1.1 OSIRIS-REx Spacecraft System Configuration

Excerpted from *DSN-OSIRIS-REx Mission Operations Interface Control Document (OICD), Rev B*, July 20, 2016.

The OSIRIS-REx spacecraft provides the essential functions for an asteroid characterization and sample return mission:

- Attitude control
- Propulsion
- Power
- Thermal control
- Telecommunications
- Command and data handling

The OSIRIS-REx spacecraft is also equipped with the structural support to ensure successful rendezvous with asteroid Bennu, characterization of its properties, delivery of the sampler to the surface, and return of the spacecraft to the vicinity of the Earth. Sample collection, performed by the Touch-and-Go Sample Acquisition Mechanism (TAGSAM), will acquire a regolith sample from the surface. Views of the spacecraft are shown in Figure 2-1 through Figure 2-4, and a block diagram of the flight system is shown in Figure 2-5.

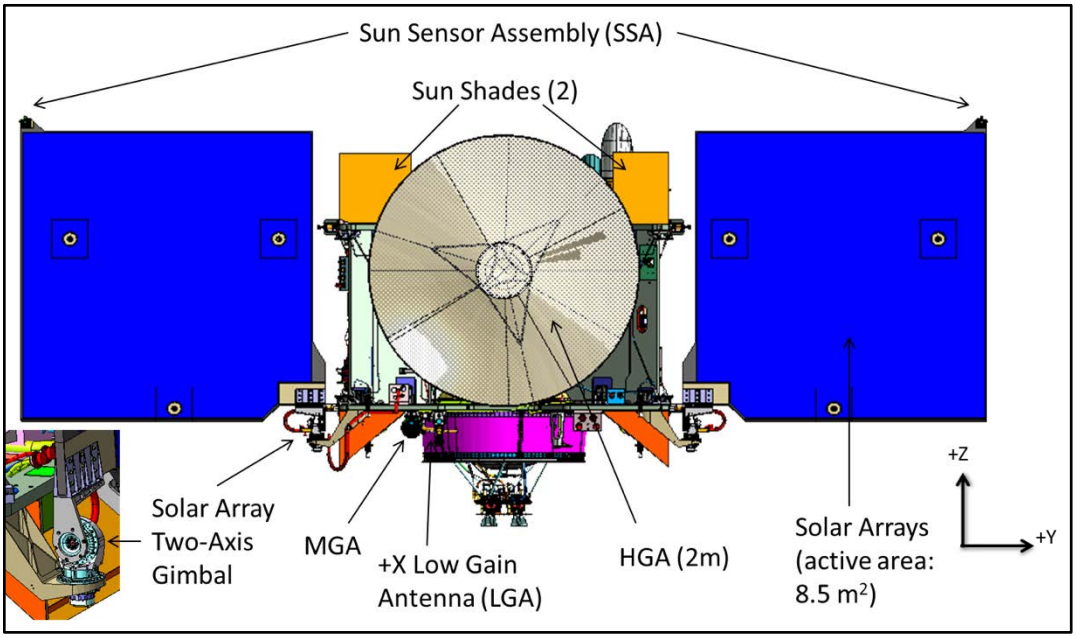

Figure 1-1. Spacecraft +X-axis View

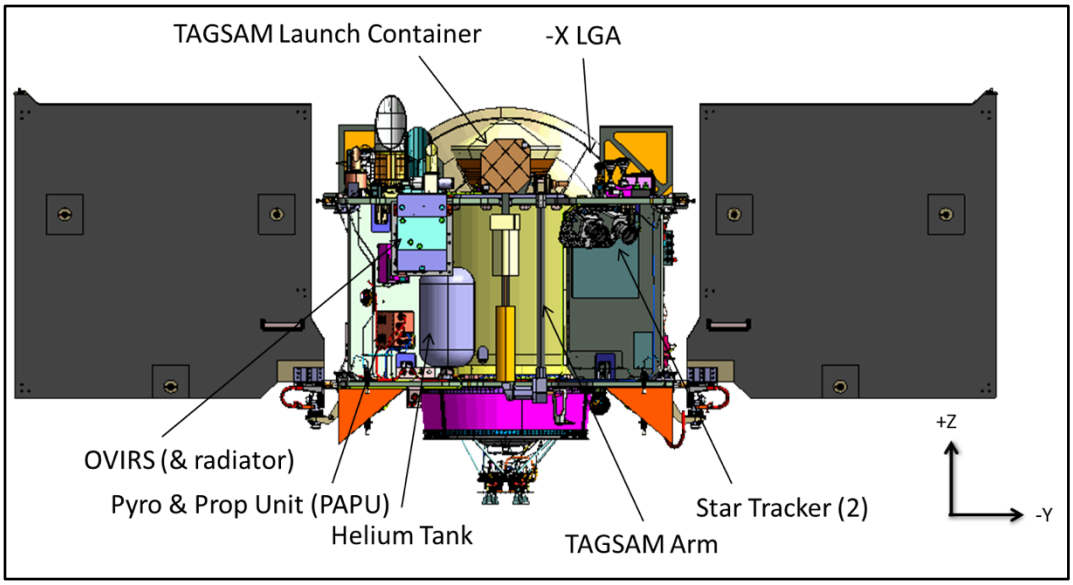

Figure 1-2. Spacecraft -X-axis View

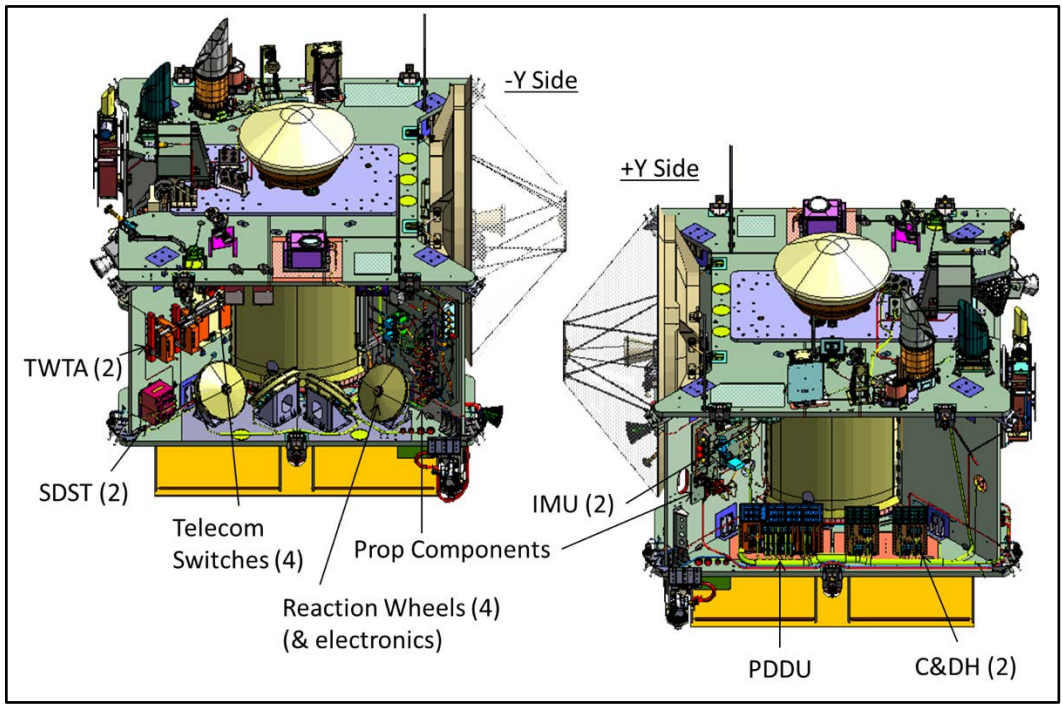

Figure 1-3. Spacecraft ±Y-axis View

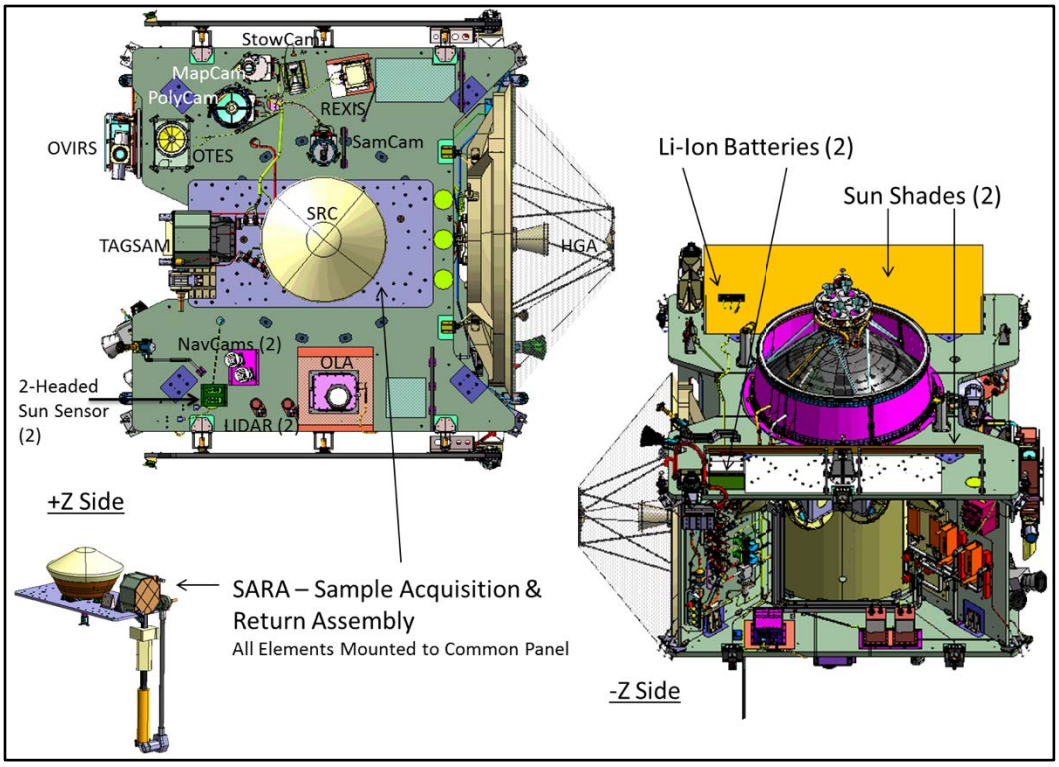

Figure 1-4. Spacecraft ± Z-axis View

1.1.1 Spacecraft Telecommunications System

OSIRIS-REx uses an X-band subsystem for deep space communications with the DSN.

X-Band

The X-band telecom subsystem is a high heritage design implementing redundant Small Deep Space Transponders (SDST), 100 W Travelling Wave Tube Amplifiers (TWTA), a 2-m direct feed parabolic dish high-gain antenna (HGA), a medium gain antenna (MGA), and two low gain antennas (LGA), and an assemblage of switches, filters, and waveguide. The HGA is used in the mission for high-rate communications ranging from a minimum downlink rate of 10 kbps to 916.667 kbps. The use of the HGA is restricted to SPE angles less than 90 degrees and solar ranges greater than 0.89 AU. The LGA is used for nominal mission communications outside the high data rate passes on the HGA. The LGA will be used routinely during the entire mission to support coherent tracking. The two LGA antennas are configured with one forward facing (+X LGA) and one aft facing (-X LGA) providing the required coverage for the SPE angles between 0 and 180 degrees. The LGA antennas also provide command path for safemode operations until the departure phase of the mission where the MGA antenna provides the necessary extra gain for the larger Earth range. For navigation, the X-band telecom system also provides ranging, Doppler, and DDOR.

Performance

The uplink performance for all antennas is represented by the calculated total power thresholds for various uplink rates for a 1E-5 bit error rate with 3dB of uplink ranging suppression assuming a 34-m BWG station. Even for safe mode, OSIRIS-REx does not require use of the 70-m DSN subnet. However, there are some critical mission phases where 70-m support may be considered as an option in the future.

The calculated total power thresholds for various downlink rates are calculated for 1E-6 bit error rate and a 34-m BWG station performance. During initial acquisition, the DSN tracking profile will be constructed with an off-point such that the receive power remains below -90 dBm.

OSIRIS-REx Small Deep Space Transponder

Excerpted from OSIRIS-REx Subsystem CDR, Telecommunication Subsystem, *D4 – Small Deep Space Transponder*, January 23-24, 2014.

- The SDST is a communications terminal providing a link between the OSIRIS-REx spacecraft and the NASA Deep Space Network (DSN)
    - Receives, demodulates, and transfers vehicle commands from Earth via an RF uplink to C&DH for processing
    - Modulates spacecraft health/status and science data from C&DH onto a RF carrier or subcarrier for RF downlink to Earth
    - Provides a RF navigational aide (ranging/Doppler)
        - Two-way turnaround ranging or differential one-way ranging (DOR)
    - Redundancy: Block redundant units (i.e. primary and backup)
- Design Heritage
    - Developed by General Dynamics in cooperation with JPL in the late 90's
        - Deep Space 1, Spitzer Space Telescope, Mars Odyssey, MRO, MER, Phoenix
    - Upgraded for MSL & Juno programs (aka GBIII), same design used on MAVEN
    - OSIRIS units are Build-To-Print of MAVEN units
    - Total operating hours to date exceeds 400,000 hours

OSIRIS-REx SDST Key Transmitter Specifications

Excerpted from OSIRIS-REx Subsystem CDR, Telecommunication Subsystem, *D4 – Small Deep Space Transponder*, January 23-24, 2014.

X-Band Command Outputs	2
X-Band Telemetry Inputs	2
X-Band Uplink Freq. Range	7.145 - 7.235 GHz
X-Band Downlink Freq. Range	8.400 - 8.450 GHz
X-Band TX/RX Ratio	880 / 749
Carrier Delay Variation	< 3 ns p-p
Ranging Delay Variation	< 15 ns p-p
Power (Vin =+22 to +36 VDC) nominal	
–Receiver only	*11.9 W*
–Receiver +X-Band Exciter	*15.7 W*
External TLM digitizing	4 analog, 1 status, 4 temp
Interfaces	Standard MIL-STD-1553B, Low Power MIL-STD-1553B, Direct Access
Noise Figure	< 2.0 dB typical @ +25°C
Carrier Loop BW (2-sided)	Selectable 20 or 50 Hz nominal at threshold
Carrier Tracking Signal Range	-70 to -157.7 dBm (20 Hz BW) -70 to -153.1 dBm (50 Hz BW)
Acquisition and tracking rate	
–20 Hz loop BW	*>320 Hz/sec@ -70 to -110 dBm*
–50 Hz loop BW	*>1000 Hz/sec@ -70 to -110 dBm*
Tracking Range	> ± 200 kHz about f_0
Command Subcarrier Frequency	16 kHz
Command Subcarrier Mod Index	0.5 - 1.5 radian peak
Command Data Rates	7.8125 - 4000 bps (2^n steps)
Ranging Uplink Suppression	0, 3, 4, and 5 dB sinewave
Ranging Filter noise BW	1500 kHz nominal
Best Lock Frequency Stability	± 6.5 ppm max (-40°C to -20°C) ± 3.0 ppm max (-20°C to +60°C)
880F1 X-Band Output Power	+13,+3,-2 dBm (temp.+tol.+EOL+rad.)
X-Band Aux Osc Phase Noise	-20 dBc/Hz (1 Hz offset) max -70 dBc/Hz (100 Hz - 100 kHz) max
AUXOSC Frequency Stability	± 5.0 ppm, 0 °C to 60 °C
Spurious & Harmonic Outputs	< -50 dBc (MAVEN: -80 dBc, LMSSC performing ringaround analysis)
NRZ-L TLM Convolutional Encoding	15-1/2, 15-1/4, 15-1/6, 7-1/2
TLM Modulation modes	Subcarrier, BPSK, QPSK
TLM Subcarrier (or beacon tone)	2 kHz to 36 MHz sq. wave (≈ 1 Hz steps)
TLM subcarrier freq. stability	± 30 ppm max (temp.+tol.+ rad)
TLM Phase Deviation	0° to 135° peak (< 2° steps)
Maximum symbol or data rate	> 10.0 Mss/Mbs (filtered mode) > 100 Mss/Mbs (goal, unfiltered mode)
Ranging Modulation Indices	4.375, 8.75, 17.5, 35, or 70° pk
Differential One-Way Ranging	2F1≈19 MHz 8F1»76 MHz (X/X/Ka 840F1 exciter)

Spacecraft Telecommunications and Metric Link Characteristics
Excerpted from *DSN-OSIRIS-REx Mission Operations Interface Control Document (OICD), Rev B*, July 20, 2016.

A.1 OSIRIS-REx Spacecraft Telecom Parameters

This section defines the OSIRIS-REx X-band spacecraft parameters that are required for DSN to configure and validate the network interfaces for operational support.

Note that the OSIRIS-REx project has been approved to use of the uplink and downlink X-band frequencies/channels assigned to the MAVEN project. Since the uplink and downlink X-band frequencies/channels are shared between the two projects, the OSIRIS-REx project will take responsibility for coordinating its operations with MAVEN operations to avoid potential mutual interference.

Table A-1. Spacecraft Telecommunications Characteristics

Description	Spacecraft Value
Frequency	
Downlink Frequency Channel:	36.6562
X-band 2-way Downlink:	8445.767679 MHz
X-band 1-way Downlink (Aux Osc):	8445.781070 MHz
X-band Uplink:	7188.499990 MHz
Transponder Tracking Bandwidth:	± 200 kHz
Transponder Frequency Ratio:	880/749
S/C Carrier Threshold	-159 dBm
Command	CCSDS Version 2
Command Modulation:	PCM/PSK/PM sinewave
Command Bit Format:	NRZ-L
Subcarrier Frequency:	16 kHz (7.8125 bps – 2000 bps)
Subcarrier Waveform:	Sinewave
Command Rates:	

Command rate (bps)	Mod Index (rad)	Mod Index (degrees)	Carrier Suppression (dB)
7.8125	0.94	53.9	-2.04
15.625	1.20	68.8	-3.46
31.25	1.5	85.9	-5.82
62.5	1.5	85.9	-5.82
125.0	1.5	85.9	-5.82
250.0	1.5	85.9	-5.82
500.0	1.5	85.9	-5.82
1000.0	1.5	85.9	-5.82
2000.0	1.5	85.9	-5.82

Uplink Command PLOP Settings	
Project:	1
DSN:	NONE
Uplink Inter-Modulation Type:	NONE

Idle Sequence:	AA
Ranging Waveform: Maximum ranging frequency: SDST ranging channel bandwidth: Pr/No (dB Hz): Ranging Modulation Index Uplink: Downlink:	 Sinewave 1 MHz 1.4 MHz TBD Mod Index (rad) Mod Index (degrees) Carrier Suppression (dB) 1.13 64.7 -3.03 0.31 17.8 -0.21
Telemetry Downlink Modulation: Subcarrier Frequency (Low): Subcarrier Frequency (High): Subcarrier Waveform Telemetry Data Rates	 QPSK/NRZ PCM/PM/NRZ PCM/PSK/PM (squarewave) 25 KHz 281.25 KHz squarewave Data Rate: Modulation: 80 – 4000 sps PCM/PSK/PM squarewave 20 – 80 ksps PCM/PSK/PM 400, 600 ksps PCM/PM/NRZ 825 – 1833.333 ksps QPSK/NRZ
DOR DOR Waveform: DOR Frequency: DOR Modulation Index:	 sinewave 19.195 MHz 70 degrees

Table A-2. Spacecraft Antenna Characteristics

Transmitter Power	Spacecraft Antenna	Frequency Band	Gain (dBic)		Path Loss (dBm)		EIRP (dBm)	Transmit Output (dBm)	Antenna Polarization	
			S/C Transmit	S/C Receive	S/C Transmit	S/C Receive	TWTA	TWTA	Uplink	Downlink
100 W 50 dBm	High gain antenna (HGA)	X-Band	43.4	41.7	1.41	2.0	92.4	50.13	RCP	RCP
100 W 50 dBm	Medium gain antenna (MGA)	X-Band	18.2	17.7	1.42	2.2	67.1	50.13	RCP	RCP
100 W 50 dBm	-X low gain antenna (LG1*)	X-Band	8.8	8.5	0.9	1.7	58.0	50.13	RCP	RCP
100 W 50 dBm	-X low gain antenna (LG2*)	X-Band	8.8	8.5	1.42	2.1	57.7	50.13	RCP	RCP

Antenna Phase Center Locations:

The spacecraft element of the OSIRIS-REx radio science instrument was the onboard telecommunications subsystem. It included a pair of cross-strapped redundant General Dynamics Small Deep Space Transponder Group Buy III X/X transponders, two cross-strapped 100-watt traveling wave tubbe amplifiers, and four antennas. Cross-strapping protected the mission against single point failures in the telecom subsystem.

The antenna location in reference to the s/c frame are defined as follows:

- the HGA frame is nominally rotated from the s/c frame by +90 degrees about Y, then by -150 about Z.
- the MGA frame is nominally rotated from the s/c frame by +106 degrees about Y.
- the LGA_PX frame is nominally rotated from the s/c frame by +135 degrees about Y.
- the LGA_MX frame is nominally rotated from the s/c frame by -45 degrees about Y.

Turnaround Ratio – 840/749
Nominal uplink and downlink frequencies – Nominal Rx Freq – 7188.499990 MHz, Nominal Tx Freq – 8445.767679 MHz
The transponder carrier delay variation is +/- 3 ns