LuGRE

LuGRE Receiver Interface Control Document

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The *LuGRE Receiver Interface Control Document (ICD)* describes the Telemetry Interface of the LuGRE payload disclosed to the public.

1.2 SCOPE OF THE PROJECT

The Lunar GNSS Receiver Experiment (LuGRE) is a joint NASA-Italian Space Agency (ASI) payload on the Firefly Blue Ghost Mission 1 (BGM1) with the goal to demonstrate GNSS-based positioning, navigation, and timing at the Moon. LuGRE was chosen by the NASA Commercial Lunar Payload Services (CLPS) program as one of ten payloads on its “19D” task order for delivery to the lunar surface in 2025.

The primary organizations involved include NASA via its Space Communication and Navigation (SCaN) Program; ASI, Qascom S.r.l., and Politecnico di Torino (PoliTo) via its Department of Electronics and Telecommunications. Qascom led development and testing of the entire payload system, including in-house development of the LuGRE GNSS receiver. PoliTo led ASI science activities as co-principal Investigator (PI) with NASA.

The LuGRE payload consists of a GNSS receiver, a high-gain L-band antenna, and a front-end assembly containing a low-noise amplifier and a radio-frequency filter. The receiver tracks GPS L1 C/A and L5, and Galileo E1 and E5a signals and returns pseudorange, carrier phase, and Doppler measurements to the ground. It also calculates least-squares point solutions and Kalman-filter based navigation solutions onboard. In addition, the receiver features the capability to record raw in-phase and quadrature (I/Q) baseband samples for downlink and ground processing.

LuGRE builds on the legacy of prior missions in the Space Service Volume (SSV) including the initial experiments by AMSAT-OSCAR 40 and others, the GOES-R series of geostationary weather satellites, and the NASA Magnetospheric Multiscale (MMS) mission, which operated on GPS-based navigation at nearly 50% of lunar distance. Further, LuGRE will be one of the very first demonstrations of GNSS signal reception and navigation in the lunar environment and on the lunar surface, paving the way for operational use by future lunar and cislunar missions. Ultimately, LuGRE science data will be released to a public data archive for the benefit of the GNSS and space communities

2 QASCOM BINARY PROTOCOL

The LuGRE GNSS receiver uses a proprietary binary protocol for telemetry (TM) / telecommand (TC) data exchange. The messages payload may include the basic formats listed in Table 2-1 with different lengths for each message type. Note that the required byte ordering is Little Endian (LE).

Name	Length [bytes]	Description
s8	1	Signed 8-bit integer
s16	2	Signed 16-bit integer
s32	4	Signed 32-bit integer
s64	8	Signed 64-bit integer
u8	1	Unsigned 8-bit integer
u16	2	Unsigned 16-bit integer
u32	4	Unsigned 32-bit integer
u64	8	Unsigned 64-bit integer
float	4	Single-precision float (IEEE-754)
double	8	Double-precision float (IEEE-754)
c8	1	Char
array	-	Fixed or variable array of any type

Table 2-1: Basic Data Format

The LuGRE TM/TC messages are structured with a standard message framing format with diversified *payload* content (see Figure 2-1).

Figure 2-1: Basic Message Structure

A standard message framing format contains a 10-bytes long header, including the preamble (1 byte), message type (3 bytes), sender (2 bytes) and data length (4 bytes). It is also provided a 3-bytes long footer with a CRC value for packet validation.

Message Part	Offset [bytes]	Length [bytes]	Name	Description
Header	0	1	Preamble	Denotes the start of the frame
	1	3	Message Type	Defines which type of message is present on *payload*
	4	2	Sender	A unique identifier of the sender
	6	4	Data Length	Payload length (bytes)
Payload	10	N	Payload	Binary message content. N varies based on the message type
Footer	N+10	3	CRC	Cyclic Redundancy Check of the frame's binary data from the Preamble up to the end of Payload
	N+13			**Total Message Length**

Table 2-2: QN400 Packet Format

Table 2-2 describes the basic message format to guarantee the communication between the LUGRE Payload and the Lander On-Board Computer (OBC).

2.1 CYCLIC REDUNDANCY CHECK

The footer contains a 3 bytes-long Cyclic Redundancy Check (CRC) component that checks the frame's binary data from the *Message*. The chosen CRC is computed considering the message part starting from the *q ASCII* within the preamble to the last *payload* byte.

Parameters	Value
CRC Check Algorithm	CRC-24-Radix-64
Polynomial	0x864CFB
Init	0
RefIn	False (reversed bit ordering)
RefOut	False

Table 2-3: CRC Polynomial Parameters

3 TELEMETRY OVERVIEW

3.1 ACQ: ACQUISITION MESSAGE

The LuGRE receiver acquisition message (ACQ) reports the information related to the acquisition stage of the GPS and Galileo signals. *Note that, even though the LuGRE receiver could use both GPS time (GPST) and Galileo System Time (GST), during the mission it used only GPST*.

Offset [bytes]	Length [bytes]	Format	Name	Unit	Description
0	8	double	rxTime	s	Receiver time (GPST/GST).
8	1	u8	signalId		Signal identifier: • GPS_L1CA = 0 • GPS_L5 = 1 • GAL_E1BC = 2 • GAL_E5A = 3 • GAL_E5B = 4
9	2	u16	svid		Satellite Vehicle Identifier.
11	8	double	doppler	Hz	Acquisition Doppler
19	8	double	codePhase	chips	Acquisition Code Phase
27	1	u8	acfCorrLength (N)		Size of the ACF correlators array
28	N	float	acfCorr		ACF correlator values.
28+N*4	4	float	noiseFloor		ACF window averaged noise floor.
32+N*4	1	u8	acqMode		Bit masks describing the acquisition mode: • 0x01 (1 == Warm start mode, 0 == Cold Start mode) • 0x02 (1 == SPCP Enabled, 0 == disabled) • 0x04 (1 == Data+Pilot Enabled, 0 == disabled)
33+N*4	8	double	cn0	dB/Hz	Estimated C/N0
41+N*4					**Total Payload Length**

Table 3-1: ACQ Message Payload

3.2 RAW: RAW DATA MESSAGE

The RAW message contains the raw measurements extracted from acquired GPS and Galileo signals. The variable "*i*" defines the index of the current raw measurements block. *Note that, even though the LuGRE receiver could use both GPS time (GPST) and Galileo System Time (GST), during the mission it used only GPST*.

Offset [bytes]	Length [bytes]	Format	Name	Unit	Description
0	8	double	rxTime	s	Receiver time (GPST/GST).
8	2	u16	numMeas (N)		Number of measurements
10+i*43	1	u8	signalId		Signal identifier • GPS_L1CA = 0 • GPS_L5 = 1 • GAL_E1BC = 2 • GAL_E5A = 3 • GAL_E5B = 4
11+i*43	2	u16	svid		Satellite Number identifier.
13+i*43	8	double	fdRaw	Hz	Doppler related to tracking loop.
21+i*43	8	double	fdRateRaw	Hz/s	Doppler Rate
29+i*43	8	double	carrierPhase	m	Estimated carrier phase.
37+i*43	8	double	prRaw	m	Estimated pseudorange.

Offset [bytes]	Length [bytes]	Format	Name	Unit	Description
45+i*43	8	double	cn0	dB/Hz	C/N0 of the input signal.
10+N*43					**Total Payload Length**

Table 3-2: RAW Message Payload

3.3 NAV: NAVIGATION AND TIMING DATA MESSAGE

The navigation message (NAV) contains the Position, Velocity and Timing (PVT) solution computed by the LuGRE receiver in ECEF coordinates. *Note that, even though the LuGRE receiver could use both GPS time (GPST) and Galileo System Time (GST), during the mission it used only GPST*.

Offset [bytes]	Length [bytes]	Format	Name	Unit	Description
0	8	double	rxTime	s	Receiver time (GPST/GST)
8	10	char [10]	appName		Application name
18	2	u16	wn	week	GPS week number.
20	4	u32	tow	s	GPS time of week.
24	8	double	decimals	s	GPS time of week (decimal part)
32	2	u16	nSat		Number of measurements used to calculate PVT solution.
34	8	double	posX	m	Target position X-coordinate (ECEF).
42	8	double	posY	m	Target position Y-coordinate (ECEF).
50	8	double	posZ	m	Target position Z-coordinate (ECEF).
58	8	double	velX	m/s	Target velocity X-coordinate (ECEF).
66	8	double	velY	m/s	Target velocity Y-coordinate (ECEF).
74	8	double	velZ	m/s	Target velocity Z-coordinate (ECEF).
82	4	float	posStd	m	Position solution accuracy.
86	4	float	velStd	m/s	Velocity solution accuracy.
90	8	double	timStd	m	Time solution accuracy.
98	8	double	clockBias	m	a0 receiver clock offset.
106	8	double	clockDrift	m/s	a1 receiver clock drift.
114	8	double	ggto	m	Galileo to GPS time offset.
122	8	double	GDOP		Global dilution of precision.
130	8	double	PDOP		Position Dilution of Precision.
138	8	double	HDOP		Horizontal dilution of precision.
146	8	double	VDOP		Vertical dilution of precision.
154	8	double	TDOP		Time dilution of precision.
162					Total Payload Length

Table 3-3: NAV Message Payload

3.4 IQS: IQ SAMPLES DATA MESSAGE

The IQS message contains raw snapshots of complex I/Q samples. N represents the total number of real/imaginary samples captured and is equal to nSamples. *Note that, even though the LuGRE receiver could use both GPS time (GPST) and Galileo System Time (GST), during the mission it used only GPST*.

Offset [bytes]	Length [bytes]	Format	Name	Unit	Description
0	8	double	rxTime	s	Receiver time (GPST/GST).
8	4	u32	nSamples (N)		Total number of samples.

Offset [bytes]	Length [bytes]	Format	Name	Unit	Description
12	4	u32	blockData		Little endian bit field, values are valid only when transfer of fragmented batches is enabled: • 0-3: batchID • 4-17: total number of blocks • 18-31: blockID
16	1	u8	samplesType		Samples format type: • 0 = real samples • 1 = complex samples
17	2	u16	spectrumInv		Spectrum inversion flag.
19	1	u8	quantBits	bit	Number of quantization bits.
20	8	double	samplingFreq	Hz	Sampling frequency.
28	8	double	centralFreq	Hz	Carrier central frequency.
36	8	double	intermediateFreq	Hz	Signal intermediate frequency.
44	8	double	bandwidth	Hz	Signal bandwidth
52	4N if samplesType == Complex, 2N otherwise	array-s16	iqSamples		Array of samples IQ interleaved.
52 + (4N or 2N)					**Total Payload Length**

Table 3-4: IQS Message Payload

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