LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LSIS - AFS)

VOLUME A

Version 1

Noted as Applicable Document 1 [AD1 Vol-A] in LNIS V5

PREFACE

LunaNet Interoperability Specification (LNIS)

The set of documents that comprise the LunaNet Interoperability Specification (LNIS) defines a framework of mutually agreed-upon standards, protocols, and interface specifications that enable interoperability. LunaNet is envisioned as a network of cooperating networks (network of networks, akin to the terrestrial Internet) upon which providers can deliver communications, position, navigation, and timing, and other services for users in transit to, around, and on the Moon.

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Comments or questions concerning this document, and proposed changes shall be addressed to:

SCaN Control Board Secretariat

Amanda.R.Allen@nasa.gov

+1-240-565-3048

NASA Headquarters

300 Hidden Figures Way

Washington, DC 20546

Change Information Page

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1. INTRODUCTION

This document forms part of the LunaNet Interoperability Specification (LNIS) and describes the characteristics of the signals and messages to support, at a minimum, the Position Navigation and Time (PNT) aspects of the Lunar Augmented Navigation Service (LANS) defined in the LNIS. This document covers specifications to ensure interoperability among LunaNet Service Providers (LNSPs) supporting the LANS. As defined in LNIS, LANS is provided by multiple provider nodes to multiple users at the same time, using a concept similar to Global Navigation Satellite Systems (GNSS). This service is to be provided in the 2483.5-2500 MHz band via the Augmented Forward Signal (AFS).

Figure 1 outlines the LNIS Position, Navigation, and Timing (PNT) services. Note that the different colors in the top left box represent different LNSPs contributing to LANS through one or multiple nodes. LANS is shown on the left, and PNT from Point-to-Point (P2P) communication signals is shown towards the right. This document (Applicable Document 1 - Volume A) provides specifications for LANS and AFS (including message definitions which are disseminated through AFS) (blue color) to ensure interoperability between different nodes from multiple LNSPs (blue, orange, green and purple colors), while Applicable Document 1 - Volume B provides recommended standards for P2P signals (including those involved in implementing PNT services).

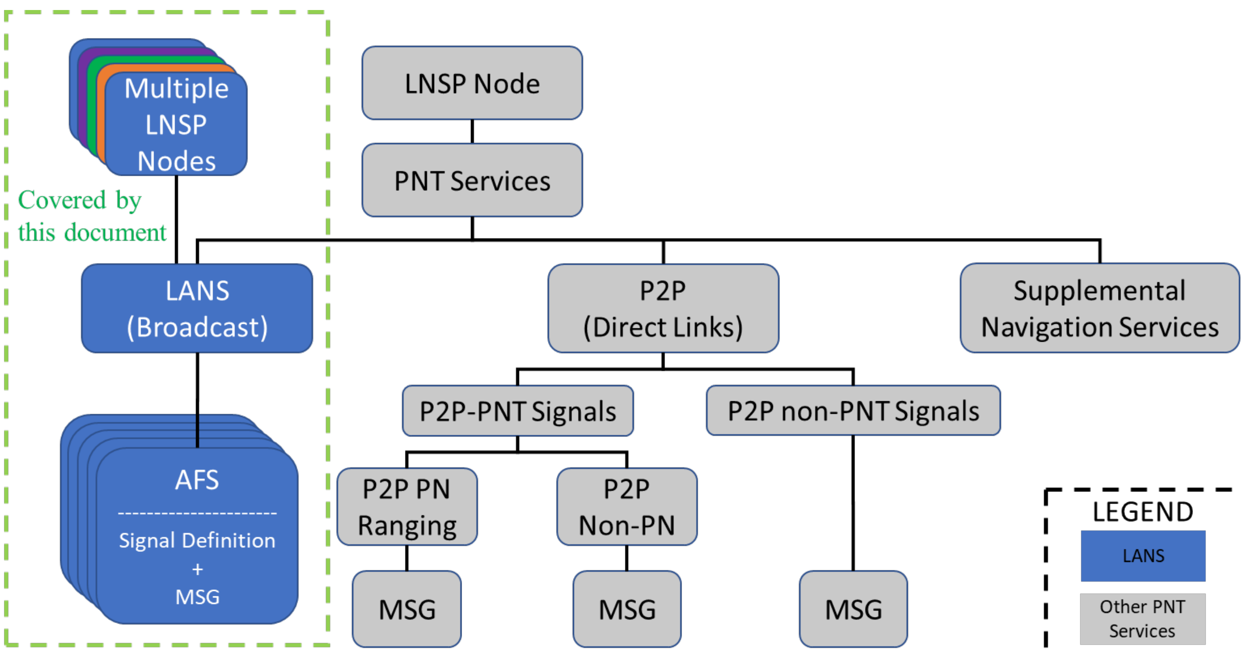

Figure 1: PNT Services Provided by Multiple LNSPs

This document is a recommended standard. The adoption of the standard by a service provider is voluntary, however, a service provider that claims to be LunaNet LANS compliant must conform to this recommended standard in all its parts.

LunaNet may encompass systems of different nature, including different orbits, different Earth segments, etc. Thus, some aspects specific to LANS might be implemented differently by different LNSPs. This standard aims at balancing the establishment of LANS interoperability, while providing flexibility to

LNSPs in certain areas of implementation. For this reason, this document implements two categories of specifications, broadly defined as follows:

1) Precise specifications that are provided to ensure the definition of key interoperability items, without ambiguity and with no flexibility to LNSP implementation.
2) Functional specifications that provide guidance to guarantee interoperability yet provide flexibility to LNSPs to define specific implementations.

Functional specifications in this document, per number 2 above, are indicated by incorporating "*FLEX*" within the applicable specification identifiers and/or via the incorporation of the following text: "*Note: This definition is a functional specification intended to provide the LNSP with implementation flexibility*". Examples of LNSP implementation flexibility include but are not limited to the message content dissemination cadence, the update rate of the message, etc.

In order to achieve interoperability, the detailed definition covered by the LNSP implementation flexibility will need to be known to develop LunaNet compatible user terminals. Therefore, it is expected that an LNSP-specific signal-in-space interface control document (SISICD) will need to be generated and made available by the LNSP to a {LSIS-TBD-1001} distribution[1].

Future versions of this document will further clarify the content associated with LNSP implementation flexibility.

In summary, each LNSP that intends to be interoperable with LANS shall:

1. comply with this document, and
2. define a SISICD[2] that provides definition to the items identified as having LNSP implementation flexibility in this document, and make it available to a {LSIS-TBD-1001} distribution, and
3. define user algorithms and models required to process the data specified in the provider specific SISICD and develop an example software implementation of the user processing of the raw navigation bits to obtain the navigation data, including test vectors, and make those available to the {LSIS-TBD-1001} distribution. A list with minimum requirements on user algorithms and models as well as test vectors is provided in Appendix G .

This document was written and reviewed by European Space Agency (ESA), the National Aeronautics and Space Administration (NASA), and the Japan Aerospace Exploration Agency (JAXA).

1.1. SCOPE

This document defines the interoperable LunaNet standards and specifications for operations on the lunar surface and in cislunar space for the LunaNet 1.0 instantiation of LunaNet, at the minimum, the specifications for interoperability among LNSPs contributing to LANS. It aims to maximize compatibility across multiple LNSPs at the user level, while, at the same time, leaving sufficient flexibility to enable tailoring of the services and potential future evolutions. This document, however, is not an interface control document. As such, it will not provide all interface control level information necessary for complete user implementation.

[1] The actual distribution list and/or the rules for the dissemination of the LNSP-specific SISICD will be clarified in the future.
[2] SISICD in this context means definition of signal characteristics and messages.

1.2. DEFINITIONS AND ANNEXES

1.2.1. DEFINITIONS

The following definitions are used throughout this document:

TBC: To Be Confirmed. It is used when a value is proposed, but it might change in future versions of this document.

TBD: To Be Determined. It is used when something is defined at a conceptual level, but no details are provided (e.g.: when a parameter is identified, but its numerical value is not yet defined).

TBW: To Be Written. It is used when a paragraph/section is planned to be written in future versions of this document.

The following conventions apply for the normative specifications in this Recommended Standard:

a. the words 'shall' and 'must' imply a binding and verifiable specification.
b. the word 'should' implies an optional, but desirable, specification.
c. the word 'may' implies an optional specification.
d. the words 'is', 'are', and 'will' imply statements of fact.

1.2.2. ANNEXES

The following annexes are part of this document (note that these annexes also link to the files marked in *italic*):

[Annex1] 001_LNIS-AD1-Vol-A-Annex1-LDPC-Tables
[Annex2] 002_LNIS-AD1-Vol-A-Annex2-LDPC-Submatrices-CSV-README
003_*#1_lunanet_ldpc_submatrices_fid0_ind*
004_*#2_lunanet_ldpc_submatrices_fid0_mat*
[Annex3] 005_LNIS-AD1-Vol-A-Annex3-PRN-Spreading-Codes-README
006_*#1_GoldCode2046hex210prns.txt*
007_*#2_l1cp_hex210prns.txt*
008_*#3_Weil1500hex210prns.txt*

2. AUGMENTED FORWARD SIGNAL SPECIFICATIONS

2.1. INTERFACE DEFINITION

This section provides specifications of the AFS to ensure minimum interoperability amongst LNSPs providing LANS. The AFS is used within the LANS GNSS-like concept as detailed in LNIS.

The interoperability among different LNSPs is ensured by the compliance with the specifications in this document, including the Signal-in-Space Error (SISE) specifications, and compliance with the Lunar Reference System and Lunar Time System Standard described in LNIS AD5 (which defines LunaNet Reference Time aligned with the Lunar Reference System), and, when relevant, compliance with LNIS AD3 (which defines LunaNet messages). The compliance to the SISE (specification LSIS-001) will ensure that the errors under control of the LNSP (e.g.: orbit prediction error, time synchronization error, satellite payload biases, etc.) are within a limit, guaranteeing the users that the errors remain within a predefined envelope.

The following approach is adopted for the messages:

- When a message is defined and/or specified in the same way (e.g.: at bit level) in multiple LunaNet PNT services (e.g. LANS and P2P), its definition is provided in LNIS AD3, so the related paragraph in Section 2.5 includes the encapsulation of the message in AFS and refers to LNIS AD3 for the message detailed definition.
- When a message is implemented differently in AFS with respect to other LunaNet PNT services, its detailed specification and/or definition are only provided in Section 2.5 of this document.

2.1.1. AFS SIGNAL AND DATA STRUCTURE

The AFS signal defined in this document is a fixed frequency signal consisting of two main components: one denoted as AFS-I that is spread by a ranging code and modulated by data messages, and AFS-Q that is spread by a ranging code without any data message (pilot component).

AFS-I and AFS-Q use Binary Phase-Shift Keying (BSPK) modulation and are linearly multiplexed to generate the AFS signal as described in 2.3.2.

The AFS-I and AFS-Q components are transmitted using ranging codes defined in Section 2.3.5.

The message structure and data encoding techniques for the data message on AFS-I are defined in Section 2.4 and the content of the message transmitted by the AFS is provided in Section 2.5.

2.2. AFS SIGNAL-IN-SPACE ERROR DEFINITION

2.2.1. SIGNAL-IN-SPACE ERROR CONCEPT

The signal-in-space error (SISE) of an LNSP node is defined as the combination of the following instantaneous errors:

1. SISE position error contribution defined as the difference between:
    a. True position of signal transmission location at the LNSP node (e.g., antenna phase center or reference point) in the lunar reference system [AD5];
    b. Position as provided in the node's navigation messages to the user, which is affected by knowledge errors (combination of position estimation and prediction), antenna reference point offsets, representation errors (i.e., due to navigation message fitting), and reference frame conversion errors.
2. SISE time error contribution represented as a distance and defined as the difference between:
    a. True time of signal transmission at the LNSP node represented in LunaNet Reference Time (LRT) [AD5];
    b. Time of transmission as provided in the node's navigation message to the user, represented in LRT. This is affected by clock offsets due to a combination of clock estimation, prediction and quantization errors; the effects of uncalibrated and unknown "group" delays; and time conversion errors between LNSP Node Time (NT), LNSP System Time (LST) and LRT.
3. SISE velocity error contribution defined as the derivative of the SISE position error contribution (point 1 above).
4. SISE time drift error contribution defined as the derivative of the SISE time error contribution (point 2 above).

This definition is independent of the orbital characteristics of each LunaNet node and establishes an upper bound on the error experienced at user level that is the result of the projection of the SISE onto the user-to-LNSP node direction[3]. This allows users to derive reliable navigation solutions when using LANS from different LNSPs. Please refer to Appendix B for a detailed list of SISE contributors.

2.2.2. SIGNAL-IN-SPACE ERROR MATHEMATICAL DEFINITION

The SISE concept can be defined both for position (SISE pos) and velocity (SISE vel) as shown below:

1. Signal-In-Space Error for positioning (SISE pos)

$$SISE_{pos} = \sqrt{(x-\tilde{x})^2 + (y-\tilde{y})^2 + (z-\tilde{z})^2 + (ct-c\tilde{t})^2}\,, \qquad \mathbf{1}$$

Where x, y, z, t are the true position and time (as described in Section 2.2.1 under 1.a and 2.a for position and time, respectively), while the corresponding tilde parameters represent the values broadcast in the navigation message (as described in Section 2.2.1 under 1.b and 2.b for position and time, respectively).

[3] *European GNSS (Galileo), Galileo Service Definition Document, issue 1.2, November 2021, Section 2.3.2.1*

2. Signal-In-Space Error for velocity (SISE vel):

$$SISE_{vel} = \sqrt{(\dot{x} - \tilde{\dot{x}})^2 + (\dot{y} - \tilde{\dot{y}})^2 + (\dot{z} - \tilde{\dot{z}})^2 + (c\dot{t} - c\tilde{\dot{t}})^2}\ , \quad (2)$$

Where $\dot{x}, \dot{y}, \dot{z}, \dot{t}$ are the true velocity and clock drift (defined by derivative of items described in Section 2.2.1 under 1.a and 2.a for position and time, respectively), while the corresponding tilde parameters represent the values broadcast in the navigation message (defined by derivative of items described in Section 2.2.1 under 1.b and 2.b for position and time, respectively).

2.2.3. SIGNAL-IN-SPACE ERROR SPECIFICATION

LSIS-001: LNSP SISE Position
Each LNSP node that provides AFS shall maintain the SISE position performance shown in Table 1 within the service volume defined in the specific LNSP SISICD.

Table 1 - LNSP SISE Position

Error	Value
SISE pos	≤ 40 {LSIS-TBC-2001} m (95%) - Calculated as the 95th percentile of the time series of instantaneous SISE values over a 24 {LSIS-TBC-2002} hours period.

Note: LSIS-001 provides maximum SISE position error values for all LNSPs. Different providers may have tighter requirements to meet the needs of their user community.

LSIS-002: LNSP SISE Velocity
Each LNSP node that provides AFS shall maintain the SISE velocity performance shown in Table 2 within the service volume defined in the specific LNSP SISICD.

Table 2 - LNSP Velocity

Error	Value
SISE vel	≤ 1 {LSIS-TBC-2003} cm/s (95%) - Calculated as the 95th percentile of the time series of instantaneous SISE values over a 24 {LSIS-TBC-2004} hours period.

Note: LSIS-002 provides maximum SISE velocity error values for all LNSPs. Different providers may have tighter requirements to meet the needs of their user community.

LSIS-005: Predicted LNSP SISE Information
Each LNSP node shall provide a predication of the SISE as part of MSG-G4 for both position (SISEpos) and velocity (SISEvel), as long as AFS is being operationally transmitted.

Note: Through the estimated SISE defined in this specification, using a concept similar to Galileo SISA (Signal-in-Space Accuracy) or GPS URA (User Range Accuracy), the SISE of different LNSPs is accounted for consistently at user level.

LSIS-006: Accuracy of Predicted LNSP SISE Position Information
{LSIS-TBW-2001}

LSIS-007: Accuracy of Predicted LNSP SISE Velocity Information
{LSIS-TBW-2002}

2.3. AFS SIGNAL SPECIFICATIONS

2.3.1. COMPOSITE SIGNAL

2.3.1.1. FREQUENCY PLAN

LSIS-010: Frequency Band
The frequency band allocated to the AFS signal shall be in S-band between 2483.5 MHz and 2500 MHz.

Note: This is in line with Space Frequency Coordination Group (SFCG) recommendation 32-2, that identifies the band between 2483.5 MHz and 2500 MHz for "In-situ Lunar based RNSS to Lunar Orbit and Lunar Surface."

LSIS-020: Carrier Frequency
The Augmented Forward Signal carrier frequency shall be 2492.028 MHz.

LSIS-030: Carrier Frequency maximum offset
The maximum deviation of the transmitted signal carrier frequency from the required signal carrier frequency shall be less than 10 Hz.

Note: The knowledge of the carrier frequency at the user level is bounded by the SISEvel specification.

2.3.1.2. SIGNAL POLARIZATION

LSIS-040: Signal Polarization
The transmitted AFS signal shall be Right-Hand Circularly Polarized (RHCP).

LSIS-050: Signal Axial Ratio
The transmitted AFS shall preserve an RHCP signal axial ratio of less than 3 dB {LSIS-TBC-2005} over the antenna beamwidth that covers the service volume defined in LNIS.

2.3.1.3. CARRIER PHASE NOISE

LSIS-060: Augmented Forward Signal Phase Noise
The phase noise spectral density of the un-modulated carrier shall allow a second-order phase locked loop with damping of 1 and with 10 Hz one-sided noise bandwidth to track the carrier to an accuracy of 0.04 {LSIS-TBC-2006} radians RMS.

2.3.1.4. SPURIOUS TRANSMISSIONS

LSIS-070: Maximum In-Band Spurious Transmissions
The aggregate EIRP of all unwanted emissions (including discrete emissions and parasitic emissions) integrated over the transmit bandwidth of each signal shall not exceed -35 dB {LSIS-TBC-2007} relative to the total power emitted in the bandwidth specified in 2.3.1.5.

LSIS-080: Maximum Out-Of-Band Emissions
{LSIS-TBW-2003}

2.3.1.5. CORRELATION LOSSES

Correlation loss is defined as the difference between the power received from the LNSP node, per component in the bandwidth defined in LSIS-090, and the signal power recovered in an ideal correlation receiver of the same bandwidth using an exact replica of the waveform within an ideal sharp-cutoff filter bandwidth centered at the carrier frequency specified in LSIS-020.

LSIS-090: Receiver reference bandwidth
The receiver reference bandwidth centered on the carrier frequency to be considered for the correlation losses shall be 15.944 MHz {LSIS-TBC-2008}.

LSIS-100: Correlation losses due to payload distortions
For each signal component, the correlation loss due to payload distortions shall be below 0.6 dB {LSIS-TBC-2009}.

2.3.1.6. AFS-I AND AFS-Q POWER RATIO

LSIS-103: Power Ratio between AFS-I and AFS-Q components
The relative power sharing between the signal components for the AFS transmit bandwidth shall be per Table 3, where the total power $P_{AFS} = P_{AFS-I} + P_{AFS-Q}$ is allocated between the power in the AFS-I signal, P_{AFS-I} and the power in the AFS-Q signal, P_{AFS-Q}. P_{AFS}, total power, is given by LSIS-110 and LSIS-120.

Table 3 - Power Ratio between AFS-I and AFS-Q signal components

Signal	Channel	Relative Power for the AFS transmit bandwidth	Tolerance of Relative Power
AFS	I	50 %	1 {LSIS-TBC-2010} %
	Q	50 %	1 {LSIS-TBC-2011} %

2.3.1.7. LUNAR GLOBAL RECEIVED POWER LEVELS

LSIS-110: Minimum and maximum received lunar global power-on-surface levels
The minimum and maximum received power level of the composite signal at the lunar geoid (as defined in LNIS AD5), with the following assumptions:

- an ideally matched 0 dBi RHCP receiver antenna
- user antenna masking angle on the local horizon of 5 degrees

shall be according to Table 4.

Table 4 - Received Minimum and Maximum Power

Received minimum power [dBW]	Received maximum power [dBW]
-160 {LSIS-TBC-2012}	-147 {LSIS-TBC-2013}

2.3.1.8. RECEIVED POWER LEVEL OUTSIDE THE LNSP-DEFINED SERVICE VOLUME

LSIS-105 [FLEX]: LNSP-Defined service volume
The LNSP shall identify in its SISICD any LNSP-specific service volume on or above the lunar geoid where its contribution to LANS is provided.

Note: The objective for LANS is to achieve full-service volume per LNIS. However, individual LNSP may focus on different volumes. LSIS-120 specification applies outside the LNSP-defined service volume.

LSIS-120: Maximum received power levels outside the LNSP-defined service volume
The maximum received power level of the composite signal at the lunar geoid (as defined in LNIS AD5) outside the LNSP-defined service volume, with the following assumptions:

- an ideally matched 0dBi RHCP receiver antenna
- user antenna masking angle on the local horizon of 5 degrees

shall be according to Table 5.

Table 5 - Received Maximum Power

Received maximum power [dBW]
-141 {LSIS-TBC-2014}

The signal may be transmitted outside the LNSP-defined service volume to enable opportunistic use. However, its power shall be within the maximum defined in Table 5 in order to minimize the impact of multiple access interference towards the user receiver.

[Text below is {LSIS-TBC-2015}]

If LSIS-120 is applicable, power-on-surface level shall override the maximum values specified by LSIS-110. The applicability of this specification (LSIS-120 and the associated power level in Table 5) are to be determined by coordination among LunaNet administrative partners. In the absence of LSIS-120, the power-on-surface shall not exceed the maximum values specified by LSIS-110 (and the associated power levels in Table 4).

Note: It is therefore expected that LNSPs will include provisions to be able to adhere to LSIS-110 even outside the LNSPs' service volume in case of need (e.g. to either decrease the power or interrupt signal transmission if necessary).

[Text above is {LSIS-TBC-2015}]

2.3.2. MODULATION

The Augmented Forward Signal is composed of two components, one in-phase and one quadrature, called respectively data and pilot. Both components use Binary Phase Shift Keying (BPSK) modulation, with chip rate of n × 1.023 (Mchip/s); the data component consists of a BPSK (1) modulation (where n = 1), while the quadrature component is a BPSK (5) modulation (where n = 5). Figure 2 provides a generic view of the AFS generation.

LSIS-125: Signal multiplexing
The AFS components shall be linearly multiplexed and modulated according to Figure 2

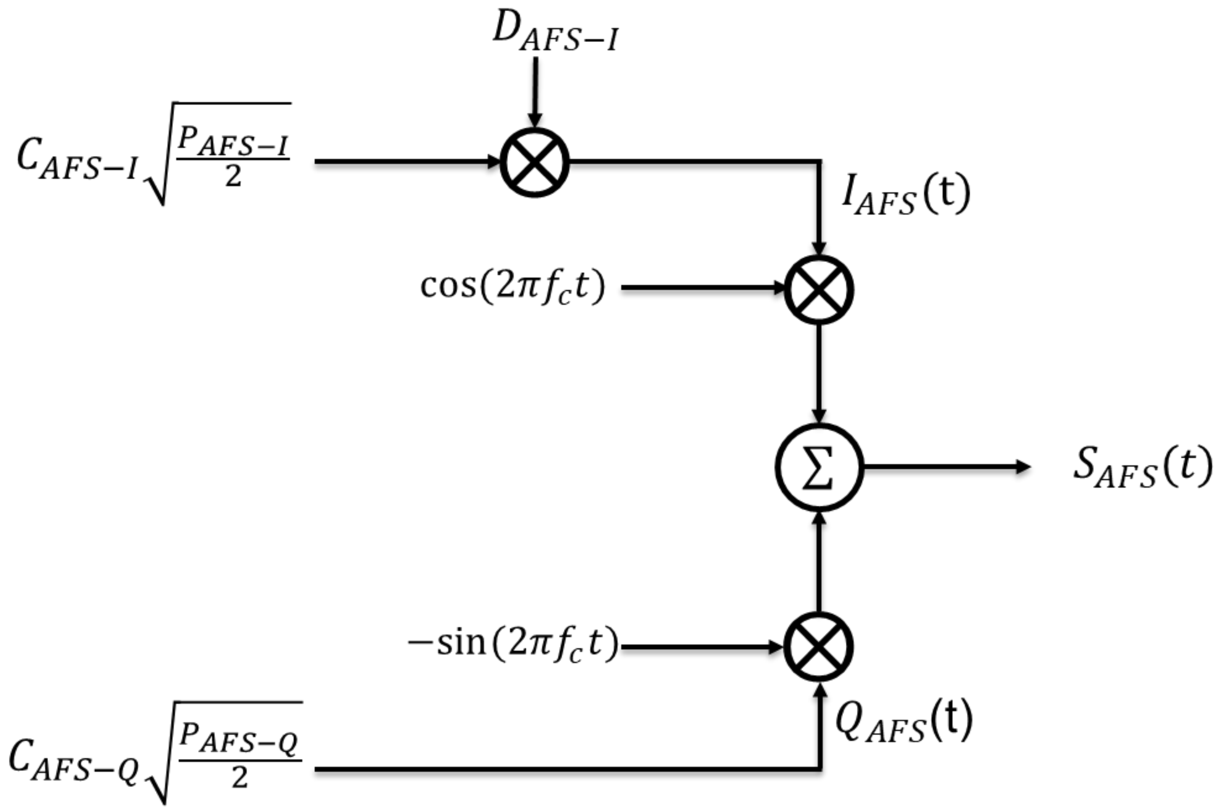

Figure 2: Modulation Scheme for AFS Signal

LSIS-130: Signal component generation
The AFS components shall be generated according to the following relation:

$$S_{AFS}(t) = I_{AFS}(t)\cos(2\pi f_c t) - Q_{AFS}(t)\sin(2\pi f_c t),$$

where,

$I_{AFS}(t) = \sqrt{\frac{P_{AFS-I}}{2}} \cdot C_{AFS-I} \cdot D_{AFS-I}$, and

$Q_{AFS}(t) = \sqrt{\frac{P_{AFS-Q}}{2}} \cdot C_{AFS-Q}$

The I channel is modulated by the I channel spreading code (C_{AFS-I}) and the data symbol sequence (D_{AFS-I}). The Q channel is modulated by a tiered spreading code (C_{AFS-Q}). Table 6 provides a description of the parameters used in the relations above.

Table 6 - Description of Signal Parameters

Parameter	Description
f_c	AFS carrier frequency as defined by LSIS-020.
C_{AFS-I}	Data channel (AFS-I) spreading code, as described in Section 2.3.5.
D_{AFS-I}	Data channel symbol sequence as described in Section 2.4.
C_{AFS-Q}	Pilot channel (AFS-Q) tiered spreading code, as described in Section 2.3.5.
P_{AFS-I}	Data channel (AFS-I) power, derived from LSIS-103, LSIS-110 and LSIS-120.
P_{AFS-Q}	Pilot channel (AFS-Q) power, derived from LSIS-103, LSIS-110 and LSIS-120.

LSIS-140: signal ranging code chip-rate and symbol-rate
The LNSP nodes shall transmit the AFS signal components with the ranging codes chip rates and symbol rates stated in Table 7.

Table 7 - AFS Chip Rates and Symbol Rates

Component	Ranging code chip-rate [Mchip/s]	Symbol-rate [symbols/s]
I	1.023	500
Q	5.115	No data (pilot component)

2.3.3. LOGIC LEVELS

LSIS-150: Logic levels for the code bits
The correspondence between the logic level code bits used to modulate the signal and the signal level shall be according to the values stated in Table 8.

Table 8 - Logical to Signal Level Assignment

Logic level	Signal level
1	-1.0
0	1.0

2.3.4. TRANSMITTED SIGNALS COHERENCY

LSIS-160: Primary code / data coherency
The start of each data symbol shall coincide with the start of a primary code sequence, with a maximum tolerance of 0.5 ns {LSIS-TBC-2016}.

Note: This means that the number of primary code chips per each data symbol is equal to the 'primary code chip-rate / data symbol-rate', according to the respective signal component (AFS-I).

LSIS-170: Secondary Code / Primary Code Coherency
The start of each secondary code chip shall coincide with the start of a primary code sequence, with a maximum tolerance of 0.5 ns {LSIS-TBC-2017}.

Note: The number of primary code chips per each secondary code chip is equal to the 'primary code chip-rate / secondary code chip-rate', according to the respective signal component (AFS-Q).

LSIS-171: Tertiary Code / Secondary Code Coherency

The start of each tertiary code chip shall coincide with the start of a secondary code sequence, with a maximum tolerance of 0.5 ns {LSIS-TBC-2017a}.

Note: The number of secondary code chips per each tertiary code chip is equal to the 'secondary code chip-rate / tertiary code chip-rate', according to the respective signal component (AFS-Q).

LSIS-172: Tiered Code Coherent Generation
All elements of the tiered code (i.e., primary, secondary and tertiary) shall be generated coherently, such that no chip slips occur throughout each iteration of the composite code generation function.

Note: code generation function as shown in Figure 3.

LSIS-180: Code-Code (Data/Pilot) Coherency
The code-code coherency between the data primary code and the pilot primary code shall be less than 0.5ns {LSIS-TBC-2018}.

Note: Code-Code Coherency is the time difference measured between code delays of two signal components within the same signal.

LSIS-190: Code/Carrier Phase Coherency
The maximum of the difference between code phase and carrier phase on any single signal component in any 8-hour period at the phase center of the LNSP transmit antenna shall be less than 0.13 ns (1-sigma) {LSIS-TBC-2019}.

2.3.5. SPREADING CODES CHARACTERISTICS

2.3.5.1. CODE LENGTHS

The ranging codes are built from so-called primary, secondary and tertiary codes using a tiered codes construction described in paragraph 2.3.5.2

LSIS-200: Codes Length and Duration
The code lengths to be used for each signal component shall be according to Table 9.

Table 9 - Code Lengths

AFS Component	Primary code period [ms]	Secondary code period [ms]	Tertiary code period [ms]	Code length [chips]		
				Primary	Secondary	Tertiary
I	2	N/A	N/A	2046	N/A	N/A
Q	2	8	12000	10230	4	1500

LSIS-210: Code-Code (Data/Pilot) Synchronicity
The data primary code and data symbols and the pilot primary, secondary and tertiary code shall be transmitted according to Figure 3. The secondary code pattern shown in this figure represents S0 (Table 10) and is included here as an example.

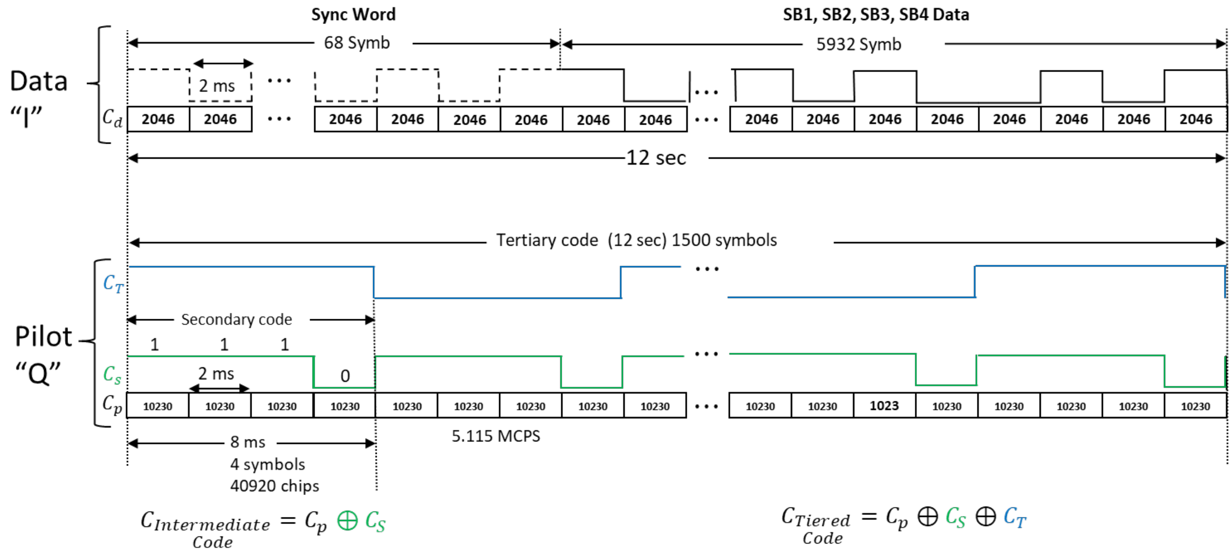

Figure 3: Data and Pilot Channel Code and Data Synchronization

LSIS-220: Tertiary Code Synchronization
The start of the tertiary code sequence shall be synchronized with the start of the AFS-I data frame structure.

Note: The code/code coherency specified by LSIS-180 drives the accuracy of the synchronization. AFS-I data frame structure is specified by LSIS-310.

2.3.5.2. PILOT CHANNEL (AFS-Q) TIERED CODES GENERATION

Long spreading codes are typically generated by a tiered code construction, whereby a secondary code sequence is used to modify successive repetitions of a primary code. The AFS pilot channel consists of three codes, a primary spreading code, a secondary code and a tertiary code, as shown Figure 4. The primary code is of length N_p and clock rate f_c (same as chip rate), the secondary code is of length N_S and chip rate f_{cs}; and the tertiary code is of length N_T and a chip rate f_{cT} (values in alignment with Table 7 and Table 9).

The duration of N_p chips is also called a primary code epoch (or repeat interval), as shown Figure 4. In logical representation, the secondary code chips are sequentially modulo 2 added with the primary code, with one chip of the secondary code per primary code period, and then the tertiary code is modulo 2 added onto the modulo 2 sums of the primary and secondary tiered code. Likewise, there is one tiered (primary + secondary) code period per tertiary code chip, to produce the final tiered AFS-Q channel ranging code, C_{AFS-Q}. This tiered code has a length of $N_p \times N_S \times N_T$ primary code spreading chips.

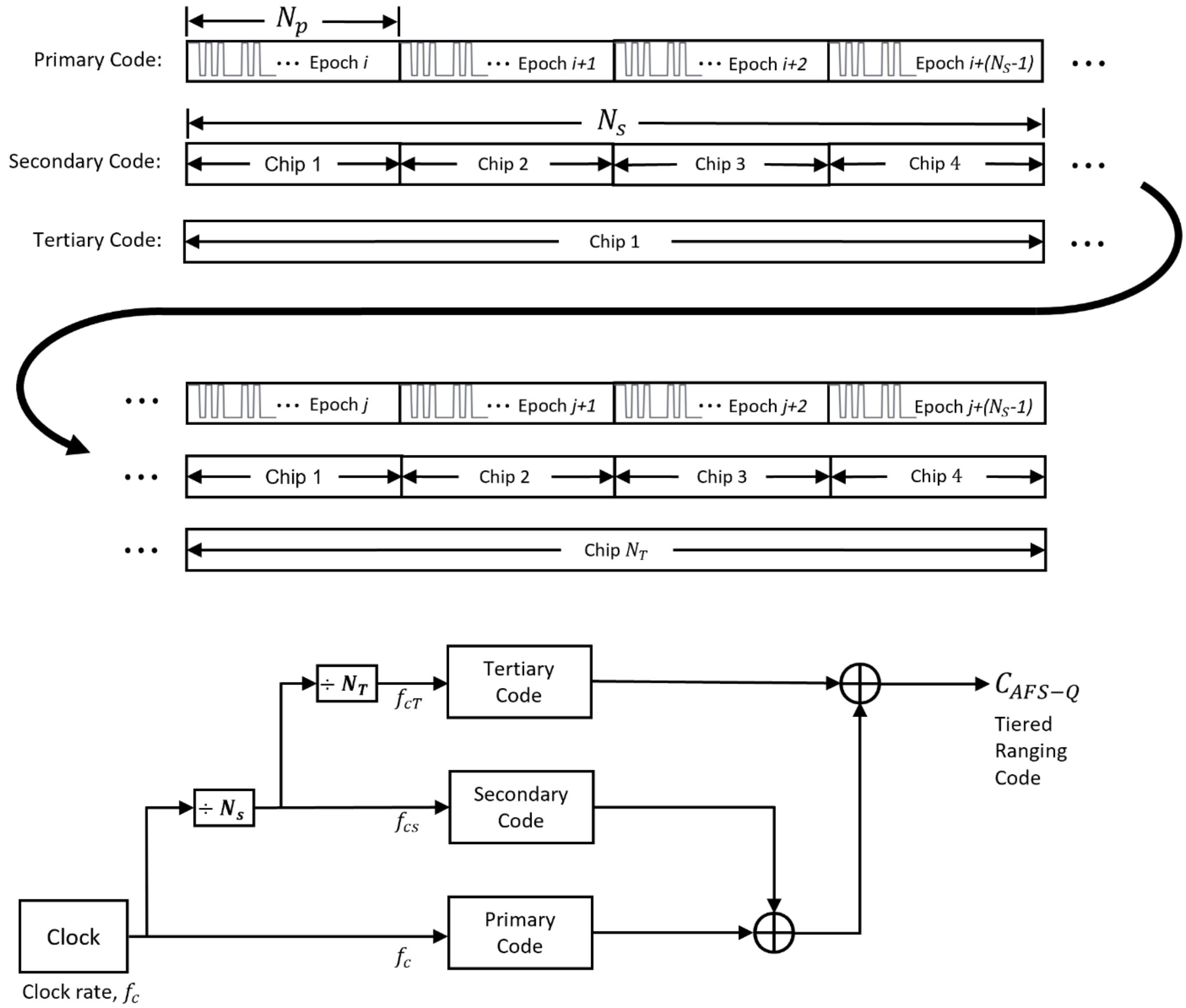

Figure 4: Tiered Codes Generation with Secondary and Tertiary Codes

There are 1500 tertiary code symbols that span the 12 second data frame and provide rapid time dissemination (within 12 seconds), and robust frame synchronization after synchronization to the tiered primary + secondary code, $C_p \oplus C_S$.

2.3.5.3. SPREADING CODES

2.3.5.3.1. DATA CHANNEL (AFS-I) SPREADING CODE DEFINITION

LSIS-221: Data Channel (AFS-I) Primary Code Definition

The data channel (AFS-I) primary code shall be a 2047 chip Gold sequence short-cycled to length 2046, as described in Appendix C and [Annex3] (hexadecimal representation).

2.3.5.3.2. PILOT CHANNEL (AFS-Q) SPREADING CODE DEFINITION

LSIS-222: Pilot Channel (AFS-Q) Primary Code Definition
The pilot channel (AFS-Q) primary code shall be a Weil sequence of length 10230 which is derived from a Legendre sequence *L(t)* of length 10223 as described in Appendix D and [Annex3] (hexadecimal representation).

*Note-1: The Weil and insertion indices (and the resulting hexadecimal codes) provided in Appendix D (and the csv file [Annex3]) are currently {*LSIS-TBC-2020*}. The codes provided in this release of the document are included to facilitate test and integration efforts only. It is therefore recommended for implementers to support a flexible code configuration, enabling code changes to be applied through configuration updates.*

LSIS-223: Pilot Channel (AFS-Q) Secondary Code Definition
The pilot channel (AFS-Q) secondary code shall be one of the four possible sequences shown in Table 10.

Table 10 - Secondary Code Definitions

Secondary Code Identifier	Secondary Code (binary)
S_0	1110
S_1	0111
S_2	1011
S_3	1101

LSIS-224: Pilot Channel (AFS-Q) Tertiary Code Definition
The pilot channel (AFS-Q) tertiary code shall be a Weil sequence of length 1500 which is derived from a Legendre sequence *L(t)* of length 1499 as described in Appendix E and [Annex3] (hexadecimal representation).

2.3.5.4. CODE ASSIGNMENT TO SATTELLITES / LNSP

LSIS-260: Matched-Codes Assignment Per LNSP Node
Each LNSP node shall be linked to a single LNSP node identifier which has a unique combination of code sequences assigned as defined in Table F- 1 (Appendix F).

*Note-1: The assignments between the LNSP node identifiers and combination of code sequences are currently {*LSIS-TBD-2001*}, and codes provided in this release of the document are included to facilitate test and integration efforts only. The assignment of codes to a particular LNSP node identifier will be completed in a future release, to allow for optimization of the assignments between primary, secondary, and tertiary codes as well as the relevant phasing of the tertiary code.*

Note-2: Interim assignments for the first 12 codes are provided in Table 11 *for integration and test purposes.*

Note-3: This document does not address the assignment of LNSP node identifiers to particular LNSP nodes.

Table 11 – Interim Test and Integration Code Assignments

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
1	1	1	S_0	1	0
2	2	2	S_1	2	0
3	3	3	S_2	3	0
4	4	4	S_3	4	0
5	5	5	S_0	5	0
6	6	6	S_1	6	0
7	7	7	S_2	7	0
8	8	8	S_3	8	0
9	9	9	S_0	9	0
10	10	10	S_1	10	0
11	11	11	S_2	11	0
12	12	12	S_3	12	0

2.4. AFS NAVIGATION MESSAGE FORMAT SPECIFICATION

2.4.1. GENERAL NAVIGATION MESSAGE STRUCTURE

LSIS-300: Spare Bits Definition
When not specified otherwise, the spare bits in the message structure shall be filled with a sequence of alternating zeros and ones starting with zero on the MSB.

LSIS-310: Message Frame Structure
Each frame shall be composed of:

1) the uncoded synchronization pattern (SP)
2) one subframe (called Subframe Block 1, SB1) that contains the Time of Interval (TOI) and the Frame Identifier (FID)
3) and subsequent subframes that depend on the specific FID value.

See Figure 5for a representation of the message frame structure.

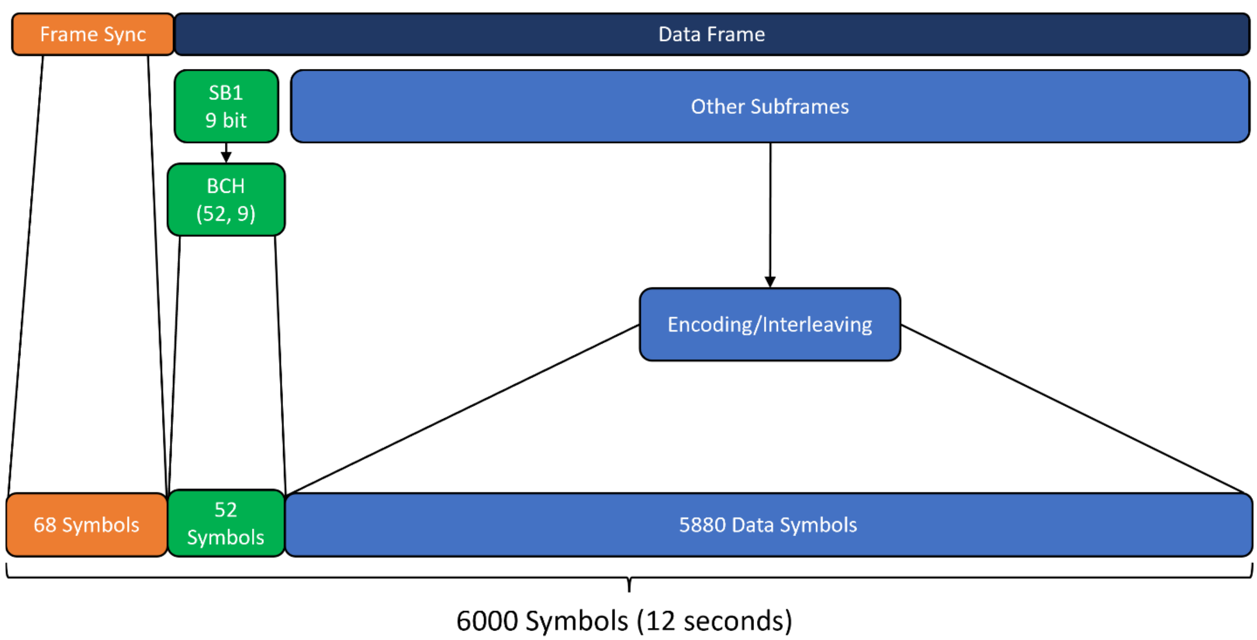

Figure 5: Navigation Message Generic Structure

2.4.1.1. BIT AND BYTE ORDERING CRITERIA

LSIS-320: Bit and Byte Ordering Criteria
All data values shall be encoded using the following bit and byte ordering criteria (as shown in Figure 6):

- 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

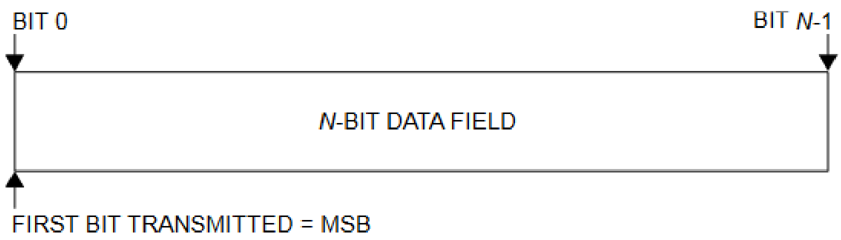

Figure 6: Bit and Byte Ordering

2.4.1.2. SYNCHRONIZATION PATTERN

LSIS-330: Synchronization Pattern (SP)
The synchronization pattern (SP) shall be according to Table 12.

Note: The synchronization pattern allows the receiver to achieve synchronization to the frame boundary. The sequence is chosen for its favorable autocorrelation properties[4].

Table 12 - Synchronization Pattern

Number of symbols	Hexadecimal pattern
68	CC63F74536F49E04A {LSIS-TBC-2021}

LSIS-340: Uncoded Synchronization Pattern
The SP shall not be encoded.

2.4.2. SUBFRAME 1 MESSAGE SPECIFICATION

2.4.2.1. SUBFRAME 1 ENCODING

Subframe 1 data is channel encoded using a Bose–Chaudhuri–Hocquenghem (BCH) code (51, 8). The eight Least Significant Bits (the rightmost bits 1 - 8) of the nine-bit SB1 field are encoded using a generator polynomial of 763 (octal). This code generator is conceptually described in Figure 6using an 8-stage linear shift register generator. The data bits are loaded into the generator, bit 1 first, as initial conditions of the registers, so that the starting condition has bit one in stage 8 and bit 8 in stage 1. The generator is then shifted 51 times to generate 51 encoded symbols. The MSB of SB1 (bit 0) shall be modulo-2 added to the 51 encoded symbols and it shall also be prepended as the MSB of the 52-symbol message. An example of a BCH(51,8) encoded SB1 is provided in Figure 7.

[4] Sükrü Ekin Kocabas, Abdullah Atalar, "Binary Sequences With Low Aperiodic Autocorrelation for Synchronization Purposes," IEEE Communications Letters, Vol. 7, No. 1, January 2003

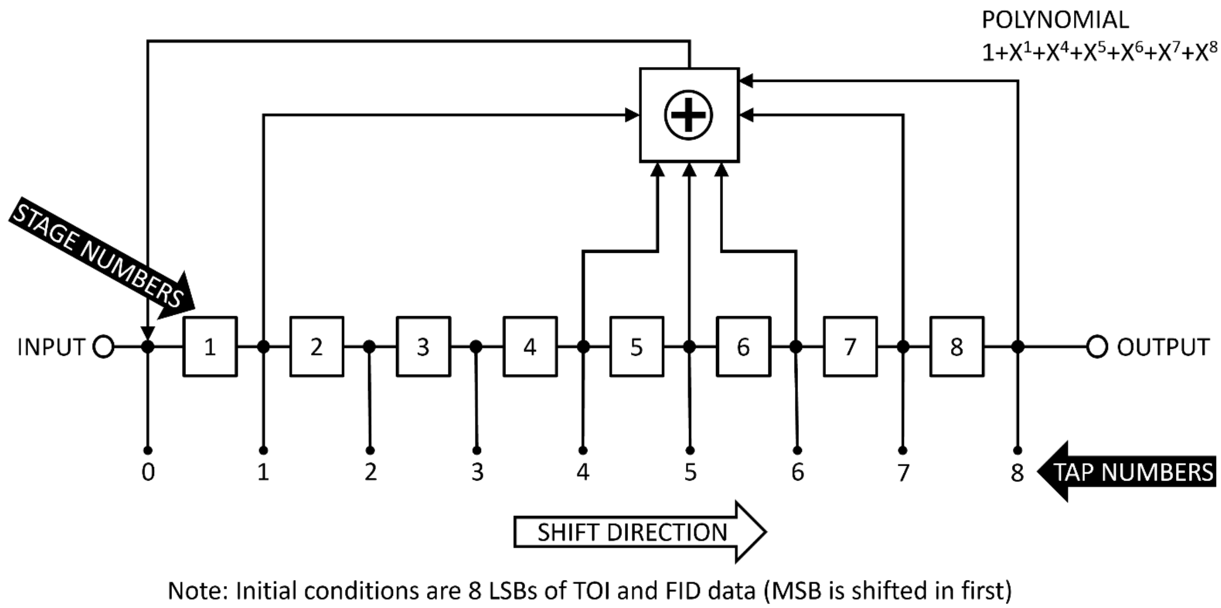

Figure 7: Subframe 1 BCH Encoding

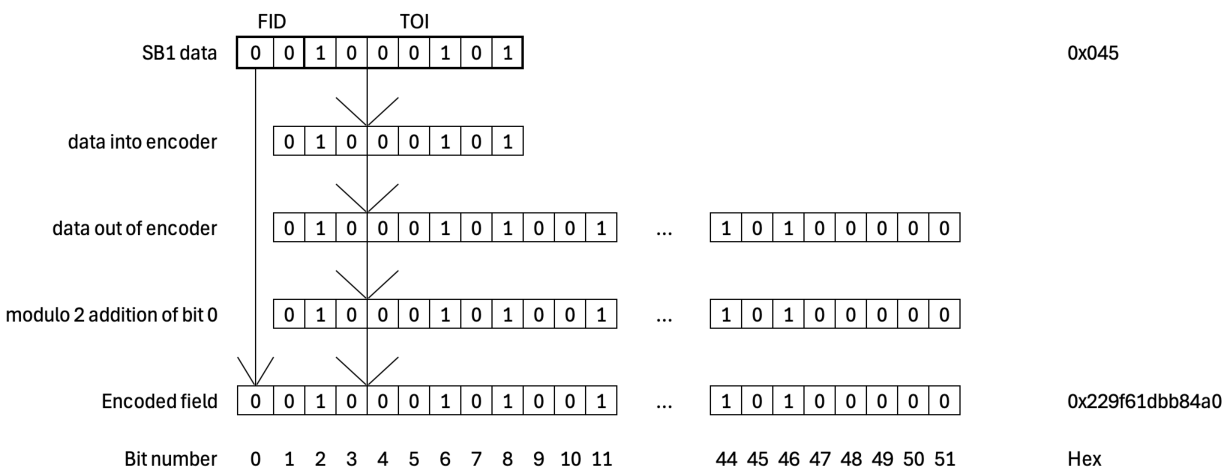

Figure 8: Example of BCH(51,8) encoder for subframe-1 (SB1)

The SB1 data field and encoded field are provided also in hexadecimal format (on the righthand side). Note that three ones (i.e., [0 0 0]) are padded to the left-hand side of the SB1 data to enable a h hexadecimal representation. The following provides an example decoding technique to decode the Subframe 1 encoded data. The 52 user-equipment-received soft decisions are stored as sign/magnitude and correlated, respectively, with the 52 symbols of a code word hypothesis corresponding to MSB = 0. (An LNSP transmitted 0 is expected to produce a sign of 0). For each soft decision, the correlation computation adds the magnitude if the sign agrees with the code word hypothesis and subtracts the magnitude otherwise. The correlation computation is repeated for all 256 code word hypotheses. The decision on the eight LSBs corresponds to the code word hypothesis producing the largest absolute value of the correlation. The decision on the MSB is 0 if this largest correlation is positive and 1 otherwise.

2.4.2.2. SUBFRAME 1 (SB1) DATA SPECIFICATION

LSIS-410: Subframe 1 Data Definition
The fields of the SB1 data shall follow the description in Table 13.

Table 13: Subframe 1 Fields Specification

Parameter	Definition	Bits	Scale factor	Unit	Values
FID	Frame ID	2	N/A	dimensionless	0…3
TOI	Time of interval	7	N/A	dimensionless	0…99

Note: The FID is used to identify the structure of the frame as described in 2.4.3. The TOI is used to reconstruct the time at the user level as described in 2.5.5.

LSIS-415: Subframe 1 Bit Assignment
Subframe 1 shall use the two MSBs to represent the FID information and the remaining seven LSBs to represent the TOI that corresponds to the NT (Node Time representing the time of the node clock) epoch at the start (leading edge) of the next 12-second frame as shown in Table 14 .

Table 14: Bit Allocation for Subframe 1

Subframe 1		Total (bits)
FID	*TOI*	
2	**7**	**9**

2.4.3. FRAME STRUCTURE

The Frame Identifier (FID) field is used to define different types of frames and allows for implementation of different schemes, including:

- different type of encoding of the "Other Subframes" other than SB1,
- different type and number of subframes.

LSIS-420: Frame Structure Identification
The frame structure shall be identified using the Frame Identifier (FID) field in SB1 in line with the values in Table 15.

Table 15: Frame Structure Identification

FID	Definition	Reference
0	Frame structure including SB2, SB3 and SB4	Paragraph 2.4.3.1
1 to 3	Reserved for future use	Future Use

2.4.3.1. FRAME ID 0 MESSAGE STRUCTURE

In addition to the synchronization pattern (SP) and SB1 that maintain the structure defined in 2.4.2, 3 additional subframe types are specified within this frame type (i.e., FID0).

Subframe 2 (SB2) is broadcast in every frame and its structure is not changing, as described in 2.4.3.1.5. This subframe contains, among others, clock and ephemeris data.

Subframe 3 (SB3) is a variable data frame that will contain different content in each frame. The specific information broadcast is identified by the subframe identifier as described in 2.4.3.1.7.

Subframe 4 (SB4) is a variable data frame that will contain different content in each frame. The data potentially supports services other than the navigation service. The specific information broadcast is identified by the subframe identifier as described in 2.4.3.1.8.

Note for the current version of this document: The structure of the frame is meant to ensure dissemination of the mandatory and optional messages as defined in LNIS. At the same time, the proposed concept leaves flexibility to the LNSPs to implement their specific concepts, so some aspects (e.g.: dissemination structure, dissemination frequency, etc.) are not specified in this version of the document. A clear example is the possibility to disseminate some messages in SB3 and/or SB4 and the possibility to use multiple frames to disseminate the complete message (e.g.: the almanac may be disseminated using multiple SB3 and/or SB4 over multiple frames). The next version of this document is expected to contain additional specifications to guide LNSPs towards a common concept and ensure interoperability.

LSIS-FID0-430: Frame ID 0 Structure Identification

The frame structure identified with FID equal to zero (i.e., FID0) shall be in accordance Figure 9.

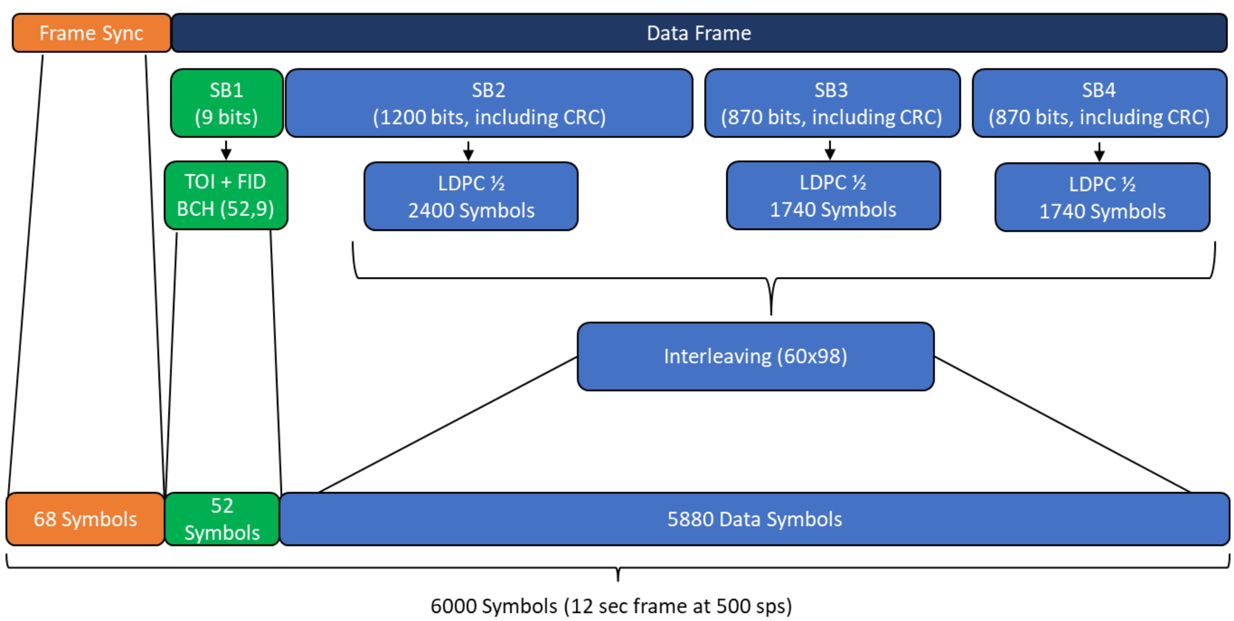

Figure 9: Frame Structure of Frame ID Equal to Zero

2.4.3.1.1. SUBFRAME ENCODING (NON-SUBFRAME 1)

LSIS-FID0-440: Subframe 2 Encoding

The 1200 bits of SB2 data, including CRC, shall be encoded using $^1/_2$ LDPC codes as described in Section 2.4.3.1.2.

LSIS-FID0-450: Subframe 3 Encoding
The 870 bits of SB3 data, including CRC, shall be encoded using $1/2$ LDPC codes as described in Section 2.4.3.1.2.

LSIS-FID0-460: Subframe 4 Encoding
The 870 bits of SB4 data, including CRC, shall be encoded using $1/2$ LDPC codes as described in Section 2.4.3.1.2.

2.4.3.1.2. LDPC ENCODING

Subframe 2, Subframe 3, and Subframe 4 are separately encoded using rate ½ LDPC codes. Subframe 2 has a total of 1200 bits consisting of 1176 bits for data and 24 bits for CRC. Subframe 3 and subframe 4 each have a total of 870 bits consisting of 846 bits for data and 24 bits for CRC. As a result of the rate ½ LDPC encoding, there are 2400 symbols (coded bits) for Subframe 2 and 1740 symbols for Subframe 3 and subframe 4 as described in Figure 9.

The LDPC encoder structure is based on a parity-check matrix *H(m, n)* of *m* rows and *n* columns. For Subframe 2, *m* = 1200, *n* = 2400 and for Subframe 3, *m* = 870, *n* = 1740. *H(m, n)* is further decomposed into 6 submatrices *A*, *B*, *C*, *D*, *O*, and *I* as shown in Figure 10. Each element of matrix *H(m, n)* is either a value of "0" or "1". "O" represents a matrix of all zeros with the designated size. "I" represents an identity matrix with the designated size.

Tables in [Annex1] Sections 2.1.1, 2.1.3, 2.1.4, 2.1.5, and 2.1.2 define the coordinates of elements with value "1" in each of the submatrices A, B, C, D, and B^{-1}, respectively, for Subframe 2.
Tables in [Annex1] Sections 2.2.1, 2.2.3, 2.2.4, 2.2.5, and 2.2.2 define the coordinates of elements with value "1" in each of the submatrices A, B, C, D, and B^{-1}, respectively, for Subframe 3 and Subframe 4.

The rate ½ LDPC encoder shall use the given matrices A, B^{-1}, C, and D defined in Annex-1 to generate the encoded symbols using the following algorithm:

$$p_1^t = B^{-1} \cdot A \cdot s^t$$
$$p_2^t = C \cdot s^t + D \cdot p_1^t$$

where,

s = Subframe 2, Subframe 3, or Subframe 4 data with "filler bits", where,

- for Subframe 2, no filler bits are needed
- for Subframe 3 and Subframe 4, 10 filler bits are needed (i.e. 10 zero bits appended to the end of the data)

$[\ ]^t$ indicates transpose,
and elements of matrices p_1 and p_2 are modulo-2 numbers.

The encoded symbols for broadcast are comprised of (s*;p*) where,

s* is the systematic portion of the codeword with the first z bits punctured and the filler bits also punctured,
z is the lifting factor multiplied by two, where,
z = 240 for Subframe 2
z = 176 for Subframe 3 and Subframe 4
and p* = (p_1;p_2) the combined parity bits appended until the subframe reaches its desired symbol count. The remaining parity bits are punctured and not transmitted across the channel.

When receiving the encoded symbols, the punctures must be restored prior to decoding the message. The punctured symbols (the first z bits of the systematic portion, filler bits, and the remainder of the parity bits) can be treated as erasures (i.e. if using log-likelihood ratios for a belief-propagation LDPC decoder, the values can be initialized as zero). A successfully decoded codeword will have the representation ($s;p_1;p_2$), where the systematic portion s is the transmitted data.

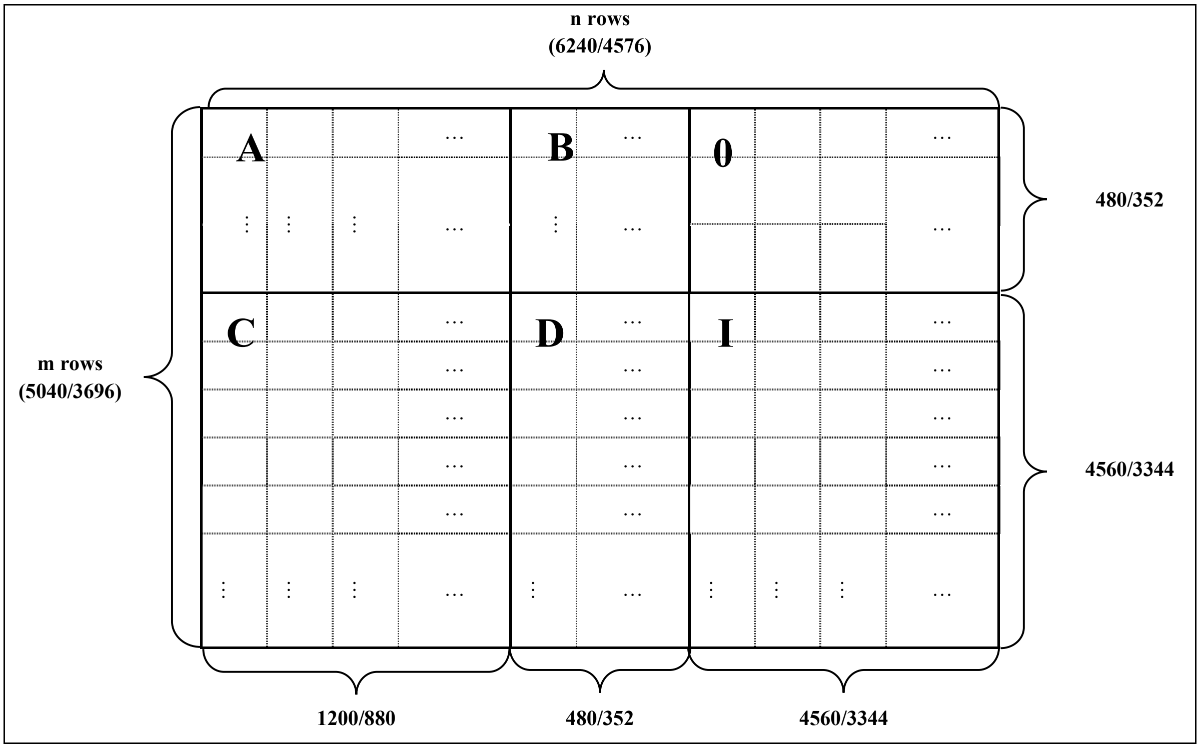

Figure 10: LDPC Submatrices

2.4.3.1.3. CHECKSUM VIA CYCLIC REDUNDANCY CHECK

The checksum, which employs a Cyclic Redundancy Check (CRC) technique, is used to detect the reception of corrupted data. For a detailed description of the CRC mechanism, please refer to Appendix G .

LSIS-FID0-465: Information guarded by CRC
The CRC shall guard all information in SB2, SB3 and SB4 including spare-bits (when applicable).

LSIS-FID0-467: Checksum Field Generator Polynomial
For the SB2, SB3 and SB4 a CRC of 24 bits shall be generated from the following generator polynomial:

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

where P(X) is the primitive and irreducible polynomial with the following definition:

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

LSIS-FID0-469: Checksum Field Computation
The CRC shall be composed of a sequence of 24 parity bits p_i with the following values.
For any i from 1 to 24, p_i is the coefficient of X^{24-i} in $R(X)$,
Where:

- $R(X)$ is the remainder of the binary polynomial algebra division of the polynomial $m(X) \cdot X^{24}$ by $G(X)$

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

2.4.3.1.4. SUMMARY OF FRAMEID 0 ENCODING

Table 16 provides a summary of the encoding parameters for the different subframes.

Table 16 - Frame ID=0 Bits and Symbols Allocation to Subframes

Subframe	bits	coding	coding rate	symbols
Subframe 2	1200	LDPC	1/2	2400
Subframe 3	870	LDPC	1/2	1740
Subframe 4	870	LDPC	1/2	1740

2.4.3.1.5. INTERLEAVING

The 5880 symbols representing all subframe types except SB1 are interleaved, after encoding, using a block interleaver for improved performance in a fading channel. The block interleaver is conceptually described using a two-dimensional array of 60 rows and 98 columns. Symbols are written first (MSB first) into the interleaver from left to right starting at Row 1. After Row 1 is filled, Row 2 is filled from left to right and this process continues until the 5880th symbol (LSB of LDPC encoded symbol of the last subframe) is written into the rightmost cell of the last (60th) row. Once all 5880 symbols are written into the array, the symbols are sequentially read out of the array, for broadcast to user, from top to bottom starting at Column 1. After reading out the last symbol of the 60th row in Column 1, Column 2 symbols are read out from top to bottom and this process continues until the last symbol in the 60th row of the last column (98th) is read out.

LSIS-FID0-470: Symbol interleaving parameters
All the symbols of the frame, except for the synchronization pattern (SP) and SB1 symbols, shall be interleaved according to the parameters in Table 17.

Table 17 - Interleaving Parameters

Parameters	Values
Block interleaver size (symbols)	5880
Block interleaver dimensions (n columns x k rows)	60 x 98

2.4.3.1.6. SUBFRAME 2 MESSAGE SPECIFICATIONS

LSIS-FID0-500: Subframe 2 Dissemination
The SB2 shall be broadcast in every frame.

LSIS-FID0-510: Subframe 2 Structure
The SB2 structure shall be identical in every frame.

LSIS-FID0-520: Subframe 2 Fundamental Type of Data Content
SB2 shall contain at least the following data:

- Clock and ephemeris data (CED) (MSG-G4, see also 2.5.3)
- Time of transmission (ToT) (MSG-G8, including Week Number (WN) and Interval Time of Week for which the definition is provided in 2.5.1)
- Health and Safety (MSG-G2, including LNSP node health status, see also 2.5.2)

- Time Conversions (MSG-G30)
- Cyclic Redundancy Check (CRC) (see Appendix G)

LSIS-FID0-530: Subframe 2 Layout
The SB2 layout shall be according to Table 18.

Table 18 - Bit Allocation for Subframe 2

Subframe 2		Total (bits)
Data	*CRC*	
1176	24	1200

LSIS-FID0-540 [FLEX]: Subframe 2 LNSP Specific Data
Additional data specified by the LNSP may be broadcast in SB2 in addition to the mandatory data.

LSIS-FID0-550: Subframe 2 Mandatory Spare Bits
{LSIS-TBC-2022} bits shall be kept as spare for future use.
Note: Spare bits shall be positioned before the CRC and are guarded by the CRC. Depending on the definition of the data field in SB2 the number of *spare bits might vary and potentially might be removed entirely.*

2.4.3.1.7. SUBFRAME 3 MESSAGE SPECIFICATIONS

The SB3 is a dynamic subframe that will have different structures depending on the SB3 type. This subframe may be used for multiple purposes, including specific custom messages from the LNSP* that are not specified in this document (e.g.: proprietary messages). Proprietary messages are not interoperable and require the LNSP to establish a SISICD for user implementation (refer to Section 2.1).

**Note: This definition is a functional specification intended to provide the LNSP with implementation flexibility.*

LSIS-FID0-560: Subframe 3 Layout
The SB3 layout shall be according to Table 19.

Table 19 – Bit Allocation for Subframe 3

Subframe 3			Total (bits)
SB3 type	*Data*	*CRC*	
4 or 6 {LSIS-TBC-2023}	840 or 842 {LSIS-TBC-2023}	24	870

LSIS-FID0-570: Subframe 3 Dynamic Data Content
The SB3 data content shall be identified by the SB3 type field.

LSIS-FID0-580: Subframe 3 Fundamental Type of Data Content
The following data shall be disseminated using SB3:

- M(ultiple) Orbit Almanac (note that the almanac data for the full constellation is expected to be disseminated using multiple SB3) (MSG-G5, see also 2.5.4).

- LunaSAR return link message (covering both MSG-S19 and MSG-S20 considering LvL1 and LvL2, with definition provided in 2.5.11) – Note that while considered mandatory, these messages are placeholders only and **not a part of LunaNet 1.0.**
- Alerts messages (MSG-G24), with definition provided in Section 2.5.15. – Note that while considered mandatory, these messages are placeholders only and **not a part of LunaNet 1.0.**
- Coordinate Frame Conversions (MSG-G32)

Note: The data listed in this specification does not need to be disseminated every frame, the frequency of the dissemination of the data *is not defined in this document. The data of a specific message might be disseminated over multiple frames.*

LSIS-FID0-590: Subframe 3 Optional Type of Data Content
The following data should be disseminated using SB3:

- M(ultiple) Antenna Properties (MSG-G3)
- GNSS Augmentation (MSG-G23)
- Maneuver (MSG-G10)
- S(ingle) Attitude State/ Ephemeris (MSG-G11)
- Conjunction (MSG-G14) – **not LunaNet 1.0**
- Augmentation differential Corrections (MSG-G31)
- Custom messages defined by the LNSP.

2.4.3.1.8. SUBFRAME 4 MESSAGE SPECIFICATIONS

The SB4 is a dynamic subframe that will have different structures depending on the SB4 type. This subframe may be used for multiple purposes, including specific custom messages from the LNSP that are not specified in the Lunar Signal-in-Space Recommended Specification (e.g.: proprietary messages*). Proprietary messages are not interoperable and require the LNSP to establish a SISICD for user implementation (refer to Section 2.1).

**Note: This definition is a functional specification intended to provide the LNSP with implementation flexibility*

LSIS-FID0-600: Subframe 4 Layout
The SB4 layout shall be according to Table 20.

Table 20 – Bit Allocation for Subframe 4

Subframe 4			Total (bits)
SB3 type	*Data*	*CRC*	
4 or 6 {LSIS-TBC-2024}	840 or 842 {LSIS-TBC-2024}	24	870

LSIS-FID0-610: Subframe 4 Dynamic Data Content
The SB4 data shall be identified by the SB4 type field.

LSIS-FID0-620: Subframe 4 Fundamental Type of Data Content

The following data shall be disseminated using SB4:

- LunaNet Network Access Information (MSG-G1).

Note: The data listed in this specification does not need to be disseminated in every frame, the frequency of the dissemination of the data is not defined in this document. The data of a specific message might be disseminated over multiple frames.

LSIS-FID0-630: Subframe 4 Optional Type of Data Content
The following data should be disseminated using SB4:

- M(ultiple) Antenna Properties (MSG-G3)
- M(ultiple) Orbit Almanac (note that the almanac data for the full constellation is expected to be disseminated using multiple SB4) (MSG-G5, see also 2.5.4)
- Maneuver (MSG-G10)
- S(ingle)Attitude State/ Ephemeris (MSG-G11)
- GNSS Augmentation (MSG-G23) – **not LunaNet 1.0**
- User Schedule Notice (information for communication service) (MSG-G28)
- Maplet (including updates of lunar maps or lunar DEM) (MSG-G15) – **not LunaNet 1.0**
- Ancillary info (MSG-G17)
- Conjunction (MSG-G14) – **not LunaNet 1.0**
- Science data (MSG-G25) – **not LunaNet 1.0**
- Acknowledge- of non-SAR MSG (MSG-G22) – **not LunaNet 1.0**
- UIS Response (MSG-G27) – **not LunaNet 1.0**
- FF Commands (MSG-G29) – **not LunaNet 1.0**
- Augmentation Differential Corrections (MSG-G31)
- Coordinate Frame Conversions (MSG-G32)
- Custom messages defined by the LNSP*.

Note: The data listed in this specification does not need to be disseminated in every frame, the frequency of the dissemination of the data is not defined in this document. The data of a specific message might be disseminated over multiple frames.

Note: Almanac data (MSG-G5) needs to be disseminated using SB3, however, to improve the latency or allow dissemination of complementary almanacs (for other LNSPs), SB4 can optionally be used for this purpose.

**Note: This definition is a functional specification intended to provide the LNSP with implementation flexibility*

2.4.3.1.9. ALLOCATION OF LUNANET MESSAGES TO SUBFRAMES

This section contains the mapping between LunaNet messages (see Table 4 of LNIS) with the subframes specified in this document, as captured by Table 211. In line with LNIS, a label is used to identify which category applies to that message/service combination within the available AFS bandwidth: F = Fundamental, meaning it shall be broadcast by the LNSP; O = Optional, meaning it might be broadcast by the LNSP; and C = Comm, meaning it may be transmitted on AFS to facilitate LunaNet services. M and S in front of MSG title words in Table 21 refers respectively to multiple and single, indicating whether the message is applicable to the LNSP node sending the message (using "S") or when the LNSP node sends the message applicable to multiple LNSP nodes (using "M"). This table also identifies applicability to LNIS

V1.0. Messages that are not part of LNIS V1.0 are included as placeholder only and will not be specified as part of LNIS V1.0.

Table 21 - LNIS Message Allocation to AFS Subframes

LunaNet Interoperability Specifications [AD.1]			LSIS (this document)		
MSG ID	**MSG Title**	**Category**	**Subframe**	**Notes**	**LNIS V1.0**
MSG-G1	LunaNet Network Access Information	F	SB4	periodic	yes
MSG-G2	Health and Safety	F	SB2	periodic	yes
MSG-G3	MAntennaProperties	O	SB3 and/or SB4	{LSIS-TBD-2002}	yes
MSG-G4	Sorbit Ephemeris & clock correction (Clock and Ephemeris Data – CED)	F	SB2	periodic	yes
MSG-G5	MOrbit Almanac	F	SB3 and/or SB4	periodic	yes
MSG-G8	Time of transmission (ToT)	F	SB1, SB2 and SB3	periodic	yes
MSG-G10	Maneuver	O	SB3 and/or SB4	Ad-hoc	yes
MSG-G11	SAttitude State/ Ephemeris	O	SB3 and/or SB4	Ad-hoc	yes
MSG-G14	Conjunction	O	SB3 and/or SB4	Ad-hoc	no
MSG-G15	Maplet	O	SB4	Ad-hoc	no
MSG-G17	Ancillary info	O	SB4	Ad-hoc	yes
MSG-S19	Acknowledge- of SAR - LvL1	F	SB3	Ad-hoc	no
MSG-S20	Acknowledge- of SAR - LvL2	F	SB3	Ad-hoc	yes (see Note-1)
MSG-G22	Acknowledge- of non-SAR MSG	O	SB4	Ad-hoc	no
MSG-G23	GNSS Augmentation	O	SB3 and/or SB4	Ad-hoc	no
MSG-G24	Detection Alert	F	SB3	Ad-hoc	no
MSG-G25	Science	C	SB4	Ad-hoc	no
MSG-G27	UIS Response	C	SB4	Ad-hoc	no
MSG-G28	User Schedule Notice	C	SB4	Ad-hoc	yes
MSG-G29	FF Commands	C	SB4	Ad-hoc	no
MSG-G30	Time Conversions	F	SB2	Periodic	yes
MSG-G31	Augmentation Differential Corrections	O	SB3 and/or SB4	Ad-hoc	yes
MSG-G32	Coordinate Frame Conversions	F	SB3 and/or SB4	Periodic	yes

Note-1: LunaNet 1.0 item, limited to reserving a bit allocation for LunaSAR Return Messages that are to be disseminated by LNSP nodes via AFS.

2.5. AFS MESSAGES AND DATA CONTENT

This chapter describes the messages and data content applicable to AFS, following the logic described in Section 2.1, and recalled here:

- When a message is defined and/or specified in the same way (e.g.: at bit level) in multiple LunaNet PNT services (e.g. LANS and P2P), its definition is provided in LNIS AD3, so the related paragraph in Section 2.5 includes the encapsulation of the message in AFS and refers to LNIS AD3 for the message detailed definition.
- When a message is implemented differently in AFS with respect to other LunaNet PNT services, its detailed specification and/or definition are only provided in Section 2.5 of this document.

Note for the current version of this document: the content of many of the messages is currently undefined and it is expected to be specified in future releases of this document. It is important to note that different messages might follow different approaches. In line with the descriptions in Section 1 of this document, the following specification categorizations apply to messages:

1) *Precise specifications that are provided to ensure the definition of key interoperability messages, without ambiguity and with no flexibility to LNSP implementation.*
2) *Functional specifications that provide guidance to guarantee interoperability yet provide flexibility to the LNSP to define specific implementations.*

With item 2 above requiring the LNSP to incorporate message definitions within the applicable SISICD.

This approach will be further detailed in future releases of this document, including which category is planned to be adopted for each of the messages.

2.5.1. LUNANET NETWORK ACCESS INFORMATION (MSG-G1)

*{*LSIS-TBW-2004*}*

2.5.2. HEALTH AND SAFETY (MSG-G2)

*{*LSIS-TBW-2005*}*

2.5.3. CLOCK AND EPHEMERIS DATA (CED, MSG-G4)

*{*LSIS-TBW-2006*}, additional information will be provided in future versions of this document, but some preliminary information is provided to allow understanding of the type of information expected to be broadcast to the user. MSG-G4 is expected to contain or specify:*

- *The data to allow a user to compute the position and velocity of the phase center of the navigation antenna (or antenna reference point) of the LNSP node transmitting the AFS, in the reference frame defined in LNIS AD5*
- *The data to allow a user to correct any clock synchronization error impacting the AFS transmitted by an LNSP node, in the time scale defined in LNIS AD5*
- *The validity period of the data contained in MSG-G4*
- *The reference epoch to which the data refers*

- *The expected quality estimated by the LNSP of the data contained in MSG-G4 (e.g.: similar to GPS URA or Galileo SISA)*

2.5.4. MORBIT ALMANAC (MSG-G5)

*{*LSIS-TBW-2007*}*

2.5.5. TIME OF TRANSMISSION (MSG-G8)

The time of transmission (ToT) may be retrieved by a receiver combining multiple fields provided in the navigation message and exploiting tracking of the spreading codes.

A user receiver may resolve the time (multiple of the frame duration) since the starting LunaNet Reference Time (LRT) epoch with the following formula:

$$t_F = WN * SECWEEK + ITOW * BI_d + TOI * F_d + \Delta t_{LRT}$$

Where

- t_F is the time in seconds since the starting LRT epoch, with increments that are a multiple of the duration of a frame.
- Δt_{LRT} is the Node Time (NT) offset with respect to LRT, which will be provided as part of MSG-G4.

The synchronization within the frame duration may be achieved counting the number of primary/secondary codes and the phase within the primary code since the leading edge of the first chip of the first code sequence of the frame (e.g.: the edge of the first chip of the synchronization pattern).

LSIS-720: ToT Fields Definition

The fields needed to retrieve time of transmission shall be in accordance with the following definitions (see **Figure 11**):

- $SECWEEK$ is the number of seconds in a week (604800).
- BI_d is the block interval duration in seconds. This is computed multiplying the frame duration with the number of TOI values (100): $BI_d = 12 * 100$ = 1200 seconds = 20 min.
- F_d is the frame duration, which length is 12 seconds.
- The Time of Interval (TOI) is represented with 7 bits and represents the number of frames from the beginning of the block interval (BI). A BI lasts 1200 seconds (20 minutes), a frame lasts 12 seconds, so TOI needs to represent 100 values. The TOI is referenced to the leading edge of the first chip of the first code sequence of the frame (leading edge of the first chip of the SP).

$$TOI = floor\left[\frac{mod(t, BI_d)}{F_d}\right]$$

  Where t is the time in seconds since the LRT start epoch.

- The Interval Time of week (ITOW) count is defined as being equal to the number of block intervals (BI) that have occurred since the transition from the previous week. The ITOW is represented with 9 bits, covering the 504*BI in a week.

$$ITOW = floor\left[\frac{mod(t, SECWEEK)}{BI_d}\right]$$

Where t is the time in seconds since the LRT start epoch.

- The Week Number (WN) is an integer counter that gives the sequential week number from the LRT start epoch. This parameter is represented with 13 bits, which covers 8192 weeks (about 157 years). Then the counter is reset to zero to cover an additional period modulo 8192.

$$WN = floor\left[\frac{t}{SECWEEK}\right]$$

Where t is the time in seconds since the LRT start epoch.

- The LunaNet Reference Time (LRT) start epoch is {LSIS-TBD-2003} (LRT is defined in LNIS AD5).

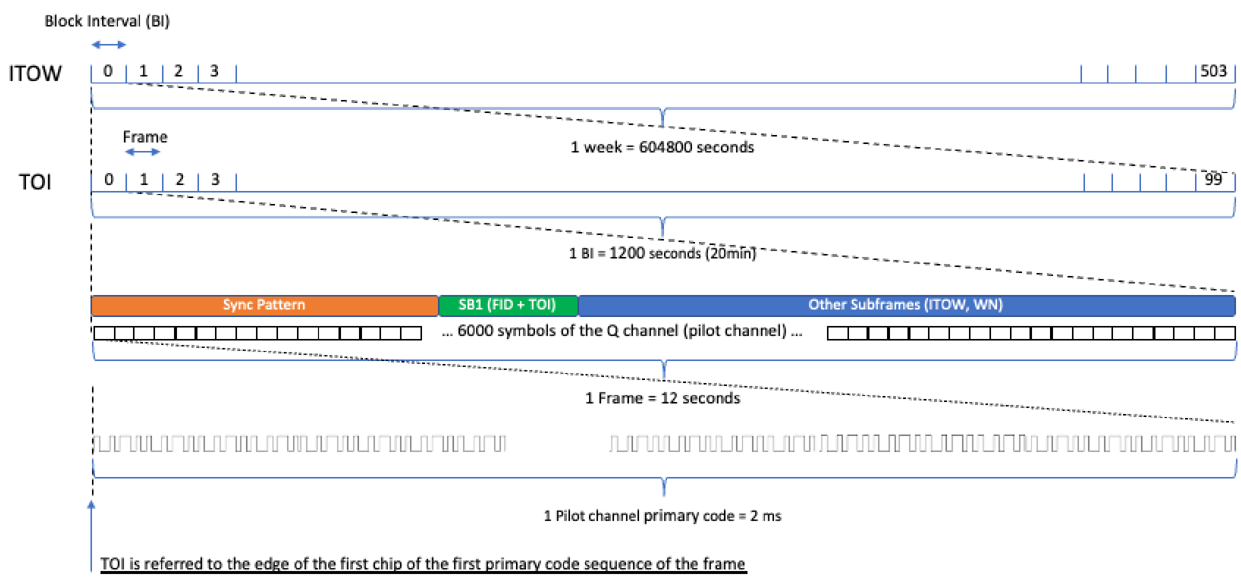

Figure 11: Time of Transmission Concept

LSIS-730: ToT Fields Binary Representation
The fields required to retrieve ToT shall be according to Table 22.

Table 22 - Time of Transmission Fields Binary Representation

Parameter	Definition	Bits	Scale factor	Unit	Values
TOI	Time of interval	7	N/A	dimensionless	0…99
ITOW	Interval time of week	9	N/A	dimensionless	0…503
WN	Week Number	13	1	week	0…8191

2.5.6. MANEUVER (MSG-G10)

*{*LSIS-TBW-2008*}*

2.5.7. SATTITUDE STATE/ EPHEMERIS (MSG-G11)

*{*LSIS-TBW-2009*}*

2.5.8. CONJUNCTION (MSG-G14)

Not a LunaNet 1.0 item. Placeholder for future implementation of conjunction messages, which are intended to inform lunar users of potential conjunctions.

2.5.9. MAPLET (MSG-G15)

Not a LunaNet 1.0 item. Placeholder for future implementation of Maplet messages, which are intended to provide localized map updates to lunar users.

2.5.10. ANCILLARY INFO (MSG-G17)

*{*LSIS-TBW-2010*}*

2.5.11. LUNASAR AUTOMATIC ACKNOWLEDGE (MSG-S19)

Not a LunaNet 1.0 item. Placeholder for future implementation of LunaSAR messages, intended to provide support for lunar search and rescue activities by providing an automatic acknowledge at the LNSP node level of receipt of a SAR beacon distress message.

2.5.12. LUNASAR RETURN MESSAGE (MSG-S20)

*LunaNet 1.0 item limited to a {*LSIS-TBD-2004*} reserved bit allocation for an acknowledgement of beacon reception from a LunaSAR authority that is to be disseminated by LNSP nodes. Detailed message definition is deferred for future implementation of LunaSAR messages, intended to provide support for lunar search and rescue activities.*

2.5.13. ACKNOWLEDGE OF NON-SAR MSG (MSG-G22)

Not a LunaNet 1.0 item. Placeholder for future implementation of message request acknowledgement messages.

2.5.14. GNSS AUGMENTATION (MSG-G23)

Not a LunaNet 1.0 item. Placeholder for future implementation of GNSS augmentation services (e.g., almanac, navigation data, etc.).

2.5.15. DETECTION ALERT (MSG-G24)

Not a LunaNet 1.0 item. Placeholder for future implementation of alert messages, which are specific messages to disseminate general or specific alerts to lunar users (e.g., solar storm alert, etc.).

2.5.16. SCIENCE (MSG-G25)

Not a LunaNet 1.0 item. Placeholder for future implementation of science supporting messages.

2.5.17. UIS RESPONSE (MSG-G27)

Not a LunaNet 1.0 item. Placeholder for future implementation of user initiated service supporting messages.

2.5.18. USER SCHEDULE NOTICE (MSG-G28)

*{*LSIS-TBW-2011*}*

2.5.19. FF COMMANDS (MSG-G29)

Not a LunaNet 1.0 item. Placeholder for future implementation of fast-forward command support messages via AFS.

2.5.20. TIME CONVERSIONS (MSG-G30)

*{*LSIS-TBW-2012*}*

2.5.21. AUGMENTATION DIFFERENTIAL CORRECTIONS (MSG-G31)

*{*LSIS-TBW-2013*}*

2.5.22. COORDINATE FRAME CONVERSIONS (MSG-G32)

*{*LSIS-TBW-2014*}*

APPENDIX A – ACRONYMS

Table A- 1 Acronyms

Acronym	Definition
δt	Delta Time
AD	Applicable Document
AFS	Augmented Forward Signal
BCH	Bose-Chaudrhuri-Hocquenghem
BI	Block Interval
BPSK	Binary Phase Shift Key
CRC	Cyclic Redundancy Check
CSV	Comma Separated Variable
EIRP	Equivalent Isotropic Radiated Power
FID	Frame Identifier
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
ITOW	Interval Time of Week
LANS	Lunar Augmented Navigation Service
LDPC	Low-Density Parity-Check code
LNIS	LunaNet Interoperability Specification
LNSP	LunaNet Service Provider
LRT	LunaNet Reference Time
LST	LNSP System Time
LSB	Least Significant Bit
MSB	Most Significant Bit
MSG	Message
NRZ	Non Return to Zero
NT	Node Time (Time at Transmitting LNSP Node)
P2P	Point-to-Point
PNT	Position, Navigation, and Timing
PRN	Pseudo-Random Noise (code)
PVT	Position, Velocity, and Time
RD	Reference Document
RHCP	Right-Hand Circularly Polarized
RNSS	Radio Navigation Satellite Service
ROI	Rollover Identifier
SB1	Subframe Block 1
SB2	Subframe Block 2

Acronym	Definition
SB3	Subframe Block 3
SB4	Subframe Block 4
SECWEEK	Seconds in a week
SFCG	Space Frequency Coordination Group
SISA	Signal-In-Space Accuracy
SISE	Signal-In-Space Error
SISEpos	Signal-In-Space Error for position
SISEvel	Signal-In-Space Error for velocity
SISICD	Signal-In-Space Interface Control Document
SP	Synchronization Pattern
sps	Symbol per second
SV	Service Volume
TOI	Time of Interval
ToT	Time of Transmission
URA	User Ranging Accuracy
WN	Week Number

APPENDIX B – SIGNAL-IN-SPACE ERROR CONTRIBUTORS

The SISE contributors for which the LNSP is responsible include the following error sources:

i. LNSP ephemeris uncertainties or errors in the orbital products tendered to users, as represented in the lunar reference frame. Figure B- 1 provides a representative illustration of ephemeris errors, where point ‘A’ refers to the actual position of the AFS-providing LNSP node at a particular point in time, and point ‘B’ represents the position information conveyed to the users via ephemeris for the same time epoch. A total norm (ΔPOS) value is formed from individual error contributions from X, Y and Z components with respect to the lunar reference frame (‘R’ in the figure). This error applies to the ephemeris portion of the navigation message, component (4) from Figure B- 1 , and includes errors due to limitations in message formatting and implementation.

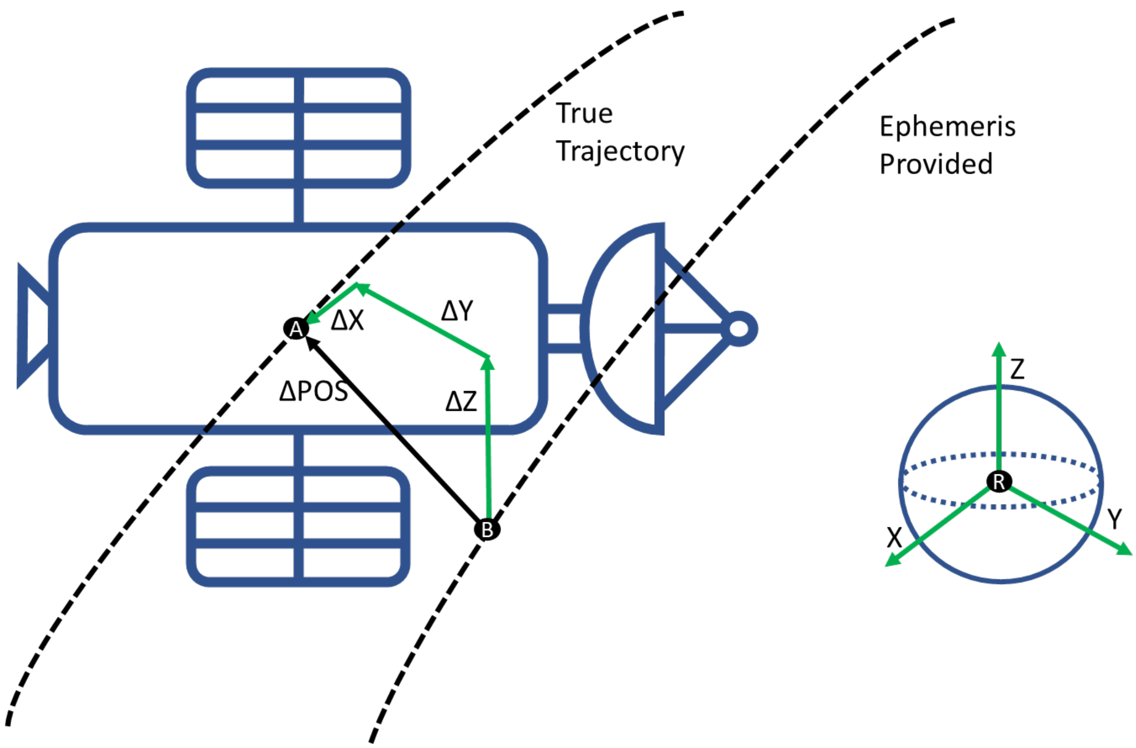

Figure B- 1: Representative illustration of ephemeris errors

ii. Position and velocity errors due to unmodeled or unreported antenna offsets with respect to the LNSP node position and velocity provided with the navigation messages. A representative antenna offset discrepancy is shown in Figure B- 2, where point ‘A’ represents the LNSP node’s reference point and ‘T’ represents the transmitting element at an offset from ‘A’. In this example, a user in the service volume ‘V’ captures measurements related with the ‘TV’ distance. If the navigation message only conveys information for deriving the ‘AV’ distance, the resulting error would correspond to the vector defined by ‘TV’ – ‘AV’. As with item i above, this error applies to the ephemeris portion of the navigation message, component (4) from Figure B- 2, and additionally includes errors due to limitations in message formatting and implementation.

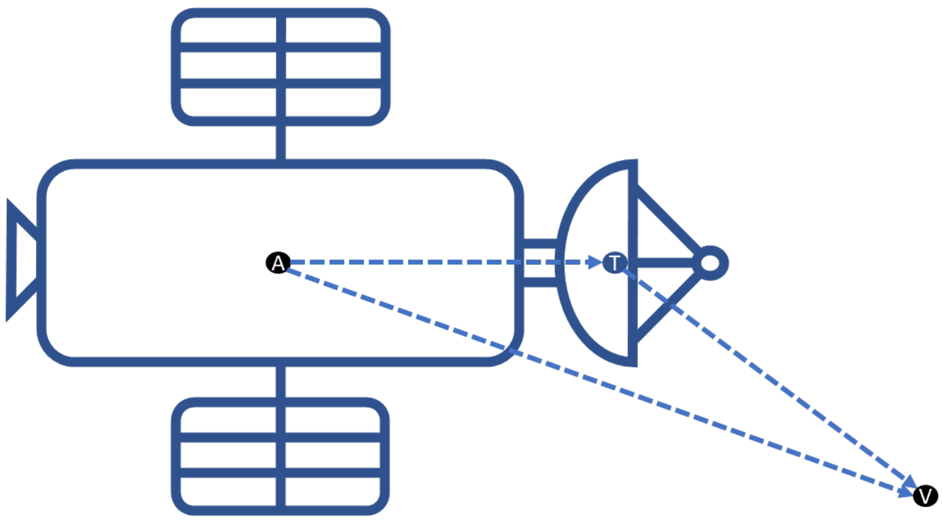

Figure B- 2: Representative illustration of antenna offset errors

iii. LNSP timing errors due to time knowledge uncertainties, inaccurate clock correction information conveyed to users, or unaccounted misalignments of time with the signal realization. This error applies to the clock portion of the navigation message, component (4) from Figure B- 3, and includes errors due to limitations in message formatting and implementation.

iv. Uncalibrated or unknown LNSP "group" delays and their variations. These group delays and variations may be due to code phase offsets, antenna phase offsets, unaccounted transmit path delays, code-to-code incoherency, code-to-carrier incoherency, etc. As with item iii above, this error applies to the clock portion of the navigation message, component (4) from Figure B- 3, and includes errors due to limitations in message formatting and implementation.

Figure B- 3 provides a representative illustration highlighting main contributor components to the SISE of a generic LNSP node. Components numbered in the figure represent (1) the frequency and timing subsystem (F&T), (2) the transmitting radio, (3) signal amplification, (4) navigation message, (5) transmit paths and related electronics, (6) transmitting antenna characteristics. Note that item (4) includes major contributions to the errors such as determining the estimates of the LNSP node's PVT.

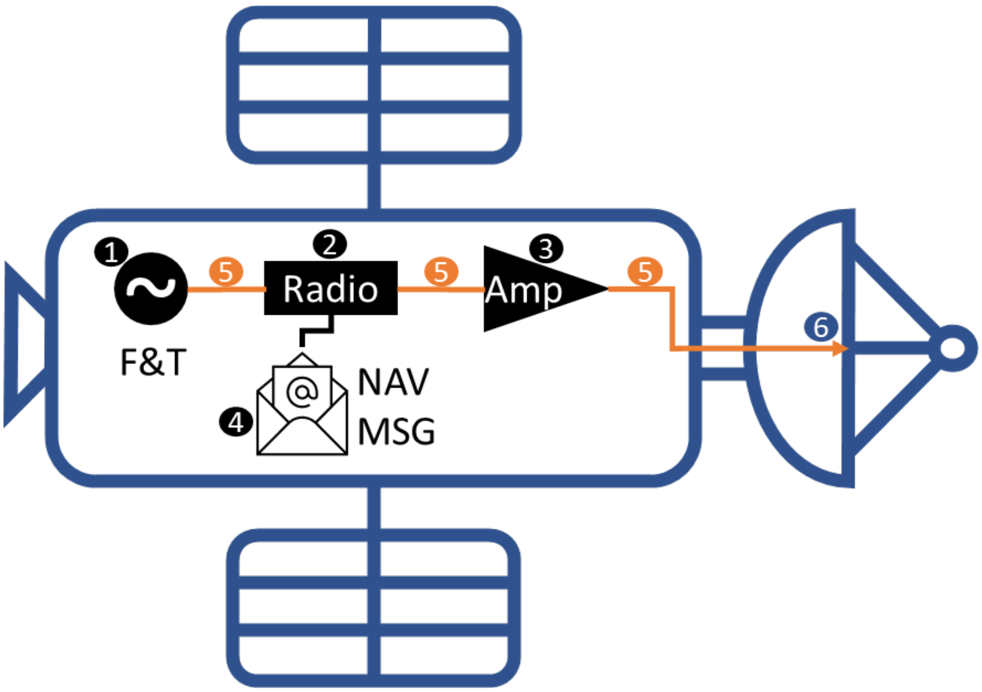

Figure B- 3: Representative illustration of main LNSP node error contributors

APPENDIX C – DATA CHANNEL (AFS-I) PRIMARY CODES

The data channel (I channel) spreading codes are of length 2046, comprised of 2047 length Gold codes that are short cycled to 2046 chips. Similar to the GPS C/A code, this sequence provides low complexity access to users. Since the code is modulated with randomized data symbols, its properties are further improved relative to the short code, due the randomization effect of the data symbols.

The Gold code is composed of a preferred pair of two maximal length sequences, each of length $2^n - 1$. Let the generator polynomial for each sequence be denoted by $g_1(x)$ and $g_2(x)$. The shift register sequence produced by $g_1(x)$ and $g_2(x)$, and the resultant Gold code for the AFS primary code are shown in Figure C- 1 with the resultant code denoted by (t).

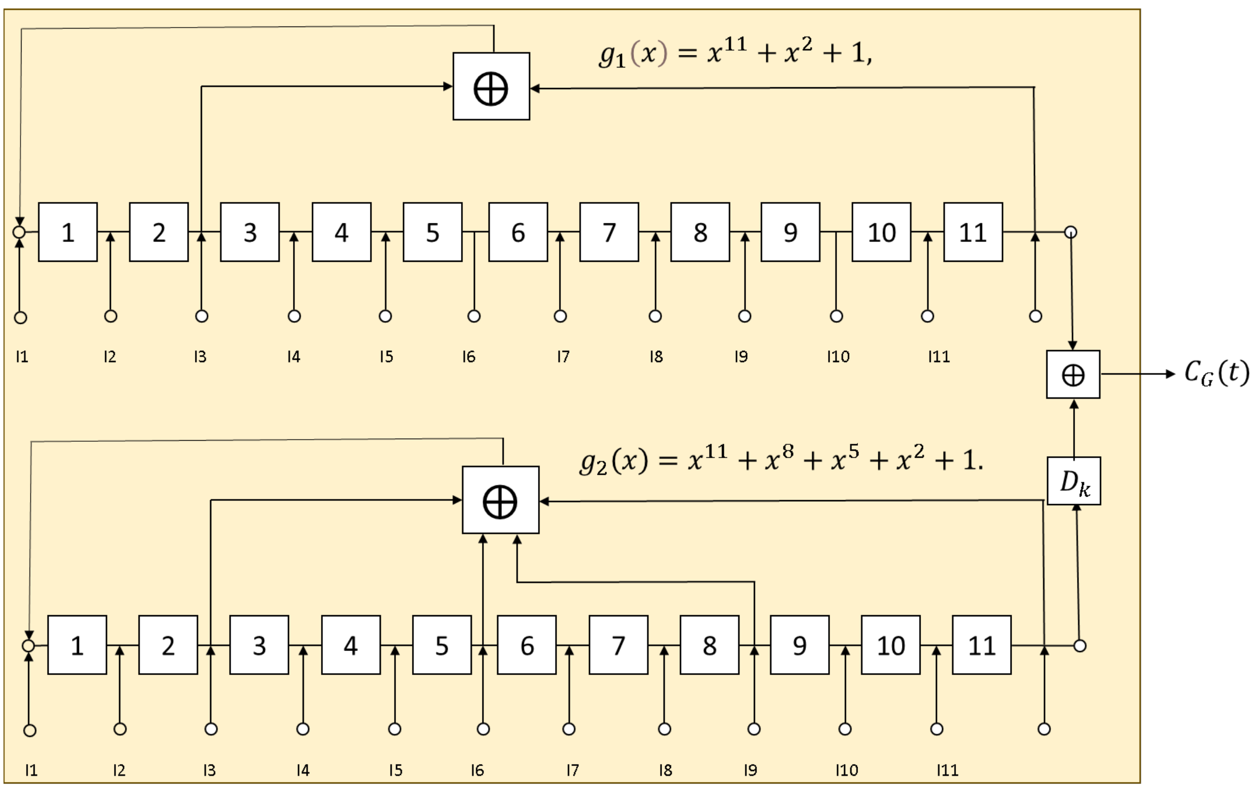

Figure C- 1: Data Channel (AFS-I) Gold code generator.

The Gold code sequence is produced by initializing the sequence to [I_1 I_2 I_3 I_4 I_5 I_6 I_7 I_8 I_9 I_{10} I_{11}] = 11111111111 and the sequence to [I_1 I_2 I_3 I_4 I_5 I_6 I_7 I_8 I_9 I_{10} I_{11}] = 11111111111, with a delay that is defined as a function of the PRN number, and reinitializing the sequence every 2046 chips (i.e. short cycling the natural length of the 2047 Gold code to 2046 chips).

I_{11} is the most significant bit (MSB) and I_1 is the least significant bit (LSB), wherein the initialization vector is fed into the register from LSB to MSB.

The initializations considering specific delays are provided in - Table C- 1 through - Table C- 5 below using the same convention as used for C/A code[5]. The first and last 24 chips are provided in hexadecimal format for validation purposes.

- Table C- 1: Gold code initializations for PRNs 1-42

PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)
1	1845	514	5D6430	CF00CE	22	1188	72C	1A77BE	FCF708
2	1071	59E	4C2FFF	CFD228	23	390	54B	568A4F	D4F9C3
3	170	49A	6CAF44	5F87BE	24	714	77C	106B22	685E33
4	2035	346	9730AD	A1C4FF	25	303	32F	9A1ECD	CF8507
5	1214	78B	0E9C61	B34161	26	1001	600	3FF94B	A6F603
6	1292	341	97C9DC	666CE4	27	707	635	3945EC	309AFB
7	1284	17D	D05F9B	71E734	28	1984	4B7	690F54	10E331
8	1894	7AB	0A99BD	31EDD1	29	139	73D	184B0C	CC4B56
9	1537	301	9FC265	633585	30	182	4BE	682F51	F95718
10	735	32E	9A355A	6EC903	31	1891	55F	5418A3	61758F
11	561	4DE	642134	7EA2C9	32	1247	775	114B27	81EA1A
12	1789	29C	AC628C	8196A2	33	1434	424	7B73BB	6875A4
13	1453	4ED	624F75	8E2A2E	34	2000	603	3F85F3	45220E
14	196	506	5F243A	1C689D	35	1843	450	75EF32	5A0C39
15	1040	30E	9E3086	EC65B3	36	865	0AB	EA83E1	3D3152
16	326	230	B9FE79	650CEB	37	616	316	9D2C31	356DC4
17	1787	270	B1F5C0	60558A	38	514	44F	760AF4	44AC55
18	982	38D	8E5B4C	05037C	39	449	477	71139F	1F0892
19	1030	2DC	A46935	84CFC3	40	1173	76F	1200BF	1A7A64
20	1380	5C8	46E185	3D9F0C	41	24	1F3	C1919D	5549C4
21	1932	61E	3C371A	191A6B	42	1383	1B9	C8C699	5A7081

-Table C- 2: Gold code initializations for PRNs 43-84

PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)
43	1940	6BE	2825B4	910419	64	1547	214	BD7E6C	C3DC4D
44	1594	6EB	229776	809D30	65	370	532	59B30A	2B4861
45	1765	336	9929ED	B7C174	66	271	733	199278	E25764
46	752	650	35E5D7	325F38	67	1353	697	2D006D	FA1C80
47	145	59C	4C78D0	8D4A21	68	635	6DD	245769	F525C5
48	1615	74F	160563	98D6D4	69	299	2FC	A06CE9	066373
49	1666	294	AD691E	C96E8F	70	697	471	71C179	79EC8D
50	1372	03F	F8067F	820FDC	71	152	42B	7A8158	E72592
51	1634	5AB	4A9358	59BED0	72	678	706	1F2EDF	743B9C
52	1068	4F2	61AAB3	908A42	73	1329	52F	5A01E3	777004
53	1181	647	370B83	640779	74	15	77F	10179A	8B8A3E
54	879	494	6D7630	719B8C	75	1974	526	5B21E6	9EC42D
55	1153	521	5BD897	596C36	76	1884	7FB	008521	A544EA
56	1621	53D	5841E9	A41857	77	1868	220	BBE95C	F4FCB1
57	927	4DF	640AA3	DFEECD	78	277	13C	D87FB5	D5F251
58	1848	4A2	6BB62F	042379	79	302	65F	341734	BD0F0E
59	402	2C3	A78CF3	9A6FAF	80	9	7E3	039996	7C4C9D
60	413	15F	D40D68	B1D38D	81	603	254	B575D5	C6852C
61	1090	3A2	8BAC73	08FFFA	82	1583	444	777DDE	EF8075
62	657	2C9	A6D04E	900F8B	83	848	041	F7C64B	BA1665
63	609	329	9ACC2B	A96118	84	1234	542	57AA4A	3D4DEA

[5] NAVSTAR GPS Space Segment/ User Segment Interfaces, IS-GPS-200N, Table 3-Ib

- Table C- 3: Gold code initializations for PRNs 85-126

PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)
85	1568	6EF	2212BF	A4E126	106	220	026	FB315F	FA4BAF
86	510	4F6	612F7A	B4F654	107	1542	298	ACE745	A5EAB4
87	1303	7C8	06EB60	55CC0D	108	188	612	3DB941	759E50
88	1921	45F	741DD1	D55C0F	109	264	1D0	C5E8F9	343179
89	823	654	35601E	16232E	110	453	2C7	A7093A	BE13B9
90	1187	659	34C5D2	DBEB11	111	68	534	5961EC	4DAC7E
91	1299	486	6F363A	A2F3DF	112	715	7BE	0820C6	252D99
92	824	72A	1AA558	9A1317	113	75	7DA	04AB6A	86A45E
93	672	191	CDC8D7	90241C	114	1095	51D	5C4435	26B4E7
94	2034	68D	2E4BF5	618CFE	115	938	39A	8CB518	535B3D
95	1388	0CD	E65F62	DC209C	116	1316	786	0F39AD	7E895E
96	13	5FE	40219A	4827F9	117	394	354	9570A7	72ACAC
97	223	604	3F7C82	828A15	118	1156	5A4	4B61BB	D6EEE6
98	1840	282	AFACDD	3E7ACA	119	166	1A4	CB7470	0648E4
99	1161	36D	92425B	88446F	120	969	529	5AD305	11941B
100	1132	231	B9D5EE	C440EF	121	269	4CE	663611	EF5293
101	365	655	354B89	B76F2A	122	179	5F2	41AFC1	24A3C2
102	2	1FF	C01FC6	39CDFF	123	957	2B0	A9E90B	6FBE29
103	924	6FB	208053	116D6A	124	400	30D	9E4C3E	0FB1BE
104	1373	41F	7C1668	D0056E	125	625	621	3BD700	8516B7
105	959	6AC	2A65BE	426C4A	126	1513	572	51B8B3	2E1100

- Table C- 4: Gold code initializations for PRNs 127-168

PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)
127	1796	455	75416C	DF3C2B	148	133	75A	14BC18	8C169C
128	100	4C5	67413B	447EB3	149	556	3C7	870C48	0A3A39
129	1660	51E	5C388D	C560EA	150	331	5D1	45D6A5	45DB7F
130	1454	676	3132ED	D61797	151	198	541	57D6F2	DE99E7
131	1613	53C	586A7E	055453	152	212	6B9	28DCC5	56AC02
132	1064	726	1B2B03	F6972C	153	1024	71E	1C3268	AD33EB
133	844	410	7DE48B	5F5558	154	1070	33C	987550	BDA150
134	518	544	5778AC	5BA9F5	155	1972	498	6CF86B	1D1FB7
135	320	430	79E157	DDF9E8	156	1573	377	9109C3	13D411
136	661	3AC	8A7507	26E3C8	157	884	664	3372E7	057FC4
137	2031	46B	728AE1	E27CF3	158	1177	476	713808	BE4496
138	694	389	8EDE85	217F6A	159	1691	6BB	288BEA	14340B
139	1143	7DE	042EA3	A2D848	160	533	55E	543334	C0398B
140	1167	3CD	8650F5	005A1D	161	480	340	97E24B	C720E0
141	1885	7FD	0057C7	C3A0F5	162	751	4A0	6BE100	46BB70
142	833	0BB	E894C4	ACC108	163	447	1DE	C4318D	1A2D4B
143	1601	60D	3E5C87	6B3E3C	164	734	65D	34401B	FF9707
144	903	6F9	20D77C	53F563	165	973	3D2	85B533	1EFA71
145	399	61A	3CB2D3	3D667D	166	857	32C	9A6275	2C510A
146	1896	7EA	02B993	95F8B4	167	1767	2CD	A65587	B4739D
147	899	798	0CF7FC	C16536	168	1548	50A	5EAA61	70ECA6

- Table C- 5: Gold code initializations for PRNs 169-210

PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	G2 Delay (chips)	G2 Initialization (HEX)	First 24 Chips (HEX)	Last 24 Chips (HEX)
169	1876	31A	9CA26A	59E9FF	190	1418	6F0	21F779	BA414A
170	614	459	74CF37	B3B810	191	295	7C5	074EAC	980432
171	1017	750	15E0A5	8676B8	192	916	331	99D09C	70696F
172	1978	5D2	45AA1D	A60F72	193	1654	7BD	085C7E	C6F994
173	275	4F3	618124	31C646	194	624	443	7784AF	28286E
174	1141	779	10C57C	ED6E21	195	706	46A	72A176	4330F7
175	1252	53B	58930F	C2FC48	196	1033	75B	14978F	2D5A98
176	1952	719	1CCB19	6A9BF0	197	1633	357	950C1F	9178A1
177	1714	146	D73A48	C997FE	198	790	22C	BA6707	98788A
178	1067	1E4	C37FC9	031185	199	1451	3B5	894227	5EA7BB
179	557	5E3	439373	141F9C	200	1300	643	378E4A	407B6F
180	522	554	556F89	CA59AF	201	459	64B	3685D8	088342
181	1159	5B4	49769E	471EBC	202	106	4D3	6584F8	B36AF6
182	545	28B	AE8CD8	D7CEE3	203	861	2B2	A9BE24	2D2620
183	1580	226	BB3BBA	9218AE	204	1541	530	59E425	69D068
184	610	594	4D7342	C5B20C	205	114	76C	127C07	F9AE69
185	935	4D4	657D89	74C2ED	206	1381	6E4	236595	0FCD06
186	1134	48C	6E6A87	A893FB	207	1945	4B5	69587B	527B38
187	780	02C	FA6DE2	F02B8B	208	1069	679	30C00E	5947A1
188	691	44E	762163	E5E051	209	242	112	DDA31D	7942D3
189	1038	43A	78BDEA	D799CC	210	356	2DE	A43E1A	C657CA

APPENDIX D – PILOT CHANNEL (AFS-Q) PRIMARY CODES

The pilot channel (AFS-Q) primary codes use the same construction as described for the L1C Q channel primary code[6]. The pilot channel (AFS-Q) primary codes are Weil sequences of length 10230, that are derived from a Legendre sequence L(t) of length 10223.

Each ranging code is derived from the length-10223 Legendre sequence, with a common 7-bit expansion sequence inserted at a PRN signal number-dependent point.

Legendre Sequence

The Legendre sequence L(t), for t = 0, …, 10222. L(t) is defined as,

L(0) = 0 ;
L(t) = 1, if there exists an integer *x* such that *t* is congruent to x^2 modulo 10223;
L(t) = 0, if there exists no integer *x* such that *t* is congruent to x^2 modulo 10223.

The above Legendre sequence is used to construct the unique length-10223 sequence used for each ranging code. The Legendre sequence defined in Table D- 1.

[6] NAVSTAR GPS Space Segment/ User Segment L1C Interfaces, IS-GPS-800J

Table D- 1- AFS-Q Primary Code 10233 Legendre Sequence in HEX

3DE552ECC61973C3E2F82F06D61DE035F019FD80BB7682DB6CD2A76F7A289CEDFC82058F75 C78883BD16FCD100B9CF36794B64313A5EF97E5FB299038FE3F9CFDFEB2210A2C729DCFE6D6 A750BA328159DEEACF17D6BC42C2A2395A5637E3472FDAC6394D0C8148E1FB0EDF95F865FF 2C5D794332704089F2977783755AF4BF54FD5D13CB0980E093013407CB98F4FC95F785144F3 B0DE4C09BF92143922AC65A5C7597B114B768CD5ECFBBFC0E231EA3130989F24EF9AECD0B6F DF21E60FE9B55EDB34AF8958EC3CC214122ACCBA3F085F5BC297BE7F506EFF5A8FA6755DE3B C0CD4E552462BEBE10DCAAE809830F5E11AE76FE7FA23C764E6D115CE9B55CEC61D764CD64 0C3F493C23A52A83F2218C36280C3CE808DD6B37852BD441FD49A64F747FAA6424CAC3DEB5 960367506BC0232517D70E322CE015A4B21B9B4AD8E5326F6A5447ACFF148C8CC13CD6DB8B CBE6C773C1D59797DD600B52B89E0DD9B2142494A30721A5D498E179DD0DB1DB696C291CF 157CF5E3825F870A9FFDB0514C465DBC7141E611B7D2B2E672BD16A97E36012AEE0A4B2191 B41413512B5568128CDFE6F3D6213247DB57275D6442A79F1F7FCED3301F5187854464F4FD8 B7BFC8236364C9F2E664B2EA72BB35D3B7D2ACA1CF699BB9590889A7AABC21FC45728C8D33 F254D9F5787D5DB098B74074D2E3F87946AE26E56B5187166C6F6B5B62F22FE4D6504143CCD AE02BC0177CEB84BD42301F106633B10A17F698BA0D23C834D213A0834AB743538023A94FC 6DB36167D82ECB13FE4E8CA27DF6CEB27B8F0C3D6564AFD579B90D8E230CBEBB9621745739 467867202BE50F4642A593D408A109E90C60C774E54A3FA1E1A9B4BDA22A4451A49943A2F3 72D9C61196DA1F26C1E9259DE7192C4C2E8F59B69D776AEE90B49A9E1E80EB5634473E73DA 1BDEBBF50D96AF6743D60AFEC6786758C5745EE588A0B3CEE393D8985502B65650F3C3886C A324106EB3A3600DCB22F9065E4C927035A8EFF8D4F44AB4FBE8D ED34FB0ED3E8B9A405EBDC8CE67DC1FCEF50B78A3045FF0AFE29330F5F7D653602EC2E494A4 27265C79D4A5626E2A758780E2D347F44B9BC9150785419356C0CD3B3AC57701EF0AA869BB BD958899A431EB2AD048D14C8AC6A2CB6662C1B364E4EFB0084B9034367757879D41FCCD23 0041C186AF765146C549076CDEE50C260133ADFA554ADD4DF5F49D9ECB6BE22ADFE4E05AA5 D0AC662CAD049DE61F5C709167735D7C9001ABC7816F8E143055C31DAF25A491C93D1185E3 9B5169EC7CEB5B6F5EC9913E1B8AD4BFE510585951F0C47260B0B892530DF33B3B5C0328775 6A426CD6392B4989ECB695FE32ECE3C505D6CEFF0A7D464FE594A10F2B36F66A807443669B5 01F750AD784CA513BFA30F3FAE4F39EEC0FAAD68EF0DB40F3F65336451E7231549A315DD263 6470EE806024629DE143CF9BFA2AB13DE0A0AE76D563533F08E11546683A940227D406085AF 09417BC0E8B32AEDF5EF30F2395B82B4C921549A03E61EC1024BD32298236C1B9BCDCEA1CE E3F0088321533A44B5DC85947169672AED8F5ED809BF3613C8C375D78415B034398B07F4DFC DBE3F9BCB0DD1503540B429544F8445AC1BBF7C6CCF585172C01678158123C81E3B5FB3D35 8E72902C74E04E56958EEAF2F70A505C32A21195FACE8BD46A5260311AC72EBDEECA0103180 E038FD9AC8160582168DCF64B5864C318BFDD3025D08FBB87144397EFB01231BAE84246AD3 2492FA448BF9019FC14FE11E527C2F82E0F0C59E7322D5610
NOTE: The above sequence is read from left to right across a row and then moves down to the next row. Since 10224 bits are listed above to represent the length 10223 Legendre sequence, the single initial bit value of 0 should be ignored. Thus, the first 27 values in the above sequence represented by HEX 3DE552E are the binary bit values: 011110111100101010100101110.

Primary Code Weil Sequences

A set of $5111 = (10223 - 1)/2$, length-10223 Weil sequences is then obtained from

$$W = \{L \oplus TL, L \oplus T^2 L, \cdots, L \oplus T^{5111} L\}$$

where the T^k operator represents the cyclic shift of the sequence for k places to the left, and ⊕ is the modulo-2 operation. For example, given the Legendre sequence in Table D- 1 is 0111101111001010101001011110… 0001000, a cyclic shift of the sequence by k = 4 results in the sequence 10111100101010100101110…000100000111.

This sequence, called a Weil-code, is the exclusive-or of L(t) and a cyclic shift of L(t). Equivalently, a Weil-code W(t ; *k*) is specified by the Weil Index *k*, ranging from 1 to 5111, which represents the cyclic shift of L(t) and is defined as,

W(t ; *w*) = L(t) ⊕ L((t + *w*) modulo 10223) for t = 0 to 10222.

Resulting Codes

Finally, the ranging code is constructed by inserting a fixed expansion sequence into the Weil code.

The expansion sequence is composed of seven-bit values, [0 1 1 0 1 0 0]. The insertion point is specified by Insertion Index *p*, where *p* = 1 to 10223. The expansion sequence is inserted before the *p*-th value of the Weil-code.

Thus, the pilot channel (AFS-Q) ranging code AFS-Q_P(t) is defined as,

AFS-Q_P(t) = Wi(t ; *k*), for t = 0, 1, . . . , *p* - 2;
AFS-Q_P(t) = 0, for t = *p* - 1;
AFS-Q_P(t) = 1, for t = *p*;
AFS-Q_P(t) = 1, for t = *p* + 1;
AFS-Q_P(t) = 0, for t = *p* + 2;
AFS-Q_P(t) = 1, for t = *p* + 3;
AFS-Q_P(t) = 0, for t = *p* + 4;
AFS-Q_P(t) = 0, for t = *p* + 5;
AFS-Q_P(t) = Wi(t - 7 ; *k*), for t = *p* + 6, *p* + 7, . . ., 10229.

For additional details in the code generation process, L1C code descriptions may serve as a reference[7].

Assignments of the Weil Index, *k*, and insertion index *p* per PRN identification number, *i*, are given by Table D- 2 through Table D- 6.

*Note-1: The Weil and insertion indices (and the resulting hexadecimal codes) are currently {*LSIS-TBC-2020*}. The codes provided in this release of the document are included to facilitate test and integration efforts only. It is therefore recommended for implementers to support a flexible code configuration, enabling code changes to be applied through configuration updates.*

[7] NAVSTAR GPS Space Segment/ User Segment L1C Interfaces, IS-GPS-800J, Section 3.2.2.1.1

Table D- 2: Weil code index k and insertion index p for PRN 1-42

PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)	PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)
1	5111	412	17D437	40F7E2	22	5014	5955	5F00B8	7F749D
2	5109	161	E0CD01	763E6C	23	5004	9805	D88397	690298
3	5108	1	686C92	00E22E	24	4980	670	3F9E2D	7E3F6B
4	5106	303	E8AA51	E63B1F	25	4915	464	9E809A	4D9164
5	5103	207	89A6BB	343BB1	26	4909	29	A85F8D	1CD50D
6	5101	4971	0751A2	6B0D78	27	4893	429	F8D776	0AF221
7	5100	4496	458726	0E7BA4	28	4885	394	4A49B8	A971B4
8	5098	5	7688B3	259D7D	29	4832	616	C9B024	C59E44
9	5095	4557	DA38C9	4C4F7D	30	4824	9457	2F78DF	8CBED8
10	5094	485	AB3393	1DDAA6	31	4591	4429	C33A66	41BD37
11	5093	253	13B63E	35104B	32	3706	4771	EEAFAB	83CBAE
12	5091	4676	A1D583	EB4786	33	5092	365	CFF4E8	A1753D
13	5090	1	682D8A	CE5EDB	34	4986	9705	6EE88D	F708C1
14	5081	66	1E7C22	9B2794	35	4965	9489	A93C2D	AAD0B6
15	5080	4485	4911E6	766ED2	36	4920	4193	D28D51	35B88C
16	5069	282	638CFE	E09D77	37	4917	9947	EEE25B	AE4BC3
17	5068	193	F7E988	CBB3A3	3	4858	824	2B4E51	E4BC14
18	5054	5211	ED0495	30418B	39	4847	864	3B40B5	070F2D
19	5044	729	9D2F16	1FD155	40	4790	347	24E2DF	EE6F11
20	5027	4848	386856	7CF289	41	4770	677	485AB0	B1F52C
21	5026	982	DA1BDC	05845C	42	4318	6544	26CC34	26AD5C

Table D- 3: Weil code index k and insertion index p for PRN 43-84

PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)	PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)
43	4126	6312	53EA04	3AA47B	64	5065	9429	0A4EC0	918AA6
44	3961	9804	304544	F057C3	65	5063	77	E7ABBC	02613D
45	3790	278	AE94B5	A912C3	66	5055	932	5656C4	177927
46	4911	9461	359E06	EB5A67	67	5012	5973	32F822	79DEB3
47	4881	444	38D294	05146A	68	4981	377	F363B4	8B84E6
48	4827	4839	DE5971	221052	69	4952	10000	4EFC32	6AA22C
49	4795	4144	9EC5E3	4A763B	70	4934	951	86C5A8	8A7C41
50	4789	9875	D45E98	CCCA90	71	4932	6212	048966	C49C84
51	4725	197	FE1BF9	D7B848	72	4786	686	6E3822	116580
52	4675	1156	F5E9A9	54EF1D	73	4762	9352	47F935	06CAB3
53	4539	4674	F768D8	3EA85E	74	4640	5999	816592	81FA85
54	4535	10035	930082	9C69F4	75	4601	9912	B8C5FC	81C8F3
55	4458	4504	4D1315	301C6E	76	4563	9620	8D0417	A1F46D
56	4197	5	A689E0	27A615	77	4388	635	129C4D	6F2200
57	4096	9937	9F956C	FBE0D5	78	3820	4951	F364F4	7AD22F
58	3484	430	DDAA9B	13A98D	79	3687	5453	A87D77	5FED25
59	3481	5	C69E0D	EA89E3	80	5052	4658	9E7929	AA13F6
60	3393	355	8D1F6C	A51A81	81	5051	4800	091363	6EF4E3
61	3175	909	AAA032	03313B	82	5047	59	4CE739	B96C3F
62	2360	1622	FC77CE	E51F85	83	5039	318	54FD88	64C22A
63	1852	6284	B9D130	A101C7	84	5015	571	325E9F	89130A

Table D- 4:- Weil code index k and insertion index p for PRN 85-126

PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)	PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)
85	5005	565	3D58C0	A5FF01	106	4259	4870	7DA99E	0E57E1
86	4984	9947	3E822F	1BC1A4	107	4256	4950	5B06C2	A9362E
87	4975	4654	A1E801	37CD5B	108	4166	4881	0BDF45	8CB07D
88	4974	148	96DBF7	201BB5	109	4155	1151	B664A7	29422C
89	4972	3929	008EF1	EE0579	110	4109	9977	82FF31	F5EA9B
90	4962	293	A19474	FDA6C4	111	4100	5122	3E363F	463A4E
91	4913	178	42982A	3567CD	112	4023	10074	109B22	8370F5
92	4907	10142	0F2FEF	2136D7	113	3998	4832	2CD9D7	D16AB3
93	4903	9683	0C84F1	BD901C	114	3979	77	FC5ECF	60782F
94	4833	137	1F3FA7	FCC6B9	115	3903	4698	069715	F4A368
95	4778	565	EBDF57	8E6A23	116	3568	1002	14B535	B3C9A1
96	4721	35	F397B0	02F8F5	117	5088	5549	A08941	159422
97	4661	5949	9FFC9D	9203F6	118	5050	9606	C2A646	8C8769
98	4660	2	3413A3	72FCE3	119	5020	9228	494DE0	A5F559
99	4655	5982	E05A7D	67AB47	120	4990	604	29E828	88BB01
100	4623	825	2D8058	DD95C6	121	4982	4678	6A9887	60F3FD
101	4590	9614	A7B2C4	9B2383	122	4966	4854	DE27B4	225B5D
102	4548	9790	3F3148	D1CB09	123	4949	4122	FD6C77	05A897
103	4461	5613	CD0720	C705E1	124	4947	9471	9A6311	6769B1
104	4442	764	31B493	B1570D	125	4937	5026	93B2CF	14049F
105	4347	660	F88784	8D842C	126	4935	272	81D4BF	6302B3

Table D- 5: Weil code index k and insertion index p for PRN 127-168

PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)	PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)
127	4906	1027	C1B800	AB6673	148	4396	5203	2D22CF	594679
128	4901	317	661930	896793	149	4340	203	02CC3F	3A17B4
129	4872	691	46EB29	AC4231	150	4335	10070	580291	B5EC1D
130	4865	509	39B0E6	D85438	151	4296	30	542794	4A3404
131	4863	9708	6B5435	10169A	152	4267	103	18F1B5	2CA716
132	4818	5033	5A986C	DFD1B3	153	4168	5692	BB9D25	AACFA5
133	4785	9938	7133E6	B34FD8	154	4149	32	88FC1D	B94640
134	4781	4314	FB6531	34B78C	155	4097	9826	B37536	803B9B
135	4776	10140	9FCFD9	05991C	156	4061	76	601073	4C938B
136	4775	4790	09C81B	B93196	157	3989	59	2A612C	95A80E
137	4754	9823	D8F696	977D8C	158	3966	6831	0A3699	8D6C79
138	4696	6093	EC1DD7	9C9271	159	3789	958	9165AD	6F7479
139	4690	469	FD95F8	AB9101	160	3775	1471	F26D0F	940F18
140	4658	1215	A74C62	7ABCAC	161	3622	10070	82B997	9CE474
141	4607	799	B81CF3	0AEEE0	162	3523	553	FE8EC1	320797
142	4599	756	8B0973	C671A8	163	3515	5487	FC4FE1	1D4941
143	4596	9994	65D2DF	B032E7	164	3492	55	1BF406	D2CBB6
144	4530	4843	5C8CF4	48DFEF	165	3345	208	827650	29F527
145	4524	5271	8757BC	70C037	166	3235	645	718184	2C7CFE
146	4451	9661	87A716	2F6C84	167	3169	5268	D48F0F	81EF8C
147	4441	6255	DEF5BE	63569E	168	3157	1873	E20051	F21CDB

Table D- 6: Weil code index k and insertion index p for PRN 169-210

PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)	PRN No.	Weil Index (k)	Insertion index (p)	Initial 24 Chips (Hex)	Final 24 Chips (Hex)
169	3082	427	55149D	05F033	190	5077	422	3D91CD	E63108
170	3072	367	F30112	9B5C39	191	4042	4918	4379C6	060C9C
171	3032	1404	283513	66A6F1	192	2111	787	47E900	216959
172	3030	5652	2F3548	3FAA28	193	4311	9864	E370A8	2741E6
173	4582	5	E6902D	C2E065	194	5024	9753	53BEFB	A76283
174	4595	368	F4C698	E3E46B	195	4352	9859	126E82	371180
175	4068	451	96A1C9	CF9B9D	196	4678	328	0AD2C0	E09E7C
176	4871	9595	E55A63	6DDC00	197	5034	1	695566	FF1AB1
177	4514	1030	F23582	C14175	198	5085	4733	20A2D9	4A4E56
178	4439	1324	D28563	7ED633	199	3646	164	22BF9C	D42522
179	4122	692	C948AF	BC2936	200	4868	135	6818BD	854752
180	4948	9819	B899CC	B92953	201	3668	174	2CAC1F	BB0B5E
181	4774	4520	42CBFA	E765D3	202	4211	132	C38171	2C21DE
182	3923	9911	7241D1	AA83CB	203	2883	538	F5DD38	370B59
183	3411	278	5C97C1	6A8D47	204	2850	176	42C78B	09F308
184	4745	642	B59B3B	A50B05	205	2815	198	6FEE31	208FA2
185	4195	6330	0C041D	2FEA11	206	2542	595	17B83C	209BB5
186	4897	5508	4A179C	571508	207	2492	574	797E33	EB138C
187	3047	1872	A0CFB1	5DFFEF	208	2376	321	10E6A3	B8D1AD
188	4185	5445	7B9756	46D6BF	209	2036	596	E6469F	B060BB
189	4354	10131	DD5A38	444851	210	1920	491	589648	2B48AC

APPENDIX E – PILOT CHANNEL (AFS-Q) TERTIARY CODES

Similar to AFS-Q primary code construction, the 1500 symbol tertiary code used for the pilot channel (AFS-Q) tertiary code is constructed as a Weil code from a Legendre sequence.

Legendre Sequence

The Legendre sequence for the pilot channel (AFS-Q) tertiary code is of 1499 length and is defined in Table E- 1.

Table E- 1: AFS-Q Tertiary Code Length-1499 Legendre Sequence in HEX

2E27C52A95BB664C711AE8C3278736BFA3F97ACEACF435494D027D81EBA6EA2A4F6 200D928C49EA44EBC091DC3B936F33C99DFEDA818FF7086606F868E6D6E6D9E292F4 77D56BA79447C3D1650ACEFBF16844237DE7BFA9A97C24AF1E1AE29E1C2B6F05A9A 8086104EF77A5C08232BD65D0F0775868A5504742DAE192625263A7827E67BC4039FA9 20119B0CC24D88F11DBF0A376A1B73AD93FEE436AEA268A1F906FD35B54F432A3285 80E80A4C786CF3A29DC73664895AAD706E2
The binary "0" of the first hex symbol "**2**" should be removed when converting the Legendre sequence to binary bits. Thus, for the first symbol, **2**=010 instead of 0010. The remainder of the symbols represent 4 binary bits each, totaling to 1499 bits.

Tertiary Code Weil Sequences

The set of 749=(1499-1)/2, length-1499 Weil sequences are then obtained as

$$W = \{L \oplus TL, L \oplus T^2 L, \cdots, L \oplus T^{749} L\}$$

where the T^k operator represents the cyclic shift of the sequence for k places to the left, and $\oplus$ is the modulo-2 operation.

This sequence, called a Weil-code, is the exclusive-or of the Legendre sequence L(t) and a cyclic shift of L(t). Equivalently, a Weil-code W(t ; *k*) is specified by the Weil Index *k*, ranging from 1 to 749, which represents the cyclic shift of L(t) and is defined as, W(t ; *w*) = L(t) ⊕ L((t + *w*) modulo 1499) for t = 0 to 1498.

Resulting Codes

To obtain the 1500 symbol tertiary sequence, a "0" is appended to the end of the sequence. This process is shown schematically in Figure E- 1.

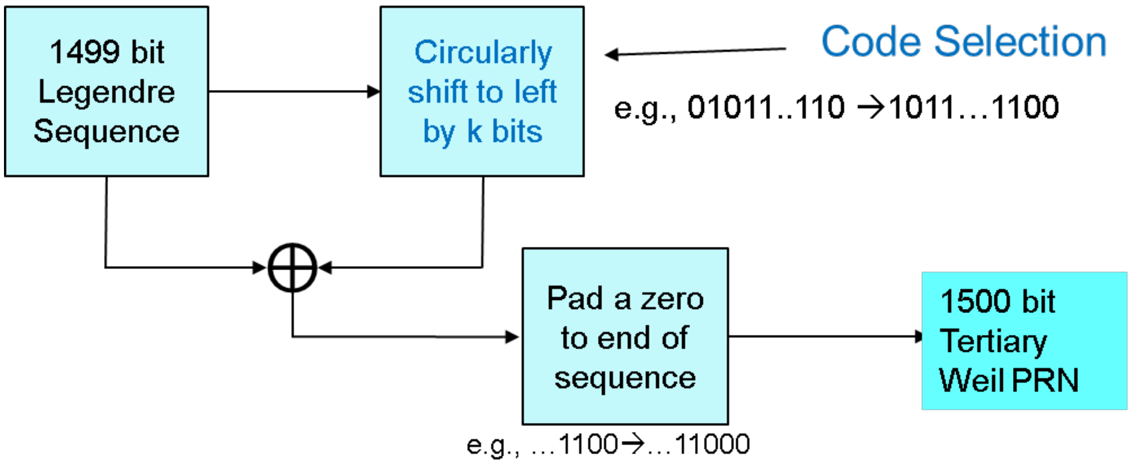

Figure E- 1: Tertiary Weil code generation process.

Assignment of Weil Index, *k*, per PRN identification number, *i*, are given by Table E- 2 through Table E- 6.

Table E- 2: 1500 Chip tertiary Weil code index k for PRN 1-42

PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)
1	1	E4D09E	F2164C	22	346	B25243	45CD54
2	229	B5F500	90CD30	23	347	807419	798CE6
3	237	E6C519	6EF816	24	350	BD9311	1204D8
4	241	F4E6B7	A150F2	25	354	41863D	6E9C18
5	253	CF970A	7D78D0	26	356	2B6954	AC4AB4
6	254	7BFE8A	08E7EE	27	357	B20236	AA8324
7	255	132D8A	E3D990	28	361	B89446	E6E3D8
8	256	C28B8B	35A56C	29	364	7A91ED	E97D2A
9	257	61C789	995C96	30	365	11F345	20EC18
10	267	7C4218	EB4428	31	366	C73614	B3CE7C
11	276	476A92	3DD544	32	368	31A9F3	D90320
12	283	CEC3C3	424DDE	33	373	E080AC	4FD15E
13	301	7BE699	C299A6	34	378	C5AB44	959EAA
14	319	12F383	27308C	35	381	9369FD	7296BC
15	327	E04697	934558	36	382	C20365	173B36
16	328	245DB1	D49CFE	37	383	60D655	DC6022
17	333	5E08FA	FC2A9A	38	384	257C35	4AD608
18	334	58C16B	0A4378	39	386	B88175	3D62F6
19	335	555249	E690BC	40	387	95D274	88D3A2
20	339	CD93B1	27DA44	41	389	7A3871	35745A
21	340	7FF7FD	BDA2C6	42	390	10A07C	98FEF8

Table E- 3: 1500 Chip tertiary Weil code index k for PRN 43-84

PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)
43	394	92B0E7	C13E0C	64	448	508F55	CDF006
44	397	2BB4E0	D79388	65	449	45CE34	69F640
45	398	B3B95E	5D315C	66	450	6F4CF6	21FACC
46	400	E394DA	62FFA2	67	451	3A4972	B1E3D4
47	401	23F92A	37E90A	68	459	5AB7E2	401D08
48	407	B1E792	D73E7A	69	460	51BF5B	722C5C
49	408	871FBB	5C6ABA	70	461	47AE29	164EF4
50	414	8843F5	37D228	71	463	33C904	4F0104
51	415	F45775	9DB21E	72	467	A4276C	BEC1C8
52	416	0C7E74	C97272	73	468	AC9E47	8F95DE
53	426	9BB40E	50D744	74	469	BDEC11	ED3DF2
54	431	A33F0C	755DF4	75	471	DAC1E7	A2CD1A
55	432	A2AE86	18ADA6	76	474	683CE1	C80B3C
56	433	A18D93	C34D02	77	475	34A95C	620034
57	436	B25F46	C40BFA	78	477	FFD4D1	9E3A06
58	437	806E12	7A01BA	79	480	409556	2FB3DE
59	438	E40CBA	06153A	80	481	65FA33	AD71F0
60	439	2CC9EA	FE3C3A	81	485	C71411	99CE82
61	440	BD434A	0E6E38	82	487	3121E7	7100D8
62	441	9E560B	EECA3E	83	488	869351	1017FC
63	447	DA2FE5	9FF324	84	489	E9F63C	D239B6

Table E- 4:- 1500 Chip tertiary Weil code index k for PRN 85-126

PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)
85	490	373CE6	566522	106	529	E1527F	C2FC8C
86	491	8AA953	5EDC08	107	531	A8385F	1DC8E0
87	492	F18239	4FAE5E	108	533	8D90DF	611952
88	495	322214	A3111E	109	538	67A53F	4C9F30
89	496	8094B6	B43470	110	540	B3E55D	244614
90	498	2F237B	C6EB12	111	542	E2E4D7	872282
91	500	91FC4F	0D969E	112	543	211930	FC534A
92	502	6A809E	2060AA	113	544	A6E2FE	0AB0D8
93	507	85AD18	63A008	114	549	09E114	39AE7A
94	509	3BC5C1	98BAF2	115	551	0AF5F3	F0833E
95	510	935B1D	C363A8	116	552	F13B78	131030
96	513	24EB37	C57EA8	117	553	06A66F	D4362E
97	515	BEDD7E	03C076	118	554	E99C40	5A7A10
98	517	D6045B	193B0A	119	555	37E81E	46E26E
99	520	0E1104	17BBBC	120	556	8B00A2	7FD290
100	521	F8F297	DD6134	121	557	F2D1DB	0DB36E
101	524	79A765	356A4E	122	562	8F85A9	D9D8AE
102	525	179E55	98C2D0	123	568	AEC772	5B572C
103	526	CBEC34	C393EC	124	570	966C6B	7B6662
104	527	7308F7	753196	125	573	0D5085	0550F8
105	528	02C170	187560	126	574	FE7194	F8B7BC

Table E- 5- 1500 Chip tertiary Weil code index k for PRN 127-168

PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)
127	575	1833B7	37936	148	608	FD1655	5EF99C
128	576	D4B7F0	F4E420	149	609	1EFC34	4FE576
129	577	4DBF7E	1BDE0E	150	610	D928F7	6DDCA0
130	578	7FAE62	C5AA50	151	612	49D27D	A14850
131	579	1B8C5B	7942EC	152	616	0590F4	5A5486
132	580	D3C828	9394	153	617	EFF176	46BF40
133	582	625101	147480	154	618	3B3272	7F68CE
134	586	BDA738	99982	155	619	92B47B	0CC7D0
135	591	6159DA	5C853C	156	621	67A04F	252592
136	592	26632B	4B1C34	157	622	2B9001	B85D68
137	594	B4FD0F	3A4A06	158	627	A7BEE2	641858
138	595	8D2A80	868242	159	628	ABAD5A	3A26FE
139	596	FE859F	FF12CA	160	631	E3590E	0F541A
140	597	19DBA1	0C33DA	161	633	A0159B	2B6AB8
141	598	D767DC	EA71F8	162	635	AD27CE	BB9032
142	599	4A1F26	26F5BE	163	638	D70DAB	02E27A
143	601	050D39	8DEC2C	164	639	4ACBC8	F7D2BA
144	604	965A17	B10280	165	640	71470E	1DB338
145	605	C864B1	90134E	166	645	FD5F07	D9D24E
146	606	7419FD	D230D2	167	647	D80DBD	7173E8
147	607	0CE365	A14850	168	648	54CBE5	10F19E

Table E- 6: - 1500 Chip tertiary Weil code index k for PRN 169-210

PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)	PRN	Weil Index (k)	First 24 Chips (HEX)	Last 24 Chips (HEX)
169	649	4D4755	D3F570	190	686	A102C1	99D3BE
170	650	7E5E34	55FCAC	191	687	A6D51D	C1B132
171	651	186CF7	59EF14	192	688	A97AA5	71742A
172	654	7D5465	111B40	193	689	B625D5	10FE1A
173	656	D82036	5257D4	194	690	889B34	D3EA7A
174	658	4DF179	5F6580	195	691	F5E6F6	55C2BA
175	660	1AB445	6BACD4	196	697	361083	5DD210
176	661	D1B814	254FE4	197	698	88F198	49B26C
177	662	47A0B7	B88986	198	702	17AEAF	D5F75E
178	665	833665	1A2FD4	199	705	0346A1	71D910
179	668	A780F5	0F1D48	200	707	206B25	D15E96
180	669	ABD174	EC2CDE	201	710	BD6AF2	549752
181	671	823470	A689AA	202	716	1511B6	08A834
182	674	AF905E	EA2EB8	203	717	CEF3F2	E34624
183	675	BBF023	264B3E	204	718	79377A	349A06
184	676	9330D9	BE8032	205	720	C9AC49	C452CC
185	678	61B2C7	EC3A1A	206	722	0BC087	0771E0
186	680	ABBABF	A6D2BC	207	723	F35190	FCF58C
187	682	839B5E	8D7022	208	725	E037E1	E5ECE0
188	683	E3E623	E8F60A	209	726	24BF5D	39CF8E
189	684	231CD8	23FA5A	210	729	9BC932	101F92

APPENDIX F – CODE ASSIGNMENTS PER LNSP

Each LNSP node identifier is assigned a unique combination of code sequences as defined in Table F- 1.

Note: The assignment between the LNSP node identifiers and combination of code sequences are currently {LSIS-TBD-2001}**, and codes provided in this release of the document are included to facilitate test and integration efforts only. The assignment of codes to a particular LNSP node identifier will be completed in a future release, to allow for optimization of the assignments between primary, secondary, and tertiary codes as well as the relevant phasing of the tertiary code.**

Primary codes for AFS-I are provided above in Appendix C . Primary, secondary and tertiary codes for AFS-Q are provided in Appendix D and Appendix E , respectively. Note that the first 12 code assignments provided in Section 2.3.5.4 in this release are for interim use for test and integration purposes only.

Table F- 1: - Code Assignments per LNSP node Identifier {LSIS-TBD-2001}

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
1	TBD	TBD	TBD	TBD	TBD
2	TBD	TBD	TBD	TBD	TBD
3	TBD	TBD	TBD	TBD	TBD
4	TBD	TBD	TBD	TBD	TBD
5	TBD	TBD	TBD	TBD	TBD
6	TBD	TBD	TBD	TBD	TBD
7	TBD	TBD	TBD	TBD	TBD
8	TBD	TBD	TBD	TBD	TBD
9	TBD	TBD	TBD	TBD	TBD
10	TBD	TBD	TBD	TBD	TBD
11	TBD	TBD	TBD	TBD	TBD
12	TBD	TBD	TBD	TBD	TBD
13	TBD	TBD	TBD	TBD	TBD
14	TBD	TBD	TBD	TBD	TBD
15	TBD	TBD	TBD	TBD	TBD
16	TBD	TBD	TBD	TBD	TBD
17	TBD	TBD	TBD	TBD	TBD
18	TBD	TBD	TBD	TBD	TBD
19	TBD	TBD	TBD	TBD	TBD
20	TBD	TBD	TBD	TBD	TBD
21	TBD	TBD	TBD	TBD	TBD
22	TBD	TBD	TBD	TBD	TBD

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
23	TBD	TBD	TBD	TBD	TBD
24	TBD	TBD	TBD	TBD	TBD
25	TBD	TBD	TBD	TBD	TBD
26	TBD	TBD	TBD	TBD	TBD
27	TBD	TBD	TBD	TBD	TBD
28	TBD	TBD	TBD	TBD	TBD
29	TBD	TBD	TBD	TBD	TBD
30	TBD	TBD	TBD	TBD	TBD
31	TBD	TBD	TBD	TBD	TBD
32	TBD	TBD	TBD	TBD	TBD
33	TBD	TBD	TBD	TBD	TBD
34	TBD	TBD	TBD	TBD	TBD
35	TBD	TBD	TBD	TBD	TBD
36	TBD	TBD	TBD	TBD	TBD
37	TBD	TBD	TBD	TBD	TBD
38	TBD	TBD	TBD	TBD	TBD
39	TBD	TBD	TBD	TBD	TBD
40	TBD	TBD	TBD	TBD	TBD
41	TBD	TBD	TBD	TBD	TBD
42	TBD	TBD	TBD	TBD	TBD
43	TBD	TBD	TBD	TBD	TBD
44	TBD	TBD	TBD	TBD	TBD
45	TBD	TBD	TBD	TBD	TBD
46	TBD	TBD	TBD	TBD	TBD
47	TBD	TBD	TBD	TBD	TBD
48	TBD	TBD	TBD	TBD	TBD
49	TBD	TBD	TBD	TBD	TBD
50	TBD	TBD	TBD	TBD	TBD
51	TBD	TBD	TBD	TBD	TBD
52	TBD	TBD	TBD	TBD	TBD
53	TBD	TBD	TBD	TBD	TBD
54	TBD	TBD	TBD	TBD	TBD
55	TBD	TBD	TBD	TBD	TBD
56	TBD	TBD	TBD	TBD	TBD
57	TBD	TBD	TBD	TBD	TBD
58	TBD	TBD	TBD	TBD	TBD
59	TBD	TBD	TBD	TBD	TBD
60	TBD	TBD	TBD	TBD	TBD
61	TBD	TBD	TBD	TBD	TBD

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
62	TBD	TBD	TBD	TBD	TBD
63	TBD	TBD	TBD	TBD	TBD
64	TBD	TBD	TBD	TBD	TBD
65	TBD	TBD	TBD	TBD	TBD
66	TBD	TBD	TBD	TBD	TBD
67	TBD	TBD	TBD	TBD	TBD
68	TBD	TBD	TBD	TBD	TBD
69	TBD	TBD	TBD	TBD	TBD
70	TBD	TBD	TBD	TBD	TBD
71	TBD	TBD	TBD	TBD	TBD
72	TBD	TBD	TBD	TBD	TBD
73	TBD	TBD	TBD	TBD	TBD
74	TBD	TBD	TBD	TBD	TBD
75	TBD	TBD	TBD	TBD	TBD
76	TBD	TBD	TBD	TBD	TBD
77	TBD	TBD	TBD	TBD	TBD
78	TBD	TBD	TBD	TBD	TBD
79	TBD	TBD	TBD	TBD	TBD
80	TBD	TBD	TBD	TBD	TBD
81	TBD	TBD	TBD	TBD	TBD
82	TBD	TBD	TBD	TBD	TBD
83	TBD	TBD	TBD	TBD	TBD
84	TBD	TBD	TBD	TBD	TBD
85	TBD	TBD	TBD	TBD	TBD
86	TBD	TBD	TBD	TBD	TBD
87	TBD	TBD	TBD	TBD	TBD
88	TBD	TBD	TBD	TBD	TBD
89	TBD	TBD	TBD	TBD	TBD
90	TBD	TBD	TBD	TBD	TBD
91	TBD	TBD	TBD	TBD	TBD
92	TBD	TBD	TBD	TBD	TBD
93	TBD	TBD	TBD	TBD	TBD
94	TBD	TBD	TBD	TBD	TBD
95	TBD	TBD	TBD	TBD	TBD
96	TBD	TBD	TBD	TBD	TBD
97	TBD	TBD	TBD	TBD	TBD
98	TBD	TBD	TBD	TBD	TBD
99	TBD	TBD	TBD	TBD	TBD
100	TBD	TBD	TBD	TBD	TBD

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
101	TBD	TBD	TBD	TBD	TBD
102	TBD	TBD	TBD	TBD	TBD
103	TBD	TBD	TBD	TBD	TBD
104	TBD	TBD	TBD	TBD	TBD
105	TBD	TBD	TBD	TBD	TBD
106	TBD	TBD	TBD	TBD	TBD
107	TBD	TBD	TBD	TBD	TBD
108	TBD	TBD	TBD	TBD	TBD
109	TBD	TBD	TBD	TBD	TBD
110	TBD	TBD	TBD	TBD	TBD
111	TBD	TBD	TBD	TBD	TBD
112	TBD	TBD	TBD	TBD	TBD
113	TBD	TBD	TBD	TBD	TBD
114	TBD	TBD	TBD	TBD	TBD
115	TBD	TBD	TBD	TBD	TBD
116	TBD	TBD	TBD	TBD	TBD
117	TBD	TBD	TBD	TBD	TBD
118	TBD	TBD	TBD	TBD	TBD
119	TBD	TBD	TBD	TBD	TBD
120	TBD	TBD	TBD	TBD	TBD
121	TBD	TBD	TBD	TBD	TBD
122	TBD	TBD	TBD	TBD	TBD
123	TBD	TBD	TBD	TBD	TBD
124	TBD	TBD	TBD	TBD	TBD
125	TBD	TBD	TBD	TBD	TBD
126	TBD	TBD	TBD	TBD	TBD
127	TBD	TBD	TBD	TBD	TBD
128	TBD	TBD	TBD	TBD	TBD
129	TBD	TBD	TBD	TBD	TBD
130	TBD	TBD	TBD	TBD	TBD
131	TBD	TBD	TBD	TBD	TBD
132	TBD	TBD	TBD	TBD	TBD
133	TBD	TBD	TBD	TBD	TBD
134	TBD	TBD	TBD	TBD	TBD
135	TBD	TBD	TBD	TBD	TBD
136	TBD	TBD	TBD	TBD	TBD
137	TBD	TBD	TBD	TBD	TBD
138	TBD	TBD	TBD	TBD	TBD
139	TBD	TBD	TBD	TBD	TBD

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
140	TBD	TBD	TBD	TBD	TBD
141	TBD	TBD	TBD	TBD	TBD
142	TBD	TBD	TBD	TBD	TBD
143	TBD	TBD	TBD	TBD	TBD
144	TBD	TBD	TBD	TBD	TBD
145	TBD	TBD	TBD	TBD	TBD
146	TBD	TBD	TBD	TBD	TBD
147	TBD	TBD	TBD	TBD	TBD
148	TBD	TBD	TBD	TBD	TBD
149	TBD	TBD	TBD	TBD	TBD
150	TBD	TBD	TBD	TBD	TBD
151	TBD	TBD	TBD	TBD	TBD
152	TBD	TBD	TBD	TBD	TBD
153	TBD	TBD	TBD	TBD	TBD
154	TBD	TBD	TBD	TBD	TBD
155	TBD	TBD	TBD	TBD	TBD
156	TBD	TBD	TBD	TBD	TBD
157	TBD	TBD	TBD	TBD	TBD
158	TBD	TBD	TBD	TBD	TBD
159	TBD	TBD	TBD	TBD	TBD
160	TBD	TBD	TBD	TBD	TBD
161	TBD	TBD	TBD	TBD	TBD
162	TBD	TBD	TBD	TBD	TBD
163	TBD	TBD	TBD	TBD	TBD
164	TBD	TBD	TBD	TBD	TBD
165	TBD	TBD	TBD	TBD	TBD
166	TBD	TBD	TBD	TBD	TBD
167	TBD	TBD	TBD	TBD	TBD
168	TBD	TBD	TBD	TBD	TBD
169	TBD	TBD	TBD	TBD	TBD
170	TBD	TBD	TBD	TBD	TBD
171	TBD	TBD	TBD	TBD	TBD
172	TBD	TBD	TBD	TBD	TBD
173	TBD	TBD	TBD	TBD	TBD
174	TBD	TBD	TBD	TBD	TBD
175	TBD	TBD	TBD	TBD	TBD
176	TBD	TBD	TBD	TBD	TBD
177	TBD	TBD	TBD	TBD	TBD
178	TBD	TBD	TBD	TBD	TBD

LNSP Node Identifier	Data Channel (AFS-I)	Pilot Channel (AFS-Q)			
	Primary PRN	Primary PRN	Secondary Code	Tertiary PRN	Tertiary PRN Phase Offset
179	TBD	TBD	TBD	TBD	TBD
180	TBD	TBD	TBD	TBD	TBD
181	TBD	TBD	TBD	TBD	TBD
182	TBD	TBD	TBD	TBD	TBD
183	TBD	TBD	TBD	TBD	TBD
184	TBD	TBD	TBD	TBD	TBD
185	TBD	TBD	TBD	TBD	TBD
186	TBD	TBD	TBD	TBD	TBD
187	TBD	TBD	TBD	TBD	TBD
188	TBD	TBD	TBD	TBD	TBD
189	TBD	TBD	TBD	TBD	TBD
190	TBD	TBD	TBD	TBD	TBD
191	TBD	TBD	TBD	TBD	TBD
192	TBD	TBD	TBD	TBD	TBD
193	TBD	TBD	TBD	TBD	TBD
194	TBD	TBD	TBD	TBD	TBD
195	TBD	TBD	TBD	TBD	TBD
196	TBD	TBD	TBD	TBD	TBD
197	TBD	TBD	TBD	TBD	TBD
198	TBD	TBD	TBD	TBD	TBD
199	TBD	TBD	TBD	TBD	TBD
200	TBD	TBD	TBD	TBD	TBD
201	TBD	TBD	TBD	TBD	TBD
202	TBD	TBD	TBD	TBD	TBD
203	TBD	TBD	TBD	TBD	TBD
204	TBD	TBD	TBD	TBD	TBD
205	TBD	TBD	TBD	TBD	TBD
206	TBD	TBD	TBD	TBD	TBD
207	TBD	TBD	TBD	TBD	TBD
208	TBD	TBD	TBD	TBD	TBD
209	TBD	TBD	TBD	TBD	TBD
210	TBD	TBD	TBD	TBD	TBD

APPENDIX G – LIST OF ALGORITHMS

{LSIS-TBW-2015}

APPENDIX H – CYCLIC REDUNDANCY CHECK DEFINITION

This CRC definition applies to Frame ID = 0 (FID0) as defined in Section 2.4.3.1.

Twenty-four bits of CRC provide protection against burst as well as random errors with a probability of undetected error $\leq 2^{-24} = 5.96\times10^{-8}$ for all channel bit error probabilities ≤ 0.5. The CRC word is calculated in the forward direction on a given message using a seed of 0. The sequence of 24 bits ($p_1,p_2,...,p_{24}$) is generated from the sequence of information bits ($m_1,m_2,...,m_k$) (MSB to LSB sequence) in a given message. This is done by means of a code that is generated by the polynomial

$$g(X) = \sum_{i=0}^{24} g_i X^i$$

where

$$g = \begin{cases} 1 \text{ for } i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 34 \\ 0 \text{ otherwise} \end{cases}$$

This code is called CRC-24Q. The generator polynomial of this code is in the following form (using binary polynomial algebra):

$$g(X) = (1 + X)p(X)$$

where p(X) is the primitive and irreducible polynomial

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

When, by the application of binary polynomial algebra, the above g(X) is divided into $m(X)X^{24}$, where the information sequence m(X) is expressed as

$$m(X) = m_k + m_{k-1}X + m_{k-2}X^2 + \cdots + m_1 X^{k-1}$$

The result is a quotient and a remainder R(X) of degree < 24. The bit sequence formed by this remainder represents the CRC sequence. CRC bit p_i, for any i from 1 to 24, is the coefficient of X^{24-i} in R(X).
This code has the following characteristics:

It detects all single bit errors per code word.
It detects all double bit error combinations in a codeword because the generator polynomial g(X) has a factor of at least three terms.
It detects any odd number of errors because g(X) contains a factor 1+X.
It detects any burst error for which the length of the burst is ≤ 24 bits.
It detects most large error bursts with length greater than the CRC length r = 24 bits. The fraction of error bursts of length b > 24 that are undetected is:

$2^{-24} = 5.96 \times 10^{-8}$, if b > 25 bits
$2^{-23} = 1.19 \times 10^{-7}$, if b = 25 bits

APPENDIX I – REFERENCE AFS LINK BUDGET

*{*LSIS-TBW-2016*}*

APPENDIX ZZ– TABLE OF TBXS

Table ZZ- 1 below lists specific to be determined (TBD), to be confirmed (TBC) and to be written (TBW) items in this document (AD1 Vol-A). These items are to be confirmed or currently undefined at the release of this version.

Each designator is numbered based on the document title, document version number when TBD/TBR was identified, parent section number, and number of the particular unresolved item. For example, "LSIS-TBD-2004" would be interpreted as the 4th unresolved TBD item identified in LunaNet Signal-In-Space Recommended Standard Section 2. Once each item is dispositioned, the resolution will be substituted in place of the designator and the item will be struckthrough {~~LSIS-TBD-2004~~} in Table ZZ- 1. If new unresolved items are identified, they will be added to this table using the above defined designation scheme. All TBD/TBR will retain their original numbers and will not be renumbered as items are added or deleted.

Table ZZ- 1: Table of TBXs

Designation	Section / Specification ID	Title	Description
LSIS-TBD-1001	1 / N/A	SISICD Distribution	Distribution to which LNSP should provide the SISICD
LSIS-TBC-2001	2.2.3 / LSIS-001	SISE Pos.	SISE Position Error specification
LSIS-TBC-2002	2.2.3 / LSIS-001	SISE Pos. period	SISE Position Error period of performance
LSIS-TBC-2003	2.2.3 / LSIS-002	SISE Vel.	SISE Velocity error specification
LSIS-TBC-2004	2.2.3 / LSIS-002	SISE Vel. period	SISE Velocity error period of performance
LSIS-TBW-2001	2.2.3 / LSIS-0006	SISE Pos. prediction accuracy	Specification for SISE position prediction messaging
LSIS-TBW-2002	2.2.3 / LSIS-007	SISE Vel. prediction	Specification for SISE velocity prediction messaging
LSIS-TBC-2005	2.3.1.2 / LSIS-050	RHCP axial ratio	Definition of RHCP axial ratio value
LSIS-TBC-2006	2.3.1.3 / LSIS-060	AFS Phase Noise	Specified value for carrier tracking error due to AFS transmitter phase noise performance.
LSIS-TBC-2007	2.3.1.4 / LSIS-070	Max in-band spurious	Maximum In-Band spurious emissions specification
LSIS-TBW-2003	2.3.1.4 / LSIS-080	Max out-of-band emissions	Specification for maximum out-of-band emissions for AFS transmitters
LSIS-TBC-2008	2.3.1.5 / LSIS-090	AFS reference bandwidth	AFS reference bandwidth specification used towards evaluating correlation losses
LSIS-TBC-2009	2.3.1.5 / LSIS-100	Correlation loss	Correlation loss specification due to transmitter payload distortions

Designation	Section / Specification ID	Title	Description
LSIS-TBC-2010	2.3.1.6 / LSIS-103	AFS-I power percentage tolerance	Tolerance value for the AFS-I power percentage allocation
LSIS-TBC-2011	2.3.1.6 / LSIS-103	AFS-Q power percentage tolerance	Tolerance value for the AFS-Q power percentage allocation
LSIS-TBC-2012	2.3.1.7 / LSIS-110	Min AFS received power within Service Volume (SV)	Minimum received power level for AFS-I (data channel) within the Service Volume
LSIS-TBC-2013	2.3.1.7 / LSIS-110	Max AFS received power within SV	Maximum received power level for AFS within the Service Volume
LSIS-TBC-2014	2.3.1.8 / LSIS-120	Max AFS received power outside of SV	Maximum received power level for AFS outside the Service Volume
LSIS-TBC-2015	2.3.1.8 / LSIS-120	Applicability of LSIS-120	Applicability of maximum power outside of LNSP SV specification
LSIS-TBC-2016	2.3.4 / LSIS-160	Primary code-data coherency	Primary code-to-data coherency value in nanoseconds
LSIS-TBC-2017	2.3.4 / LSIS-170	Pilot code-code coherency	Code-to-code coherency value in nanoseconds for the primary to secondary pilot codes
LSIS-TBC-2017a	2.3.4 / LSIS-171	Pilot code-code coherency	Code-to-code coherency value in nanoseconds for the secondary to tertiary pilot codes
LSIS-TBC-2018	2.3.4 / LSIS-180	Data to pilot code-code coherency	Code-to-code coherency value in nanoseconds for the data code to pilot code
LSIS-TBC-2019	2.3.4 / LSIS-190	Code-carrier coherency	Code-to-carrier coherency value in nanoseconds for both data and pilot channels
LSIS-TBC-2020	2.3.5.3.2/ LSIS-222	(AFS-Q) Primary Code Definition	Confirmation of AFS-Q (pilot) spreading codes.
LSIS-TBD-2001	2.3.5.4 / LSIS-260	Code assignments per LNSP node identifier	Code assignments per LNSP node identifier shown in Table F- 1
LSIS-TBC-2021	2.4.1.2 / LSIS-330	Synch pattern	Specification of the bit sequence for the synchronization pattern
LSIS-TBC-2022	2.4.3.1.6 / LSIS-FID0-550	Subframe 2 spare bits	Quantity of mandatory spare bits to be kept for future use in SB2
LSIS-TBC-2023	2.4.3.1.7 / LSIS-FID0-560	Subframe 3 bit allocation	Allocations of bits to each field of SB3
LSIS-TBC-2024	2.4.3.1.8 / LSIS-FID0-600	Subframe 4 bit allocation	Allocations of bits to each field of SB4

Designation	Section / Specification ID	Title	Description
LSIS-TBD-2002	2.4.3.1.9 / Table 21	MSG-G3 subframe allocation	MAntennaProperties LNIS message subframe allocation
LSIS-TBW-2004	2.5.1	MSG-G1 specification	LunaNet Network Access Information message specification
LSIS-TBW-2005	2.5.2	MSG-G2 specification	Health and Safety message specification
LSIS-TBW-2006	2.5.3	MSG-G4 specification	Clock and Ephemeris Data message specification
LSIS-TBW-2007	2.5.4	MSG-G5 specification	MOrbit Almanac message specification
LSIS-TBD-2003	2.5.5 / LSIS-720	LRT start epoch definition	LunaNet Reference Time start epoch definition in LNIS AD5
LSIS-TBW-2008	2.5.6	MSG-G10 specification	Maneuver message specification
LSIS-TBW-2009	2.5.7	MSG-G11 specification	SAttitude State/Ephemeris message specification
LSIS-TBW-2010	2.5.10	MSG-G17 specification	Ancillary info message specification
LSIS-TBD-2004	2.5.12	MSG-S20 specification	Specification of number of bits allocated to MSG-S2
LSIS-TBW-2011	2.5.18	MSG-G28 specification	User Schedule Notice message specification
LSIS-TBW-2012	2.5.20	MSG-G30 specification	Time Conversion message specification
LSIS-TBW-2013	2.5.21	MSG-G31 specification	Augmentation Differential Corrections message specification
LSIS-TBW-2014	2.5.22	MSG-G32 specification	Coordinate Frame Conversions message specification
LSIS-TBW-2015	Appendix G	User algorithms	Example algorithms for user implementation
LSIS-TBW-2016	Appendix I	Reference AFS Link Budget	Reference link budget for the AFS signal