IM-1

Nova-C to LTN to Nova Control Communication System Description, Interface Control and Requirements Document

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1 Introduction

This document describes the Nova-C to Lunar TT&C Network (LTN) to Nova Control communication systems and interfaces being utilized for the IM-1 mission in Nov 2021. As the communications systems are maintained and upgraded for future lunar missions conducted by IM, this document will be revised to reflect those changes.

The Nova-C unmanned lunar lander is currently expected to launch in the November 2021 timeframe, but could be as early as October 2021 or as late as December 2021. The Nova-C lander is developed by Intuitive Machines for the NASA Commercial Lander Payload Services (CLPS) program and will be carrying at least six payloads to the lunar surface. Nova-C will land in the sunlight, at the beginning of the lunar day, and is planning for 14 Earth days of payload data collection and transmission during the surface mission.

2 Concept of Operations

2.1 Launch Phase

The IM-1 Nova-C launch is currently expected to occur in the November 2021 timeframe. The mission begins approximately 90 seconds after launch vehicle separation. At this point, Nova Control will establish communications with Nova-C as quickly as possible after separation from the Launch Vehicle to begin tracking the spacecraft and compute the Trans-Lunar Injection (TLI) burn. After a successful TLI, the IM-1 mission enters the Transit Phase.

2.2 Transit Phase and Lunar Orbit Phase

The Transit Phase from Earth orbit to Lunar orbit is approximately 5 days. Nova-C will primarily utilize Thales Alenia transponders with hemispherical antennas during transit phase. Nova-C will have two Thales Alenia transponders, with 8 Watt transmit RF power and four low gain antennas (~3dBiC) for redundancy. Both Thales radios will be active on receive using independent antennas. Only the prime radio will be active for transmit. During transit, two tone ranging and doppler data are required. Nova-C will also intermittently utilize one of two Quasonix transmitters, with up to 25W RF power, in conjunction with a high gain antenna (~15dBiC) during the transit phase. The Thales and Quasonix radios will both be utilized during the Lunar Orbit Phase covering 12 orbits of the Moon in preparation for the autonomous descent and landing on the lunar surface. During each orbit of the Moon, Nova Control will lose contact with Nova-C when it goes behind the Moon and the LTN will need to re-acquire when in line-of-sight.

2.3 Lunar Surface Phase

Communications are always required during the Lunar Surface Phase. For lunar surface operations, the Quasonix transmitters will be used extensively during this phase to transmit science data to Earth. The Thales radios will continue to be utilized for commanding and status telemetry for spacecraft systems, with the Quasonix transmitter and Thales radios operating at the same time. The Thales Alenia transponders will have a transmit and receive frequency that will be different from the Quasonix transmit frequency, with all frequencies in Unified S-Band. This will require the use of two simultaneous downlink frequencies. The Lunar surface operations phase is expected to last 14 Earth days.

3 Description of Hardware

Figure 3.1 and 3.2 show the antenna placements and overall architecture, respectively.

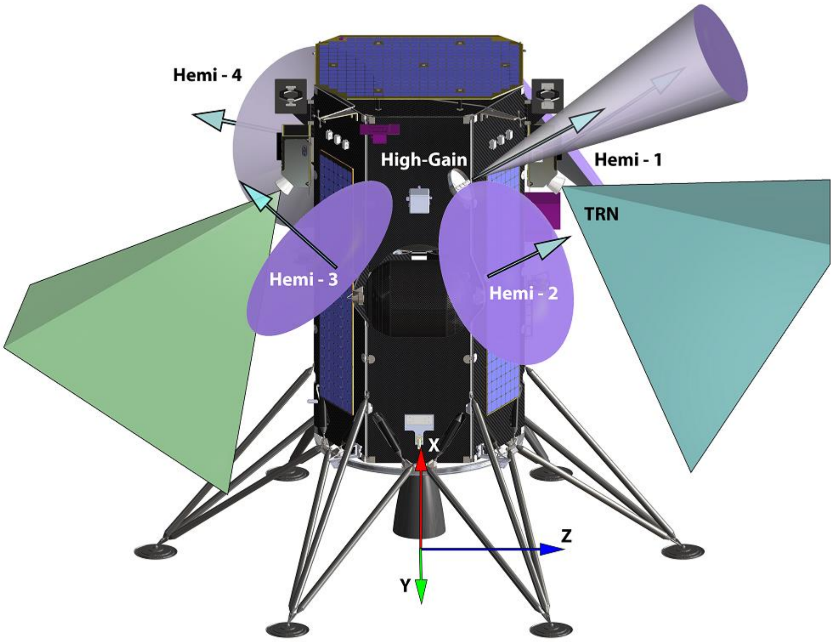

Figure 3.1 Nova-C Antenna Placements

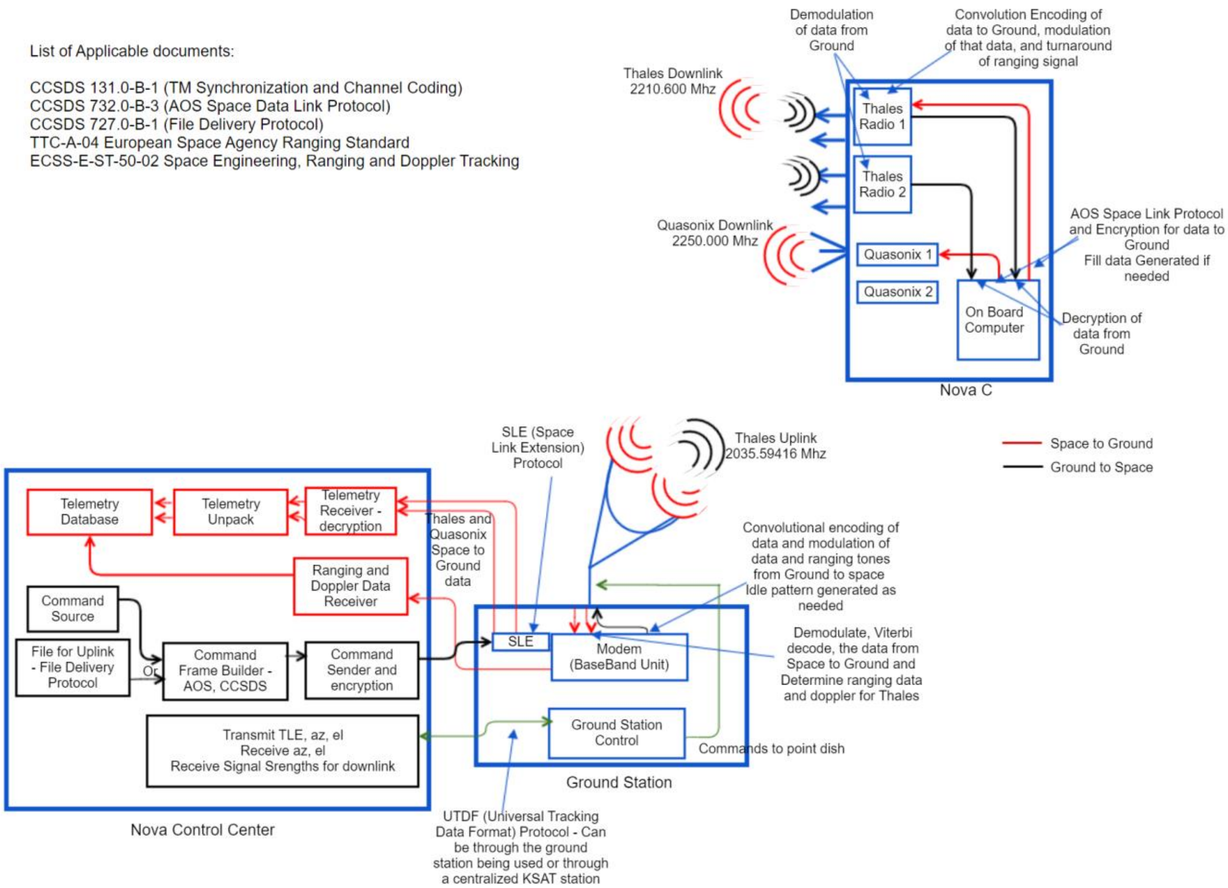

Figure 3.2 Overall System Architecture

3.1 Thales Alenia Transponders

The Thales radios are transmit and receive radios. The Thales radios use convolutional encoding (1/2 rate with K=7), follow CCSDS 131.0-B-1, and have no randomization for downlink. Uplink can be either convolutional encoded or unencoded. All data will be encrypted by the Nova-C computer and control center such that randomization is not required. The modulation scheme is BPSK for uplink and downlink. The Thales radios use synchronous RS-422 for telemetry and have various output types for commanding and status data. The radios are compatible with ESA two tone system for ranging. The Thales radios have 8W transmit power, and will use 2 kbps (encoded rate or unencoded rate) for Ground to Space telemetry. The data rate for Space to Ground is 2.5 kbps (encoded rate).

The transponder will provide a phase locked downlink carrier signal which is locked to the S-Band uplink frequency. The ranging function is based on PM modulated two tones. The downlink tones shall be locked to the uplink to provide ranging to the ground station (see details in requirements section). The coherency ratio shall be FTX/FRX = 240/221.

The transponder will provide downlink telemetry signal modulation corresponding to the composite signal received from the Nova-C's telemetry data system. The downlink is PM/BPSK with the telemetry BPSK modulated on a downlink S-band subcarrier and the downlink tone ranging PM modulated onto the carrier.

The Thales radio provides a channel with a flatness and bandwidth compatible with the standards TTC-A-04 for Tone Ranging and ECSS-E-ST-50-02C for MPTS with tone around 100 kHz. That is, it is flat in the range 16 kHz – 100 kHz. Therefore, you can use the sequence of tones in TTC-A-04. It must be taken into account that the MSBT does not perform any processing of the ranging signal, only performs the PM demodulation of the ranging signal of uplink and modulates (PM modulation) the received ranging signal into the downlink signal.

The use of other major tone frequency is possible taking into account the defined ranging filter pass band and assuming proper frequencies and indexes definition to avoid significant degradation due to interference between modulations: Ranging & TM (& TC if needed), in case of need for simultaneous transmission.

The ranging capability can be turned on and off. IM-1 does not intend to utilize ranging OFF. Below are the characteristics of the Thales radios Space to Earth transmissions with ranging ON:

Ranging ON characteristics:

- Input telemetry data: NRZ-L format and Bit Rate 1.25 kbps
- Input telemetry clock: 1.25 kHz
- Convolutional codification of telemetry data to yield 2.5 kbps
- Subcarrier frequency 30 kHz (12* fsymb after conv encoding)

- Modulation BPSK/PM (subcarrier BPSK modulated, Rs:2.5 kbps (encoded), downlink carrier PM modulated with 1 rad pk with telemetry only)
- When TM and Ranging are both transmitted (TM BPSK + Ranging) the total PM modulation index will be lower than 1.5 rad pk

The Ground Station receiving antenna shall demodulate the data stream and decode using Viterbi decoding (see details in requirement section).

The composite command information shall be transmitted by Ground Station (see details in requirement section) as 2 kbps (input as NRZ-L) BPSK modulating a Subcarrier of 8 kHz which PM modulates the carrier. The Thales S-band command receiver will demodulate the uplink signal to produce the baseband data. The command modulation index will be 1 rad (for the Subcarrier of 8 kHz).

Figure 3.1.1 Nova-C IM-1 Thales Transponder

3.2 Quasonix Downlink Only Transmitter

The Quasonix transmitters are transmit only. The Quasonix transmitters use convolutional encoding (1/2 rate with K=7), follow CCSDS 131.0-B-1, and have no randomization. All data will be encrypted by the Nova-C computer such that randomization is not required. The modulation scheme is OQPSK modulation. The Quasonix transmitters use synchronous RS-422 for telemetry, and asynchronous RS-422 for commanding and status information. The Quasonix transmitters are reconfigurable per commanding. The expected configuration will be 25W RF transmit power, with encoded bit rate between 200 kbps rate and 8 Mbps.

Figure 3.2.1 Nova-C IM-1 Quasonix Transmitter

3.3 High Gain Antenna (~15dBiC)

There is one high gain antenna that will be used primarily for lunar surface operations, but it may also be used intermittently during transit. The high gain antenna will be a dish type antenna. It is expected that the high gain antenna will be used primarily with the Quasonix transmitter, but RF switches do allow for the Thales radios to use the high gain antenna.

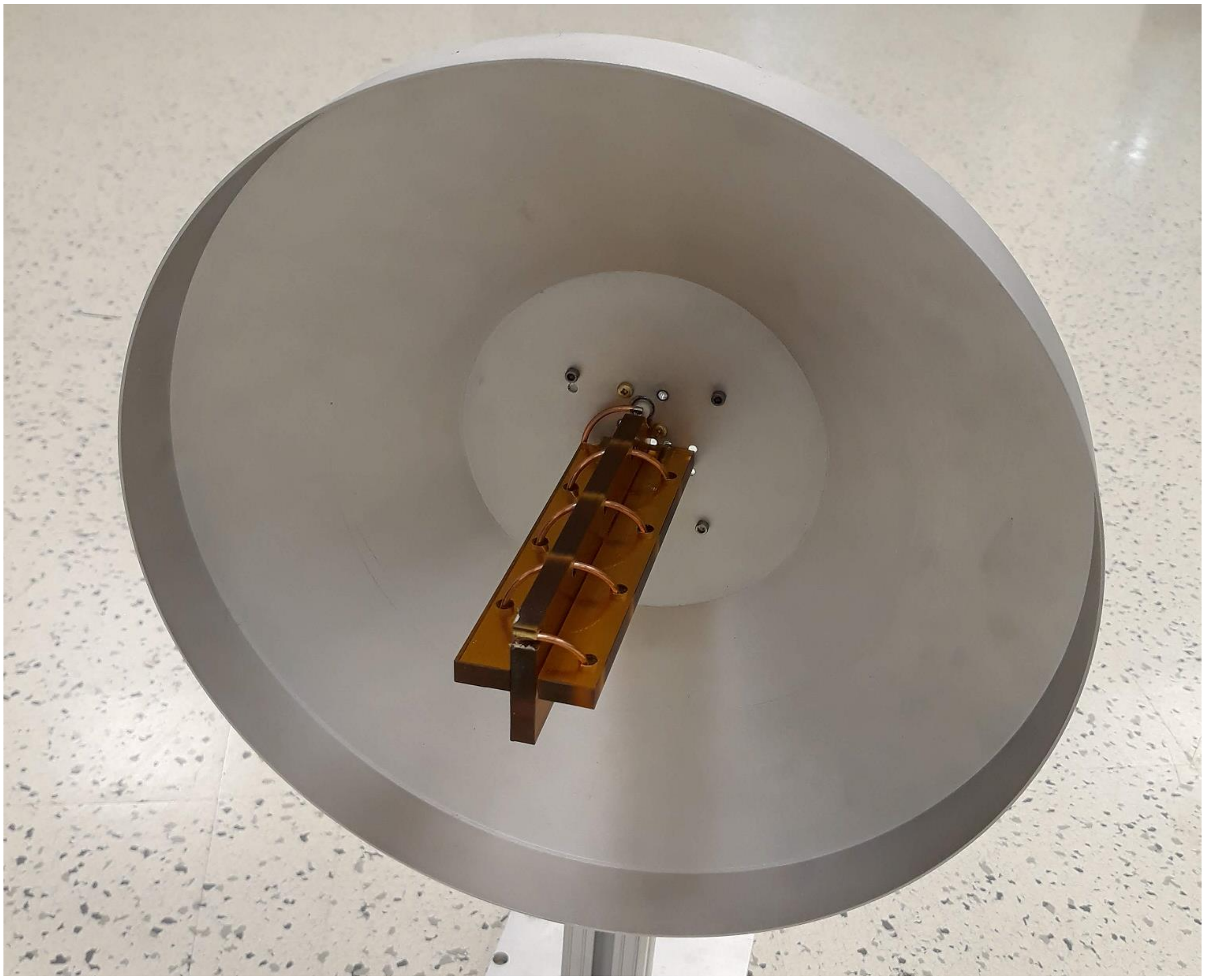

Figure 3.3.1 Nova-C IM-1 High Gain Antenna

3.4 Hemispheric Antennas (~3dBiC)

Four turnstile hemispheric antennas are located in various locations on Nova-C, with only two active at any time. RF switches allow for switching between the various antennas. It is expected that the Thales radios will primarily use the hemispheric antenna, but the RF switches do allow for the Quasonix transmitters to use the hemispheric antennas.

Figure 3.4.1 Nova-C IM-1 Hemispherical Antenna

3.5 Nova-C Flight Computer and Comm and Track Controller

The Nova-C flight computer will use the CCSDS 131.0-B-1 (TM Synchronization and Channel Coding) as well as CCSDS 732.0-B-3 (AOS Space Data Link Protocol) for telemetry formatting. The Nova-C flight computer will encrypt all data before it is sent to the radios for transmission to Earth. The Nova-C flight computer will decrypt all data sent from Earth. The Thales radios do not perform the Viterbi decoding. The uplink can either be sent unencoded, or the uplink signal can be routed to the Nova-C Comm and Track Controller which can perform the Viterbi decoding. The current plan is to send the uplink unencoded.

3.6 Lunar Tracking, Telemetry and Command Network (LTN)

When the Nova -C transmits over S-band, the RF signals are received by the LTN. The LTN is comprised of a geographically diverse set of large dish antennas under contract with Intuitive

Machines. IM is working with a variety of dish operators to accomplish the lunar mission as shown in Table 3.6.1

Table 3.6.1 LTN Dish Network

Ground Station	Size (m)
Morehead Space Sciences Center (USA)	21
Parkes Observatory (Australia)	64
Goonhilly Satellite Earth Station (England)	32
Indian Deep Space Network	32
Indian Deep Space Network	18
Maspalomas Station	15
Kourou	15
Singapore	9.1
Dubai	7
Mauritius	7

Many of the ground stations will provide access to Base Band Units that Nova Control will connect to in order to send commands and receive telemetry. At least three of the sites will host base band units provided by Intuitive Machines. Hosting our own equipment, see Figure 3.6.2, allows more control in testing the terrestrial interfaces and raises confidence in mission success related to the communications systems.

Figure 3.6.2 Nova Half Rack with Amergint Base Band Unit

3.7 Nova Control Center

The Nova Control Center (a.k.a. Nova Control) is the hub for all communications with the Nova-C over the LTN and will encrypt all data before it is sent to any ground station for uplink. Nova Control will also decrypt all data received from all ground stations.

Nova Control operations procedures for data handling ensure that data stored on board Nova-C will not be erased until confirmation that the data has been downlinked and verified. During downlinks there are no less than 3 copies of the data. These include the Nova-C onboard instance, the raw downlink instance in Nova Control, and the unencoded, encrypted instance in Nova Control that is transferred to payload-specific Amazon Web Services (AWS) GovCloud storage.

Nova Control uses the CCSDS AOS and COTP protocols to ensure error-free telemetry and command. IM tests the integrity of the downlink telemetry streams during the Mission Sequence Test, End-to-End Data Flow Test, and Flight Control Training. The Nova-C transmits data over the LTN in near real time as we plan to schedule continuous communication coverage from the Moon. After every downlink any received spacecraft or payload data is verified as having no gaps or missing data by checksum comparison to ensure data integrity.

All payload data is encrypted onboard the Nova-C prior to downlink using the NIST 800-53 standard and AES-256 protocol. Each payload customer is provided an encryption key and only the payload customers will have the ability to decrypt their data. Payload data is downlinked from Nova-C over the LTN and stored encrypted in AWS GovCloud storage for customer retrieval via secure large file transfers over the internet.

4 Summary of Nova-C Communication System Parameters

- Flight Configuration in section 1 with Ranging ON is active from Launch and until after moon landing.
- Post Landing Configuration in section 2 with Ranging OFF is active after spacecraft has landed on the moon.
- Payload downlink in section 3 can be activated during all the mission phases.

Table 4.1 Thales Configuration with Ranging ON, used during Transmit

Parameters	Downlink – Telemetry	Uplink - Commanding
Frequency	2210.600 MHz	2035.59416 MHz

Coherency ratio FTX/FRX	240/221	
Polarization	RHCP	RHCP
RF Bandwidth		
Modulation Scheme – Ranging ON	BPSK/PM (PM plus BPSK modulated subcarrier) phase modulate the telemetry unto the subcarrier using BPSK, and tones are phase modulated onto the carrier using Bi-Phase.	BPSK/PM (PM plus BPSK modulated subcarrier) phase modulate the telemetry unto the subcarrier using BPSK, and tones shall be phase modulated onto the carrier using Bi-Phase.
Subcarrier frequency	30 kHz	8 kHz
Modulation index	Data (subcarrier): 0.80 Ranging (main carrier): 0.70	Commanding (subcarrier): 0.90 Ranging (main carrier): 0.80
Effective bitrate - unencoded	1.25 kbps	2.0 kbps
Convolutional Coding/encoding	Convolutional ½ rate, K=7	No encoding
Total bitrate	2.5 kbps	2.0 kbps
Randomization	N/A	N/A
Pulse Code Modulation (PCM) encoding	NRZ-L	NRZ-L
Frame sync	Before header	TBD
Frame sync word – Attached Sync Marker	0x1ACFFC1D	TBD
Frame size	1240 bits	TBD
Block encoding	N/A	N/A
Telemetry/Telecommand standard	CCSDS, AOS	CCSDS, BCH
Uplink sweep Range	N/A	TBD
Uplink Sweep Rate	N/A	TBD
Idle Pattern	N/A	TBD
Type of Ranging	ESA Tone Ranging	
Ranging Major Tone	100 kHz (Minor Tones Set 1) or 50 kHz (Minor Tones Set 2) (TBD)	
Ranging Minor Tones	Cycles through the following (TBD): Set 1: 20 kHz, 16 kHz, 16.16 kHz, 16.032 kHz or 16.008 kHz	

	Cycles through the following Set 2 (TBD): 52.9364706 kHz, 52.9176471 kHz, 52.8235294 kHz, 52.7777778 kHz, 51.7647059 kHz, 47.0588235 kHz
Doppler Measurements	Two Way Doppler in Coherent Mode
TT&C Interface IM HQ	• Telemetry: Space Link Extension (SLE) RACF/RCF • Commanding: SLE CLTU • Ranging: Real Time Base Band Unit (BBU) port • Doppler: Real Time BBU port • TLE: UTDF

Table 4.2 Thales Radio with Ranging OFF, using primary after landing

Parameters	Downlink – Telemetry	Uplink - Commanding
Frequency	2210.600 MHz	2035.59416 MHz
Coherency Ratio FTX/FRX	240/221	
Polarization	RHCP	RHCP
RF Bandwidth		
Modulation Scheme – Ranging OFF	BPSK direct on the carrier and no subcarrier	BPSK direct on the carrier and no subcarrier
Subcarrier	N/A	N/A
Modulation index	N/A	N/A
Effective bitrate - unencoded	1.25 kbps	2.0 kbps
Convolutional Coding	Convolutional ½ rate, K=7	No encoding
Total bitrate	2.5 kbps	2.0 kbps
Randomization	N/A	N/A
PCM encoding	NRZ-L	NRZ-L
Frame sync	Before header	TBD
Frame sync word – Attached Sync Marker	0x1ACFFC1D	TBD
Frame size	1240 bits	TBD
Block encoding	N/A	N/A
Telemetry/Telecommand format	CCSDS, AOS	CCSDS, BCH
Uplink sweep Range	N/A	TBD
Uplink Sweep Rate	N/A	TBD
Idle Pattern	N/A	TBD

Type of Ranging	OFF
Ranging Major Tone	N/A
Ranging Minor Tones	N/A
Doppler Measurements	TBD
TT&C Interface IM HQ	• Telemetry: SLE RACF/RCF • Commanding: SLE CLTU • Ranging: Real Time BBU port • Doppler: Real Time BBU port

Table 4.3 Quasonix downlink

Bit rate will change depending on which ground station is being used.

Parameters	Downlink – Quasonix
Frequency	2250.0 MHz
Polarization	RHCP
RF Bandwidth	
Modulation Scheme	OQPSK
Modulation index	N/A
Effective bitrate – unencoded	62.5 kbps – 4000 kbps
Convolutional Coding/encoding	Viterbi ½ rate, K=7
Total bitrate – encoded	125 kbps – 8000 kbps
Randomization	N/A
PCM encoding	NRZ-L
Frame sync	After header
Frame sync word – Attached Sync Marker	0x1ACFFC1D
Frame size	various with bit rate
Block encoding	N/A
Data Interface IM HQ	Base Band Unit: CCSDS

5 Space to Earth, Downlink, Format

Below is the format for the data sent from Nova-C flight computer to the Thales radio or Quasonix transmitter for transmission to Earth. Thales and Quasonix apply convolutional encoding to the bit stream. This telemetry format is defined in CCSDS 131.0-B-1, TM Synchronization and Coding.

Table 5.1

Attached Sync Marker	**Frame Header**	**Data Zone - encrypted** **Number of bits varies depending on the Quasonix data rate but is fixed for Thales.**	**Frame Trailer and Cyclic Redundancy Check (CRC)**
0x1ACFFC1D (32 bits)	160 bits	Variable size for Quasonix. Fixed at 1008 bits for Thales.	48 bits

Question for Ground Station - Do we need to agree beforehand on the possible bit rates to be used with Quasonix and what those frame sizes are?

The attached sync marker, frame header, frame trailer, and CRC are all unencrypted.

After the ground station performs the Viterbi decoding, this same bit stream will be present, with the Attached Sync Marker (ASM) available. ASM will be 0x1ACFFC1D as defined in CCSDS TM Synchronization and Coding CCSDS 131.0-B-1.

6 Ground to Space, Uplink, Format

Below is the format for the data sent from the Nova control center to Ground Station ground station asynchronously. This format is defined in CCSDS 231.0-B-1.

Table 6.1 TC Synchronization and Channel Coding.

Command Link Transmission Unit (CLTU)

Start Sequence	Bose-Chaudhuri-Hocquenghem (BCH) code block.	Tail Sequence
0xEB90 (16 bits)	Varies. Max is 1014 bytes, min is 22 bytes. First 6 bytes are unencrypted header information.	0xC5C5C5C5C5C5C579 (64 bits)

The start and tail sequences are unencrypted, in addition to the first 6 bytes of the code block. The rest is encrypted.

For the uplink, the data must be sent at 2.0 kbps rate unencoded rate.

7 Link Analysis and Quasonix Bit Rates per Ground Station

The following table shows various parameters for the ground stations. The maximum encoded Quasonix bit rate is an estimate.

Table 7.1 Ground Station Parameters

Ground Station	Dia-meter (m)	Clear Sky G/T dB/K	EIRP dBW	Distance from Earth that Thales Ranging ON Link Closes	Max Encoded Quasonix Bit Rate Supported from Lunar Distance kbps
Morehead Space Sciences Center (USA)	21	30.8	72	lunar	1100
Parkes Observatory (Australia) downlink only	64	39*	N/A	lunar	8000
Goonhilly Satellite Earth Station (England)	32	33*	TBD	lunar	1750
Indian Deep Space Network	32	36.5	74-94	Lunar	4200
Indian Deep Space Network	18	30.5	60-80	Lunar	1100
Maspalomas Station	15	28.1	72.6	Lunar with angle off hemi at 50	750

				deg or better	
Kourou	15	29.1	74.6	Lunar with angle off hemi at 50 deg or better	800
Singapore	9.1	19.5	56	~150,000 km at 50 deg off boresite	N/A
Dubai	7	18	54	~150,000 km at 50 deg off boresite	N/A
Mauritius	7	18*	TBD	TBD	N/A

*Indicates estimate based on diameter

Figure 7.1 below shows graphically the distance from the Earth that the various ground stations will be able to close the link to the Thales downlink for various Nova-C hemi antenna off-boresite angles. Figure 7.2 graphically shows the various Quasonix bit rates that can be achieved for the different ground stations. And Figure 7.3 shows the uplink link analysis which shows that uplink is not an issue, with the 15 m Masapalomas station able to easily close the link at lunar distances.

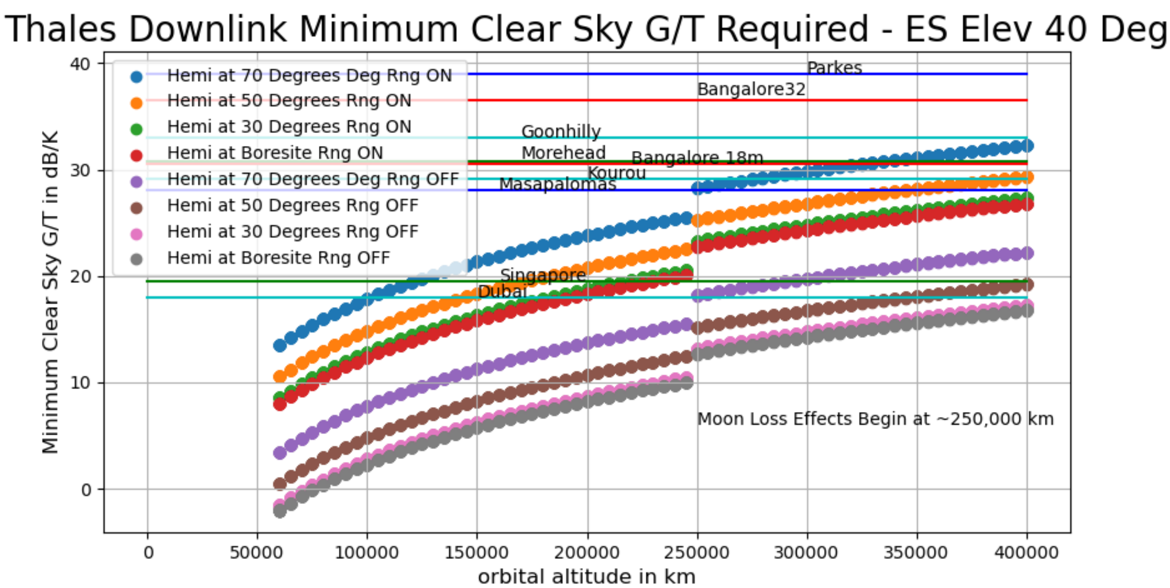

Figure 7.1 Thales Downlink Minimum G/T Analysis for Different Distances from the Earth

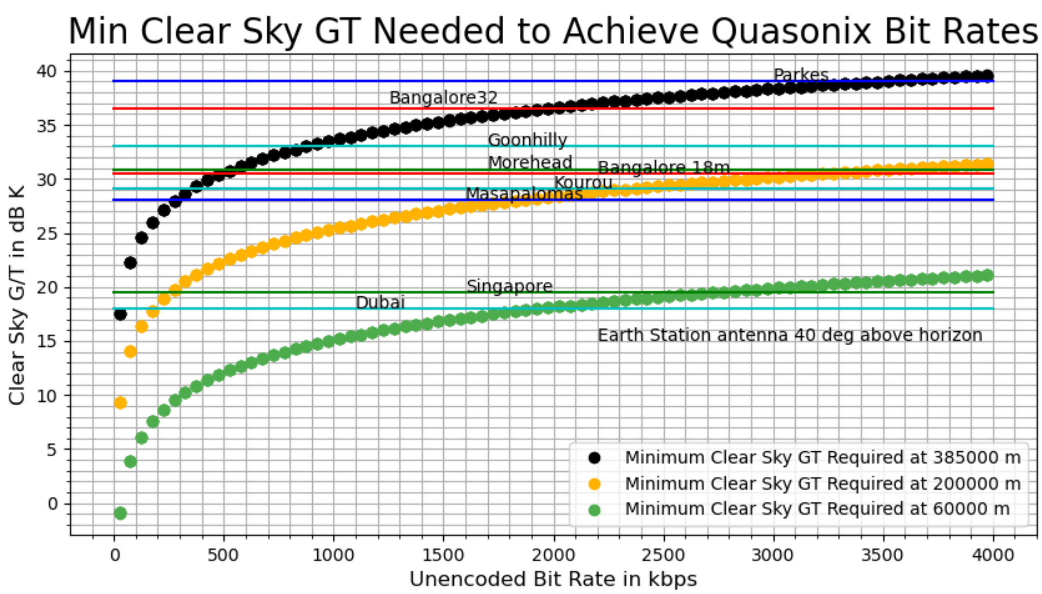

Figure 7.2 Quasonix Minimum G/T for Downlink Rates

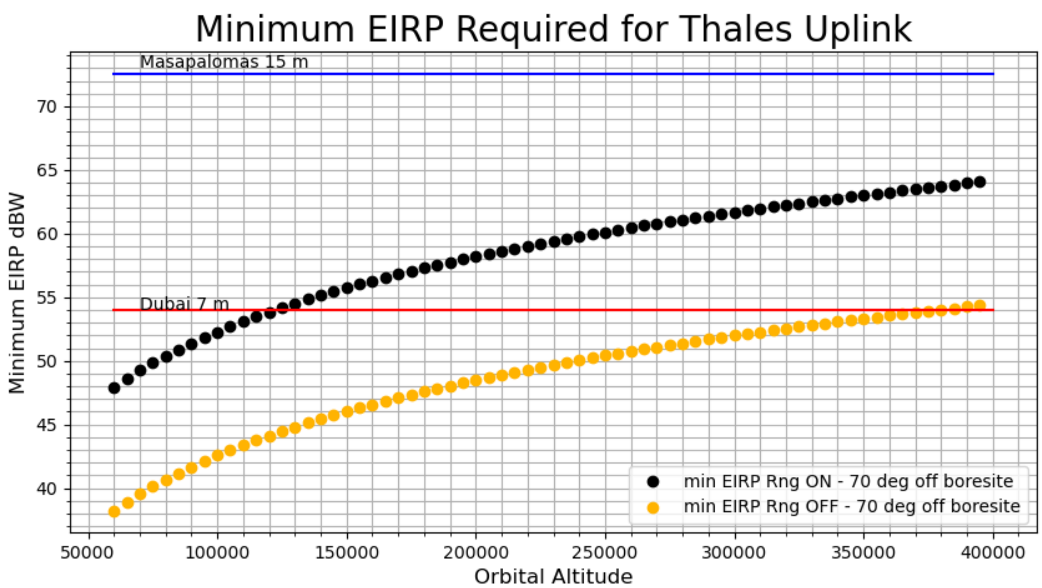

Figure 7.3 Thales Uplink Minimum EIRP Required

8 Reference Documents and Requirements

List of Applicable documents:

- CCSDS 131.0-B-1 TM Synchronization and Channel Coding
- CCSDS 732.0-B-3 AOS Space Data Link Protocol
- CCSDS 727.0-B-1 File Delivery Protocol
- CCSDS 231.0-B-1, TC Synchronization and Channel Coding
- CCSDS 232.0-B-1, TC Space Data Link Protocol
- CCSDS 133.0-B-1, Space Packet Protocol
- TTC-A-04, European Space Agency Ranging Standard
- ECSS-E-ST-50-02, Space Engineering, Ranging and Doppler Tracking

General Requirements

[Requirement-G1] Ground Station shall establish communications with Nova-C as quickly as possible after separation from launch vehicle

[Requirement-G2] Ground Station shall transmit at carrier frequency of 2035.59416 MHz for Earth to Space at 2.0 kbps rate with the ability to transmit telemetry data only or telemetry data and a ranging signal.   Uplink data with either be sent unencoded at 2.0 kbps rate. The data for uplink will be sent from Nova Control Center to Ground Station in accordance with ICD TBD.

[Requirement-G3] Ground Station shall receive Thales radio telemetry and ranging data at carrier frequency of 2210.600 MHz for Space to Earth at 2.5 kpbs encoded rate for both the case of receiving telemetry only and receiving telemetry and ranging signal.

[Requirement-G4] Ground Station shall receive Quasonix transmitter telemetry, no ranging signal, at carrier frequency of TBD MHz for Space to Earth at 150 kpbs to 1000 kbps encoded rate.

[Requirement-G5] Ground Station shall generate idle pattern data and uplink to Space during times when Nova Control Center is not sending any data to Ground Station for uplink.

[Requirement-G6] Ground Station shall encode all data for transmission to Space using convolutional encoding (Convolutional ½ Rate, K=7) as defined in CCSDS 131.0-B-1.

[Requirement-G7] Ground Station shall decode all data received on Earth utilizing a Viterbi decoder

[Requirement-G8] Ground Station shall be able to simultaneously process the Thales uplink, Thales downlink, and Quasonix downlink.

[Requirement-G9] Ground Station shall provide time stamps on the downlink data corresponding to the time of receipt of the frame. The time stamp shall be accurate to within TBD seconds.

Command Acquisition Sequence Definition for Thales Radio

[Requirement-ThalesAcq-01] The following sequence shall be followed for the command acquisition sequence for the Thales radio:

For a proper locking of the transponder receiver, it is mandatory that ground station generates an unmodulated uplink carrier (whose frequency is swept across the locking range). The maximum sweep rate is 32 KHz/s, and the acquisition range must be +/- R KHz. The value R has to meet:

$R \geq 50 \text{ kHz} + D$

Where D is the expected Doppler deviation in kHz. The value of 50 kHz corresponds to the worst case value of Rest Frequency deviation (+/- 2 ppm).

The nominal carrier acquisition procedure is as follows:

1) Generate an unmodulated carrier at nominal uplink frequency.

2) Sweep the frequency from nominal value (Frx) to Frx +R kHz at a sweep rate less or equal to 32 kHz/s.

3) Sweep the frequency from Frx + R kHz to Frx – R kHz at a sweep rate less or equal to 32 kHz/s.

4) Sweep the frequency from Frx – R kHz to Frx at a sweep rate less or equal to 32 kHz/s.

Alternatively, the carrier acquisition procedure can be also as follows:

1) Generate an unmodulated carrier at nominal uplink frequency.

2) Sweep the frequency from nominal value (Frx) to Frx - R kHz at a sweep rate less or equal to 32 kHz/s.

3) Sweep the frequency from Frx - R kHz to Frx + R kHz at a sweep rate less or equal to 32 kHz/s.

4) Sweep the frequency from Frx + R kHz to Frx at a sweep rate less or equal to 32 kHz/s.

At the end of one of the previous acquisition procedures the RX shall be locked to the uplink and the telemetry signal CARRIER LOCK OUT will take a High Level.

Once the RX is locked to the unmodulated carrier, the uplink generator station shall set the BPSK/PM modulation by a Preamble of 128 bits with the “1010” pattern. If the level at RF common port of the Transponder is higher or equal to TC Command Threshold) at the end of this preamble the RX will be bit locked and the status telemetry signal TC DATA VALID will take a High level.

Transmit Earth to Space Requirements for Ranging ON using the 2035.59416 MHz Carrier to the Thales Radio

[Requirement-U2] Ground Station shall transmit the composite command information at 2 kbps rate ±0.008% input as NRZ-L, BPSK modulating a Subcarrier of 8 kHz which PM modulates the carrier.

[Requirement-U3] Ground Station shall phase modulate the telemetry unto the subcarrier using BPSK, and tones shall be phase modulated onto the carrier using Bi-Phase.

[Requirement-U4] Ground Station shall use the ranging tones of 100 Khz major tone, with the sequence of minor tones of 20 Khz, 16 Khz, 16.8 Khz, 16.16 Khz, 16.032 Khz, and 16.008 Khz, as defined in TTC-A-04 (these may not be the final set of ranging tones).

Transmit Earth to Space Requirements for Ranging OFF using the 2035.59416 MHz Carrier to the Thales Radio

[Requirement-U2] Ground Station shall transmit the composite command information at 2 kbps rate ±0.008% input as NRZ-L, PM modulating unto the carrier using BPSK

[Requirement-U3] Ground Station shall phase modulate the telemetry unto the carrier using BPSK

Receive Space to Earth Requirements for Ranging ON using the 2210.600 MHz Carrier from the Thales Radio

[Requirement-D1] Ground Station shall demodulate the signal, decode the telemetry signal using a Viterbi decoder, and provide that telemetry to Nova Control Center in accordance with ICD TBD.

[Requirement-D2] Ground Station shall demodulate the signal, separate the ranging signal, and provide ranging data and doppler information to Nova Control Center in accordance with ICD TBD.

Receive Space to Earth Requirements for Ranging OFF using the 2210.600 MHz Carrier from the Thales Radio

[Requirement-D3] Ground Station shall demodulate the signal, decode the telemetry signal using a Viterbi decoder, and provide that telemetry to Nova Control Center in accordance with ICD TBD.

Receive Space to Earth Requirements using the 2250.00 MHz MHz Carrier from the Quasonix Transmitter

[Requirement-D3] Ground Station shall demodulate the signal, decode the telemetry signal using a Viterbi decoder, and provide that telemetry to Nova Control Center in accordance with ICD TBD.