris for each satellite is composed by 15 parameters (6 keplerian parameters, 6 harmonic coefficients, inclination and LAN rates plus mean motion correction). To these, the IOD (Issue Of Data) and the toe (reference time for the ephemeris data set) are added.

The total data size of these 17 parameters is 362 bits.

5.1.1.1 Ephemeris Parameters

The ephemeris parameters for each Galileo satellite are defined in the following table:

#	Parameter	Definition	Bits	Scale factor	Unit
1	M_0	Mean Anomaly at Reference Time	32	2^{-31}	Semi-circles
2	Δn	Mean Motion Difference From Computed Value	16	2^{-43}	Semi-circles/s
3	e	Eccentricity	32	2^{-33}	N/A
4	$(A)^{1/2}$	Square Root of the Semi-Major Axis	32	2^{-19}	$Meters^{1/2}$
5	$(OMEGA)_0$	Longitude of Ascending Node of Orbit Plane at Weekly Epoch	32	2^{-31}	Semi-circles
6	i_0	Inclination Angle at Reference Time	32	2^{-31}	Semi-circles
7	ω	Argument of Perigee	32	2^{-31}	Semi-circles
8	OMEGADOT	Rate of Right Ascension	24	2^{-43}	Semi-circles/s
9	IDOT	Rate of Inclination Angle	14	2^{-43}	Semi-circles/s
10	C_{uc}	Amplitude of the Cosine Harmonic Correction Term to the Argument of Latitude	16	2^{-29}	Radians
11	C_{us}	Amplitude of the Sine Harmonic Correction Term to the Argument of Latitude	16	2^{-29}	Radians
12	C_{rc}	Amplitude of the Cosine Harmonic Correction Term to the Orbit Radius	16	2^{-5}	Meters
13	C_{rs}	Amplitude of the Sine Harmonic Correction Term to the Orbit Radius	16	2^{-5}	Meters
14	C_{ic}	Amplitude of the Cosine Harmonic Correction Term to the Angle of Inclination	16	2^{-29}	Radians
15	C_{is}	Amplitude of the Sine Harmonic Correction Term to the Angle of Inclination	16	2^{-29}	Radians
16	t_{0e}	Ephemeris Reference time	14	60	seconds
17	IODnav	Ephemeris and clock correction IOD	9	N/A	N/A
		Total Ephemeris Size	**363**		

Table 16: Ephemeris parameters definition

5.1.1.2 Ephemeris Uniqueness

A single ephemeris shall be applicable for all signals of a satellite at any time.

5.1.1.3 Ephemeris Validity Interval

The validity interval (fit interval) for the Galileo ephemeris message is 4 hours.

Four messages will cover the 12 hour orbit predictions generated from the OD process. All messages can be computed and uploaded to the satellite in a single step.

5.1.1.4 Ephemeris Periodicity

The nominal period of update shall be 3 hours.

The 1-hour overlap interval, which will be helpful against short outages or delays.

5.1.2 Time parameters and Clock correction parameters

5.1.2.1 Clarification on satellite time correction data requirements

In order to perform pseudo-range measurements, the user receiver needs to have an accurate knowledge of a common reference time (Galileo System Time, GST) and the satellite signal Time Of Transmission (TOT) in this reference time.

Due to the impossibility of directly steering the physical satellite clocks to the system time, it is necessary for each satellite, to transmit Satellite Time Corrections. These corrections enable the user to compute for each given signal the predicted offset of the physical satellite signal TOT (transmitted to the user through the PRN code) with respect to the satellite signal TOT in GST, according to the following formula:

TOT(X)c=TOT(X)m-(Δt_{SV}) X

where:

- TOT(X)C is the corrected satellite signal X TOT in GST time
- TOT(X)m is the physical satellite signal X TOT, which is retrieved through pseudo-range measurements.
- (Δt_{SV}) X is the Satellite Time Correction for a specific signal X computed by the user using the data retrieved from the navigation message. This parameter is modelled through a second order polynomial, namely:

  (Δt_{SV}) X=ao(X)+a1(X) [t-toc(X)]+a2(X) [t-toc(X)]2 (s)

where:

- ao(X), a1(X) , a2(X) and to(X) are the polynomial correction coefficients corresponding to phase error, frequency error and rate of change of frequency error for satellite clock on dual frequency signal X.
- toc is the reference time (in seconds) for the clock correction
- t is the GST in seconds.

Note that the specified Satellite Time Correction model only describes the evolution over the valid time interval of the offset of the physical TOT referenced to satellite antenna phase centre wrt the satellite signal TOT in GST. This offset is induced by satellite clock noise or satellite inter-frequency group delay variations over the prediction time interval.

Consequently:

- With this information any dual-frequency user receiver is able to synchronise the received time signals to the Galileo System Time.
- For the single frequency user, it is necessary to add to this information the Broadcast Group Delay and the ionospheric correction with the following guidelines:
- The coefficients of the model do not include correction for relativistic effect. The user will therefore apply the relativistic correction separately.
- A user performing PR measurements with signal X does not need to apply inter-frequency bias correction.
- A user performing PR measurements with any signal different from X and using the satellite time model for signal X needs to apply an appropriate inter-frequency bias correction to retrieve the satellite TOT. The inter-frequency bias correction term will be determined using the BGD values.

5.1.2.2 Galileo System Time (GST)

The GST is given as 32-bit binary number separated in two parts as follows:

- The Week Number is an integer counter that gives the sequential week number from the origin of the Galileo Time.

- This parameter is coded on 12 bits to cover 4096 weeks (about 78 years). Then the counter is reset to zero to cover 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 604800 seconds and is reset to zero at the end of each week. This leads to code this parameter on 20 bits. Note that this TOW is generated by the satellite as it gives the epoch when the navigation data is down-linked from the satellite.

5.1.2.2.1 Galileo System Time Parameters

The GST parameters are transmitted according the characteristics stated in the following table.

#	Parameter	Definition	Bits	Scale factor	Unit
1	WN	Week Number	12	N/A	week
2	TOW	Time of Week	20	1	second
		Galileo System Time - Total	**32**		

Table 17: GST Parameters

5.1.2.2.2 Galileo System Time Epoch

The start time for the Galileo System Time is [TBD]

5.1.2.3 Clock Correction and SISA

These parameters are necessary due to the impossibility of directly steering the physical satellite clocks to the system time. Thus it is necessary to transmit correction parameters, which represent the difference between the transmitted physical clock time and the system time (Clock correction).

With this information any dual-frequency user receiver is able to synchronise the received time signals to the Galileo System Time (GST). For the single frequency user, it is necessary to add to this information the Broadcast Group Delay and the ionospheric correction (see following sections).

SISA enables to indicate to the user the quality of the SIS broadcast by satellites and in particular the quality of the OD&TS outputs.

5.1.2.3.1 Clock Correction and Signal in Space Accuracy Parameters

The Clock Correction and Signal In Space Accuracy parameters are transmitted according to the values stated in the following table.

#	Parameter	Definition	Bits	Scale factor	Unit
1	T_{0c}	Clock Reference time	14	60	Seconds
2	a_0	Constant Parameter	28	2^{-33}	Seconds
3	a_1	1st order parameter	18	2^{-45}	s/s
4	a_2	2nd order parameter	12	2^{-65}	s/s^2

Clock Correction Parameters - Total	**72**		

Table 18: Galileo clock correction parameters

The SISA Index shall be encoded on 8 bits.

5.1.2.4 Ionospheric corrections

A global model shall be used to apply the ionospheric corrections for all services, including the following parameters:

- 1 global Effective Ionisation Level Az parameter computed thanks to 3 broadcast coefficients a_0, a_1 and a_2.

1 "Ionospheric Disturbance Flag" (also referred to as "model storm flag" or "storm flag"), provided separately for five different regions.

5.1.2.5 UTC Conversion

This data include the parameters (99 bits) for the relation of GSTS to the Universal Time Coordinated (UTC).

5.1.2.5.1 UTC Conversion

The UTC time t_{UTC} is computed through 3 different cases as follow:

- Case a: whenever the effectivity time indicated by the WN_{LSF} and the DN values 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 at DN + 3/4 and ends at DN + 5/4, t_{UTC} is computed according to the following equation:

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

Where:

- t_E is the GST relative to the start of the week, as estimated by the user through its GST determination algorithm
- Δt_{UTC} is computed as:

$$\Delta t_{UTC} = \Delta t_{LS} + A_0 + A_1 \cdot \left(t_E - t_{0t} + 604800 \cdot (WN - WN_t)\right)$$

- Case b: whenever the user's current time falls within the time span of DN + 3/4 to DN + 5/4, t_{UTC} is computed according to the following equation:

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

Where:

- W = (t_E - Δt_{UTC} - 43200) [Modulo 86400] + 43200, seconds
- Definition of t_E and Δt_{UTC} are the same as specified in case a

- Case c: whenever the effectivity time of the leap second event, as indicated by the WN_{LSF} and DN values, is in the "past" (relative to the user's current time), t_{UTC} is computed according to the following equation:

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

where:

- A_0: constant term (in seconds) of polynomial describing the offset between Galileo and TAI time scales at the time t_E.
- A_1: rate of change (in seconds per second) of the offset between GST and TAI time scales;
- Δt_{LS}: is the offset due to the integer number of seconds between TAI and UTC;
- t_{0t}: time of validity of the UTC offset parameters;
- WN_t: UTC reference week number.
- WN_{LSF}: week number for the leap second adjustment, namely Galileo week number modulo 256 to which the DN is referenced;
- DN: day number for the leap second adjustment; "Day one" is the first day relative to the end/start of week. The range of the DN is one week and the accuracy is 1 day. Then it is coded on 3 bits.
- Δt_{LSF}: is the offset due to the introduction of a leap second at WN_{LSF} and DN

5.1.2.5.2 UTC Conversion parameters

The parameters for UTC conversion are defined according the values stated in the following table:

Parameter	Definition	Bits	Scale factor	Unit
A_0	Constant term of polynomial	32	2^{-30}	seconds
A_1	1st order term of polynomial	24	2^{-50}	seconds/sec
Δt_{LS}	Delta time due to leap seconds	8	1	seconds
t_{0t}	Reference time for UTC data	8	3600	seconds
WN_t	UTC refence Week Number	8	1	weeks
WN_{LSF}	Week Number of the Leap Second	8	1	weeks
DN	Day Number of the Leap Second	3	1..7	days
Δt_{LSF}	Delta Time due to Leap Second	8	1	seconds
GST - UTC Connection Parameters - Total		99		

Table 19: Parameters for the GST - UTC conversion

5.1.2.6 GPS to Galileo System Time

The following parameters allow to relate the GPS time to the Galileo System Time:

5.1.2.6.1 GPS Time Conversion

The difference between the Galileo and GPS time scale is computed by the expression below:

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where:

- A_{0G}: constant term (in seconds) of polynomial describing the offset $\Delta t_{systems}$ between the Galileo and the GPS system time scales at the time $t_{Galileo}$, which is the Galileo time estimated by the user;
- A_{1G}: rate of change (in seconds per second) of the offset $\Delta t_{systems}$ between Galileo and GPS time scales;
- t_{0G}: Reference time for GGTO data.

5.1.2.6.2 GPS Time Conversion Parameters

The GPS Time Conversion Parameters are formatted according the values stated in the following table.

Parameter	Definition	Bits	Scale Factor	Unit
A_{0G}	constant of polynomial	16	2^{-35}	seconds
A_{1G}	1st order term of polynomial	12	2^{-51}	Seconds/sec
t_{0G}	Reference time for UTC data	8	3600	Seconds
GST-GPS Connection Parameters - Total		36		

Table 20: Parameters for the GPS Time Conversion

5.1.3 Service parameters

5.1.3.1 Satellite ID

The satellite Identification is coded with 7 bits, being the encoding logic stated in the following table.

Parameter	Definition	Bits	Scale Factor	Unit	Values
SV_{ID}	Satellite Ident	7	N/A	unitless	1 to 128

Table 21: Satellite ID

5.1.3.2 Issue Of Data

The Issue of Data (IOD) is needed to indicate to the user which set (applicable issue) of data is broadcasted by the satellite. Indeed, in normal operations the navigation data that are monitored by the ground monitoring facility (ephemeris, clock corrections & SISA have a limited validity duration (depending on the data type) and several batches of data are stored on board the satellite. Then each batch is identified by an issue. This enables:

- To ensure at user level consistency between the different batches of data received from different satellites.
- To indicate to the OS user the validity of the data (that have to be updated thanks to new navigation issue of data).

For that purpose, the IOD are transmitted in each page that includes navigation data, so that to enable the user to compute the full batch of data even if he looses some pages or receive the data in the middle of the transmission.

The IOD are transmitted in each page of the message, the size of which depends on the data type according to the following table:

Data type	Number of bits
Ephemeris and Clock correction	9
Almanacs	2
PRN mask	2

Table 22: IOD Values Mapping on Data type

5.1.3.3 Signal and Data Health Status

The signal and data health status refer to the transmitting satellite, being the size and meaning of values specific for each signal.

The validity and the update rate of the health status will depend on the applications needs. This health status could be used as a service performance level notification (e.g. notification of satellite non availability) for some applications requiring high level of safety. The health status update rate is optimised to meet such requirements.

5.1.3.3.1 I/NAV Navigation Signal and Data Health Status

The I/NAV Navigation Signal Health Status, related to the Safety of Life Service Signal Status (SOLSS), shall be coded on 5 bits.

The I/NAV Navigation Data Health Status, related to the Safety of Life Service Data Status (SOLDS), shall be coded on 3 bits.

5.1.4 Almanacs

The almanac data are reduced-precision subset of the clock and ephemeris parameters of the active satellites in orbit.

The almanacs are broadcast by every satellite so that to enable the user to improve the acquisition time of the satellite to reduce the search window. Indeed, knowing an approximate position of the satellite, the user can estimate the Doppler Effect due to this position and then speed up the synchronisation between the codes of the satellite and the one generated locally.

The proposed Galileo almanac orbital parameters consist of:

- Mean of semi-major axis,
- Eccentricity
- Inclination
- Right ascension of the ascending node
- Argument of Perigee
- Mean anomaly

A reduced set of clock correction parameters are provided in the almanac for each satellite, including:

The Time of applicability t0a of the almanac data. This almanac reference time (t0a) shall be referenced to the almanac reference week (WNa).

The WNa term consists of eight bits which shall be a Modulo 256 binary representation of the GST week number.

Additionally, a predicted satellite health status is be provided for each of these satellite, giving indications on the satellite's signal components health and satellite's NAV data health. In particular, this Health status shall inform the user when one satellite is temporally out or will be temporally out during a predicable period. One bit is used to summarise the predicted health of the navigation data. The number of possible signal health status values will depend on the service and on the frequencies allocated to each service.

In the almanac, the applicable Galileo NAV data structure for each satellite will be defined by DataID using 2 bits.

Finally, the IODA allows to identify without ambiguity an almanac batch. The update rate being slow, two bits are enough.

5.1.4.1 Almanac Parameters

The almanac parameters shall be transmitted according the characteristics stated in the following table:

#	Parameter	Definition	Bits	Scale factor	Unit
0	SV_{ID}	ID of the satellite (1 constellation of 36 satellites)	7	1	dimensionless
1	$(A)^{1/2}$	Square Root of Mean of Semi-Major Axis	24	2^{-11}	$meters^{1/2}$
2	e	Eccentricity	16	2^{-21}	dimensionless
3	I_0	Inclination at Reference Time (relative to i_0 = 56°)	16	2^{-19}	semi-circles
4	$OMEGA_0$	Right Ascension	24	2^{-23}	semi-circles
5	OMEGADOT	Rate of Right Ascension	16	2^{-38}	semi-circles/sec
6	ω	Argument of Perigee	24	2^{-23}	semi-circles
7	M_0	Satellite Mean Anomaly at Reference Time	24	2^{-23}	semi-circles
8	a_{f0}	Satellite Clock Correction Bias "Truncated"	15	2^{-20}	Seconds
9	a_{f1}	Satellite Clock Correction Linear "Truncated"	11	2^{-38}	Seconds/sec
10	SV_{SHS}	Satellite Signal Health Status	5		dimensionless
11	SV_{DHS}	Satellite Data Health Status	3	NA	dimensionless
13	$Data_{ID}$	Data ID	2		dimensionless
	Almanac Satellite Parameters - Total		**187**		
14	IODA	Almanac Issue Of Data	2	NA	dimensionless
15	t_{0a}	Almanac Reference Time	8	4096	Seconds
16	WN_a	Almanac Reference Week Number	8	1	Week
	Almanac Reference Parameters - Total				

Table 23: Almanacs Orbit Parameters

5.1.4.2 I/NAV Almanac Mask Field

The Almanac Mask shall encode if a given satellite is present (bit set to 1) or not (bit set to 0) in the sequence of satellite parameters included in the second and next pages of the almanac. The format of the Almanac Mask is defined in the following figure.

Plane 1					Plane 2					Plane 3				
SV_1	SV_2	…	SV_{11}	SV_{12}	SV_1	SV_2	…	SV_{11}	SV_{12}	SV_1	SV_2	…	SV_{11}	SV_{12}
1	1	8	1	1	1	1	8	1	1	1	1	8	1	1

Table 24: I/NAV Almanac Mask Field

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