POLITECNICO DI MILANO
DEPARTMENT OF AEROSPACE ENGINEERING

Space Systems Engineering and Operations

AA 2023-2024

Professor: Michèle Roberta Lavagna

OSTM/Jason-2 Mission

Assignment 3: Tracking Telemetry & Telecomand Subsystem

Group 25

Person Code	Surname	Name
10726898	Juvara	Matteo Giovanni
10717230	Beretta	Beatrice
10705062	Nicolucci	Edoardo
10973691	Separovic	Marko Tomislav
10735389	Orsenigo	Samuele
10728962	Modelli	Simone

April 14, 2024

Contents

Acronyms

BER Bit Error Rate. 9

CCSDS Consultative Committee for Space Data Systems. 6

CDAS Command and Data Acquisition Stations. 5, 8–10

CNES Centre National d'Études Spatiales. 10

DHU Data Handling Unit. 5

DORIS Doppler Orbitography and Radiopositioning Integrated by Satellite. 5

ESA European Space Agency. 9

EUMETSAT European Organisation for the Exploitation of Meteorological Satellites. 5

FOV Field of View. 7

GPS Global Positioning System. 5

GPSP Global Positioning System Payload. 5

GS Ground Station. 6, 8

HKTM-P House Keeping Telemetry Pass. 7

HKTM-R House Keeping Telemetry Record. 7

JASON Joint Altimetry Satellite Oceanography Network. 5

JPL Jet Propulsion Laboratory. 10

LRA Laser Retroreflector Array. 5

MGA Medium Gain Antennas. 5, 8

NASA The National Aeronautics and Space Administration. 10

NOAA National Oceanic and Atmospheric Administration. 5, 8, 10

OSTM Ocean Surface Topography Mission. 5

PLTM Payload Telemetry. 7

POD Precise Orbit Determination. 5

PROTEUS Plateforme Reconfigurable pour l'Observation, les Télécommunications Et les Usages Scientifiques. 5–7, 9, 10

QPSK Quadrature Phase Shift Keying. 6

SHM Safe Hold Mode. 8

SOCC Satellite Operations Control Center. 5

SSA Solid State Amplifier. 9

TC Telecomand Data. 5–9

TM Telemetry Data. 5, 6, 8, 9

TRSR-2 Turbo Rogue Space Receiver-2. 5

TTC racking, Telemetry and Command. 8

TTMTC Tracking Telemetry & Telecommand. 2, 5, 7–9

1 Architecture and Design

1.1 Ground Segment Architecture

In order to meet all of the science and mission requirements, Jason-2 must be able to communicate with all other systems through its TTMTC architecture. The complexity of this subsystem is the result of several companies working together, with different ground and space segments. The overall structure of Jason 2's space system is illustrated in Figure 1. The raw telemetry data streams from the Jason platform are sent to NOAA's Wallops and Fairbanks Command and Data Acquisition Stations (CDAS) and at EUMETSAT's tracking station located in Usingen, Germany (Figure 2). These stations provide the ground terminals and part of the ground network to the OSTM, also handling the processing, archiving, and distribution of mission data acquired in near real-time. Subsequently, these streams are forwarded to other Jason-2 subsystems at NOAA's Satellite Operations Control Center (SOCC), situated in Suitland, Maryland, for further processing.

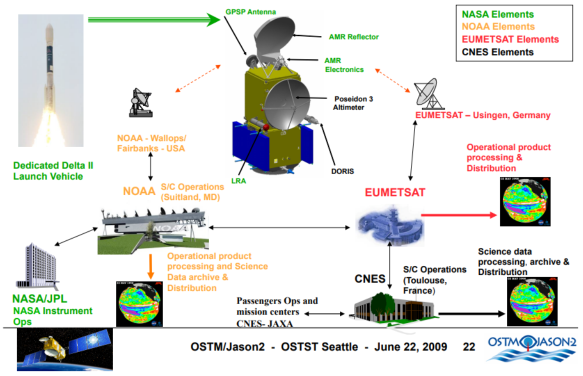

Fig. 1: Jason 2 System Architecture

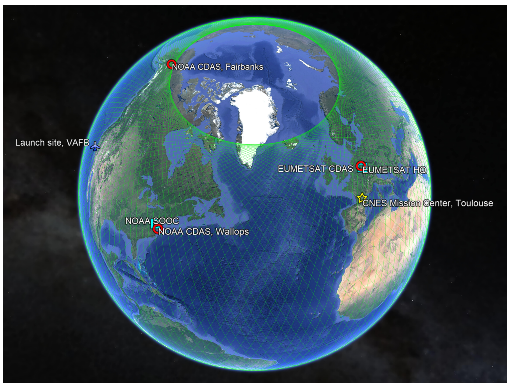

Fig. 2: Ground Stations

During launch, satellite tracking ground stations in South Africa, Kiruna (Sweden), and Kourou (French Guiana) will supplement the existing network. The ground station in Hartebeesthoek, South Africa, is responsible for confirming the separation of OSTM/JASON 2 from the Delta II rocket.

In order for the satellite to function properly, it needs to establish connections with other spacecraft and specialized stations. Specifically, contact with ground stations such as Harvest, California (USA)[8] and Cap Senetosa, Corsica (France)[7] is required for the functioning of thePrecise Orbit Determination (POD) system [10], consisting of various components such as DORIS, TRSR-2 (GPSP), and LRA.

In particular, DORIS utilizes a ground network of approximately 50 ground beacons to measure the Doppler effect of dual-frequency signals, allowing for the calculation of the satellite's velocity to ensure accurate positioning in orbit; this system is supported by the TRSR-2, a 16-channel GPS receiver, which maintains an average connection with 8 GPS satellites being tracked simultaneously [9].

1.2 Signal Elaboration and TTMTC Architecture

In this section, only the principal Tracking Telemetry & Telecommand (TTMTC) system will be studied and modelled. This task is entrusted to the PROTEUS platform, which communicates with Earth through a radio transmitter and receiver, both of which operate in the microwave S-band, using two spiral-shaped Medium Gain Antennas (MGA), as shown in Figure 3. Two redundant antennas pointing opposite directions are needed to guarantee data transfer for all possible orientations of the satellite. According to PROTEUS documentation [6], a Data Handling Unit (DHU) is used by the payload on Jason-2 to interface with the Proteus platform. The DHU is in charge of a number of duties, such as creating, preserving, and downlinking Telemetry Data (TM) as well as elaborating and executing Telecomand Data (TC) that it receives from the ground stations.

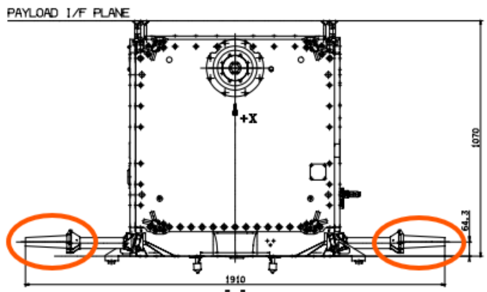

Fig. 3: Detailed view of the antennas on the Proteus platform

The overall payload data path is shown in Figure 4, while the specific telemetry flow from the payload to the ground system is shown in Figure 5.

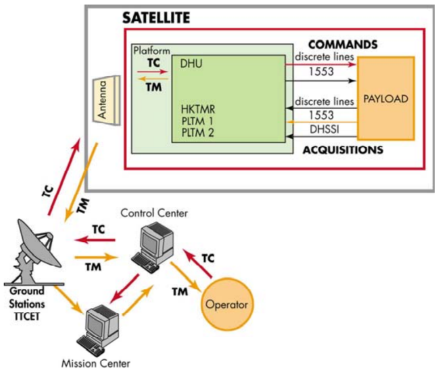

Fig. 4: PROTEUS Data Path Scheme

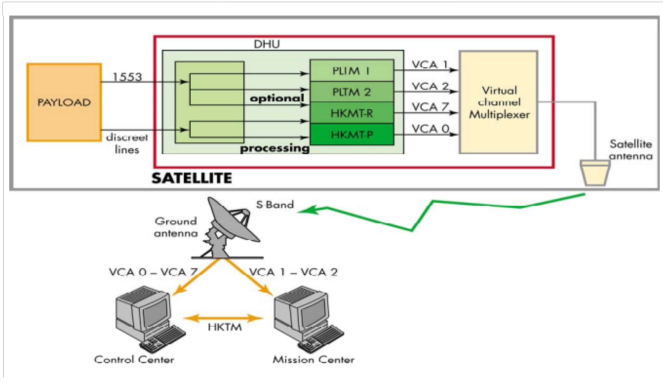

Fig. 5: PROTEUS Telemetry Scheme

Regarding the reception method, it can be noted that TM reception can occur in both right and left circular polarizations. For TC in normal mode, however, left polarization is used in Earth pointing mode. Finally, for inertial or solar pointing, the ground polarization changes according to the current attitude during each visibility. It can be observed that for each mission, telecommunication frequencies are chosen from the frequency pairs presented in Table 1; however, the choice is made depending on the orbit and frequencies already allocated.

1.3 Signal Selection

	Up-link frequency	Down-link frequency	UIT publication
Couple 1	2040.34300 - 2040.64300 MHz	2214.920 - 2216.920 MHz	AR/11A/1828
Couple 2	2088.72819 - 2089.02819 MHz	2267.515 - 2269.415 MHz	AR/11A/1826
Couple 3	2101.56000 - 2101.86000 MHz	2281.400 - 2283.400 MHz	AR/11A/1827

Table 1: Frequency couples reserved at UIT for PROTEUS

As summarized in Table 1 PROTEUS uses S-band frequencies, with the use of Reed-Solomon or Viterbi encoding and QPSK modulation. The protocols used by the Ground Station for telemetry encoding and telecommand decoding are CCSDS packet standard.

The S-band is a particular section of the microwave band that ranges from 2 to 4 GHz. In the recent years it has been devoted to satellite telecommunication, as the S-band offers several advantages for satellite communication. Its signals can penetrate through atmospheric conditions more effectively compared to higher frequency bands, which makes it suitable for reliable and robust communication, particularly in challenging weather conditions or densely populated areas where signal interference may occur.
Since the Jason-2 has to sustain almost real-time communication in every condition, choosing frequencies in the S-class for uplink and downlink should guarantee the reliability needed with the required data rate.

Quadrature Phase Shift Keying (QPSK) is a type of digital modulation scheme that is commonly implemented in satellite communication systems. This has a series of advantages over other modulation schemes, the main ones are:

- **Higher data rates**: QPSK is able to transmit data at a higher rate than other modulation schemes, as it can encode two bits of information per symbol, rather than just one. This makes it suitable for applications that require high data rate such as telemetry transmission.
- **Improved performance in noisy environments**: QPSK is more resistant to noise and interference than other modulation schemes, as it is able to transmit information using both phase and amplitude changes in the carrier signal. This makes it more robust in noisy or fading environments, such as those found in Earth-pointing satellite communications.
- **Greater spectral efficiency**: QPSK requires less bandwidth than other modulation schemes for a given data rate. This makes it more spectrally efficient, which is important in satellite communication systems where bandwidth is a limited resource.

2 Modes and Mission Phases

During its lifetime, the Jason-2 satellite's data volume and contact strategy varied depending on numerous factors, such as signal disturbances, sensor or system failure, data type and format for downlink and much more. In this section the initial requirements will be analyzed and subsequently the mission phases telemetry and telecommand are better explained.

2.1 Initial Requirements

On the PROTEUS User's Manual [6] some limitations of the PROTEUS's TTMTC subsystem are highlighted:

- The maximum size of the source packet shall not exceed 1 kbyte ($512 \cdot 16$ bits) to prevent data losses and avoid longer transmission periods.
- The uplink data-rate shall be fixed at 4 kbit/s for the whole lifetime of the spacecraft, independently from the active mode of the satellite.
- The downlink data-rate during all routine phases shall be 722.116 kbit/s at maximum.
- The downlink data-rate during emergency phases shall be 85.966 kbit/s at maximum.

2.2 Satellite Active Modes

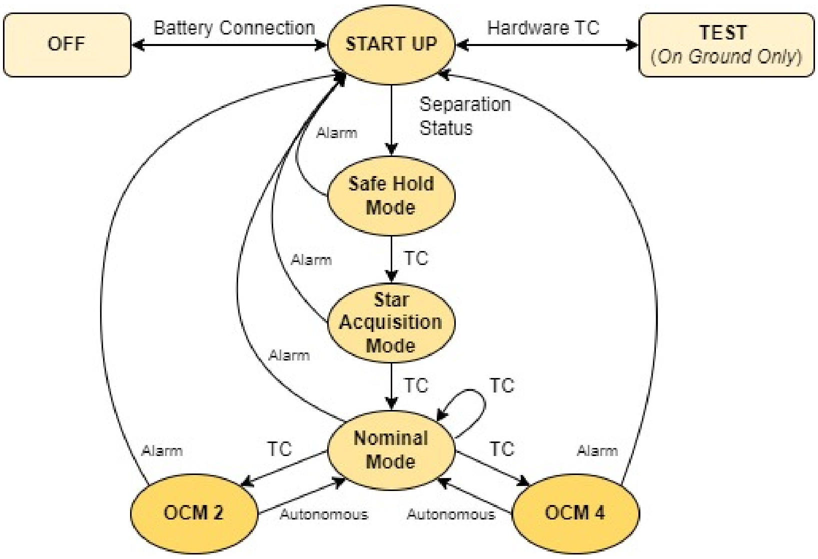

Fig. 6: Jason-2's Phases [6]

Telemetry and telecommand strategies vary in function of the current active mode of the satellite. The main active modes are explored in the following paragraph:

- During Launch the satellite receivers are active, making possible issuing Telecomand Data for the satellite to follow.
- While in Nominal Mode the satellite operates maintaining all its functionalities. The uplink data-rate is fixed at 4 kbits/s whereas downlink data-rate has a maximum capability of 722.116 kbit/s, as already seen in the previous paragraph. In this mode three possible types of data may be transmitted:
  - HKTM-P, which are information on the current state of the satellite and must always be transferred to the ground station, when in visibility and with the emitter is switched on;
  - HKTM-R, which provide history of recent data on the satellite. This data is stored on board and can be transmitted upon request from the ground station;
  - PLTM, which is also stored on board on a dedicated internal mass memory of 2 Gbits, until a ground station enters the satellite's Field of View (FOV) and it can transferred.
- During orbital maneuvers the satellite maintains full operability, however, since the control is obtained through thrusters aligned with the +X satellite axis, the satellite is reoriented during this phase so data acquisition through the payload might not be possible.

- In case of emergency the satellite enters in the Safe Hold Mode (SHM), with the objective of reaching a safe attitude with the -X satellite axis pointed to the Sun. In this mode the satellite TM is reduced only to essential data, but its receiver is always on to receive TC and start to transition to another mode.

3 Reverse Sizing

In this section a preliminary reverse sizing of the TTMTC subsystem will be discussed taking into account its most important aspects.

3.1 Losses

The channel losses computation is composed of four distinct types of contributions. Free space, pointing, cable and atmospheric losses have been taken into account.

Free space losses account for the distance between the satellite and the Ground Station. The sizing is performed at the worst case, which is at maximum distance:

$$L_{free\,space} = 20 \cdot log_{10}\left(\frac{c}{4\pi \cdot f \cdot r}\right) \qquad [dB] \tag{1}$$

where c is the speed of light, f is the wave frequency, r is the maximum distance of the spacecraft from Earth, which is 1370 km.

Pointing losses, which account for the pointing accuracy and receiver beam-width are defined as:

$$\begin{cases} L_{pointing} = -12 \cdot \left(\frac{\eta_p}{\theta_{rx}}\right)^2 & [dB] \\ \theta_{rx} = 70 \cdot \frac{c}{f \cdot D} & [deg] \end{cases} \tag{2}$$

where D is the antenna diameter and η_p is the pointing efficiency. For the diameter D for downlink, 21 meters was used, as it is the diameter of the largest S-band antenna at NOAA's Wallops and Fairbanks Command and Data Acquisition Stations [4]. On the other hand the diameter used for uplink losses used was 65 mm as it is the diameter of RUAG's S-band Helix TTC Antennas [5]. The pointing accuracy for the uplink MGA antenna was assumed to be 0.1 while for the downlink receiver antenna the accuracy was assumed 0.05 due to the precise pointing capabilities of the CDAS antenna.

Through graphical analysis we can assume the atmospheric losses around $L_{atm} = -0.04\ dB$ and cable losses are assumed to be $L_{cab} = -2\ dB$.

The following table shows the main signal losses of the system.

	Downlink	**Uplink**
$L_{free\,space}$	-162,0894	-161,3763
$L_{pointing}$	-0,1474	$-4,792 \cdot 10^{-6}$
L_{atm}	-0,04	-0.04
L_{cables}	-2	-2

Table 2: Uplink and downlink signal losses $[dB]$

3.2 Antennas

The antennas used for both downlink and uplink are analysed in the following paragraph.
The gain for both antennas is obtained through the formula:

$$G = 10 \cdot log_{10}\left(\mu \cdot \left(\frac{\pi \cdot D \cdot f}{c}\right)^2\right) \qquad [dB] \tag{3}$$

where μ is the antenna efficiency, which is $\mu_{helix} = 0.70$ for helix antennas and $\mu_{para} = 0.55$ for parabolic antennas. The gains for the receiver and for the transmitter antennas has been calculated for all frequencies used and is reported in the following table.

	Downlink	Uplink
G_{tx}	2.023	50.4487
G_{rx}	51.1618	1.3099

Table 3: Transmitter and receiver gains $[dB]$

The system noise density N_0 related to the receiving antenna can be computed as:

$$N_0 = 10 \cdot log_{10}(kT_s) \qquad [dB] \tag{4}$$

where k is the Boltzmann constant $(1.38 \cdot 10^{-23}\ Ws/K)$ and T_s is the system temperature, which was assumed to be $T_s = 250.35\ K$ for the Fairbanks CDAS as this was the lowest average monthly temperature [2], while for the Jason-2's antenna it was assumed to be $T_s = 233.15\ K$ as it was indicated as the lowest temperature for operational payload systems. [3]
The noise density can now computed: for the downlink receiver antenna $N_0 = -204.616\ dB$ while for the uplink receiver antenna $N_0 = -204.925\ dB$.

3.3 Amplifier

As no information on the amplifier used was found on the documentation, it was assumed the use of a Solid State Amplifier (SSA). This was done mainly because of two reasons: the SSA is usually preferred at the frequencies used (2MHz) and the scientific payload of the Jason-2 mounted a SSA as well.
It was assumed the use of a largely used amplifier in Jason-2's period such as the Airbus Defence and Space S-Band SSA with an output power of $P_{tx} = 15\ W$ and an efficiency of $\mu_{amp} = 0.31$.[11]. From this the power input can be computed as:

$$P_{in} = \frac{P_{tx}}{\mu_{amp}} = 48.387\ W \tag{5}$$

Knowing from the PROTEUS User's Manual [6], the power budget for the bus is 300 W, which means that an input power of almost 50 W for the TTMTC System is an acceptable estimate.

For the ground station, the smallest power output of all antennas was selected as a worst case scenario. The power output used for the ground station is $P_{tx} = 50\ W$. [1]

3.4 Link Budget

To calculate the link budget a Bit Error Rate (BER) has to be selected. For TM and downlink a BER of 10^{-5} was selected, while for the TC a higher BER of 10^{-7} was selected to guarantee higher accuracy.
Knowing that the modulation used is QPSK and the encoding used is Reed-Solomon or Viterbi we can compute the real data rate of the system by multiplying the maximum expected data rate with modulation and encoding coefficients. For QPSK modulation $\alpha_{enc} = 2$ while for Reed-Solomon encoding usually k = 223 and n = 255 which translates in an encoding coefficient $\alpha_{enc} = 1.1435$.

$$R_{data\ real} = R_{data}\frac{\alpha_{enc}}{\alpha_{mod}} = 1262.8\ kbit/s \tag{6}$$

With the BERs obtained earlier, the necessary error per bit to noise density ratio is $\frac{E_b}{N_0} = 5.5\ dB$ for downlink and $\frac{E_b}{N_0} = 6\ dB$ for uplink. To this a 3 dB margin is added, as per ESA regulations. The system's error per bit to noise density ratio can be computed as:

$$\frac{E_b}{N_0} = 10 \cdot log_{10}(P_{tx}) + Gtx + Grx + L_{total} - N_0 - 10 \cdot log_{10}(R_{data\ real}) \qquad [dB] \tag{7}$$

From this equation the link budget for both downlink and uplink is extensively verified with $(\frac{E_b}{N_0})_{down} = 84.356\ dB$ and $(\frac{E_b}{N_0})_{up} = 101.435\ dB$, which means that the system is suitable for its required applications in the worst case scenario.

References

[1] ASF Enterprise Ground Station.
https://asf.alaska.edu/asf-enterprise-ground-station/.

[2] Climate Data on Fairbanks, USA.
https://en.climate-data.org/united-states-of-america/alaska/fairbanks-1403/.

[3] eoPortal Jason-2.
https://www.eoportal.org/satellite-missions/jason-2.

[4] NOAA's Wallop and Fairbank CDAS website.
https://www.nesdis.noaa.gov/about/our-offices/fairbanks-command-and-data-acquisition-station-fcdas.

[5] RUAG's S-Band TTC Antennas Data Sheet.
https://spacesupplier.ir/wp-content/Catalog-S-band-TTC-Antennas.pdf.

[6] NASA & Alcatel. PROTEUS User's Manual, 2004.

[7] Aviso. Calibration Campaign Contribution.
https://www.aviso.altimetry.fr/calval/absolute-calibration/corsica-calibration-sites.html.

[8] Aviso, NASA, NOAA and JPL. Harvest Altimetry Calibration.
https://www.aviso.altimetry.fr/0220Haines20harvest2011.pdf.

[9] Christophe MARECHAL, CNES. Jason-2 Project Status, 2019.
https://ostst.aviso.altimetry.fr/OSTST2019/J2StatusMarechalv3.0.pdf.

[10] NASA. Jason-2 SLR System & POD Status, 2008.
https://ilrs.gsfc.nasa.gov/docs/ja1-2-slr-pass.pdf.

[11] W. Lohmeyer,R. Aniceto, K. Cahoy.
Communication satellite power amplifiers: current and future SSPA and TWTA technologies.
International Journal of Satellite Communications and Networking, 2015.
https://core.ac.uk/download/pdf/85123635.pdf.