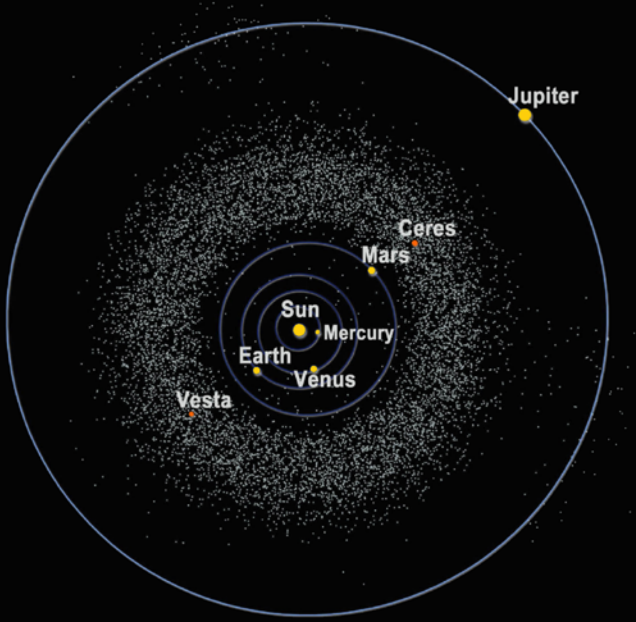
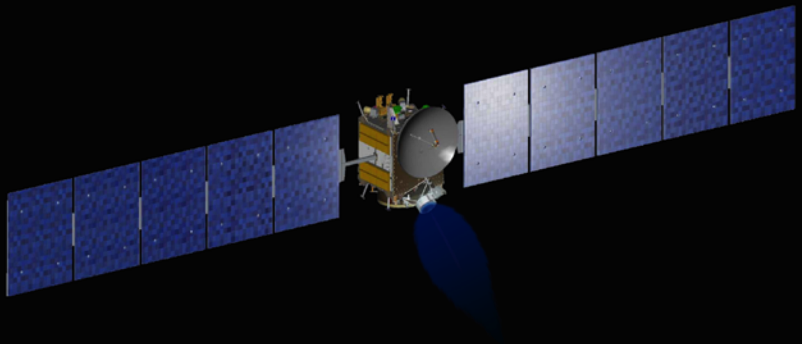
Dawn Telecommunications

Jim Taylor





August 2009

Jet Propulsion Laboratory
California Institute of Technology

DESCANSO
Deep Space Communications and Navigation Systems
Center of Excellence

Design and Performance Summary Series

DESCANSO Design and Performance Summary Series

Article 13

Dawn Telecommunications

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National Aeronautics and
Space Administration
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DESCANSO DESIGN AND PERFORMANCE SUMMARY SERIES

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Foreword

This Design and Performance Summary Series, issued by the Deep Space Communications and Navigation Systems Center of Excellence (DESCANSO), is a companion series to the DESCANSO Monograph Series. Authored by experienced scientists and engineers who participated in and contributed to deep-space missions, each article in this series summarizes the design and performance for major systems such as communications and navigation, for each mission. In addition, the series illustrates the progression of system design from mission to mission. Lastly, it collectively provides readers with a broad overview of the mission systems described.

Joseph H. Yuen

DESCANSO Leader

Acknowledgements

My writing of this article was made possible by access to information and documents provided by members of the Dawn spacecraft development and test team, with members from both Orbital Sciences Corporation (OSC) and the Jet Propulsion Laboratory. I am especially grateful to Mark Peterson (OSC) for the telecom subsystem descriptions and to James Mullen (OSC) and Mark Brown (JPL) for the descriptions, art work, and characteristics of the other spacecraft subsystems and the overall spacecraft.

Some of the spacecraft and mission descriptive material, including this article's cover art, appears on the Dawn public webpage, and I am grateful to the Dawn Mission outreach office for assembling current information that has made my job easier.

As a member of the Dawn flight team, I appreciate the information I have received from the mission manager Marc Rayman (JPL) and, again, to Mark Peterson who participated with me during launch operations and the initial checkout phase.

The data screenshots and telecom performance plots in this article were made possible by the Dawn ground data system team, particularly Kyran Owen-Mankovich (JPL), and by telecom team member Monika Danos (JPL) who created the plot templates that greatly automate the daily analysis and trending work for the project.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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1 Mission and Spacecraft Summary

1.1 *Mission Description*

With the Dawn spacecraft launched in September of 2007 and reaching its first target in August 2011, the Dawn mission will characterize the early Solar System and the processes that dominated its formation. The Dawn mission primary goal is to characterize two of the largest main-belt asteroids: Vesta and Ceres[1].

From the Dawn mission plan (Ref. [1]), the Dawn science goals at each body are:

- Understand the conditions and processes acting at the Solar System's earliest epoch
- Determine the shape and internal structure
- Constrain the thermal history and compositional evolution
- Determine the role of water in controlling asteroid evolution
- Provide a geological context for meteorites

Both Vesta and Ceres are believed to have accreted early in the history of the Solar System. They have been selected not only for their size but for the information they retain on conditions and processes early in the formation of the Solar System. They represent two very different planetary bodies. Vesta is a dry differentiated body with a surface showing signs of resurfacing. Ceres has a primitive surface containing water-bearing minerals and may possess a weak atmosphere.

1.2 *Mission Timeline*

Table 1-1 shows the Dawn mission timeline.

Table 1-1. Dawn mission timeline.

Launch	September 27, 2007
Mars gravity assist	February 2009
Vesta arrival	August 2011
Vesta departure	May 2012
Ceres arrival	February 2015
End of primary mission	July 2015

Figure 1-1 shows the interplanetary trajectory of the spacecraft with major activities marked. The current location of Dawn appears on a similar figure on the Dawn project page (http://dawn.jpl.nasa.gov/ Ref. [2])[2].

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[1] Ceres, along with Pluto, is now called a dwarf planet; the term was adopted in 2006 by the International Astronomical Union. See http://en.wikipedia.org/wiki/Dwarf_planet for more on this definition. In this article, when Vesta and Ceres are mentioned together, the term "asteroid" may be used for brevity.

[2] The resulting figure is produced by the Mystic tool (Ref. [3]). Mystic was developed by Dr. Greg Whiffen and others at the JPL. The tool uses a Static/Dynamic optimal control (SDC) method to perform nonlinear optimization. Mystic is a tool to solve the *n*-body problem (http://en.wikipedia.org/wiki/N-body_problem), and it can analyze

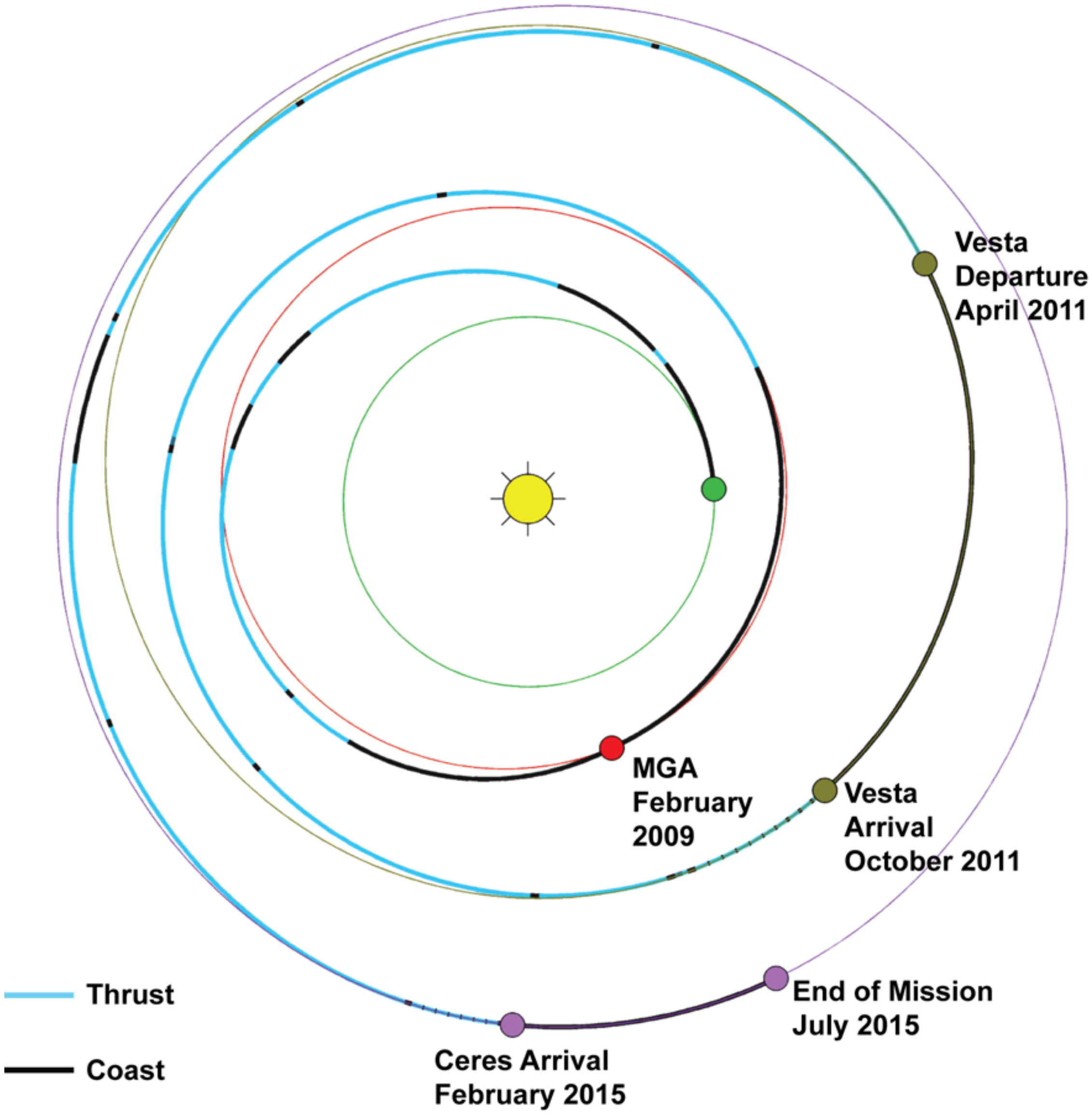

Figure 1-1. Mystic display of Dawn trajectory as of August 2009.

The spacecraft was launched with a spacecraft battery supplying power to a minimum set of equipment. The fault protection (FP) subset of the on-board flight software initiated a number of sequences in response to a signal from the third stage indicating separation, with the spacecraft starting in a standard safemode configuration. The separation sequence activities were autonomous, with no ground interaction required, but with each waiting for a definite signal from the previous sequence to FP indicating completion (or that an unexpected fault had occurred.)

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interplanetary missions as well as planet-centered missions in complex gravity fields. One of Mystic's strengths is its ability to automatically find and use gravity assists. Mystic also allows the user to plan for spacecraft operation and navigation activities. The mission input and post processing can be performed using a MATLAB-based graphical user interface (GUI). Mystic is currently used on the Dawn mission, and is considered a high fidelity optimization and simulation program. The use of Mystic on Dawn will later serve at validation of the low-thrust trajectory tools (LTTT) suite. Mystic is currently available to NASA only.

Because post-separation activity was all considered critical, FP was designed to do all it could to complete the sequences. Among these critical sequences were the deployment of the solar panels and the power-on of the traveling wave tube amplifier (TWTA), the power amplifier of the telecom subsystem. The telecom sequence also enforced the selection of the mzLGA, one of the three low gain antennas[3]. Completion of the separation sequences left the spacecraft in safe mode. Safemode is also applicable to any time during the mission and is required to keep the spacecraft safe for up to 72 hours: power-positive, thermally safe, and commandable.

After launch (L), the Dawn team spent the next 60 days checking out the spacecraft and the instruments. At L+80 days, the Dawn spacecraft started using its ion propulsion system to journey out to its first destination, Vesta. To help reach Vesta, the Dawn spacecraft performed a Mars gravity assist (MGA) in February of 2009.

The arrival date at Vesta will be in August 2011 assuming all times of thrusting in the mission are done as designed and the Ion Propulsion System (IPS) duty cycle and ion thrusting performance meet specifications. The arrival at Vesta could be as late as October 2011, including mission margin for times when planned or unplanned activities interrupt thrusting. These other activities include those planned after the completion of the current mission design but that are not compatible with thrusting. The other activities also include safe-mode entries that halt thrusting and the subsequent safe-mode recovery.

For the cruise out to Vesta, maximizing the efficiency of the thrusting campaign to move up the arrival date at Vesta is a priority. An earlier arrival time is key in making the mission more robust to problems that occur at Vesta while still providing for a departure to Ceres that fits within the budget, which depends on total mission duration. The longer duration at Vesta created by an early arrival will also be used to optimize the placement of activities in the science campaign and to provide more flexibility and options to the Dawn mission overall.

Once at Vesta, the spacecraft will enter a series of circular near-polar orbits that will provide a vantage point for studying the entire surface of the asteroid. These different orbits will be varied in altitude and orientation relative to the Sun to achieve the best positioning for the various observations planned. The stay at Vesta must be at least 7 months to meet the Level 1 science requirements.

After completing its work at the asteroid Vesta in May 2012, the Dawn spacecraft will use its IPS to leave Vesta and travel on to the dwarf planet Ceres, making it the first spacecraft ever to orbit one extraterrestrial body, depart, and then orbit a second body. It will arrive at Ceres by early February 2015 or earlier, and as it did at its rendezvous with Vesta, it will enter a series of circular near-polar orbits. The spacecraft will complete its prime mission, its duration constrained by the budget, by spending at least 5 months at Ceres at various altitudes in these orbits collecting science data with its instrument complement.

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[3] Each low gain antenna is named for the direction of its maximum gain, its boresight. The three antennas are named mZLGA (which has maximum gain along the minus Z spacecraft axis), pZLGA (plus Z axis), and pXLGA (plus X-axis).

1.3 Initial Acquisition Activities

For telecom, the first important series of activities was associated with the reception of the first downlink signal (carrier and telemetry data) at a tracking station, the first uplink back to the spacecraft, and the first commanding via the uplink. These activities occurred over the first several hours after launch, and together they are called “initial acquisition”.

After the spacecraft separation from the launch vehicle, the following activities took place in series (and in the order shown) before the TWTA first began transmitting a downlink signal.

- Preparation for solar array deployment, including reduction of launch-vehicle spin rate
- Solar array deployment (two arrays)
- Transition to Sun-point mode, including spin rate nulling and Sun (sensor) acquisition
- Preparation for acquisition of signal (AOS), including TWTA power-on and reaction wheel power-on

The earliest possible time from separation to the initiation of TWTA radio frequency (RF) radiation was 33 minutes (min). In the absence of a spacecraft fault, the longest time was 78 min. In fault scenarios, the TWTA power-on and RF radiation would have been further delayed.

Figure 1-4 through Figure 1-6 show the spacecraft axes (for antenna pointing directions) and spacecraft equipment configuration. At the end of the Launch phase, the spacecraft was in a Sun-pointing attitude control system (ACS) mode with the +X face toward the Sun with a slow roll at a rate of one revolution per hour about the x-axis. The minus Z low-gain antenna (mZLGA) was the selected antenna. With the roll about the x-axis, the ground could see signal from the antenna approximately 30 to 35 min out of each hour.

The project could give the Deep Space Network (DSN) only an approximate time for first “seeing” the downlink at a station. First, the start of radiation from the TWTA was nearly the final step in a series of post-launch start-up activities directed by fault protection. Second, the TWTA radiation direction (toward the Earth or not) was initially unknown due to the mZLGA pattern phasing with respect to the once per hour roll rate.

All post-AOS onboard activities were started by ground command. Two commanded activities were time-critical. The first was to reset the command loss timer from the launch value to a value of 14 hours to first action. The second was to initiate launch data playback, within about 2 weeks. A third ground command, to switch the telecom subsystem ranging channel on, was necessary for the DSN to receive turnaround ranging.

Though the spacecraft was monitored 24 hours per day for the first several days after launch, commanding was planned for the prime shift at JPL, with only spacecraft monitoring on the backup shift. At the end of the first prime shift, the spacecraft was transmitting at 124 thousand bits per second (kbps) with an uplink rate of 1000 bits per second (bps).

1.4 Initial Checkout Activities

Table 1-2 prioritizes these and the other activities planned for the two-month initial checkout (ICO) period.

Table 1-2. Project activity priorities during the initial checkout.

Priority	Definition	Activities
1	Establish and maintain the health and safety of the spacecraft. Required for the spacecraft to safely begin its journey to Vesta	• Transition to Inertial Target • IPS Checkout 1 • Thruster Characterization 1 • Long Duration Systems Thrust Sequence • High-Gain Antenna (HGA) Transition • Flight Software (FSW) Parameter Update
2	Verify the health and characterization of a component that will improve long term thrusting planning and trajectory analysis, i.e. checkout and characterization of the final two thrusters	• IPS Checkout 2 • IPS Characterization 2 • IPS Checkout 3 • IPS Characterization 3
3	Spacecraft checkouts requiring support by the Orbital Sciences Corporation (OSC) Dawn development/test team, for example, the characterization of the ACS subsystem performance	• Coarse Sun Sensor (CSS) Calibration • ACS Sensor Calibration • Reaction Control Subsystem (RCS) Trajectory Correction Maneuver (TCM) Checkout
4	Verify the health of an instrument: Instrument health and safety checkouts	• Gamma Ray and Neutron Detector (GRaND) Functional • Framing Camera (FC) Functional • Visible Infrared Mapping Spectrometer (VIR) Functional and Internal Calibration
5	Improves science or optical navigation measurements later in the mission: instrument calibrations to demonstrate performance of imaging sensors including optical navigation checkout activities and checkout of the backup instrument hardware	• FC Performance • FC Calibration • GRaND Adjust • VIR Star & Planet Calibration • FC/VIR Interference Checkout • FC/VIR Co-Alignment Checkout • Optical navigation (OpNav) Stray Light Calibration • OpNav FC/ACS Alignment

The priorities did not always determine the order of events, since some activities require different ground resources and some are dependent on spacecraft geometry.

The first part of the ICO phase was to transition the spacecraft from Sun pointing mode to inertial target mode, to stop the roll and switch the spacecraft into three-axis control. Once the roll was stopped by firing the Reaction Control System (RCS) thrusters, the spacecraft remained with +X pointed at the Sun to complete the coarse Sun sensor (CSS) calibration for about an hour or two. Once that was completed, the spacecraft was commanded into the nominal ICO background attitude[4] and commenced the use of the reaction wheels for subsequent attitude maintenance.

There were two standard attitudes defined for ICO. For the first several weeks, at relatively small Earth-spacecraft distances, the ICO background attitude was sufficient to maintain the highest rate (124 kbps) downlink communication over the Sun–Probe–Earth (SPE) angles present during that time. After that, the increasing Earth-spacecraft distance eventually required an HGA Earth-facing attitude (+X axis to the Earth) to maintain the 124 kbps downlink rate during post-ICO phases of the mission.

When in the background attitude the mZ LGA could support rates of 2000 bps uplink and 124 kbps downlink for the majority of the ICO phase. Because not all activities could keep the spacecraft in the background attitude, depending on the attitude and the activity needs in terms of telemetry, different LGAs were selected. Thruster characterization activities required contact with the ground. Thus, the spacecraft was switched to use the pXLGA and the pZLGA as well during ICO. All four antennas, including the high-gain antenna (HGA) had been utilized by the end of ICO. And all four worked as designed.

1.5 Low-Thrust Mission Design

The use of an ion propulsion system (IPS) on Dawn dictated some fundamental differences from missions that rely on conventional chemical propulsion. The IPS would be used for all post-launch trajectory control, including interplanetary cruise; trajectory correction maneuvers on approach for Mars gravity assist; rendezvous, orbit insertion, departure at both Vesta and Ceres; and orbit corrections and transfers[5] at Vesta and Ceres. The RCS would be only be used for initial post-launch Sun pointing, for reaction wheel angular momentum de-saturations, and for some contingency cases.

By the time the Dawn mission has been completed, it will have spent more than five years thrusting with IPS during its eight-year mission to Vesta and Ceres. Ion Propulsion enables Dawn to be the first spacecraft to orbit two different bodies within the Solar System. To

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[4] The ICO background attitude was chosen to continue to use the mZLGA, which was also the antenna used at Launch. This attitude had the –Z face pointed toward Earth but with a 30-degree (deg) offset in the x–z plane in the +x direction. Figure 1 4(b) shows the spacecraft coordinates and the Z face. The 30-deg offset was inserted to guarantee the background attitude worked for all of (or at least majority of) the ICO without violating Sun-pointing constraints and to give planning flexibility on the date for the initial use of the second background attitude and transitioning to the HGA.

[5] An orbit transfer moves the spacecraft from a high altitude mapping orbit (HAMO) to a low altitude mapping orbit (LAMO). An orbit correction maneuver (OCM) is used for adjustments in the orbit within the HAMO or the LAMO phase.

maximize science return and increase mission margin, the Dawn mission will spend most of the Cruise Phase maximizing the amount of power to the IPS subsystem and the amount of time spent thrusting during thrusting periods.

The spacecraft has three non-parallel IPS thrusters, only one of which is operated at any time. The trajectory design determines the time-dependent optimal thrust vector (subject to a number of constraints) so that apart from the choice of the thruster to be used, the spacecraft attitude will be determined by the trajectory design during IPS thrusting. If allowed by adequate mass and power margins, thrusting in suboptimal attitudes or times may be chosen to increase operational flexibility or reduce operational risk.

Because communications through the body-fixed HGA requires an attitude that will generally be different from the optimal thrust attitude, thrusting is not possible 100 percent of the time during thrust periods. Turns to Earth and back to thrust attitude, and HGA communications with Earth, use up about 8 hours each week during thrust periods.

During the cruise phase, when geometry allows, thrust verification (TV) passes will be accomplished through the LGA while the spacecraft continues thrusting on the thrust attitude. TV passes return 2-way Doppler and low-rate engineering telemetry to confirm IPS and spacecraft health. Use of TV passes contributes to a higher thrust duty cycle and an overall improvement in mission performance.

During orbit transfers at the asteroids, more DSN coverage will be needed than in interplanetary cruise, and further interruptions in thrusting will be required because the acquisition of optical navigation data will not be compatible with the optimal thrust attitude. Therefore, dedicated periods of “forced” coasting will be inserted in the trajectory design. For example, a multi-month period without thrusting ended in June 2009.

1.6 Science Description

The science investigations use three on-board instruments and the radio signal. These instruments consist of: redundant Framing Cameras (FC), a Visible and Infrared mapping spectrometer (VIR), and a Gamma Ray and Neutron Detector (GRaND). The radio signal is the X-band downlink from the SDST and the TWTA.

1.6.1 Imaging Science and Topography

Images returned from the visible-spectrum cameras onboard the Dawn spacecraft will be used to understand the geological history of the targets. The ages of Vesta and Ceres can be determined by exploring crater frequency and size. Analysis of geomorphic features will give insights into volcanism, weathering, impact processes, and other surface-altering processes. Imaging will also provide a means of creating an overall topography map and determining spin axis.

A topographic model will be developed of each target body using images from the visible camera. Stereo imagery and photoclinometry techniques[6] will be used. The visible camera will

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[6] Photoclinometry is the process by which a two-dimensional image of a surface is transformed into a surface map that represents different levels of elevation. It uses the shadows and light direction as reference points. Geologists and those that study planetary science use it to get an idea of how the surface of a planet looks. The techniques depend on very specific conditions, especially light direction. When light reflects off an object it creates shadows. These shadows can be used to create a bump map of a surface, and this map uses grayscale levels to depict the height of a point on a surface. (http://en.wikipedia.org/wiki/Photoclinometry)

collect three separate angle images of each area of the surface to provide ample data for the topography model. This model, when combined with the gravity measurements, will give insight into the internal structures of Vesta and Ceres.

1.6.2 Visible and Infrared Spectroscopy

Determining surface mineral compositions will be a major goal of the Dawn mission. Shape, strength, and wavelength of absorption spectra in the visible and near infrared will allow the onboard mapping spectrometer to identify these minerals. The spatial dimension of this instrument allows for informative comparison with visible camera data to provide an overall view of the geological events on the bodies’ surfaces.

1.6.3 Gamma-Ray and Neutron Spectroscopy

Elemental composition will be one of the important items to be explored at each target, for which the Dawn spacecraft will be carrying the GRaND instrument. Gamma ray and neutron data will accurately indicate nearly all of the major rock-forming elements as well as a number of trace elements. Higher orbits at Vesta will give an overall look into elemental composition; while at the lower orbits, regional areas of composition can be mapped and compared with surface morphology from the visible camera and spectrometer and density variations from the gravity model.

1.6.4 Gravity

The gravity field of both asteroids will be measured including the determination of gross masses and higher order harmonic gravity terms. A complete gravity model of Vesta will be constructed using navigation data from the both the visible camera and the radiometric tracking (two-way Doppler at the ground station). This gravity model will then be utilized with the shape model and the observed nutational motion of the bodies to estimate density variations and thereby glean insight into differentiation and possible core formation as well as other internal structures such as impacts.

1.7 Launch Vehicle Description

Figure 1–2 is a view of the Dawn launch vehicle major components and the spacecraft.

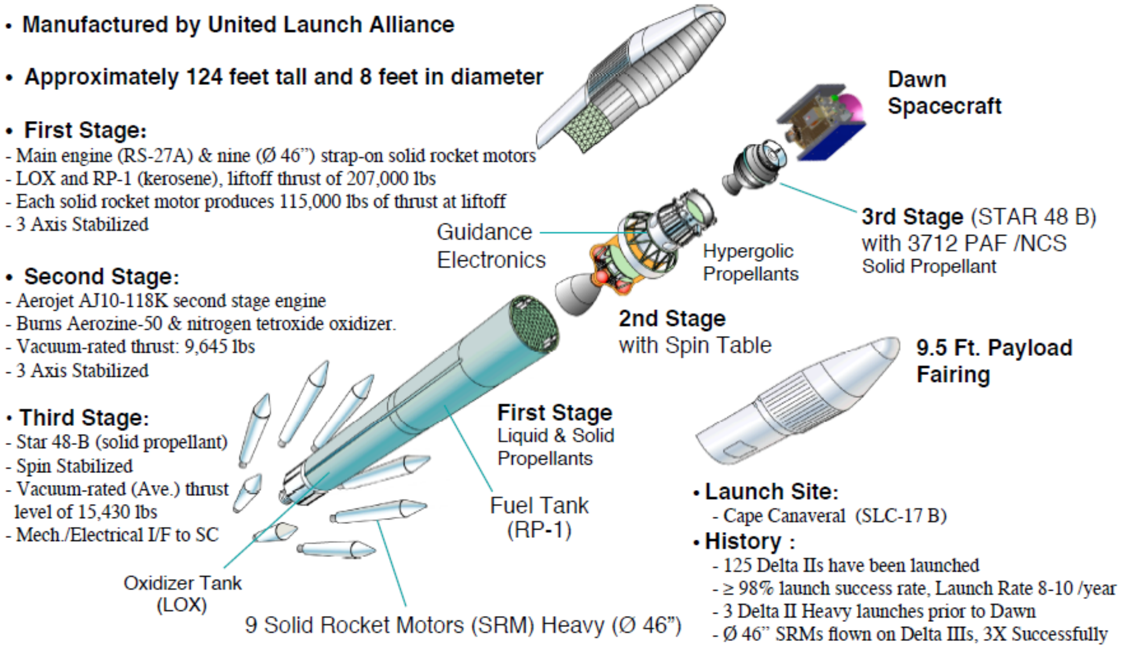


Figure 1-2. Three-stage launch vehicle for Dawn.

1.8 Flight System Description

The Dawn spacecraft (Flight System and science Payload) were developed (integrated and tested) by Orbital Sciences Corporation. The descriptions of the flight system components and the payload instruments in the following sections are taken from Ref. [4] an Orbital document.

Figure 1-3 is a block diagram of the spacecraft bus, providing an overview of the architecture of the flight system. Major power connections are indicated by red lines, 1553 digital interfaces by blue lines, and telecom subsystem waveguide by black lines. The legend in the figure also indicates the heritage of the components: green is existing design, yellow is significant modification, and so forth.

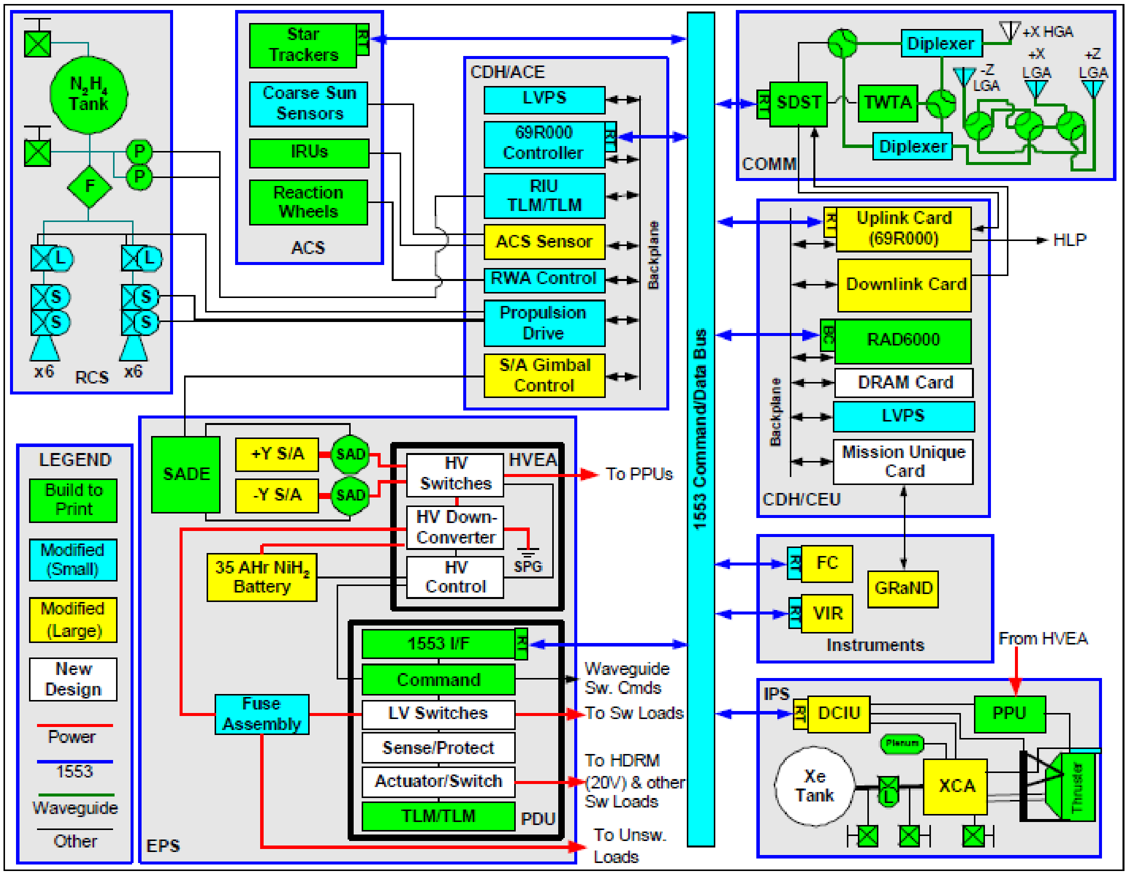


Figure 1-3. Dawn spacecraft bus block diagram.

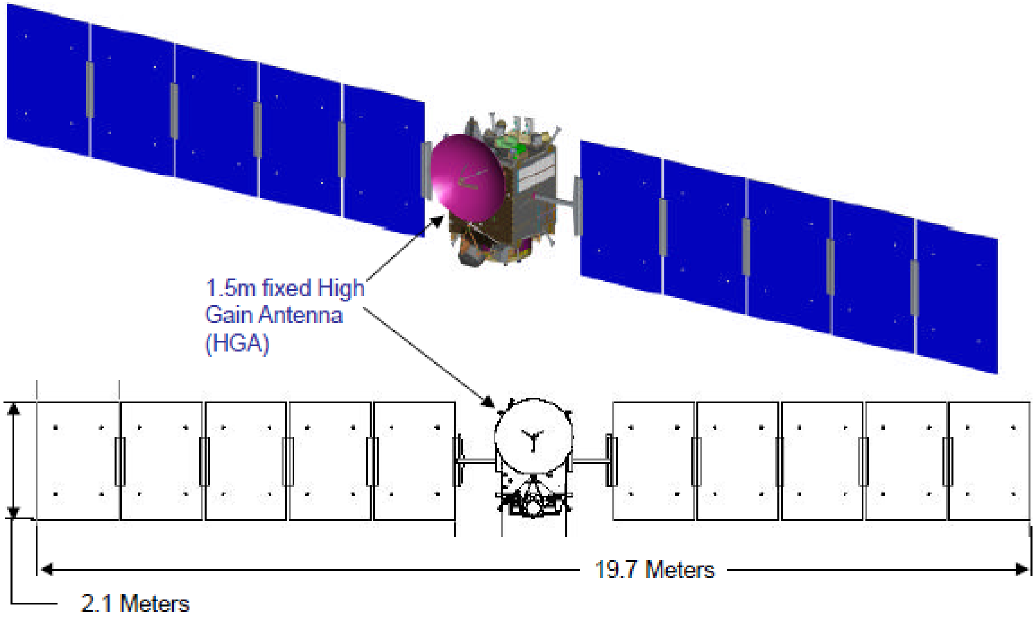
Legend, previously undefined abbreviations used in Figure 1–3:

Ahr	**ampere hour**	**N_2H_4**	**hydrazine**
DCIU	**digital control interface unit**	**L**	**latch valve**
BC	**bus controller**	**P**	**pressure transducer**
DRAM	**dynamic random-access memory**	**PPU**	**power processing unit**
F	**filter**	**RT**	**remote terminal**
FC	**framing camera**	**S**	**solenoid valve**
HDRM	**hold-down and release mechanism**	**SADE**	**solar array drive mechanics**
HLP	**hardware logic pulse**	**SDST**	**small deep space transponder**
HV	**high voltage**	**VIR**	**visible and infrared (mapping spectrometer)**
HVEA	**high voltage electronics assembly**		
IRU	**inertial reference unit**	**XCA**	**xenon control assembly**
LVPS	**low voltage power supply**		

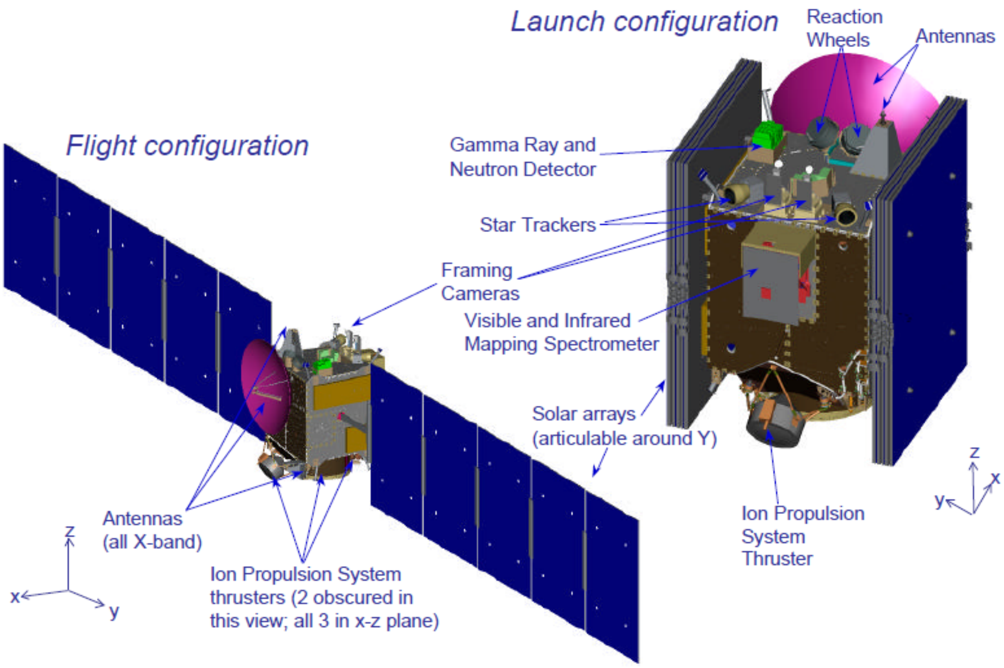
The spacecraft has a 1.5-meter (m) diameter HGA and a large solar array, as shown in Figure 1-4. The solar array provides power for the ion thruster as well as the spacecraft subsystems and the payload instruments over the planned range of Sun-spacecraft ranges (between 1 and 3 AU).

Spacecraft axes are as defined in Figure 1-4 for the launch (stowed) and flight (deployed) configurations. The HGA and one of the LGAs have their boresights along the +X axis. The other two LGAs have boresights on the +Z axis and the –Z axis, respectively. Figure 1-5 shows the locations of the science instruments (GRaND and Framing Cameras), and ACS elements

(IRUs, RWAs and CSSs) on the +Z face, as well as the HGA. Figure 1-6 shows the locations of the antennas, the RCS, and some mechanical and thermal elements on the +X and +Y faces.



(a) Solar array and high gain antenna overall dimensions



(b) Labeled major components in launch and flight configurations

Figure 1-4. Overall View of Spacecraft and solar array in launch (stowed) and flight (deployed) configurations.

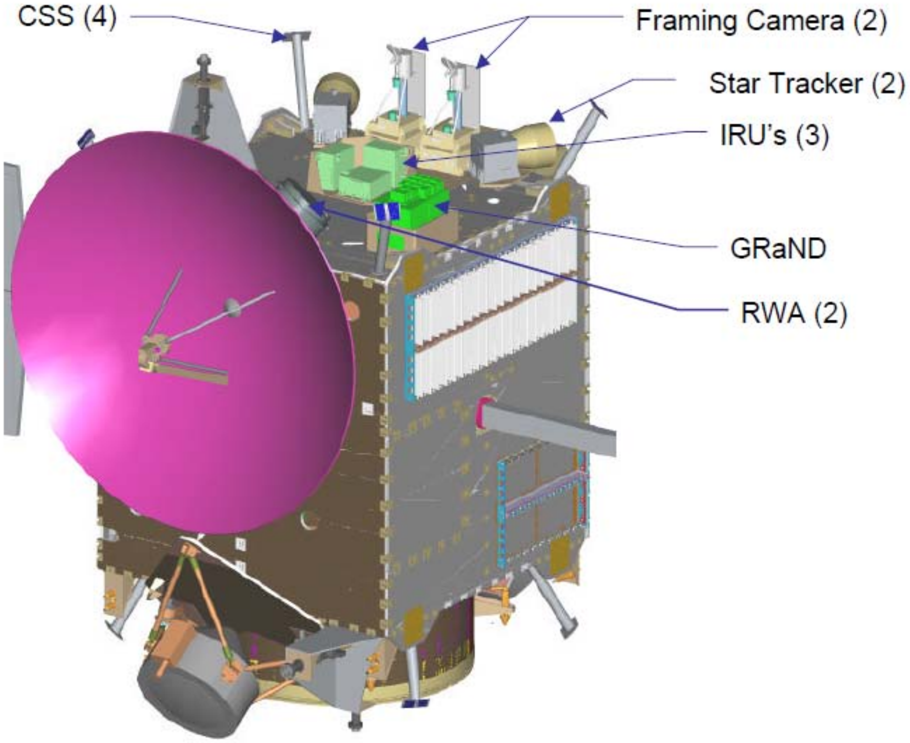


Figure 1-5. Science instrument and attitude control element locations.

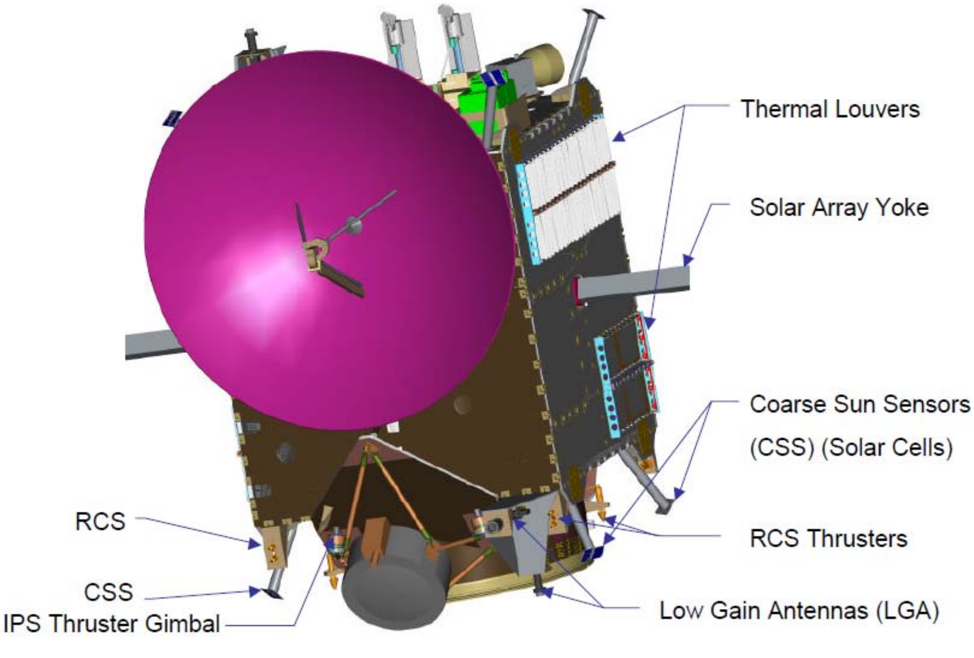


Figure 1-6. Antennas, RCS, and attitude control sensor element locations.

1.9 Telecom Subsystem (Telecom) - Overview

The DAWN telecom subsystem provides an X-band uplink and downlink for command, telemetry, and radiometric Science and Navigation compatible with the Deep Space Network (DSN). Section 2 of this article describes the components of the subsystem in more detail. Table 1-3 lists the telecom subsystem components.

Table 1-3. Telecom subsystem components

Component	Quantity
Tx/Rx Low-Gain Antenna (LGA)	3
Tx/Rx High-Gain Antenna (HGA)	1
X-band Small Deep Space Transponder (SDST)	2
X-band Travelling Wave Tube Amplifier (TWTA)	2
Diplexer	2
Waveguide Transfer Switch	5
Isolator	2
Test Coupler	4
Quadrature Hybrid	1
Select In Test (SIT) Attenuator	4
Coax Cable	various
Waveguide	various

Table 1-4 lists the major telecom subsystem parameters.

Table 1-4. Major telecom subsystem uplink and downlink parameters.

Parameter	Uplink	Downlink
Channel	29	29
Carrier Frequency (MHz)	7179.650464	8435.370372
Carrier Modulation	PCM (NRZ-L)/BPSK/PM	PCM (NRZ-L)/BPSK/PM
Polarization	RCP	RCP
Baseband Encoding	NRZ-L	NRZ-L
Subcarrier Type	Sinewave	Squarewave
Subcarrier Freq. (kHz)	16	25 (for rates > 2 kbps, data modulated directly on carrier)
Subcarrier Modulation	BPSK	BPSK
Coding	BCH (Bose-Chaudhari-Hocquenghem)	Turbo-coding (Rate 1/6), 3568 bit code block
Data Rate (bps)	7.8125, 15.625, 31.25, 62.5, 125, 250, 500, 1000, 2000	10, 40, 998, 199 5.99, 41250.46, 61875.69, 123751.39

Figure 1-7 shows the configuration of active elements (SDSTs and TWTAs) and the antennas.

Each antenna can simultaneously receive the uplink signal (DSN to Dawn) and transmit the downlink signal (Dawn to DSN). The HGA is fixed mounted to the +X panel, with high rate data communications for science data return achieved by spacecraft pointing. The three LGAs (pXLGA, pZLGA, and mZLGA) are mounted along the +x, +z, and –z axes for low data rate communications for all possible spacecraft orientations with respect to earth while thrusting on any of the three IPS engines and during safe mode. The two active components, SDST and TWTA, are mounted on the +Y panel over sections of the heat pipe network. The passive RF network components are located on both the +X and +Y panels.

Figure 1-8 shows the subsystem functions and interfaces. The telecom subsystem block diagram (Figure 2-1) is in Section 2.

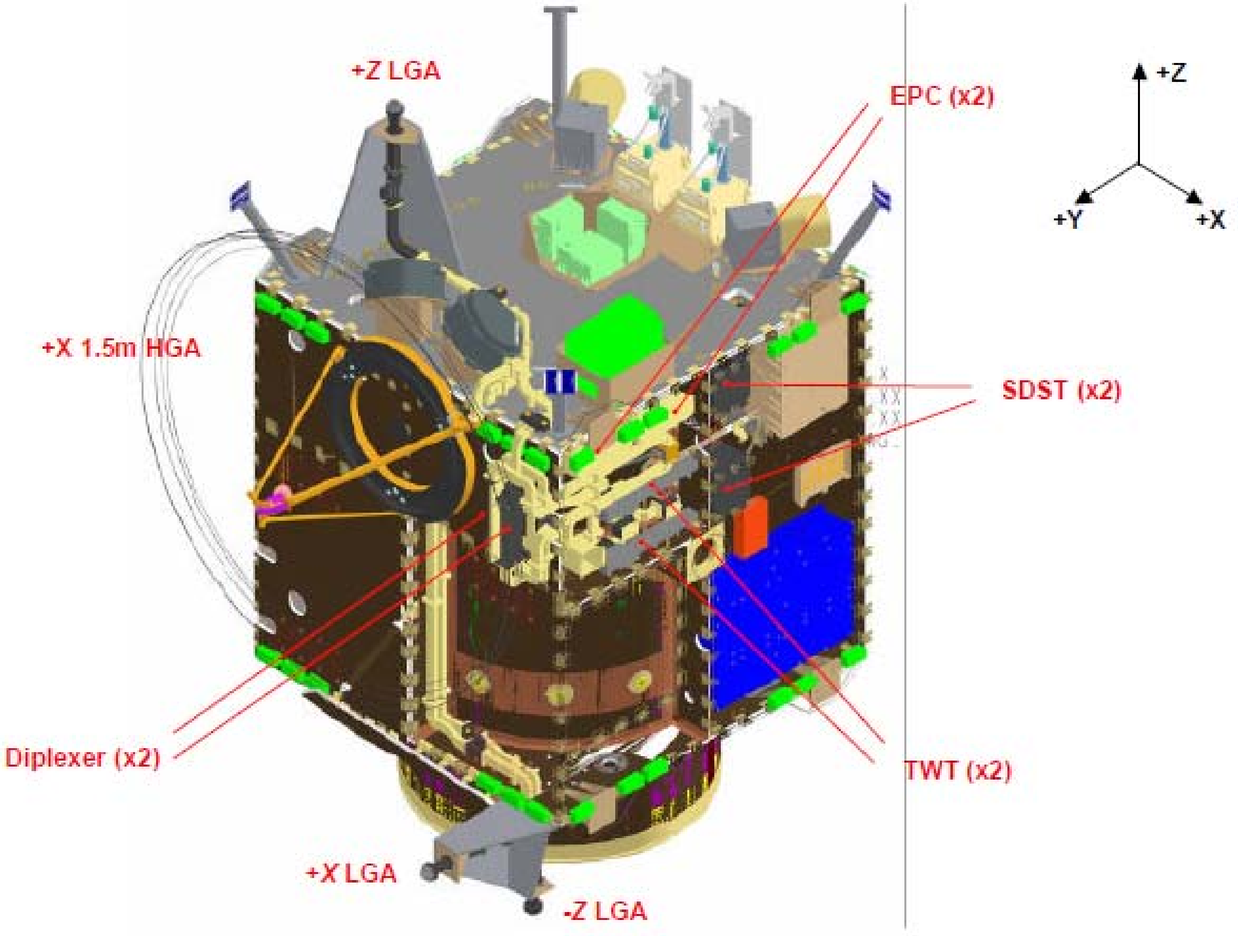


Figure 1-7. Telecom SDST, TWTA, and antenna configuration.

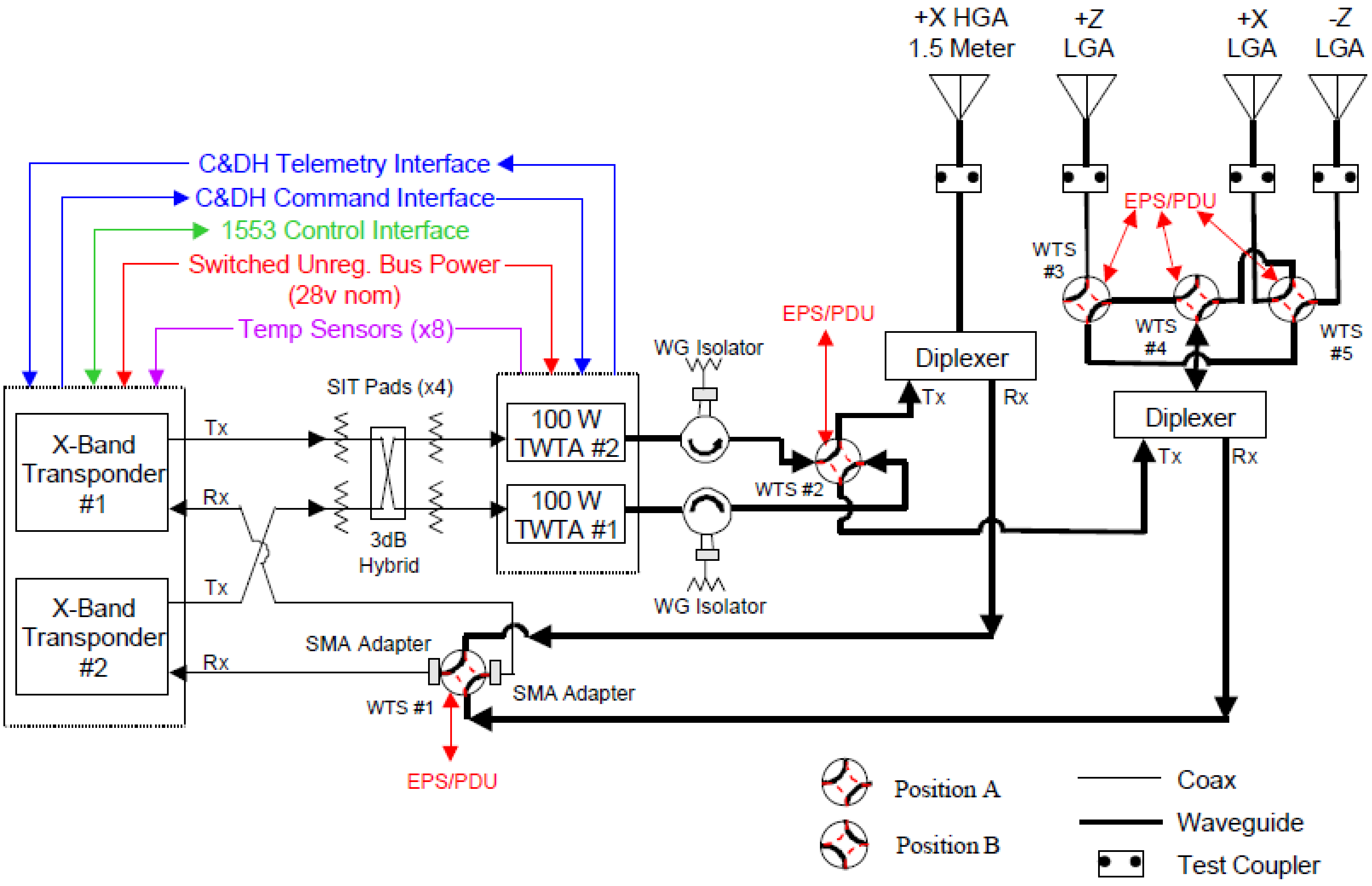


Figure 1-8. Telecom subsystem functions and interfaces.

1.10 Thermal Control Subsystem (TCS)

The Thermal Control Subsystem (TCS) consists of hardware and software components. The hardware includes thermistors, thermostats, heating elements, heat pipes, and radiators. These are distributed throughout the Flight System (FS) to maintain operational or survival temperature ranges for all necessary components. Passive radiators with optical solar reflectors are used to reject internally generated heat dissipations while reflecting incoming solar radiation. Redundant heaters maintain minimum temperatures.

Early cruise conditions near 1 AU heliocentric range were the worst-case “hot” thermal conditions for the spacecraft. The hottest cases occurred during the initial checkout phase at 1 AU during IPS thrusting with the maximum power dissipations and environmental fluxes. Thrusting conditions at 3 AU provide the minimum power dissipations and lowest environmental fluxes for heater power demand when available power is most critical. Asteroid orbits are also cold conditions due to the heliocentric range.

1.11 Electrical power subsystem (EPS)

The Electrical Power Subsystem (EPS) includes an internally redundant power distribution unit (PDU), a fuse protect assembly (FPA), an internally redundant high voltage electronics assembly (HVEA), 2 solar array (S/A) wings, 2 solar array drive electronics (SADE), 2 solar array drive assemblies (SADA), and a battery.

Each wing has five panels with multijunction gallium arsenide (GaAs) solar cells. A high-voltage solar array bus feeds switched power to the IPS PPU. The S/A bus voltage range is 85 V to 140 V. The IPS PPU input voltage range is 80 V to 140 V. The high voltage bus is down-converted to the unregulated bus (22 V to 35 V), for use by the rest of the spacecraft components, and instruments. The nickel hydrogen battery is connected to the unregulated bus. This battery has a 35-Ahr nameplate capacity. The battery supports discharge/charge cycling, including a significant depth of discharge (DOD), due to load variations, such as heater cycling).

Under normal conditions, the array is always pointed toward the Sun either by the Flight System’s three-axis-stabilized Attitude Control System (ACS), or by the single-axis SADA for each S/A wing, also controlled by the ACS.

The EPS provides commanding for the Telecom Subsystem’s waveguide transfer switches.

1.12 Command and Data Handling Subsystem (CDH)

The CDH hardware includes: two Central Electronics Units (CEU), which house the command decode, flight computer, and processor-reset functions; two attitude and control electronics (ACE), which are the primary interface for ACS components and solar array drive assemblies (SADA); and the 1553-B data bus.

Each CEU contains an uplink (UL) card with 69R000 processor, an on-board computer (OBC) with RAD6000 processor, a dynamic random access memory (DRAM) card with electrically erasable programmable read-only memory (EEPROM), a low-voltage power supply (LVPS) card, downlink (DL) card, and an instrument mission unique card (MUC).

The CDH software is executed by the UL, OBC, and ACE processors; and this software includes command processing, telemetry collection and distribution, interface protocol, memory management, basic health monitoring functions, and fault protection (FP).

The CDH subsystem provides the interfaces for uplink commanding and downlink telemetry. The subsystem also provides the necessary telemetry inputs and command outputs for monitoring and control of the Telecomm Subsystem.

Each CEU contains a downlink card to format telemetry data for output to the small deep space transponder (SDST). The downlink card accepts telemetry data in the form of PVCDUs (partial virtual channel data units), formats them into Turbo-Coded CADU's (channel access data units), and outputs the turbo-coded symbols to the SDST exciter. The downlink card optionally CCSDS randomizes[7] the telemetry symbols, and outputs the data in NRZ-L format.

Among the functions of the uplink card is output of the mode control (standby-transmit) to the traveling wave tube amplifier (TWTA).

1.13 Flight Software (FSW)

The flight software subsystem is comprised of heritage modules from the GALEX (Galaxy Evolution Explorer) and SORCE (SOlar Radiation Climate Experiment) programs with added functionality to support redundancy management, fault detection and correction, and payload operations. The primary flight software modules are: CMD/TLM handling, instrument interface, thermal management, ACS processing, and other spacecraft services (such as mode transitions, launch/separation telemetry, transmitter control, and data bus management).

Overall, the C&DH FSW employs a layered approach including two primary layers:

- System Services Layer
- Flight Software Applications Layer

The system service layer provides application "boot" via the bootloader and patch Manager, and includes the operating system (OS) kernel surrounded by the necessary low-level drivers and support tools.

The flight software applications layer contains the core control applications providing the required subsystem control. Flight software applications manage, control, operate, and telemeter the spacecraft hardware subsystems. This layer includes the higher level drivers critical to spacecraft resource utilization. The flight software applications support the following spacecraft subsystems:

- OBC System Management
- Command Processing using Jet Propulsion Laboratory (JPL)-supplied Virtual Machine Language (VML)
- Relative Time Commanding
- Telemetry Processing
- Telemetry Monitoring and Response
- Attitude Determination and Control

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[7] The CDH randomizes the turbo code block per CCSDS Blue Book 101.0-B-6 section 6, see [13].

- Ion Propulsion
- Thermal Control
- Science Instruments
- Fault Protection

1.14 Attitude Control Subsystem (ACS)

The ACS provides attitude determination and control during all mission phases from launch vehicle separation through mission termination. The ACS consists of the following elements:

- Star Trackers (2), on the instrument deck looking in the –X direction
- Inertial Reference Unit, consisting of three gyro assemblies, the gyros on the instrument deck mounted mutually orthogonal
- Reaction Wheel Assemblies (RWA) and Electronics (4), two on the instrument deck and two on the internal –Z deck (Figure 1-9)
- Coarse Sun Sensors (16), solar cells mounted in pairs on 8 standoffs in the corners of the spacecraft box
- Attitude Control Software, resident in the Central Electronics Unit processor

The RWA is a rotating mechanism with control electronics integrated into a single housing. Each RWA consists of an electric DC drive motor, a rotating flywheel assembly, tachometer outputs, motor drive electronics, commutation electronics, and associated power supplies. In addition, the RWA includes a temperature sensor that provides bearing and/or motor temperature information.

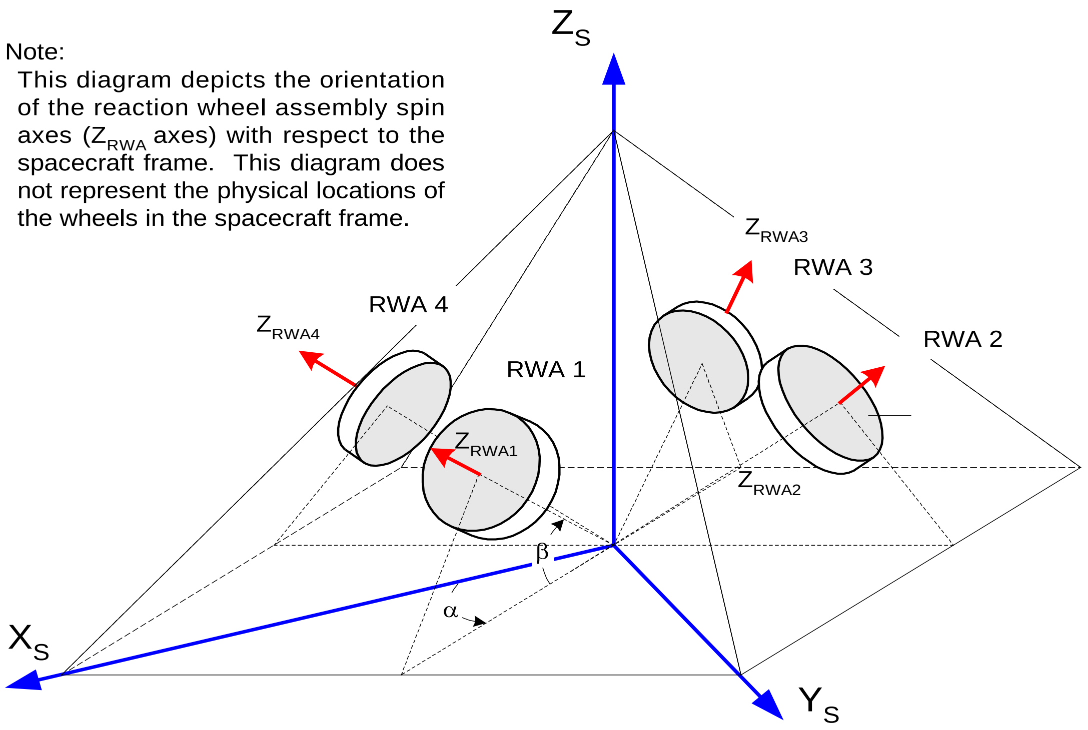

Figure 1-9. Reaction wheel assembly functional configuration.

The ACS performs the following functions:

- Autonomously control the spacecraft attitude, body rates, and stored momentum throughout the mission.
- Null the spacecraft rates and acquire a Sun-pointing attitude following separation from the launch vehicle.
- Maintain proper pointing of the thrust vector during delta-V maneuvers while maintaining proper orientation of the solar arrays for power generation.
- Provide the capability of pointing a vector in the body frame to any specified target while maintaining proper orientation of the solar arrays for power generation.
- Maintain spacecraft pointing in the asteroid orbits consistent with science requirements while maintaining proper orientation of the solar arrays for power generation.
- Provide autonomous control mode transition and fault detection and correction logic.
- Provide for ground override of all autonomous functions.
- Provide a Sun-pointing mode to maintain a benign power, thermal, and communications attitude indefinitely.

1.15 Reaction Control Subsystem (RCS)

The Reaction Control Subsystem provides the velocity increments and control torques required during all phases of the mission. The subsystem provides the following functions:

- Control during launch vehicle separation
- Roll control during cruise
- Momentum unloading during cruise
- Momentum unloading in Vesta and Ceres orbits
- Delta-V for contingency orbit-raising at Vesta and Ceres.

The RCS is a monopropellant hydrazine, blowdown system. The system contains twelve 0.9 N (0.2 lbf) (nominal thrust) rocket engine assemblies (REAs). In addition, the RCS has one 48-cm (19-in.) diaphragm propellant tank. The tank is located in the central cylinder, and it stores and pressurizes 60 liters (45.35 kg) of hydrazine fuel for the REAs.

Liquid hydrazine[8] is stored at low pressure (< 400 psia (2.8 megapascals, MPa) in the propellant tank, and the tubing is filled to the REA valve seats. The propellant tank contains a diaphragm propellant management device (PMD) to ensure that gas-free propellant is delivered to the REA manifold once the system is activated. The REAs provide impulse for maneuvers through the catalytic decomposition of hydrazine. A system filter and inlet filters on the latch valves and

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[8] Hydrazine is an inorganic chemical compound with the formula N_2H_4. It is a colorless liquid and is derived from the same industrial chemistry processes that manufacture ammonia. However, hydrazine has physical properties that are more similar to those of water. Hydrazine is highly toxic and dangerously unstable, and is usually handled as aqueous solution for safety reasons. In all hydrazine monopropellant engines, the hydrazine is passed by a catalyst such as iridium metal supported by high-surface-area alumina (aluminum oxide) or carbon nanofibers, or more recently molybdenum nitride on alumina, which causes it to decompose into ammonia, nitrogen gas, and hydrogen gas. These reactions are extremely exothermic. The catalyst chamber can reach 800 °C in a matter of milliseconds. (http://en.wikipedia.org/wiki/Hydrazine#Rocket_fuel)

thrusters prevent particulate contamination of subsystem components. The pressure in the propellant tank is measured using redundant pressure transducers. The temperatures of the propellant tank, lines, thruster valves, and chambers are monitored with sensors.

1.16 Ion Propulsion Subsystem (IPS)

The Dawn IPS uses the xenon ion engine technology developed on the NSTAR (NASA Solar electric propulsion Technology Applications Readiness) Project and flown on the Deep Space 1 (DS1) spacecraft.

The IPS for Dawn will be used for the heliocentric transfer from the Earth to Vesta, orbit capture at Vesta, transfer to a low Vesta orbit, departure and escape from Vesta, the heliocentric transfer from Vesta to Ceres, and transfer to a low Ceres orbit. In addition, the IPS will provide pitch and yaw control of the spacecraft during IPS thrusting. The total delta-V provided by the IPS is greater than 11 km/s.

The IPS design is required to be single fault tolerant while being able to process 450 kg of xenon over a mission duration of ten years. The input power will range from 524 to 2567 W with input voltages ranging from 80 to 140 V. The Dawn IPS is made up of building blocks designed to allow configurations ranging from a single thruster system like DS1 to multiple thruster systems like Dawn.

The flight IPS is partitioned into the following five elements:

- Digital control interface unit (DCIU), including gimbal-drive electronics (GDE)
- Flight thruster (FT)
- Power processor unit (PPU)
- Xenon feed system (XFS)
- Thruster gimbal assembly (TGA)

The ion thrusters, PPUs, DCIUs, and xenon control assembly (XCA) are modified versions of their DS1 counterparts, and the gimbals and xenon tank are new designs.

Figure 1-10 is a block diagram showing the three thrusters and the elements that power and control them. Figure 1-11 shows the locations of the IPS components and the thrust directions relative to spacecraft axes.

Among the IPS high level functional capabilities are the following.

- Throttling Capability: Enables mission planners to fully utilize the solar power profile available for thrusting by enabling throttling of the ion propulsion thrust level over the duration specified for the mission.
- Operating Cycle: Designed with the capability to remain in an unpowered state for extended periods as required by the Dawn mission trajectory, and also, to execute the shutdown and restart cycles required by the mission.
- Automatic Operation: Except for gimbal controls, the IPS operates automatically; i.e., independent of spacecraft control and monitoring and requiring only periodic relaying of commands and telemetry by the spacecraft.
- Safing and Restart: Capable of reliably and automatically transitioning to a safe state in response to designated faults, off-normal spacecraft and IPS conditions, or loss of

command input in excess of the allotted time. It is capable of automatically clearing designated faults and returning to normal operating conditions if permitted by hardware and software constraints.

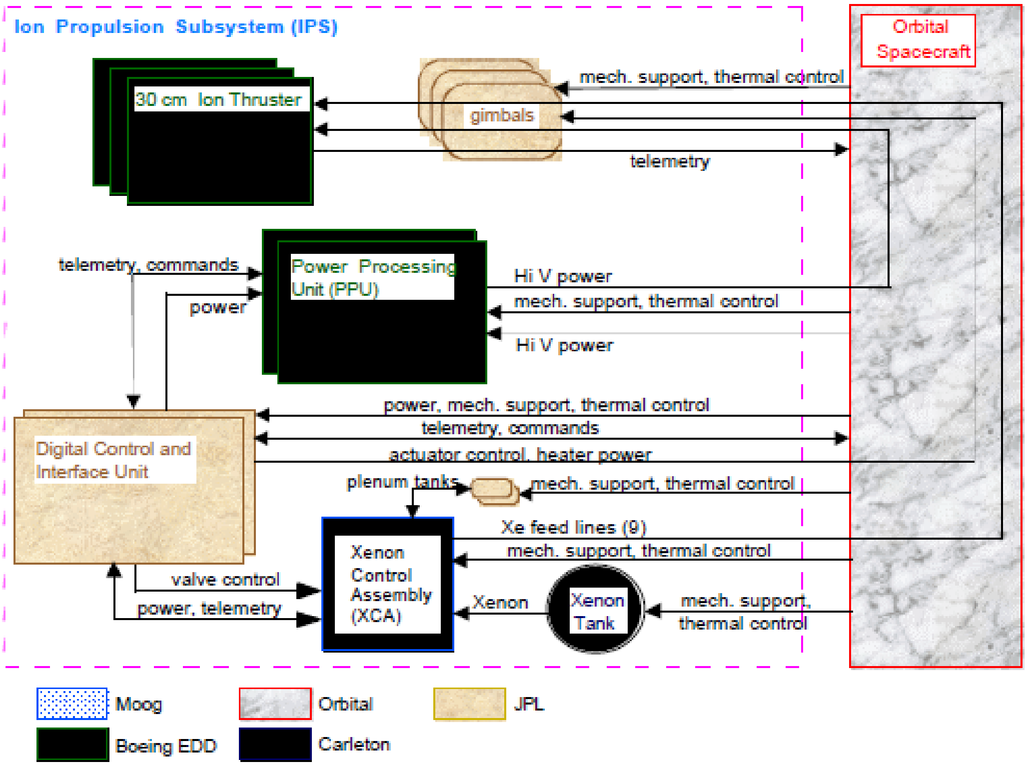

Figure 1-10. IPS functional block diagram, showing redundancy.

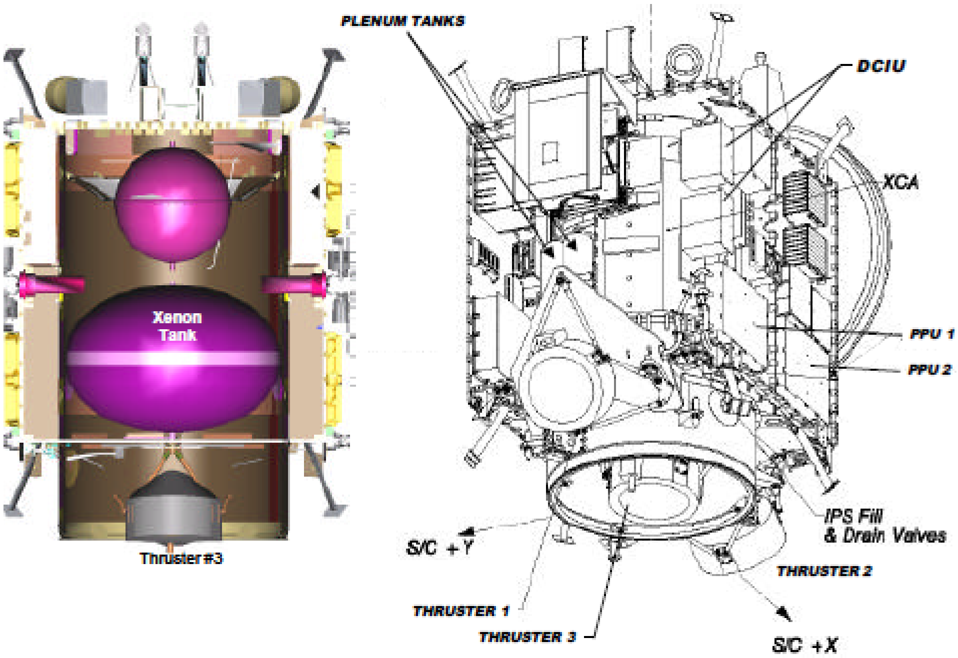

Figure 1-11. IPS component locations.

The NASA 30-cm diameter ring-cusp xenon ion engine (Figure 1-12) operates over a variable input power range from 0.5 to 2.3 kW. The total mass of a flight thruster is approximately 8.2 kg.

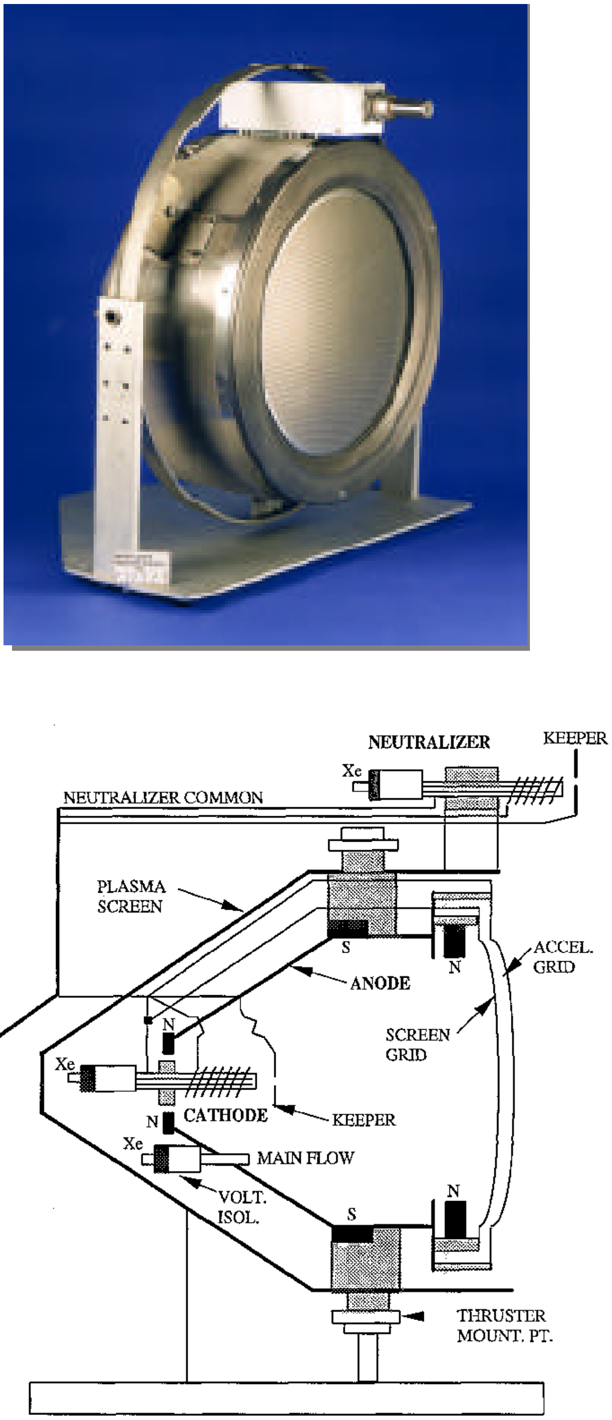

Figure 1-12. NASA 30-cm ring-cusp Xenon ion engine.

The capability to throttle thruster operation to match available input power is important for Dawn, for which the distance to the Sun varies from 1.0 AU to 2.8 AU. As less power is available as the range increases, the thruster can be commanded to a lower power level. There are presently 112 unique power levels in the Dawn throttle table. This granularity is used to optimize the thruster power usage as controllers match the power available from the solar arrays to the highest throttle table entry.

For the Dawn mission, each thruster is used for long periods of continuous thrusting, stopping for required navigation updates or communication opportunities. Over the course of the mission, a thruster will be cycled on and off a few hundred times, similar to the duty cycle in the DS1 flight. These cycles are a resource of importance to thruster lifetime and will be minimized.

1.17 Science Instruments

1.17.1 Framing Camera (FC)

DAWN has two identical framing cameras (Figure 1-13), which are designed and built by MPAe Germany in co-operation with DLR Berlin and IDA Braunschweig. They are used to provide images of the surface of the target asteroids and will also be used for optical navigation of the Flight System. The FC uses f:1/7.5 radiation-hardened refractive optics with a focal length of 150 mm. The field of view of 5.5 deg × 5.5 deg is imaged onto a frame-transfer charge coupled device (CCD) with 1024 × 1024 sensitive pixels. With a pixel pitch of 14 µm (microns), the camera samples the scene at 9.3 m/pixel from a distance of 100 km.

Each FC has a camera head and a data processing unit. The camera head consists of the housing, refractive lens system, filter-wheel, front door, focal plane, and readout electronics with 2.5 kg total mass and typical power consumption of 4W. The filter wheel has eight positions and is equipped with one clear filter and seven spectral filters. A stray-light baffle shades the pupil from reflections from the spacecraft body and allows imaging as close as 20 deg from the Sun (sun avoidance angle). A re-closable cover is used in front of the optics to protect against contamination from external sources and exposure to direct sunlight. Figure 1-14 shows the framing camera orientations; note that the pointing directions of the two cameras are not the same.

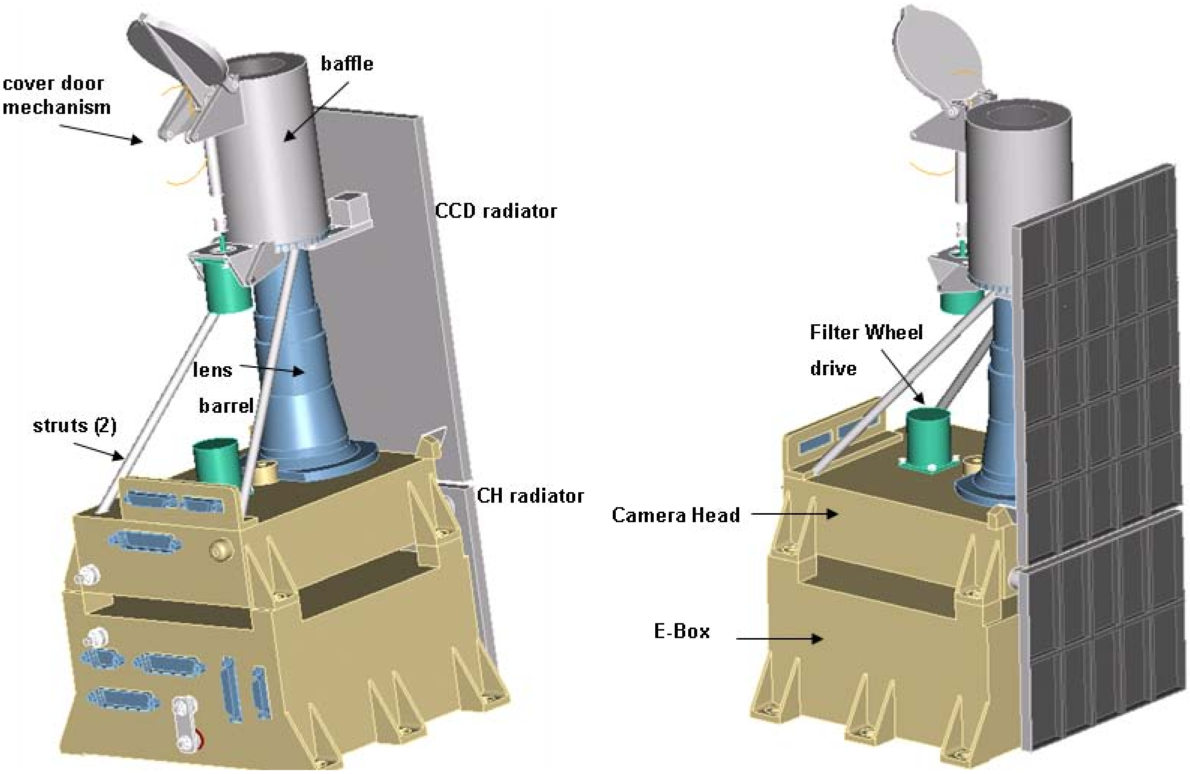

Figure 1-13. Two views of the individual framing camera mechanical configuration.

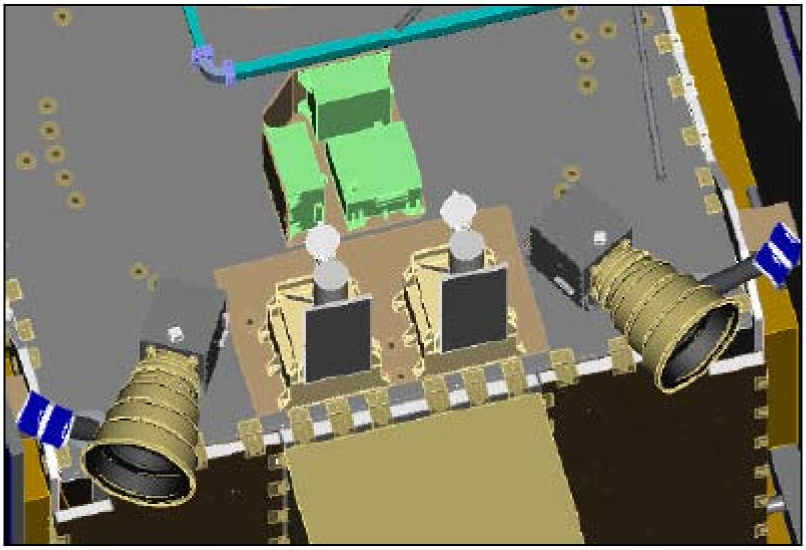

Figure 1-14. View of the two framing cameras showing their pointing directions.

1.17.2 Visible Infrared Mapping Spectrometer (VIR)

The Visible and InfraRed (VIR) Mapping Spectrometer (Figure 1-15) comes from the IFSI/Galileo Avionica. The purpose of the instrument is to measure the surface reflectance of Vesta and Ceres from 0.25 to 5 microns with sufficient spectral resolution to distinguish the major compositional minerals.

The VIR Mapping Spectrometer consists of two boxes: the VIR Main Electronics (ME) and the Optics Module, which includes the Optical Head, the Cryocooler, and the Proximity Electronics Module (PEM).

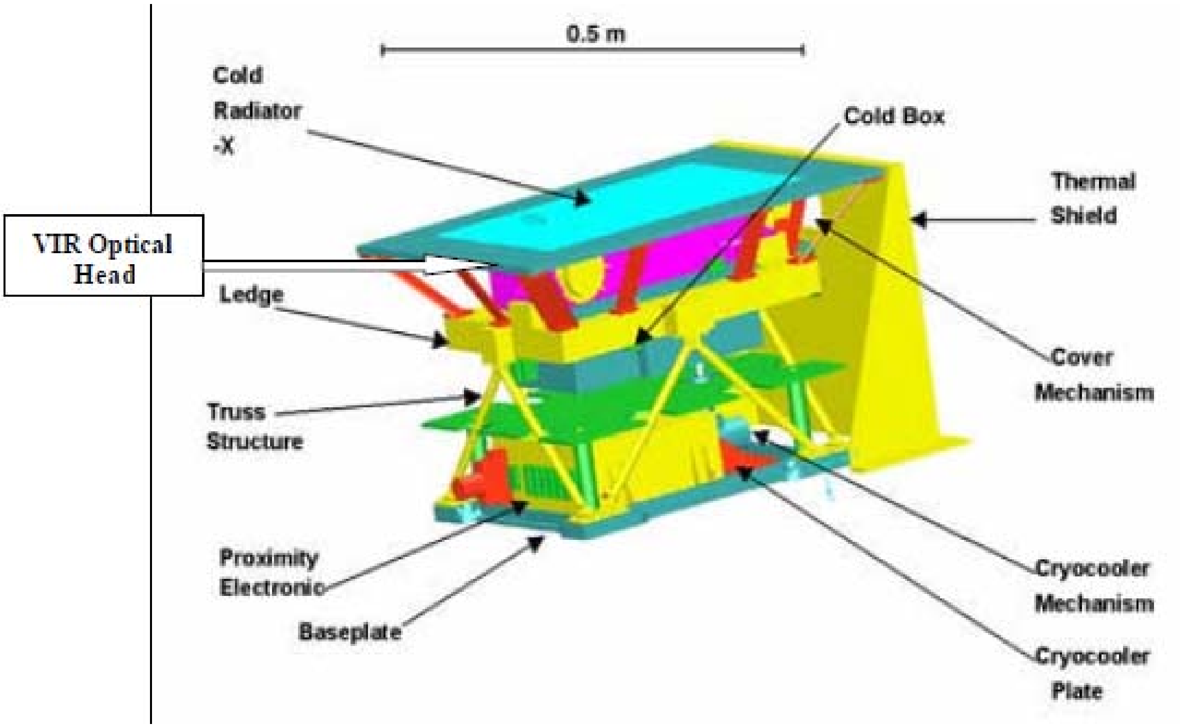

Figure 1-15. VIR optics module mechanical configuration.

The VIR optical head contains three mechanisms—an aperture cover, a shutter, and a scan mirror. The single VIR aperture feeds the IR and visible spectrometers. The VIR focal planes are a mercury cadmium telluride (HgCdTe) focal plane array for the IR spectrometer, and a CCD for the visible spectrometer. A cryocooler and radiators are used to maintain both focal planes at appropriate operating temperatures.

1.17.3 Gamma Ray and Neutron Detector (GRaND)

The Gamma-Ray and Neutron Detector (GRaND, Figure 1-16) is supplied to the Dawn Project by the Los Alamos National Laboratory. The instrument measures gamma-rays and neutrons that originate in the top ~ 1 meter of the surface of Vesta and Ceres. These neutral radiations are caused by either natural radioactive decay or the interaction of galactic cosmic rays with the materials that comprise the asteroid surface. Considerable information about the composition and distribution of these surface materials can subsequently be derived from the neutrons and gamma-rays detected at the spacecraft.

The GRaND consists of a single box that occupies of the order of 4.4×10^{-3} m^3(0.15 ft^3), has a mass of ~10 kg and consumes ~12 W. The box will be thermally isolated from the spacecraft deck, but conductively mounted to an Orbital-provided radiator bracket, which is thermally isolated from the +Z deck. The electrical interface to the spacecraft consists of two connectors and a grounding strap.

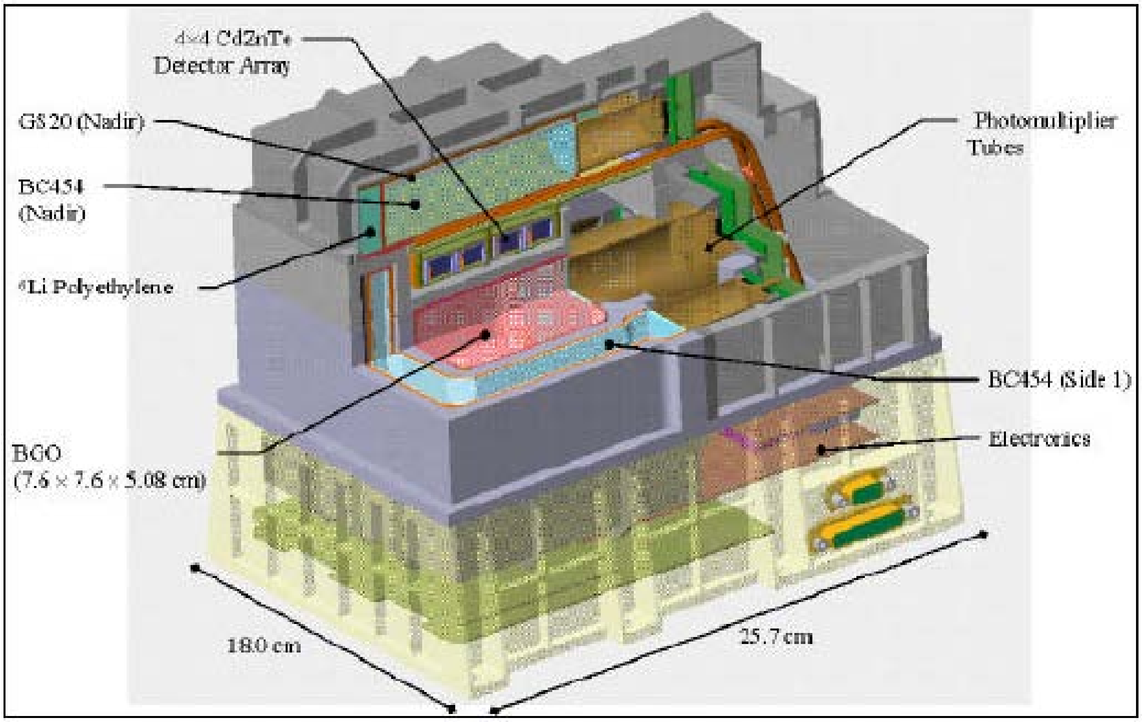

Figure 1-16. GRaND instrument mechanical configuration.

GRaND consists of a number of radiation sensors and their supporting electronics, including a field-programmable gate array (FPGA), a microcontroller and interface electronics, as well as both high-voltage and low-voltage power supplies. There are four kinds of radiation sensors in the GRaND: an array of sixteen cadmium-zinc-telluride (CdZnTe) solid state crystals used to detect gamma-rays, a single bismuth germanate (BGO) scintillating crystal used in both neutron and gamma-ray detection, and BC454 scintillating organic plastics and lithiated-glass (GS20) scintillators used for neutron and charged particle detection. All of the scintillators are optically coupled to photomultiplier tubes (PMTs) that convert the scintillation light into pulses of electrons that can be counted and analyzed by the detector electronics.

Unlike the FC or the VIR, the GRaND has no mechanisms, apertures, optics, deployables, or consumables.

2 Telecom Subsystem

Figure 2-1 is the telecom subsystem block diagram.

2.1 Small Deep Space Transponder (SDST)

The SDST[9] is a standard transponder for spacecraft beginning with DS1 and including the Mars Rovers, Deep Impact, Odyssey, the Mars Reconnaissance Orbiter (and others) as well as Dawn. The SDST incorporates the functionality of the predecessor Cassini Deep Space Transponder (DST), Cassini Command Detector Unit (CDU), and Cassini Telemetry Modulation Unit (TMU).

The SDST is the functional interface between the Telecom Subsystem and the spacecraft command and data handling subsystem. The X-band uplink signal is directed to the SDST receiver from any LGA or the HGA via the appropriate microwave components. The receiver acquires and tracks the uplink carrier by means of a phase-locked loop and produces a voltage controlled oscillator (VCO) signal whose phase is coherent with the uplink carrier. With the aid of a phase-locked loop demodulation process, the ranging and command components of the composite uplink signal are demodulated. The ranging component is coupled to a turnaround ranging channel for downlink modulation. The command subcarrier is demodulated and sent to a bit synchronizer for data extraction.

When coherent downlink transmission is required, the receiver VCO frequency is utilized in the exciter to obtain a coherent X-band carrier. When coherency is not required, the downlink carrier is derived from the auxiliary oscillator, an SDST internal frequency source.

The downlink carrier can be modulated by the turnaround ranging signal or differential one-way ranging (DOR) tone, and the composite telemetry signal from the spacecraft telemetry subsystem. The Dawn telemetry data is turbo-encoded in the CDH. For bit rates of 2 kbps or lower, the encoded data from the CDH is binary phase shift key (BPSK) modulated on a 25 kHz subcarrier in the SDST before phase modulation on the X-band downlink carrier. For higher bit rates, the encoded data directly phase modulates the carrier. Dawn telemetry does not use the internal encoding capability of the SDST.

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[9] The Dawn SDST is from the Group 2 Buy, which included transponders for the Mars Exploration Rover, Deep Impact, and Starlight projects as well. Dawn SDST performance specifications are in Ref. [14], and the major ones are also defined in other articles of this series.

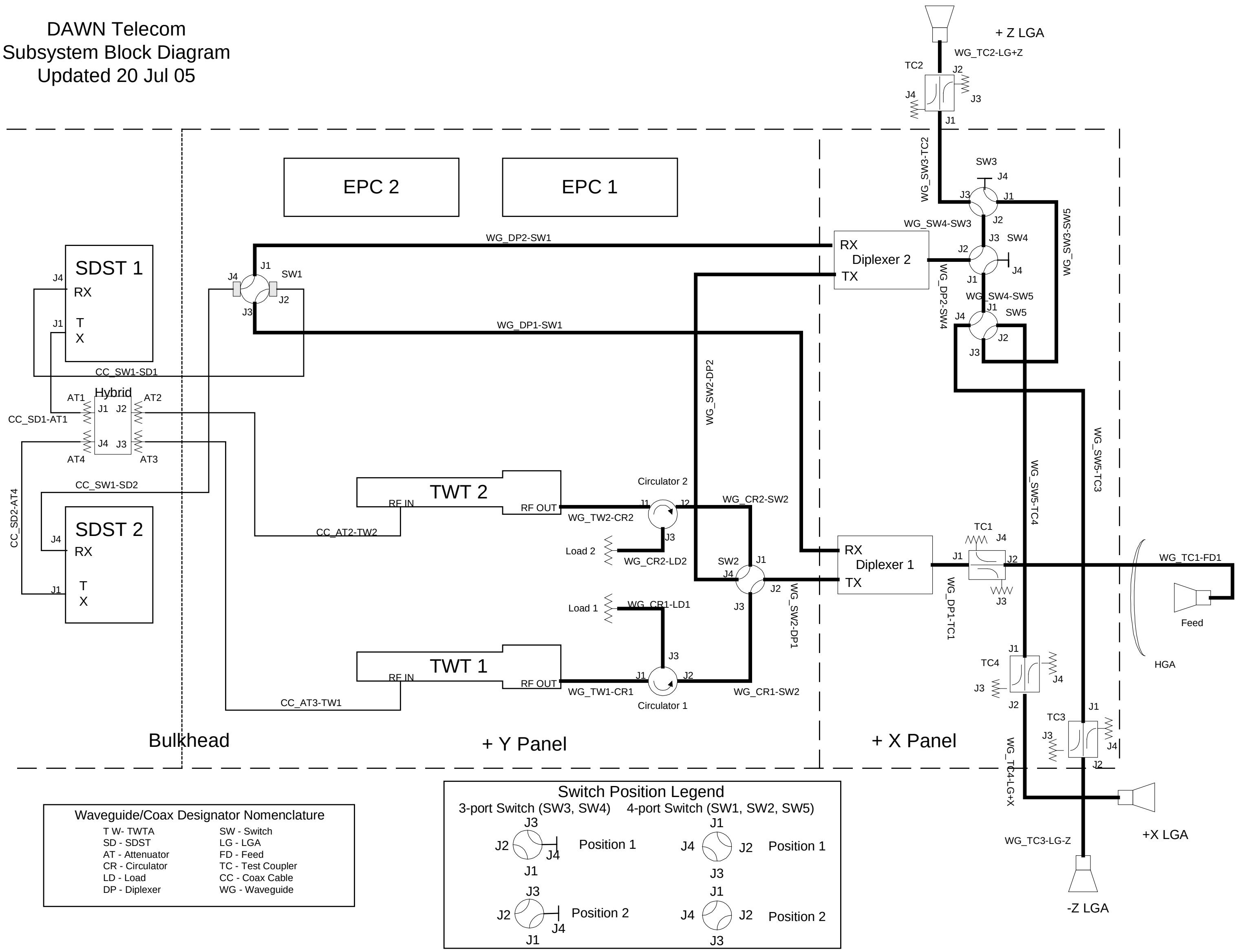

Figure 2-1. Telecom subsystem block diagram.

Figure 2-2 is a high level block diagram of the SDST functions. Note that Dawn does not have an external ultrastable oscillator (USO).

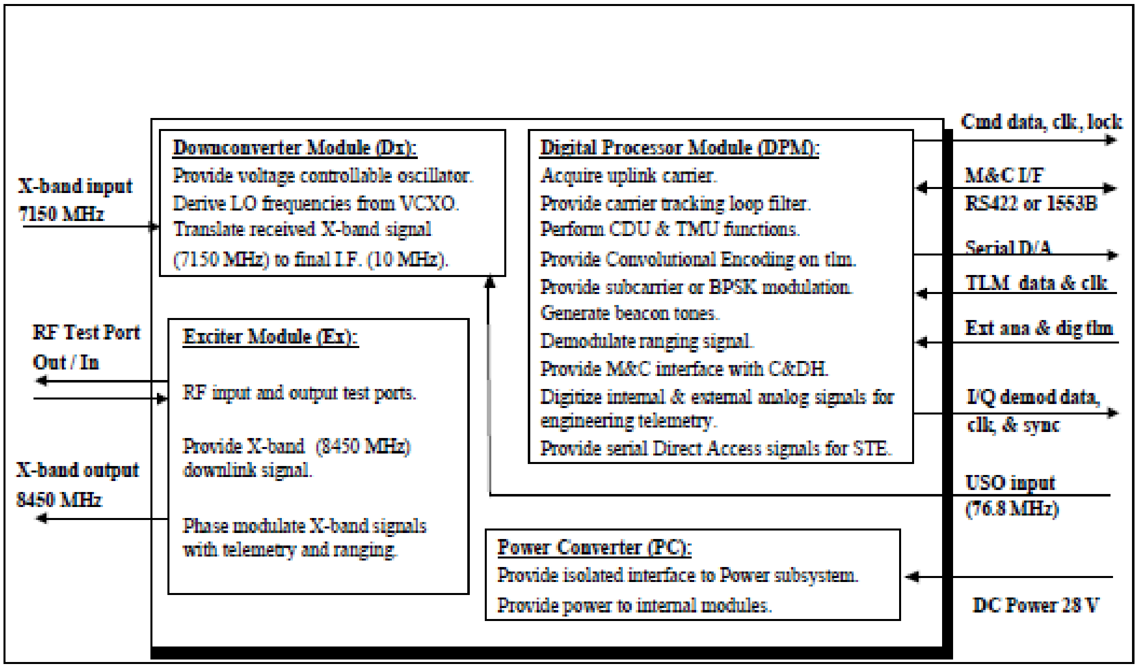

Figure 2-2. High level SDST functions (M&C = monitor and control).

2.2 Traveling Wave Tube Amplifier (TWTA)

The X-band TWTA consists of a Traveling Wave Tube (TWT) and an Electronic Power Conditioner (EPC). The TWT provides X-Band signal amplification to the required output power level. The EPC provides the voltages, currents, and protection circuits required by the TWT. The EPC also provides the temperature telemetry, the analog, the digital, and the status telemetry.

Table 2-1 lists the major specifications for the Dawn TWTA.

Table 2-1. TWTA specifications.

Parameter (units)	Requirement
Frequency Range (MHz)	8395 – 8450
Bandwidth (MHz)	55 min.
Input Saturation Drive Level (dBm)	1
Output RF Output Level (W)	100 min.
Gain (dB)	50 min.
Mass (kg)	3
DC Power Filament On (W)	20 max.
DC Power Beam On / RF Off (W)	120 max.
DC Power Beam On / RF On (W)	200 max.

2.3 High Gain Antenna (HGA)

The HGA consists of an integrated reflector and a feed network.

The integrated HGA reflector assembly consists of a reflector shell with support structure and struts, a feed antenna with integrated polarizer, a waveguide run, and thermal control devices. The reflector is a 1.524-m diameter, 0.3083 f/D prime-focus (f = 0.4699 m), axisymmetric paraboloid.

The feed network consists of a feed horn, a polarizer to generate the LCP for the feed radiation, and the waveguide bend and WR-112 Tx/Rx waveguide port. There is one RF interface port in WR-112, exiting as an E-bend from the feed. The Dawn HGA antenna is illustrated in Figure 2-3 with the reflector seen edge-on and the resulting boresight is toward the right.

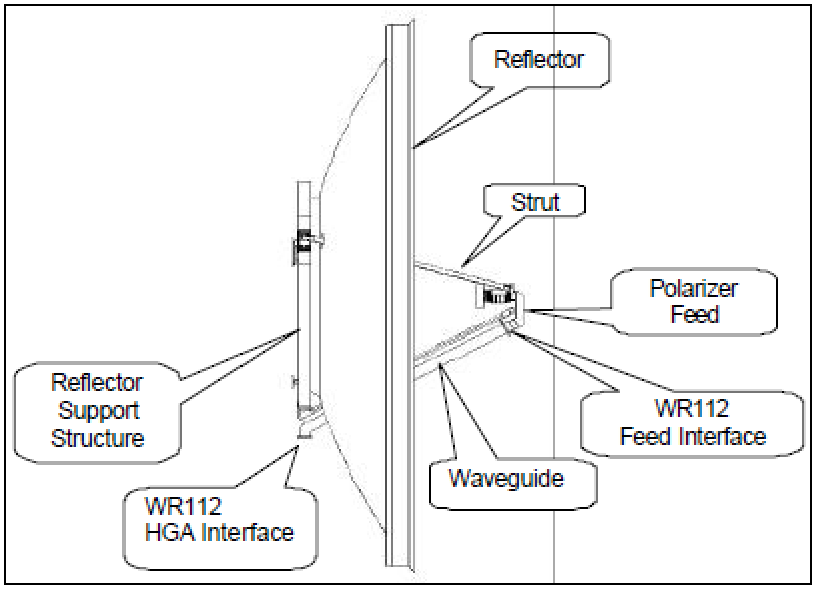

Figure 2-3. High gain antenna assembly.

The DAWN X-band High Gain Antenna assembly operates over the entire range of receive and transmit bands (7.170–7.190 GHz and 8.425–8.445 GHz). The HGA assembly is used for transmitting and receiving X-band signals simultaneously, with right circular polarization (RCP). A diplexer behind the HGA assembly is used to separate the transmit signals from the receive signals

2.4 Low-Gain Antenna (pXLGA, pZLGA, mZLGA)

The DAWN X-band low-gain Antenna (LGA, Figure 2-4) consists of a circular choke horn radiator, a polarizer, and a waveguide yoke.

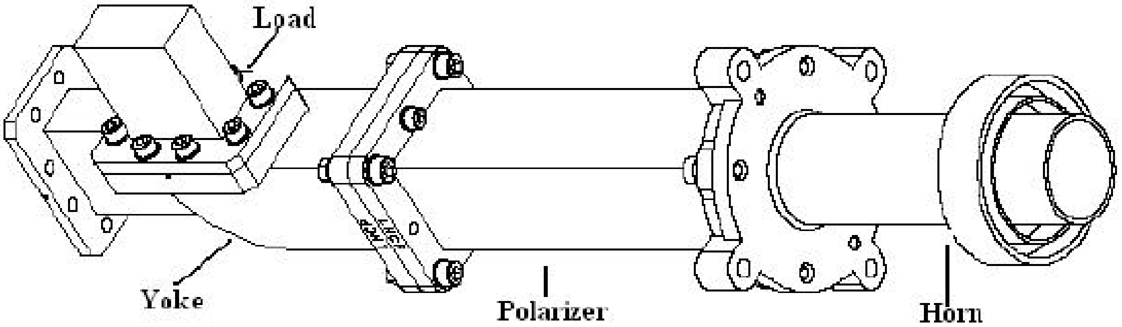

Figure 2-4. LGA Assembly (each LGA).

The waveguide yoke has one WR-112 port for the RCP port of the polarizer and a terminated WR-112 port for the unused LCP port.

Like the HGA, the DAWN X-band LGA assembly operates over the entire range of uplink and downlink bands (7.169–7.189 GHz and 8.425–8.445 GHz). The transmit center frequency is approximately 8.435 GHz, and the receive center frequency is approximately 7.180 GHz. Receive and transmit signals are separated and isolated by the X-band diplexer.

The DAWN LGAs sacrifice gain for beamwidth in order to provide a relatively uniform coverage over a wide range of angles. The DAWN X-band LGA horn design is inherited from the Mars Exploration Rover (MER) Cruise LGA. The peak (boresight) gain of the Dawn LGA is about 6 dBi, and the gain has fallen by 3 dB from that value at about 45 deg from boresight.

2.5 X-Band Diplexer

The telecom system has two X-band transmit/receive diplexers (Figure 2-5); they provide redundancy as well as connecting the transponders to all the communications antennas on the spacecraft. The diplexer is a three-port device that provides separate and isolated ports for the transmit (Tx) and receive (Rx) signal paths and a common port for both signal paths to mate to the (transmit/receive) antenna port.

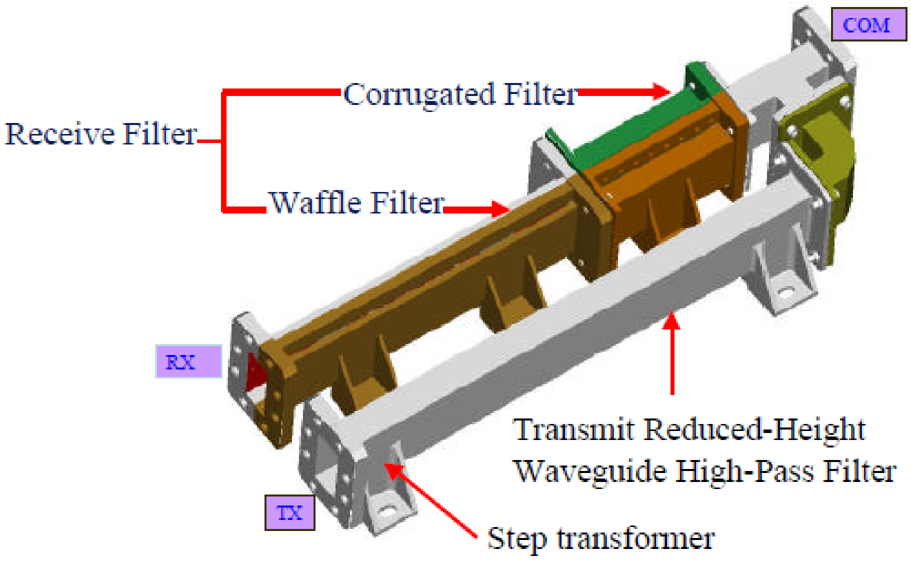

Figure 2-5. Diplexer assembly.

2.6 Waveguide Isolator

The isolator is a ferrite device used to provide a low-loss signal path in the forward direction while providing high isolation and protection in the reverse direction, capable of safely dissipating the full RF power of a 100-W TWTA. It is comprised of two separate components: a WR-112 circulator and a WR-112 100W matched load. The circulator is a three-port device that redirects any reflected signals to a terminated port. The circulator design is a planar resonator ferrite Y junction design enclosed in aluminum silverplate to minimize insertion loss. Matching into the junction from the WR-112 waveguide is achieved via a quarter-wavelength transformer section.

2.7 Quadrature hybrid

The X-band hybrid is a four-port RF device providing RF power splitting. The device will receive the RF signal on either or both of the two input ports and split the signal equally in power to the two output ports. On Dawn the hybrid provides RF output from the operating SDST exciter to both TWTAs (Figure 2-1). The hybrid operates over both uplink and downlink bands.

2.8 Waveguide Transfer Switches (WTS)

The X-band switches are RF waveguide devices that direct uplink and downlink signals between the antennas and to select between redundant TWTAs and select between redundant SDSTs, providing low-loss signal paths with high isolation. RF chokes provide isolation between paths. The waveguide switches are electromechanical devices that latch in one position upon receipt of a command signal. Switch electronics provide telemetry to identify switch position.

The waveguide switch consists of a switch housing and RF rotor/actuator assembly. The switch assembly provides mechanical and structural rigidity, providing a highly reliable, low-loss switch. Three kinds of WTS (Figure 2-6) are used on Dawn. Left to right these are (1) four-port switch, (2) four-port switch with SMA transition, and (3) three-port switch with shorting plate.

Figure 2-6. Waveguide transfer switches used on Dawn.

The switch assembly is comprised of the following components:

- switch housing
- RF rotor/actuator
- switch electronics
- mounting bracket
- waveguide windows

The actuator rotates the rotor to either position with a single command pulse. The waveguide rotor and actuator magnet rotate as a common assembly. The rotor settles into position within the command pulse. There are no other moving parts. A magnetically coupled telemetry circuit provides indication for both switch positions.

2.9 Telecom Subsystem Power and Mass Summary

Table 2-2 summarizes the mass and the input bus power for the Dawn telecom subsystem components.

Only the operating SDST and the operating TWTA draw power from the spacecraft bus. The TWTA power is 10W in standby mode and the 187 W (shown in the table) in operate mode.

Table 2-2. Mass and power summary of Dawn telecom subsystem components.

Component	**No. of units**	**Input Power (W)**	**Mass/Unit (kg)**	**Total Mass (kg)**
SDST	2	11.7	2.7	5.4
TWTA-TWT	2	187	0.8	1.6
TWTA-EPC	2		1.5	3.0
LGA	3		0.5	1.5
HGA	1		7.7	7.7
Coaxial cable	1		0.6	0.6
TWTA cable	2		0.1	0.2
Waveguide assemblies	1		3.2	3.2
Waveguide shims	1		0.1	0.1
Diplexer	2		0.6	1.2
Hybrid	1		0.04	0.04
SMA attenuator	1		0.02	0.02
Waveguide isolator	2		0.2	0.4
Waveguide switch	5		0.3	1.5
Total		**198.7**		**26.3**

3 Ground Systems

3.1 The Deep Space Network

As described in the Mars Science Laboratory article in this series (Ref. [5] the DSN currently includes ground stations (Deep Space Stations, DSS) at three sites around the world: near Canberra, Australia; near Madrid, Spain; and at Goldstone in the California desert (Ref. [6]).

Each site includes a complement of 34-m stations, referring to the diameter of the antenna in meters, and one 70-m station. Individual stations at a site may be arrayed together to provide for more downlink margin (and currently experimentally also for the uplink). Each site also has a central control hub with people who communicate with DSN control in Pasadena, California and with each project control center during tracking support of that project.

Figure 3-1 from Ref. [6] is a view of the Madrid complex showing the 70-m antenna and the 34-m stations, with the newest 34-m beam waveguide (BWG) antenna at the right. Ref [6] also has photos of other DSN sites and their stations.

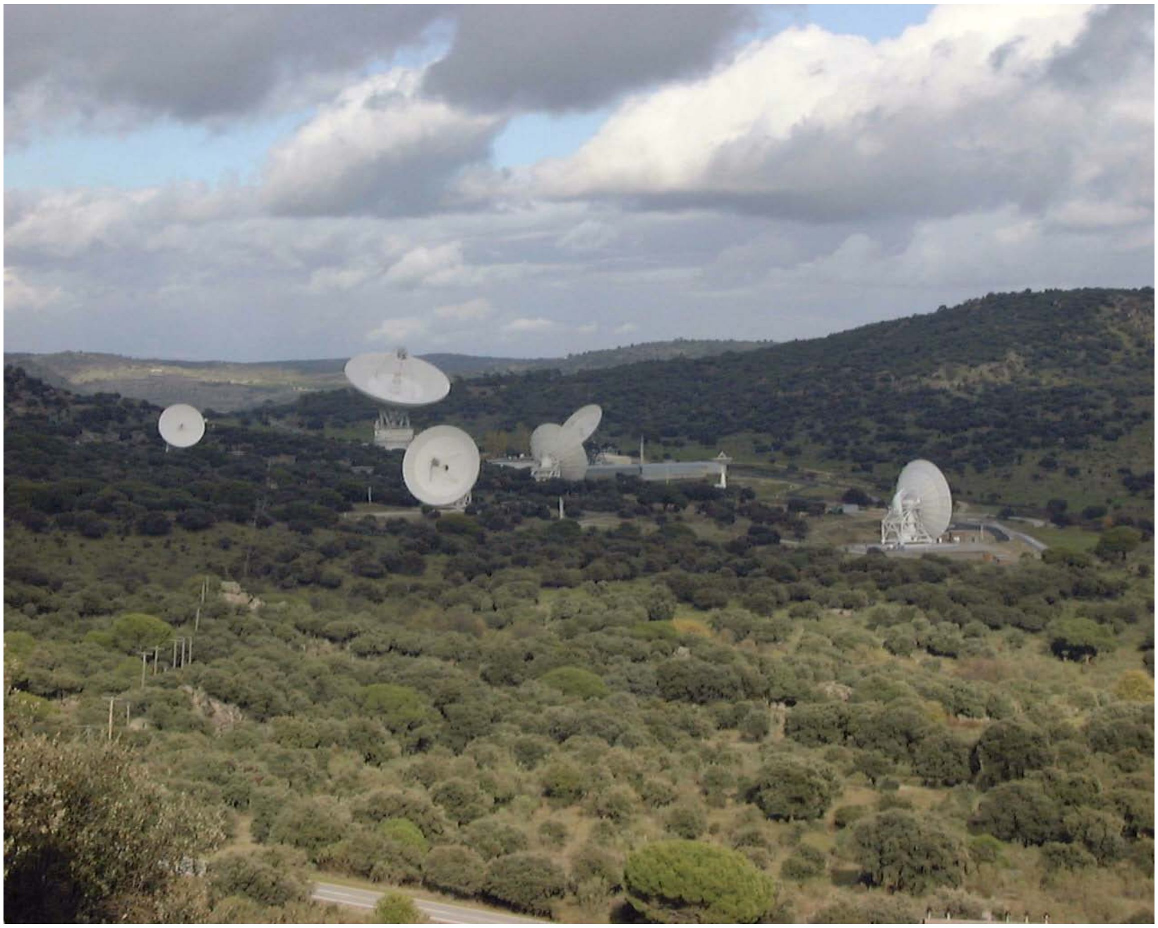

Figure 3-1. DSN Madrid site with 70-m and 34-m antennas.

The Dawn mission mainly uses single (non arrayed) 34-m stations for most purposes. The 70-m stations have been scheduled for mission activities requiring their greater capability – such as to reduce the time to uplink major command loads (by using up to 4 times the data rate achievable by a 34-m station) or to receive the downlink when the vehicle is in safe mode using its LGA.

3.2 Initial Acquisition Support by European Space Agency

For the original launch window (June 2007), significant time would elapse from the end of launch vehicle powered flight until the separated Dawn spacecraft would rise above the horizon at the first DSN site, Canberra. The project made plans to use the ESA tracking station near Perth in western Australia.

For the actual Dawn launch window in September–October 2007, the DSN Goldstone site would see the spacecraft first, but the European Space Agency (ESA) station at Kourou in French Guiana, South America, and later the Perth station, could provide “shadow tracks” to check out the planned low-Earth orbit interagency support for the benefit of future projects.

The ESA support agreement (Ref. [7]) provided for the following.

- Perth (Australia) and Kourou (French Guiana) 15-m tracking stations, with X-band uplink and downlink to acquire Doppler data. The Kourou station (Ref. [8]) would also perform telemetry symbol stream recording.
- European Space Operations Centre (ESOC) at Darmstadt, Germany to coordinate operations with DSN and Dawn Project.
- Data line connections between ESOC and JPL (existing leased lines), with sufficient bandwidth to support timely transfer of Integrated Facilities Management System (IFMS) data files, and possibly Voice over Internet Protocol (VoIP) communications.
- Voice connection, either by telephone patched into JPL voice nets or by VoIP on existing data lines to support real-time status reporting and coordinate real-time operations.

In addition, the agreement called for pre-launch compatibility checkout activities with the Spitzer spacecraft (standing in for Dawn) at ESA’s New Norcia station in Australia.

The original concept of operations had Perth acquiring the Dawn spacecraft as soon after station rise and spacecraft TWTA turn on as soon as possible in a one-way or three-way mode (with Canberra uplink). The concept for the September launch was the same except that it was presumed the DSN stations at Goldstone would initially acquire one-way track and possibly two-way tracking before Perth rise. In order to facilitate the Perth acquisition, the agreement called for the DAWN Mission Controller (call sign “ACE” on the voice net) to inform the European Space Tracking (ESTRACK) Operations Manager of the phasing of the spacecraft rotation.

Normally, no uplink would be performed, but Perth would be ready to start the uplink on request (e.g., in case of a failure at the Canberra Deep Space Communications Complex (CDSCC). The Perth station would track Dawn until sufficient Doppler and carrier signal power level data (receiver AGC) were acquired (or end of view).

Perth and/or Kourou stations would record 1-/2-/3-way Doppler data as appropriate and periodically send the IFMS files to JPL via SFTP (secure file transfer protocol). Station pointing angle data and meteorological data would also be provided.

ESOC was also requested to provide voice status reporting including receiver AGC and symbol SNR readings, and they would periodically fax listings of these parameters to the Dawn Project. For the June–July launch dates, these readings were considered particularly important in order to determine the phasing of the Dawn downlink signal as the spacecraft performs its once-per-hour roll. In September–October, the phasing was considered likely to be determined from the initial Goldstone tracks; and therefore, signal acquisition/loss (AOS/LOS) information was planned to be provided to ESOC from the Project instead of vice versa.

Since ESOC cannot process Turbo code telemetry, a special audio-format recording of the symbol stream would be made both at Perth and Kourou track as long as the downlink telemetry were either 60 or 12000 symbols per second. Telemetry audio files[10] would be sent to the Dawn project in non-real time.

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[10] These files, in *.wav format, had the telemetry symbols on an audio frequency subcarrier. Test files were created by the Dawn project providing a representative turbo-encoded symbol stream on a subcarrier to ESOC. There, the subcarrier frequency was lowered (as would be done by the station receiving a 25-kHz subcarrier from Dawn), and the resulting subcarrier signal was recorded on ESOC equipment. The recorded file was returned to JPL, where it was processed through a demodulator and a turbo decoder, to reproduce the original telemetry data stream.

4 Telecom Link Configuration and Performance

Dawn telecom configuration is maintained by use of telecom blocks (of commands) to operate the system in a few well-defined modes. Similarly, station subsystem configuration is maintained by use of tables that are accessed by software to set up the receiver, telemetry, command, and ranging for a Dawn pass.

4.1 Spacecraft Configuration

Transmitter	TWTA1 [11]
Receiver	SDST1

High gain antenna

Attitude	Earthpoint (zero deg offpoint assumed for prediction)
Ranging	On, “low” (17.5 deg) mod index
Telemetry	124 kbps, 72 deg mod index, direct carrier modulation
Command	2 kbps

Low gain antenna

Attitude	As required for thrusting or science activities
Antenna	pxLGA, pzLGA, or mZLGA for off-Earth angle 45 deg maximum
Ranging	Off (earlier, link supported “on”, with “high” (35 deg) mod index)
Telemetry	40 bps, 53 deg mod index, direct carrier modulation
Command	31.25 to 250 bps (earlier, higher rates up to 2 kbps were used)

4.2 Station Configuration (34-m or 70-m Antenna)

Command mod	1.3 rad mod index for 31.25 bps, 1.5 rad for 2 kbps
Ranging	3 dB carrier supp, T1, T2 = 10, 8 s; cycle time = 157 s

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[11] TWTA1 and SDST1, each selected before launch as prime, continue in use as of August 2009. The redundant elements (TWTA2 and SDST2) are unpowered.

4.3 Uplink and Downlink Modulation Parameters

Table 4-1. Uplink modulation parameters.

			Ground test			Space
Data Rate	**Command mod. index**	**Command mod. index**	**Max Pt**	**Threshold Pt/No**	**Carr Sup**	**Estimated Threshold, 1E-5 BER**
bps	**radians**	**degrees**	**dBm**	**dB-Hz**	**dB**	**dB-Hz**
7.8125	0.94	53.9	–145.90	25.86	–2.04	25.86
15.625	1.20	68.8	–144.75	27.01	–3.46	27.01
31.25	1.30	74.5	–142.50	29.26	–4.15	29.26
62.5	1.50	85.9	–140.30	31.46	–5.82	31.46
125	1.50	85.9	–137.30	34.46	–5.82	34.46
250	1.50	85.9	–135.00	36.76	–5.82	36.76
500	1.50	85.9	–132.00	39.76	–5.82	39.76
1000	1.50	85.9	–129.00	42.76	–5.82	42.76
2000	1.50	85.9	–125.20	46.56	–5.82	46.56

Note: Yellow-shaded command data rates were used from launch through June 2009. The unshaded rates were each tested in fight in June 2009 and are now available for use during the rest of the mission.

Table 4-2. Downlink modulation parameters.

					sdst 1/ sn207	sdst 2/ sn208			
Code	Coded Bit Rate	Symbol Rate (out of uldl card)	Subcarrier Frequency	Optimum Mod Index	Mod Index	Mod Index	Carrier Loop Bandwidth	Subcarrier Loop Bandwidth	Symbol Loop Bandwidth
	bps	**sps**	**kHz**	**degrees**	**DN**	**DN**	**Hz**	**Hz**	**Hz**
Turbo 1/6	10.0	60.606	25	35	24	25	3	0.20	0.05
Turbo 1/6	40.0	242.405	25	53	35	37	3	0.25	0.07
Turbo 1/6	998.0	6,048.400	25	72	48	50	3	0.50	0.10
Turbo 1/6	1,996.0	12,096.800	25	72	48	50	10	0.50	0.10
Turbo 1/6	41,250.5	250,000.000	direct carrier	72	48	48	10	N/A	1.00
Turbo 1/6	61,875.7	375,000.000	direct carrier	72	48	48	10	N/A	1.00
Turbo 1/6	123,751.4	750,000.000	direct carrier	72	48	48	10	N/A	1.00

Notes: 1. All of the downlink rates have been used in flight.

2. SDST1 is currently prime. The communications blocks allow selection of SDST1 or SDST2.

4.4 Telecom Communication (“comm.”) Blocks

Almost all routine Dawn telecom subsystem configurations are commanded as telecom blocks (Ref. [9]). Use of a block ensures that each configuration meets spacecraft and subsystem constraints in terms of commands issued, the ordering of these commands, the timing between commands, and the timing of the telecom configuration relative to spacecraft activities that it depends on or that depend on it. Each block provides several parameters which may be set to specific logical or named values to control the action of a particular instance of the block.

4.4.1 Communications Begin

The Communications Begin block (abbreviated cbeg) is an onboard block that configures the telecom subsystem for uplink and downlink communications with the DSN. In most cases, it calls the Antenna Switch block and the Change Telemetry Rate block to complete the configuration.

This block performs the following actions:

- Either points the HGA to Earth or leaves the spacecraft in its existing attitude
- Calls the **Antenna Switch** block to select the HGA if the HGA is to be pointed to Earth
- Powers on an exciter (as selected by a block parameter) that drives the TWTA (as selected by a block parameter)
- Sets uplink rate of selected SDST to the value as defined in a block parameter
- Sets telemetry encoding mode of selected SDST to "bypassed"
- Sets telemetry subcarrier frequency of selected SDST to "25 kHz"
- Sets coherency of selected SDST to "enabled"
- Powers on the selected TWTA (if defined in a parameter of the block); otherwise does not power a TWTA on.
- Calls the Change Telemetry Rate block with the telemetry rate and the ranging channel on/off state as defined in block parameters
- Counts out delays associated with pointing the HGA to the Earth and powering on the TWTA
- Issues a ”no operation” command to mark the end of each delay

Assumptions before calling this block:

- One of the SDSTs is powered on and only one.
- S/C is in target-pointing mode or higher (delta-V and Science).
- Enough DC power is available to power on and operate the TWTA.
- Telecom is configured on the LGA that has the best look angle to the Earth for uplink.
- Valid spacecraft ephemeris and earth body file on-board.

4.4.2 Communications End

The Communications End block (abbreviated cend) is an onboard block that prepares the telecom subsystem for the end of a period of downlink communications with the DSN. It calls the Change Telemetry Rate block and calls the Antenna Switch block if the final state requires an antenna change. This block has the option of either powering off the selected TWTA and both of the SDST exciters after the pass is complete or leaving the selected TWTA and selected exciter on.

The block has an option to include a user-specified delay time to watch the turn back to thrust attitude and resume thrust. During this time, it can optionally configure for an unmodulated downlink carrier for maximizing power in carrier for two-way Doppler.

This block performs the following absolute or conditional actions:

- Calls the Change Telemetry Rate block with the selected telemetry rate and the selected SDST (as determined by block parameters) but always with the ranging channel off.
- Sets uplink rate of both SDSTs to the value defined in a block parameter.
- Calls the Antenna Switch block if a block parameter indicates that a different antenna is to be selected.
- Puts the selected TWTA into the "on" mode (TWTA producing RF output) if there is to be a change in antenna.
- Turns off C&DH telemetry input to modulators of both SDSTs and sets their telemetry modulation index value to zero if a block parameter indicates that carrier-only operation is required for a period of time defined by a block parameter
- Waits for the above period of time to complete.
- If there was a period of carrier-only operation, changes the C&DH telemetry input mode of both SDSTs back to "bypassed" and restores the telemetry modulation index by calling the Change Telemetry Rate block a second time.
- If a block parameter specifies the downlink is to be powered off,
    - Puts both TWTAs into the "standby" mode (no RF output) and
    - Powers off the selected TWTA; and
    - Powers off both SDST Exciters.

4.4.3 Antenna switch

The Antenna Switch block (abbreviated swant) is an onboard block that turns off the TWTA RF output on the downlink and then configures the SDST and the TWTA to specific antennas by switching waveguide transfer switch (WTS) positions only. The block assumes the selected SDST and its exciter and the selected TWTA are already powered on and does not power them on. This block is not usually used standalone because it does not turn the TWTA RF output back on.

This block performs the following absolute or conditional actions:

- Puts both TWTAs into the "standby" mode (no RF output).
- Changes WTS-1 position to connect the selected antenna to the selected SDST.
- Changes WTS-2 position to connect the selected antenna to the selected SDST.
- Changes WTS-3 position, WTS-4 position, and (if the selected antenna is pXLGA or mZLGA) WTS-5 position to connect the selected LGA to the selected SDST and TWTA.

Note: The block issues each WTS position command to pulse the WTS. If that WTS is already in the correct position, the command serves to reinforce the existing position rather than causing an actual position change.

Many combinations of SDST, TWTA, and antennas can be achieved by sets of commands other than those implemented in this block.

Use of this block assumes the telecom subsystem configuration shown in Figure 2-1, the telecom subsystem block diagram.

Proper operation of the block assumes that all five of the WTS, both SDSTs, and both TWTAs are working.

If an element fails, the block and sequence generation (seqgen) adaptation should be carefully reviewed and probably will need to be updated before continued use. It may be possible to still achieve acceptable operating configurations through selection of the backup SDST, the backup TWTA, or (for some LGAs) different sets of WTS positions.

4.4.4 Change Telemetry (Downlink) Rate

The Change Downlink Rate block (abbreviated cdlr) is an onboard block that changes the downlink data rate, the SDST telemetry modulation mode and modulation index, the SDST ranging on/off state, and the SDST ranging modulation index. Care must be taken when using the block standalone because it does not fully configure the SDST.

This block performs the following actions:

1. For either SDST1 or SDST2 (as determined by a block parameter), and the downlink bit rate (a block parameter), selects the telemetry mod index and the modulation mode (direct carrier or subcarrier) control consistent with Table 4-2
2. Sets the ranging channel to "on" in either SDST1 or SDST-2 if a block parameter defines ranging on, or sets both ranging channels to “off”
3. Selects the ranging mod index as defined in a block parameter for the “on” ranging channel

This block can be but is not normally used stand-alone as its configuration of the SDST is not complete. For example, it does not touch the uplink rate, the coherency, the subcarrier frequency, or the encoding mode. The Change Downlink Rate block is almost always called by either the Communications Begin block or the Communications End block.

SDST 1 is serial number (s/n) 207, and SDST 2 is s/n 208. When the mission requires a particular downlink data rate, this comm block will be used to select a compatible mod index data number value for 207 or 208 from the Table 4-2 mod index columns.

4.4.5 Playback Blocks

There are several inter-related blocks used to control playback of science and engineering data.

Playback_engineering

This is an onboard block used routinely to playback the engineering virtual recorders. It will playback dataset 0 and release dataset3. It selects the uplink VCDU release rate compatible with playback.

Playback

This onboard block can be called by the cpbe_comm_pb_engineering block or used stand-alone, possibly with some additional commands needed.

It allows the user to play back a single dataset of a single virtual recorder (VR), if desired release a single dataset.

A user may also use the block to simply release a data set by issuing a normal playback command with a playback dataset ID of "NONE"

Playback_resume_pause

This is an onboard block used with the start_continuous_playback strategy. It assumes the start_continuous_playback command has been already sent and the normal style playback is not being used on whichever VRs have been put in the continuous mode. It assumes the continuous playback will be stopped at some later time.

This block allows the user to playback as many as three VRs for a specified duration given in minutes. The VRs may be repeated (e.g., VR4, VR5, VR4). Setting the duration to zero seconds will cause the code to skip playing anything back from that VR.

4.4.6 Delta DOR

The ddor block is used during the Cruise and MGA phases to provide delta differential one-way ranging (DDOR) measurements for navigational purposes, as an independent data type from Doppler and Ranging. DDOR involves collecting radiometric data from the spacecraft. The process consists of using two widely separated DSN antennas to collect radiometric data simultaneously, using very long baseline interferometry. The antennas will collect a few minutes of data from the spacecraft, then turn to collect data from a known stellar radio source, then return to collect data from the spacecraft. By analyzing the interference patterns, due to the data being collected at the two different stations, the angular position and distance of the spacecraft can be determined.

The block will configure the SDST as required to turn on the DOR tone. Configuring the SDST requires turning coherency, ranging and telemetry off and then turning the DOR tones on. After the user-specified duration, the block reconfigures the SDST back to the nominal configuration.

Note: to ensure adequate warm-up time for the auxiliary oscillator, the delta-DOR block normally is preceded by stand-alone coherency_disable commands to the SDST.

4.5 Telecom idiosyncrasies

Constraints involving the SDST S1 timeout. The DAWN SDST hardware is the same as that used on MER and Mars Odyssey, et al. While in State 1 (S1) or downlink only mode, these SDSTs raise their 1553 busy flag once every 10 minutes for approximately 100 ms. (This does not occur in two-way). During this "busy" period, the SDSTs do not send status information, and they are incapable of receiving commands. On Dawn, SDST commands are expected to be issued from blocks during one-way communication in order to set up for upcoming pass communication. Since fault protection responses can run at any time, relative timed sequences

(RTSs) are also affected. A rough estimate of the chances of not receiving an individual command is 1 in 6000.

FSW poll and S1 timeout. This SDST idiosyncrasy is related to the State1 time-out and the ‘busy bit’. It is possible for the FSW to poll the SDST when it has started its timeout, but has not yet updated the ‘busy flag’ (small time window of vulnerability, about 5 ms). So the FSW sees no ‘busy bit’ and the SDST doesn’t respond, which causes the OBC to report a remote terminal (RT) error.

Implication to Dawn flight ops: SDST commands in comm blocks are doubled. The FP response is configured avoid trips due to normal S1 timeout operation. The actual busy bit duration is about 152 ms.

Uplink acquisition sweep. Uplink RF acquisition should be performed using a ± 10 kHz sweep around best lock frequency (BLF) at a rate of 200 Hz/s. A maximum sweep range of ± 20 kHz can be used if necessary.

Implication to Dawn flight ops: The DSN configuration table for the uplink carrier frequency sweep uses a MAQ template, with a sweep rate SR = 200 Hz/s and a tuning range TR = 10 kHz. MAQ stands for Magellan acquisition. Templates are defined in terms of tuning rate (TR) and sweep range (SR). The contingency procedure for Loss of Dawn Uplink/Commandability specifies the use of alternate SR and TR as well as FRO (frequency reference offset) to work around SDST conceivable acquisition problems. Note: widening the SR too much puts the acquisition at risk due to the DAC rollover glitch problem described below.

Command spacing to SDST. Commands to the SDST should be spaced a minimum of 25 ms.

Implication to Dawn flight ops: SDST commands in the block dictionary (Ref. [9]) or those created in Seqgen are separated by 1 second, thus complying with this constraint.

SDST uplink signal level telemetry. The carrier accumulator has a 3-s integration time. That means that a) when the SDST drops lock, the signal to the telemetry doesn’t show the signal level change right away, and b) carrier lock accumulator (CLA) values do not update rapidly.

Limitations of wb_agc telemetry. The Wideband AGC (wb_agc) is very coarse. It is useful only for a strong uplink (Pt = –70 dBm to –105 dBm), but the AGC gain varies significantly with temperature, and the data number (DN) to dBm cal curves are not very useful (there's a large amount of noise).

Limitations of cla_agc telemetry. The cla_agc drops significantly at strong uplink (uplink Pt > –120 dBm) when carrier is modulated by command or ranging.

Implication to Dawn flight ops: Telecom flight ops will observe and query all three SDST receiver signal level measurements (cla_agc, nb_agc, or wb_agc) and will refer to normal signatures for comparison. The measurement rate is also constrained by the real time and recorded packet structure and the downlink rate. The wb_agc measures total received power whereas nb_agc or cla_agc measure the carrier only. Each of the receiver signal-level measurements has an operating range, outside of which the measurement saturates at a limit value.

This cla_agc limitation was seen commonly on Deep Impact. It is the result of an unmodulated carrier at high signal level being in the saturated region of cla_agc, but with carrier suppression of 5–6 dB for command modulation or 3–6 dB for ranging modulation, the channel goes into a linear range which is converted into an apparent dBm level that is larger than the carrier suppression.

Exciter static phase error telemetry. The exc_spe "rails" when it's OFF (meaning it rapidly varies between maximum and minimum DN values, thus it looks like it is stuck along rails). The exciter SPE is taken from a DRO (dynamic resonance oscillator). Ignore the large DN when the SPE is OFF.

Implication to Dawn flight ops: This condition is routinely seen on MER SDST telemetry, where a common operating mode is SDST on and Exciter off. It should be much less common on Dawn, where the normal operating mode of the powered SDST is Exciter on.

Command detection function. The SDST will drop CDU lock only after the carrier and sub-carrier signals have been missing for minimum number of bits (or clock transitions), thus noise data is passed to the CEU.

Implication to Dawn flight ops: This phenomenon has caused loss of commands in ATLO (the Assembly, Test, and Launch Operations phase) on various projects. The random bits may falsely indicate a command start word. In flight, the probability of this is very small because the delay between commands is either very short (less than 1 start word) or long (greater than 4 seconds)

A flight rule takes this time into account, specifically for commanding the SDST to make an uplink rate change. The rule requires a minimum of 4 seconds (27 bit times at the lowest command rate) after the completion of a command for the CDU to drop lock and declare out of lock to the C&DH hardware command decoder (HCD). When the CDU function has been out of lock, it requires 176 bit times to lock up and declare lock to the HCD.

DAC "glitch". The SDST tracking loop has a digital-to-analog converter (DAC). During a swept uplink carrier, the SDST may lose lock when the raw value of SPE is a power of 2 (e.g., 64 DN, 128 DN).

Implication to Dawn flight ops: When the VCO's DAC transitions from a data number with many zeroes to one with many ones, it produces a voltage spike in the receiver static phase error (SPE) that can cause the VCO to lose lock on an already acquired uplink carrier. The glitch is worse at cold temperatures (0°C and -25C measured), at high uplink received power (greater than –120 dBm) and when the SPE is changing in a positive direction. The MAQ tuning template includes one positive-going segment from –10 kHz to 0. Thermal control will keep the SDST above 0°C (baseplate controlled to 9-11C nominal. With 1 DN equivalent to 170 Hz, 64DN represents 10.8 kHz, and 128 DN represents 21.8 kHz, outside the Dawn tuning range.

Receiver DN to EU calibration. The calibration (data number to engineering unit) calibration curves for the SDST receiver signal level telemetry outputs are strong functions of VCO temperature, particularly in the range of –20°C to –10°C.

Implication to Dawn flight ops: None. The DN-EU calibration look-up tables used in the Dawn DMD and query for cla_agc and cla_snr, nb_agc, and wb_agc and wb_snr have separate portions for each of three temperature ranges.

RF leakage into the receiver VCO. Some SDSTs are more sensitive to this than others. This results in the VCO frequency drifting from best lock when unlocked. The amount of drift in susceptible receivers is strongly temperature dependent. (One MER receiver drifts several kilohertz between S1 timeouts at some temperatures and hardly at all at others.

Implication to Dawn flight ops: None currently. The Dawn SDST receivers did not exhibit this phenomenon in ATLO operations, and it has not occurred in flight. If it should begin, it is harmless in one-way mode, and (if severe) can be accounted for in the uplink tuning profile for uplink acquisition.

Receiver carrier loop hysteresis between drop-lock and acquire-lock. SDST receivers drop lock at about –156 dBm. They acquire lock at about –153 dBm. This behavior is to avoid having the receiver toggle constantly between lock states when the uplink is around -155 dBm. The toggling changes the downlink frequency between the aux osc and the VCO in the Dawn operating configuration, each change causing the station receiver to drop lock.

Implication to Dawn flight ops: None currently. The SDST receiver is expected to operate well above -153 dBm total uplink power. The only likely exceptions might be due to antenna angles during turn maneuvers or as a result of Safemode.

Ranging channel modulation index. The nominal values (17.5 deg and 35 deg) defined by the ranging modulation index command do not represent the actual modulation index. The actual modulation index values (27.5 deg peak or 55 deg peak) are accounted for in the link prediction models and do not represent a problem with ranging or telemetry performance.

Implication to Dawn flight ops: None. The ratios of (1) carrier power to total power and of (2) data power to total power that determine carrier tracking, telemetry, and ranging performance account for the actual ranging modulation index values.

Telemetry subcarrier frequency. The nominal value (25 kHz) defined by the telemetry subcarrier frequency command is not the actual value (25000.33 Hz). This is inherent in the SDST design, which allows for only discrete subcarrier frequency values.

Implication to Dawn flight ops: None. The Deep Space Network's receiver configuration tables for Dawn define the single Dawn telemetry subcarrier frequency to be 25000.33 Hz.

Command bit errors at 7.8125 bps at strong uplink levels. These may occur if uplink carrier suppression by command modulation is set too high. This has been newly documented in 2007, but it is a characteristic of earlier SDSTs as well. It is caused by an overflow in the final matched filter accumulator of the command detector unit (CDU) portion of the ASIC (application specific integrated circuit). Command errors do not occur at this rate if the total power is less than –100 dBm, nor do they occur at any higher rate if the total power is less than the SDST specification of –70 dBm. Errors can be avoided at 7.8125 bps at –70 dBm and lower if the carrier suppression is no higher than 0.94 radians.

Implication to Dawn flight ops: None. The Deep Space Network's command configuration tables for Dawn (and other projects) link the setting of the carrier suppression to the uplink rate, as does modeling for link planning in the telecom forecaster predictor (TFP). The 7.8125-bps uplink rate is linked to 0.9 dB carrier suppression.

4.6 Flight Rules

Flight rules constrain how the telecom subsystem can be configured or operated by means of sequenced or real time commands sent to it. Details are in Ref [10] (a Dawn project internal document). Telecom flight rules are in the least restrictive of three categories: those that result in, at most, the temporary degradation of loss of uplink or downlink data transfer, or loss of a consumable such as the number of switch cycles.

- Telecom subsystem flight rules define prohibition or constraints regarding
- “Hot switching” of the WTS
- Operation of both SDSTs or both TWTAs simultaneously
- Use of communication blocks (comm. blocks) to operate subsystem
- Uplink rates (values, and changing from one to another) for real time commanding
- SDST “bypass” encoding mode
- Maximum received uplink and downlink power during initial acquisition
- Subsystem default modes for fault protection responses
- “Doubling” of sequenced commands issued to the SDST

5 Flight Operations

From late in spacecraft development through the end of the flight mission, the telecom analyst is responsible for

- Definition of requirements on the ground data system to support telecom analysis, the interface agreements with other parts of the mission operations system, and development of plans to test the requirements and interfaces;
- analysis of subsystem performance data for incorporation into ground software communication link prediction models;
- development of both nominal and contingency telecom subsystem operations plans and procedures;
- resource management, including link performance margins and hardware operating cycles;
- safe real time commanding and stored sequencing of the subsystem;
- subsystem configuration, status, and performance monitoring;
- engineering and scientific data delivery;
- anomaly resolution;
- performance assessment and trending data analysis; and
- identification of operations process improvements.

After launch, the “telecom job” on Dawn is a kind of planning/analysis feedback loop

- (starting point) plan future operations using the telecom subsystem
- predict the uplink and downlink performance during these activities
- monitor spacecraft telemetry and station data in real time for critical activities
- query, analyze and trend data in non real time for routine activities
- (ending point) update link prediction models based on analyzed and trended data

There are two Dawn telecom procedures for routine operations

- Ref. [11] for link prediction and sequence review
- Ref. [12] for data analysis and trending

5.1 Telecom Link Prediction

Dawn telecom predictions are used for mission planning, sequence design, and monitoring the performance of the links in real time. They are generated in a Telecom group account on a flight workstation. Dawn telecom analysts use the Telecom Forecaster Predictor (TFP) software. The TFP software is formally delivered to the project.

TFP is run from a graphical user input (GUI) interface (Figure 5-1). Running the GUI starts a script that accesses the delivered TFP models and scripts files, sets up a Matlab command window and a window for the GUI, and starts Matlab. At the conclusion of a run, the user can generate tabulated predictions (Figure 5-2) or plots of predicted quantities versus time (Figure 5-3).

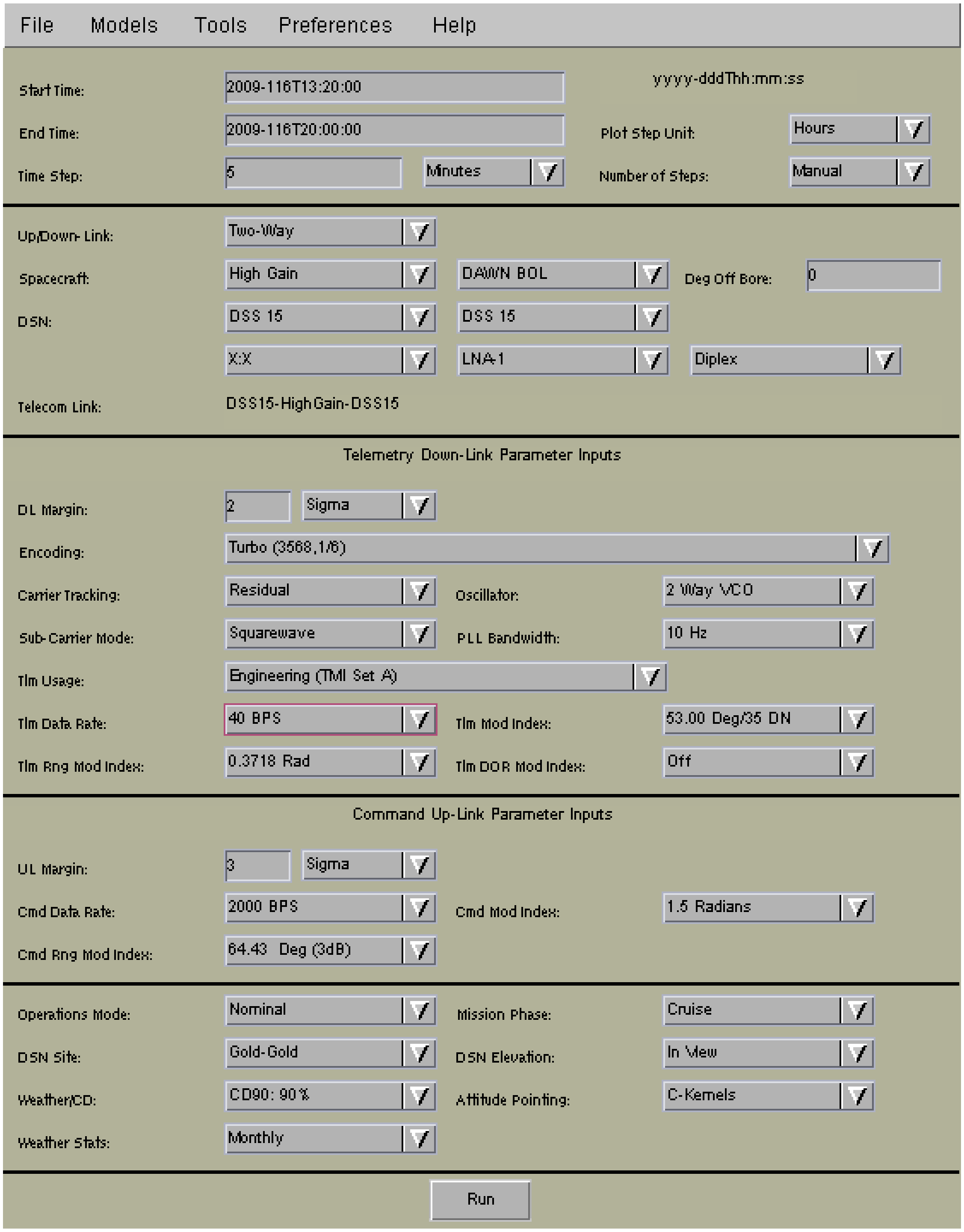
Table 5-1 is a representative uplink link budget (design control table) for the low gain antenna, and Table 5–2 is a representative downlink link budget for the high gain antenna.

5.2 Sequence Review

The primary purpose for review of sequence products is to ensure that only correct commands affecting the telecom subsystem are sent to the spacecraft and that the DSN keywords file that accompanies the product delivery defines station configurations that support the sequence.

A correct sequence includes only the necessary commands, at the right times and in the right order, to ensure the safety of the hardware (by complying with the flight rules) and to operate in the correct series of configurations to correspond to the uplink and downlink data rate requirements, use of the ranging channel and the delta-DOR tones, and telecom link capabilities.

A correct sequence produces configurations that match the allocated tracking stations for the sequence interval, in terms of tracking times, station equipment configuration codes, and predicted capabilities



Start Time: 2009-116T13:20:00 yyyy-dddThh:mm:ss

End Time: 2009-116T20:00:00

Plot Step Unit: Hours

Time Step: 5 Minutes

Number of Steps: Manual

Up/Down-Link: Two-Way

Spacecraft: High Gain DAWN BOL

Deg Off Bore: 0

DSN: DSS 15 DSS 15

X:X LNA-1 Diplex

Telecom Link: DSS15-HighGain-DSS15

Telemetry Down-Link Parameter Inputs

DL Margin: 2 Sigma

Encoding: Turbo (3568,1/6)

Carrier Tracking: Residual

Oscillator: 2 Way VCO

Sub-Carrier Mode: Squarewave

PLL Bandwidth: 10 Hz

Tlm Usage: Engineering (TMI Set A)

Tlm Data Rate: 40 BPS

Tlm Mod Index: 53.00 Deg/35 DN

Tlm Rng Mod Index: 0.3718 Rad

Tlm DOR Mod Index: Off

Command Up-Link Parameter Inputs

UL Margin: 3 Sigma

Cmd Data Rate: 2000 BPS

Cmd Mod Index: 1.5 Radians

Cmd Rng Mod Index: 64.43 Deg (3dB)

Operations Mode: Nominal

Mission Phase: Cruise

DSN Site: Gold-Gold

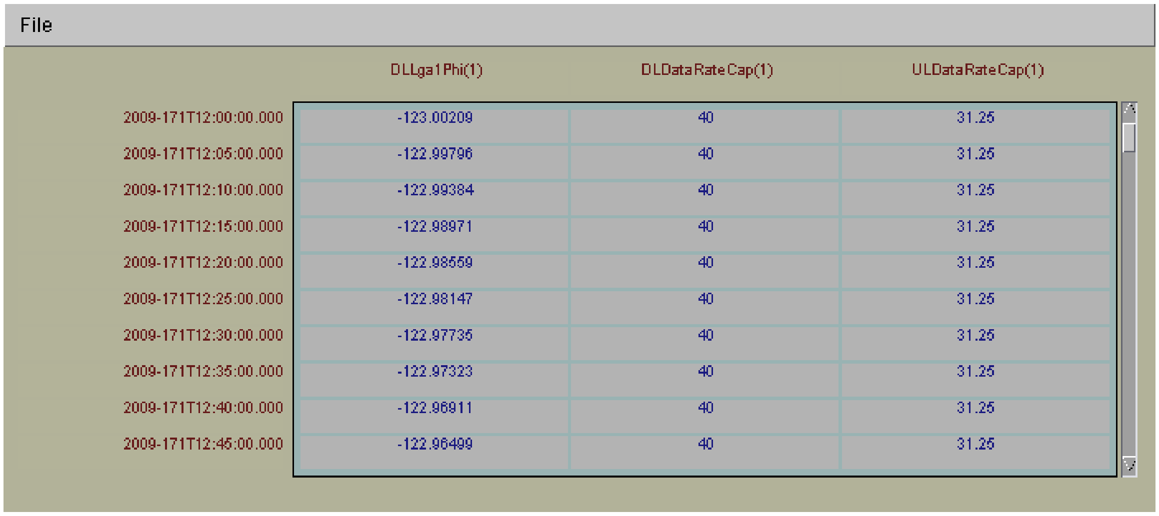
DSN Elevation: In View

Weather/CD: CD90: 90%

Attitude Pointing: C-Kernels

Weather Stats: Monthly

Figure 5-1. Dawn Telecom Forecaster Predictor user input (GUI).



	DLLga1Phi(1)	DLDataRateCap(1)	ULDataRateCap(1)
2009-171T12:00:00.000	-123.00209	40	31.25
2009-171T12:05:00.000	-122.99796	40	31.25
2009-171T12:10:00.000	-122.99384	40	31.25
2009-171T12:15:00.000	-122.98971	40	31.25
2009-171T12:20:00.000	-122.98559	40	31.25
2009-171T12:25:00.000	-122.98147	40	31.25
2009-171T12:30:00.000	-122.97735	40	31.25
2009-171T12:35:00.000	-122.97323	40	31.25
2009-171T12:40:00.000	-122.96911	40	31.25
2009-171T12:45:00.000	-122.96499	40	31.25

Figure 5-2. Example of report of pXLGA antenna angle and supportable rates.

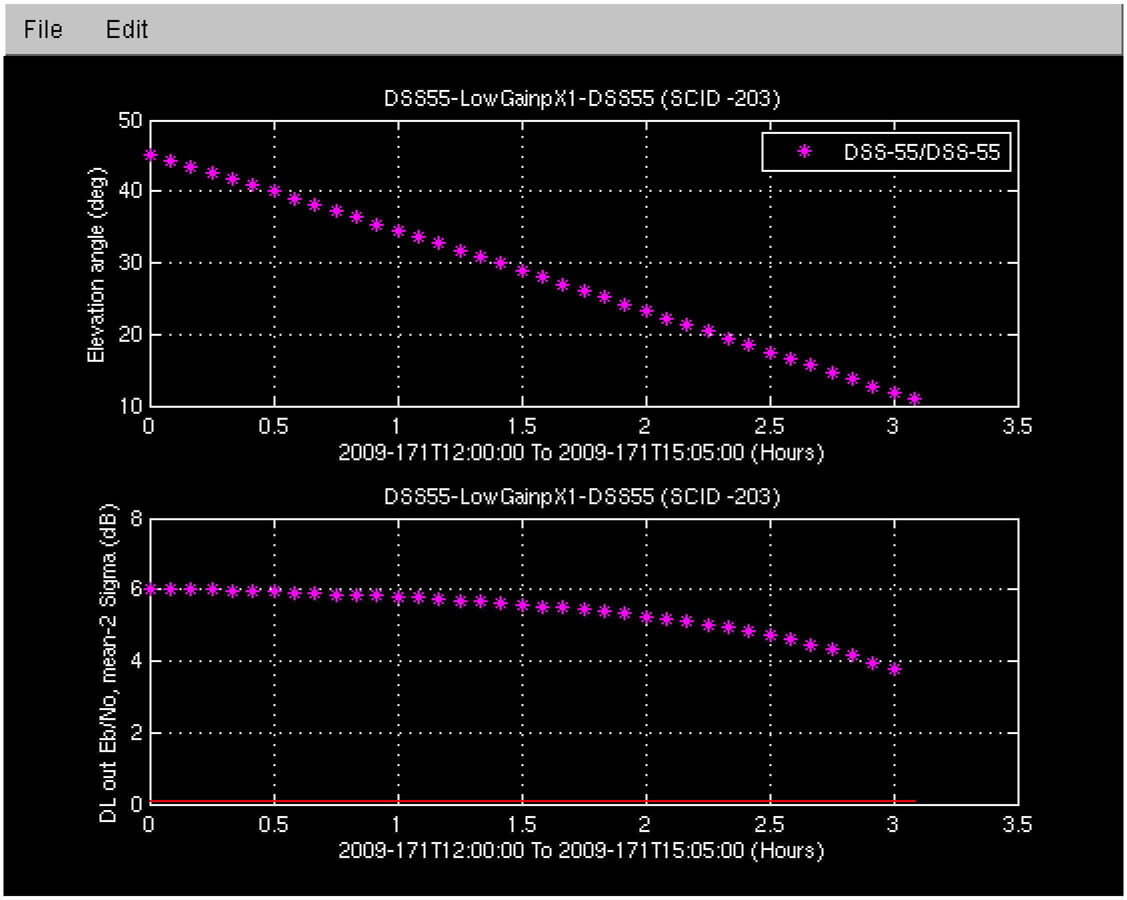


Figure 5-3. Example of plot of predicted elevation angle and symbol SNR.

Table 5-1. Dawn uplink design control table for 34m station and pXLGA.

```
-----------------------------------------------------------------------------------------
COMMAND UP-LINK PARAMETER INPUTS
Cmd Data Rate              31.2500  bps
Cmd Mod Index              1.30     Radians
-----------------------------------------------------------------------------------------
Operations Mode            Calibration
DSN Elevation              In View
Weather/CD                 90
Attitude Pointing          C-Kernels
-----------------------------------------------------------------------------------------
EXTERNAL DATA
Range                         (AU)           1.9482e+00
Station Elevation(s)          (deg)          67.97
pXLGA pointing angle          (deg           32.39
-----------------------------------------------------------------------------------------
DSN Site Considered:       DSS-25/DSS-25
At Time:                   2009-177T16:30:00.000 UTC
-----------------------------------------------------------------------------------------
                                                     Design     Fav     Adv   Mean     Var
Link Parameter                               Unit    Value      Tol     Tol  Value
-----------------------------------------------------------------------------------------
TRANSMITTER PARAMETERS
 1. Total Transmitter Power                  dBm       71.76   0.50   -0.50  71.76 0.0417
 2. Xmitter Waveguide Loss                   dB        -0.40   0.10   -0.10  -0.40 0.0017
 3. DSN Antenna Gain                         dBi       67.04   0.20   -0.30  67.01 0.0106
 4. Antenna Pointing Loss                    dB        -0.10   0.10   -0.10  -0.10 0.0017
 5. EIRP (1+2+3+4)                           dBm      138.27   0.71   -0.71 138.27 0.0556
-------------------------------------------------------------------
PATH PARAMETERS
 6. Space Loss                               dB      -278.86   0.00    0.00-278.86 0.0000
 7. Atmospheric Attenuation                  dB        -0.05   0.00    0.00  -0.05 0.0000
-------------------------------------------------------------------
RECEIVER PARAMETERS
 8. Polarization Loss                        dB        -0.03   0.10   -0.10  -0.03 0.0033
 9. Degrees-off-boresight (DOFF) Loss        dB        -1.87   0.26   -0.44  -1.96 0.0412
10. S/C Antenna Gain (at boresight)          dBi        7.35   0.50   -0.50   7.35 0.0417
11. Lumped Circuit Loss                      dB        -1.45   0.10   -0.10  -1.45 0.0033
-------------------------------------------------------------------
TOTAL POWER SUMMARY
12. Tot Rcvd Pwr (5+6+7+8+9+10+11)           dBm     -136.74   1.14   -1.14-136.74 0.1451
13. Noise Spectral Density                   dBm/Hz  -174.38  -1.34    0.74-174.58 0.1846
14. System Noise Temperature                 K        264.43 -70.17   48.88 257.33 596.8432
15. Received Pt/No (12-13)                   dB-Hz     37.84   1.72   -1.72  37.84 0.3297
16. Received Pt/No, mean-3 Sigma             dB-Hz     36.12   0.00    0.00  36.12 0.0000
-------------------------------------------------------------------
CARRIER PERFORMANCE
17. Recovered Pt/No (15+[AGC+BPF])           dB-Hz     37.84   1.72   -1.72  37.84 0.3297
18. Command Carrier Suppression              dB        -4.15   0.42   -0.42  -4.15 0.0287
20. Carrier Power (AGC)                      dBm     -140.89   1.25   -1.25-140.89 0.1738
21. Received Pc/No (17+18+19)                dB-Hz     33.69   1.80   -1.80  33.69 0.3584
22. Carrier Loop Noise BW                    dB-Hz     16.58  -0.20    0.15  16.55 0.0102
23. Carrier Loop SNR (CNR) (21-22)           dB        17.13   1.82   -1.82  17.13 0.3686
24. CNR, mean-3 Sigma                        dB        15.31   0.00    0.00  15.31 0.0000
25. Recommended CNR                          dB        12.00   0.00    0.00  12.00 0.0000
26. CNR Margin (23-25)                       dB         5.13   1.82   -1.82   5.13 0.3686
27. CNR Margin, mean-3 Sigma (24-25)         dB         3.31   0.00   -0.00   3.31 0.0000
-------------------------------------------------------------------
CHANNEL PERFORMANCE
28. Command Data Suppression                 dB        -2.64   0.18   -0.20  -2.64 0.0060
30. Received Pd/No (17+28+29)                dB-Hz     35.20   1.74   -1.74  35.20 0.3356
31. Received Pd/No, mean-3 Sigma             dB-Hz     33.46   0.00    0.00  33.46 0.0000
32. Data Rate (dB-Hz)                        dB-Hz     14.95   0.00    0.00  14.95 0.0000
33. Available Eb/No (30-32)                  dB        20.25   1.74   -1.74  20.25 0.3356
34. Implementation Loss                      dB        -2.08   1.00   -1.00  -2.08 0.1667
35. Output Eb/No (33-34)                     dB        18.17   2.13   -2.13  18.17 0.5023
36. Output Eb/No, mean-3 Sigma               dB        16.04   0.00    0.00  16.04 0.0000
37. Required Eb/No                           dB         9.60   0.00    0.00   9.60 0.0000
38. Eb/No Margin (35-37)                     dB         8.57   2.13   -2.13   8.57 0.5023
39. Eb/No Margin, mean-3 Sigma (36-37)       dB         6.44   0.00   -0.00   6.44 0.0000
                        -----------------------------------------------------------------
```

Table 5-2. Dawn downlink design control table for 34-m station and HGA.

```
-------------------------------------------------------------------------------------
RF Band                    X:X
Diplex Mode                Diplex
-------------------------------------------------------------------------------------
TELEMETRY DOWN-LINK PARAMETER INPUTS
Encoding                   Turbo (3568,1/6)
PLL Bandwidth              10.00    Hz
Tlm Data Rate/Mod Index    123751   bps/ 72.00    Degrees
Tlm Rng/DOR Mod Index      0.37     Rad/ 0.00     Degrees
-------------------------------------------------------------------------------------
Weather/CD                 90
Attitude Pointing          EarthPointed
-------------------------------------------------------------------------------------
EXTERNAL DATA
DL One-Way Light Time         (hh:mm:ss)            00:31:31
Station Elevation(s)          (deg)                 64.2
DL DOFF: Hga,                 (deg)                 0.60
-------------------------------------------------------------------------------------
DSN Site Considered:       CANBERRA
At Time:                   2014-350T00:00:00.000 UTC
-------------------------------------------------------------------------------------
                                              Design     Fav     Adv    Mean     Var
Link Parameter                      Unit    Value       Tol     Tol   Value
-------------------------------------------------------------------------------------
TRANSMITTER PARAMETERS
 1. S/C Transmitter Power           dBm       50.00    0.30   -0.10   50.07  0.0072
 2. S/C Xmit Circuit Loss           dB        -0.41    0.10   -0.10   -0.41  0.0033
 3. S/C Antenna Gain                dBi       39.60    0.60   -0.60   39.60  0.0600
 4. Degrees-off-boresight (DOFF) Loss dB      -1.40    0.05   -0.04   -1.40  0.0007
 5. EIRP (1+2+3+4)                  dBm       87.86    0.80   -0.80   87.86  0.0712
-------------------------------------------------------------------------------------
PATH PARAMETERS
 6. Space Loss                      dB      -286.04    0.00    0.00 -286.04  0.0000
 7. Atmospheric Attenuation         dB        -0.07    0.00    0.00   -0.07  0.0000
-------------------------------------------------------------------------------------
RECEIVER PARAMETERS
 8. DSN Antenna Gain                dBi       68.30    0.10   -0.20   68.26  0.0039
 9. DSN Antenna Pnt Loss            dB        -0.10    0.10   -0.10   -0.10  0.0033
10. Polarization Loss               dB        -0.02    0.10   -0.10   -0.02  0.0033
-------------------------------------------------------------------------------------
TOTAL POWER SUMMARY
11. Tot Rcvd Pwr (5+6+7+8+9+10)     dBm     -130.11    0.86   -0.86 -130.11  0.0818
12. SNT in Vacuum                   K         18.97   -1.00    2.00   19.30  0.3889
13. SNT due to Elevation            K          0.02    0.00    0.00    0.02  0.0000
14. SNT due to Atmosphere           K          4.36    0.00    0.00    4.36  0.0000
15. SNT due to the Sun              K          0.89    0.00    0.00    0.89  0.0000
16. SNT due to other Hot Bodies     K          0.00    0.00    0.00    0.00  0.0000
17. SNT (12+13+14+15+16)            K         24.25   -1.00    2.00   24.75  0.2500
18. Noise Spectral Density          dBm/Hz  -184.75   -0.18    0.34 -184.67  0.0077
19. Received Pt/No (11-18)          dB-Hz     54.56    0.90   -0.90   54.56  0.0895
20. Received Pt/No, mean-2 Sigma    dB-Hz     53.96    0.00    0.00   53.96  0.0000
21. Required Pt/No                  dB-Hz     52.30    0.00    0.00   52.30  0.0000
-------------------------------------------------------------------------------------
CARRIER PERFORMANCE
22. Recovered Pt/No (19+[AGC+BPF])  dB-Hz     54.56    0.90   -0.90   54.56  0.0895
23. Telemetry Carrier Suppression   dB       -10.20    2.78   -4.35  -10.72  2.1516
24. Ranging Carrier Suppression     dB        -0.30    0.06   -0.06   -0.30  0.0006
26. Carrier Power (AGC) (11+23+24+25) dBm   -141.13    4.48   -4.48 -141.13  2.2339
27. Received Pc/No (22+23+24+25)    dB-Hz     43.54    4.49   -4.49   43.54  2.2417
28. Carrier Loop Noise BW           dB-Hz     10.00    0.00    0.00   10.00  0.0000
29. Carrier Loop SNR (CNR)          dB        33.54    4.49   -4.49   33.54  2.2417
30. CNR, mean-2 Sigma               dB        30.55    0.00    0.00   30.55  0.0000
31. Recommended CNR                 dB        10.00    0.00    0.00   10.00  0.0000
32. CNR Margin (29-31)              dB        23.54    4.49   -4.49   23.54  2.2417
33. CNR Margin, mean-2 Sigma (30-31) dB       20.55    0.00   -0.00   20.55  0.0000
-------------------------------------------------------------------------------------
TELEMETRY PERFORMANCE
34. Telemetry Data Suppression      dB        -0.44    0.28   -0.43   -0.49  0.0215
35. Ranging Data Suppression        dB        -0.30    0.06   -0.06   -0.30  0.0006
```

```
36. DOR Data Suppression           dB         0.00   0.00    0.00    0.00 0.0000
37. Received Pd/No (22+34+35+36)   dB-Hz     53.77   1.00   -1.00   53.77 0.1116
38. Received Pd/No, mean-2 Sigma   dB-Hz     53.11   0.00    0.00   53.11 0.0000
39. Data Rate, Symbols (dB-Hz)     dB-Hz     50.93   0.00    0.00   50.93 0.0000
40. Symbols Per Bit (dB)           dB         7.78   0.00    0.00    7.78 0.0000
41. Available Eb/No (37-39)        dB         2.85   1.00   -1.00    2.85 0.1116
42. Es/No, SSNR (37-39-40)         dB        -5.27   0.00    0.00   -5.27 0.0000
43. Total System Losses            dB         0.33   0.00   -0.00    0.33 0.0000
44. Output Eb/No (41-43)           dB         2.52   1.00   -1.00    2.52 0.1116
45. Output Eb/No, mean-2 Sigma     dB         1.85   0.00    0.00    1.85 0.0000
46. Required Eb/No                 dB         0.10   0.00    0.00    0.10 0.0000
47. Eb/No Margin (44-46)           dB         2.42   1.00   -1.00    2.42 0.1116
48. Eb/No Margin, mean-2 Sigma     dB         1.75   0.00   -0.00    1.75 0.0000
49. Down Data Rate Cap (20,21)     bps      123751   0.00    0.00  123751 0.0000
```

5.3 Query, Analysis, and Trending

This section describes the duties of the Dawn telecom analysts on the Spacecraft Team to display, query, analyze, trend, and report on the performance of the Dawn telecom subsystem and the links with the Deep Space Network.

The data to be handled includes telemetry (subsystem-generated voltages, currents, DC and RF power levels, and temperatures) from the spacecraft as well as monitor (signal levels, signal-to-noise ratios, frequencies, and system noise temperatures) from the tracking station.

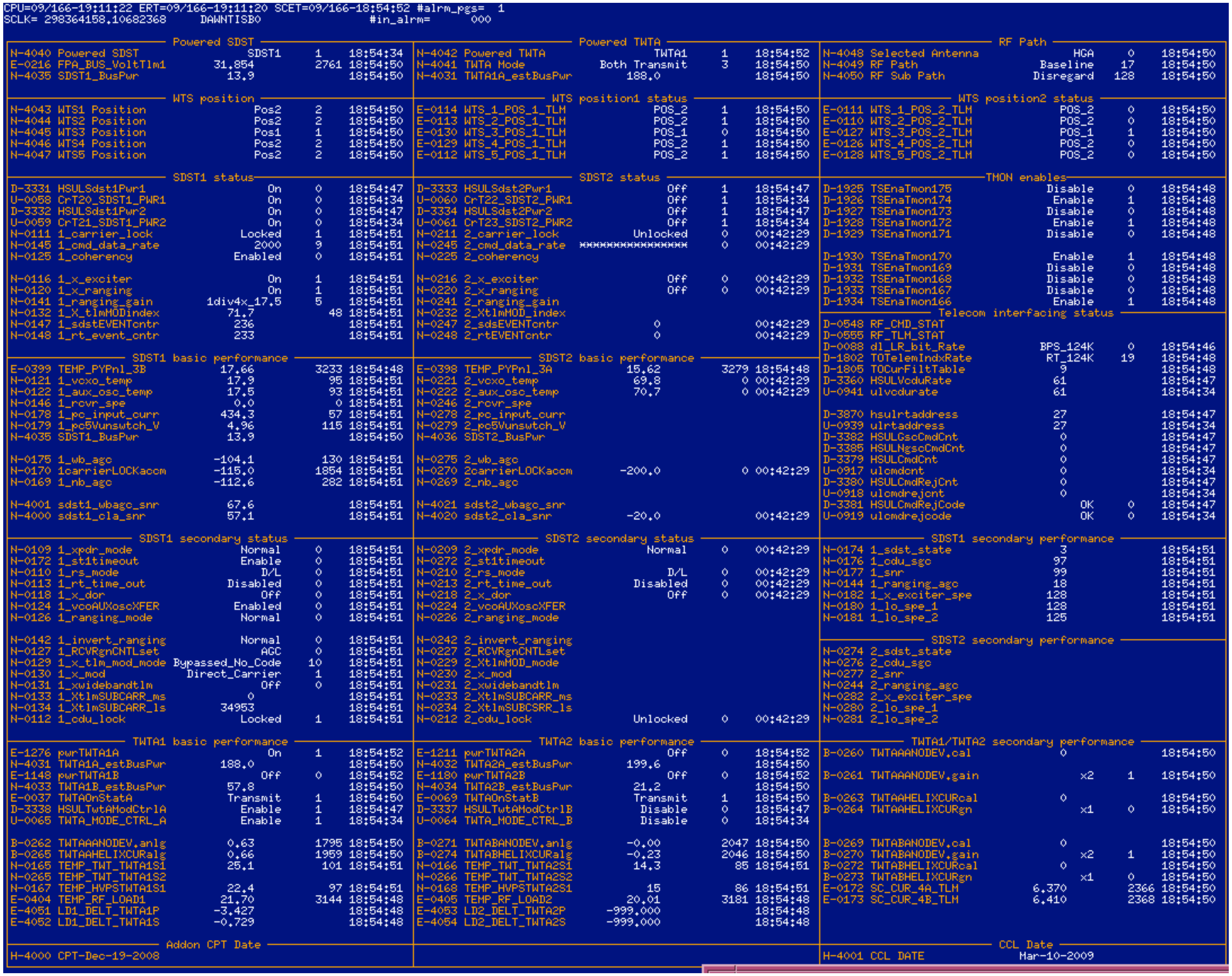
Note: As has been the precedent on other Deep Space missions, the “power” and “thermal” subsystem analysts “own” the telemetry generated by their subsystems, such as bus voltage, bus current to subsystems, and the output of thermal sensors. However, the telecom analyst remains responsible for keeping a “second pair of eyes” on channels that indicate the health of the telecom subsystem. Telecom also maintains trending data relative to data values measured pre-flight or specified in allowable operating ranges or in subsystem hardware specifications.

Reporting includes by voice net during real time (“on line”) support of defined activities, standard periodic (such as daily or weekly) written reports, problem (“incident-surprise-anomaly”) reports, and performance and trend reports at the end of defined mission phases. As required, follow-up to reporting of anomalous configuration or performance includes the analysis and discussion required to help isolate the source of the problem and to develop workarounds.

Both telemetry data and monitor data can be observed in real time. The data is provided by the project’s ground data system in the form of a DMD (data monitor and display) “page” on the workstation. Figure 5-1 and Figure 5-5 are examples of DMD pages used by the telecom analyst while on console. The blue table is an example of telemetry data received with the spacecraft HGA selected. The black table an example of a 34m station’s receiver and telemetry processing performance during a Dawn pass with the spacecraft on the LGA.

Both the station and spacecraft data can be queried as soon as they are stored on the project data base, typically seconds after being displayed in real time. Figure 5-6 is a plot of two of the station quantities, in this case the telemetry symbol SNR and the telemetry data rate, during this 34-m LGA pass.

On Dawn, the trended telecom data is reported to the project weekly in two forms: a short-term tabulation (Table 5-3) and plots that provide one data point per station pass going back to launch (Figure 5-7). The example plot shows temperatures and estimated power drawn from the spacecraft bus for both the SDST and the TWTA. These quantities have remained stable since launch, with the two distinctly different TWTA powers displaying the definition of “estimated” from two distinct power sources.



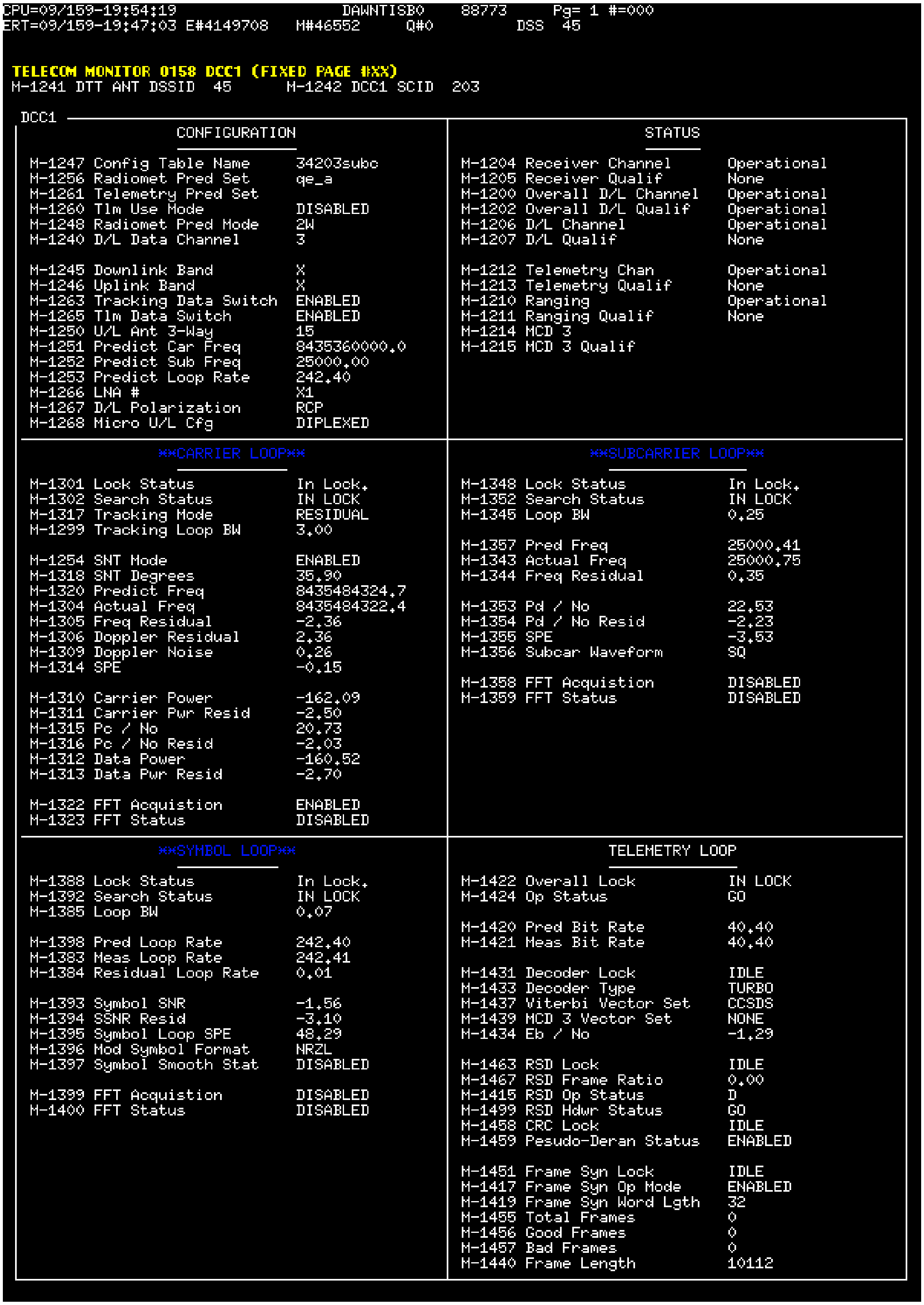
```
CPU=09/166-19:11:22 ERT=09/166-19:11:20 SCET=09/166-18:54:52 #alrm_pgs=  1
SCLK= 298364158.10682368     DAWNTISB0              #in_alrm=      000
```

```
                         Powered SDST
N-4040 Powered SDST                 SDST1     1     18:54:34
E-0216 FPA_BUS_VoltTlm1       31.854       2761 18:54:50
N-4035 SDST1_BusPwr             13.9            18:54:50

                         WTS position
N-4043 WTS1 Position                 Pos2     2     18:54:50
N-4044 WTS2 Position                 Pos2     2     18:54:50
N-4045 WTS3 Position                 Pos1     1     18:54:50
N-4046 WTS4 Position                 Pos2     2     18:54:50
N-4047 WTS5 Position                 Pos2     2     18:54:50

                         SDST1 status
D-3331 HSULSdst1Pwr1                   On     0     18:54:47
U-0058 CrT20_SDST1_PWR1                On     0     18:54:34
D-3332 HSULSdst1Pwr2                   On     0     18:54:47
U-0059 CrT21_SDST1_PWR2                On     0     18:54:34
N-0111 1_carrier_lock              Locked     1     18:54:51
N-0145 1_cmd_data_rate               2000     9     18:54:51
N-0125 1_coherency                Enabled     0     18:54:51

N-0116 1_x_exciter                     On     1     18:54:51
N-0120 1_x_ranging                     On     1     18:54:51
N-0141 1_ranging_gain         1div4x_17.5     5     18:54:51
N-0132 1_X_tlmMODindex          71.7         48 18:54:51
N-0147 1_sdstEVENTcntr           236            18:54:51
N-0148 1_rt_event_cntr           233            18:54:51

                   SDST1 basic performance
E-0399 TEMP_PYPnl_3B           17.66       3233 18:54:48
N-0121 1_vcxo_temp              17.9         95 18:54:51
N-0122 1_aux_osc_temp           17.5         93 18:54:51
N-0146 1_rcvr_spe                0.0          0 18:54:51
N-0178 1_pc_input_curr         434.3         57 18:54:51
N-0179 1_pc5Vunswtch_V          4.96        115 18:54:51
N-4035 SDST1_BusPwr             13.9            18:54:50

N-0175 1_wb_agc               -104.1        130 18:54:51
N-0170 1carrierLOCKaccm       -115.0       1854 18:54:51
N-0169 1_nb_agc               -112.6        282 18:54:51

N-4001 sdst1_wbagc_snr          67.6            18:54:51
N-4000 sdst1_cla_snr            57.1            18:54:51

                    SDST1 secondary status
N-0109 1_xpdr_mode                 Normal     0     18:54:51
N-0172 1_st1timeout                Enable     0     18:54:51
N-0110 1_rs_mode                      D/L     0     18:54:51
N-0113 1_rt_time_out             Disabled     0     18:54:51
N-0118 1_x_dor                        Off     0     18:54:51
N-0124 1_vcoAUXoscXFER            Enabled     0     18:54:51
N-0126 1_ranging_mode              Normal     0     18:54:51

N-0142 1_invert_ranging            Normal     0     18:54:51
N-0127 1_RCVRgnCNTLset                AGC     0     18:54:51
N-0129 1_x_tlm_mod_mode Bypassed_No_Code     10     18:54:51
N-0130 1_x_mod             Direct_Carrier     1     18:54:51
N-0131 1_xwidebandtlm                 Off     0     18:54:51
N-0133 1_XtlmSUBCARR_ms          0                  18:54:51
N-0134 1_XtlmSUBCARR_ls      34953                  18:54:51
N-0112 1_cdu_lock                  Locked     1     18:54:51

                    TWTA1 basic performance
E-1276 pwrTWTA1A                       On     1     18:54:52
N-4031 TWTA1A_estBusPwr        188.0                18:54:50
E-1148 pwrTWTA1B                      Off     0     18:54:52
N-4033 TWTA1B_estBusPwr         57.8                18:54:50
E-0037 TWTAOnStatA               Transmit     1     18:54:50
D-3338 HSULTwtAModCtrlA            Enable     1     18:54:47
U-0065 TWTA_MODE_CTRL_A            Enable     1     18:54:34

B-0262 TWTAAANODEV.anlg         0.63       1795 18:54:50
B-0265 TWTAAHELIXCURalg         0.66       1959 18:54:50
N-0165 TEMP_TWT_TWTA1S1         25.1        101 18:54:51
N-0265 TEMP_TWT_TWTA1S2
N-0167 TEMP_HVPSTWTA1S1         22.4         97 18:54:51
E-0404 TEMP_RF_LOAD1           21.70       3144 18:54:48
E-4051 LD1_DELT_TWTA1P        -3.427            18:54:48
E-4052 LD1_DELT_TWTA1S        -0.729            18:54:48

                       Addon CPT Date
H-4000 CPT-Dec-19-2008
```

```
                         Powered TWTA
N-4042 Powered TWTA                 TWTA1     1     18:54:52
N-4041 TWTA Mode           Both Transmit     3     18:54:50
N-4031 TWTA1A_estBusPwr        188.0                18:54:50

                     WTS position1 status
E-0114 WTS_1_POS_1_TLM              POS_2     1     18:54:50
E-0113 WTS_2_POS_1_TLM              POS_2     1     18:54:50
E-0130 WTS_3_POS_1_TLM              POS_1     0     18:54:50
E-0129 WTS_4_POS_1_TLM              POS_2     1     18:54:50
E-0112 WTS_5_POS_1_TLM              POS_2     1     18:54:50

                         SDST2 status
D-3333 HSULSdst2Pwr1                  Off     1     18:54:47
U-0060 CrT22_SDST2_PWR1               Off     1     18:54:34
D-3334 HSULSdst2Pwr2                  Off     1     18:54:47
U-0061 CrT23_SDST2_PWR2               Off     1     18:54:34
N-0211 2_carrier_lock            Unlocked     0     00:42:29
N-0245 2_cmd_data_rate  ****************     0     00:42:29
N-0225 2_coherency

N-0216 2_x_exciter                    Off     0     00:42:29
N-0220 2_x_ranging                    Off     0     00:42:29
N-0241 2_ranging_gain
N-0232 2_XtlmMOD_index
N-0247 2_sdsEVENTcntr              0                00:42:29
N-0248 2_rtEVENTcntr               0                00:42:29

                   SDST2 basic performance
E-0398 TEMP_PYPnl_3A           15.62       3279 18:54:48
N-0221 2_vcxo_temp              69.8          0 00:42:29
N-0222 2_aux_osc_temp           70.7          0 00:42:29
N-0246 2_rcvr_spe
N-0278 2_pc_input_curr
N-0279 2_pc5Vunswtch_V
N-4036 SDST2_BusPwr

N-0275 2_wb_agc
N-0270 2carrierLOCKaccm       -200.0          0 00:42:29
N-0269 2_nb_agc

N-4021 sdst2_wbagc_snr
N-4020 sdst2_cla_snr           -20.0            00:42:29

                    SDST2 secondary status
N-0209 2_xpdr_mode                 Normal     0     00:42:29
N-0272 2_st1timeout
N-0210 2_rs_mode                      D/L     0     00:42:29
N-0213 2_rt_time_out             Disabled     0     00:42:29
N-0218 2_x_dor                        Off     0     00:42:29
N-0224 2_vcoAUXoscXFER
N-0226 2_ranging_mode

N-0242 2_invert_ranging
N-0227 2_RCVRgnCNTLset
N-0229 2_XtlmMOD_mode
N-0230 2_x_mod
N-0231 2_xwidebandtlm
N-0233 2_XtlmSUBCARR_ms
N-0234 2_XtlmSUBCSRR_ls
N-0212 2_cdu_lock                Unlocked     0     00:42:29

                    TWTA2 basic performance
E-1211 pwrTWTA2A                      Off     0     18:54:52
N-4032 TWTA2A_estBusPwr        199.6                18:54:50
E-1180 pwrTWTA2B                      Off     0     18:54:52
N-4034 TWTA2B_estBusPwr         21.2                18:54:50
E-0069 TWTAOnStatB               Transmit     1     18:54:50
D-3337 HSULTwtAModCtrlB           Disable     0     18:54:47
U-0064 TWTA_MODE_CTRL_B           Disable     0     18:54:34

B-0271 TWTABANODEV.anlg        -0.00       2047 18:54:50
B-0274 TWTABHELIXCURalg        -0.23       2046 18:54:50
N-0166 TEMP_TWT_TWTA2S1         14.3         85 18:54:51
N-0266 TEMP_TWT_TWTA2S2
N-0168 TEMP_HVPSTWTA2S1           15         86 18:54:51
E-0405 TEMP_RF_LOAD2           20.01       3181 18:54:48
E-4053 LD2_DELT_TWTA2P      -999.000            18:54:48
E-4054 LD2_DELT_TWTA2S      -999.000            18:54:48
```

```
                           RF Path
N-4048 Selected Antenna               HGA     0     18:54:50
N-4049 RF Path                   Baseline    17     18:54:50
N-4050 RF Sub Path              Disregard   128     18:54:50

                     WTS position2 status
E-0111 WTS_1_POS_2_TLM              POS_2     0     18:54:50
E-0110 WTS_2_POS_2_TLM              POS_2     0     18:54:50
E-0127 WTS_3_POS_2_TLM              POS_1     1     18:54:50
E-0126 WTS_4_POS_2_TLM              POS_2     0     18:54:50
E-0128 WTS_5_POS_2_TLM              POS_2     0     18:54:50

                         TMON enables
D-1925 TSEnaTmon175               Disable     0     18:54:48
D-1926 TSEnaTmon174                Enable     1     18:54:48
D-1927 TSEnaTmon173               Disable     0     18:54:48
D-1928 TSEnaTmon172                Enable     1     18:54:48
D-1929 TSEnaTmon171               Disable     0     18:54:48

D-1930 TSEnaTmon170                Enable     1     18:54:48
D-1931 TSEnaTmon169               Disable     0     18:54:48
D-1932 TSEnaTmon168               Disable     0     18:54:48
D-1933 TSEnaTmon167               Disable     0     18:54:48
D-1934 TSEnaTmon166                Enable     1     18:54:48
                  Telecom interfacing status
D-0548 RF_CMD_STAT
D-0555 RF_TLM_STAT
D-0088 dl_LR_bit_Rate           BPS_124K      0     18:54:46
D-1802 TOTelemIndxRate           RT_124K     19     18:54:48
D-1805 TOCurFiltTable          9                    18:54:48
D-3360 HSULVcduRate           61                    18:54:47
U-0941 ulvcdurate             61                    18:54:34

D-3870 hsulrtaddress          27                    18:54:47
U-0939 ulrtaddress            27                    18:54:34
D-3382 HSULGscCmdCnt           0                    18:54:47
D-3385 HSULNgscCmdCnt          0                    18:54:47
D-3379 HSULCmdCnt              0                    18:54:47
U-0917 ulcmdcnt                0                    18:54:34
D-3380 HSULCmdRejCnt           0                    18:54:47
U-0918 ulcmdrejcnt             0                    18:54:34
D-3381 HSULCmdRejCode                  OK     0     18:54:47
U-0919 ulcmdrejcode                    OK     0     18:54:34

                 SDST1 secondary performance
N-0174 1_sdst_state            3                    18:54:51
N-0176 1_cdu_sgc              97                    18:54:51
N-0177 1_snr                  99                    18:54:51
N-0144 1_ranging_agc          18                    18:54:51
N-0182 1_x_exciter_spe       128                    18:54:51
N-0180 1_lo_spe_1            128                    18:54:51
N-0181 1_lo_spe_2            125                    18:54:51

                 SDST2 secondary performance
N-0274 2_sdst_state
N-0276 2_cdu_sgc
N-0277 2_snr
N-0244 2_ranging_agc
N-0282 2_x_exciter_spe
N-0280 2_lo_spe_1
N-0281 2_lo_spe_2

              TWTA1/TWTA2 secondary performance
B-0260 TWTAAANODEV.cal         0                    18:54:50

B-0261 TWTAAANODEV.gain                x2     1     18:54:50

B-0263 TWTAAHELIXCURcal        0                    18:54:50
B-0264 TWTAAHELIXCURgn                 x1     0     18:54:50


B-0269 TWTABANODEV.cal         0                    18:54:50
B-0270 TWTABANODEV.gain                x2     1     18:54:50
B-0272 TWTABHELIXCURcal        0                    18:54:50
B-0273 TWTABHELIXCURgn                 x1     0     18:54:50
E-0172 SC_CUR_4A_TLM           6.370       2366 18:54:50
E-0173 SC_CUR_4B_TLM           6.410       2368 18:54:50

                           CCL Date
H-4001 CCL DATE              Mar-10-2009
```

Figure 5-4. Dawn telecom spacecraft Data Monitor and Display (DMD).



```
CPU=09/159-19:54:19                  DAWNTISBO    88773     Pg= 1 #=000
ERT=09/159-19:47:03 E#4149708   M#46552     Q#0         DSS  45

 TELECOM MONITOR 0158 DCC1 (FIXED PAGE #XX)
 M-1241 DTT ANT DSSID  45      M-1242 DCC1 SCID  203

  DCC1
                   CONFIGURATION                                     STATUS

   M-1247 Config Table Name     34203subc         M-1204 Receiver Channel      Operational
   M-1256 Radiomet Pred Set     qe_a              M-1205 Receiver Qualif       None
   M-1261 Telemetry Pred Set                      M-1200 Overall D/L Channel   Operational
   M-1260 Tlm Use Mode          DISABLED          M-1202 Overall D/L Qualif    Operational
   M-1248 Radiomet Pred Mode    2W                M-1206 D/L Channel           Operational
   M-1240 D/L Data Channel      3                 M-1207 D/L Qualif            None

   M-1245 Downlink Band         X                 M-1212 Telemetry Chan        Operational
   M-1246 Uplink Band           X                 M-1213 Telemetry Qualif      None
   M-1263 Tracking Data Switch  ENABLED           M-1210 Ranging               Operational
   M-1265 Tlm Data Switch       ENABLED           M-1211 Ranging Qualif        None
   M-1250 U/L Ant 3-Way         15                M-1214 MCD 3
   M-1251 Predict Car Freq      8435360000.0      M-1215 MCD 3 Qualif
   M-1252 Predict Sub Freq      25000.00
   M-1253 Predict Loop Rate     242.40
   M-1266 LNA #                 X1
   M-1267 D/L Polarization      RCP
   M-1268 Micro U/L Cfg         DIPLEXED

                 **CARRIER LOOP**                               **SUBCARRIER LOOP**

   M-1301 Lock Status           In Lock.          M-1348 Lock Status           In Lock.
   M-1302 Search Status         IN LOCK           M-1352 Search Status         IN LOCK
   M-1317 Tracking Mode         RESIDUAL          M-1345 Loop BW               0.25
   M-1299 Tracking Loop BW      3.00
                                                  M-1357 Pred Freq             25000.41
   M-1254 SNT Mode              ENABLED           M-1343 Actual Freq           25000.75
   M-1318 SNT Degrees           35.90             M-1344 Freq Residual         0.35
   M-1320 Predict Freq          8435484324.7
   M-1304 Actual Freq           8435484322.4      M-1353 Pd / No               22.53
   M-1305 Freq Residual         -2.36             M-1354 Pd / No Resid         -2.23
   M-1306 Doppler Residual      2.36              M-1355 SPE                   -3.53
   M-1309 Doppler Noise         0.26              M-1356 Subcar Waveform       SQ
   M-1314 SPE                   -0.15
                                                  M-1358 FFT Acquistion        DISABLED
   M-1310 Carrier Power         -162.09           M-1359 FFT Status            DISABLED
   M-1311 Carrier Pwr Resid     -2.50
   M-1315 Pc / No               20.73
   M-1316 Pc / No Resid         -2.03
   M-1312 Data Power            -160.52
   M-1313 Data Pwr Resid        -2.70

   M-1322 FFT Acquistion        ENABLED
   M-1323 FFT Status            DISABLED

                 **SYMBOL LOOP**                                  TELEMETRY LOOP

   M-1388 Lock Status           In Lock.          M-1422 Overall Lock          IN LOCK
   M-1392 Search Status         IN LOCK           M-1424 Op Status             GO
   M-1385 Loop BW               0.07
                                                  M-1420 Pred Bit Rate         40.40
   M-1398 Pred Loop Rate        242.40            M-1421 Meas Bit Rate         40.40
   M-1383 Meas Loop Rate        242.41
   M-1384 Residual Loop Rate    0.01              M-1431 Decoder Lock          IDLE
                                                  M-1433 Decoder Type          TURBO
   M-1393 Symbol SNR            -1.56             M-1437 Viterbi Vector Set    CCSDS
   M-1394 SSNR Resid            -3.10             M-1439 MCD 3 Vector Set      NONE
   M-1395 Symbol Loop SPE       48.29             M-1434 Eb / No               -1.29
   M-1396 Mod Symbol Format     NRZL
   M-1397 Symbol Smooth Stat    DISABLED          M-1463 RSD Lock              IDLE
                                                  M-1467 RSD Frame Ratio       0.00
   M-1399 FFT Acquistion        DISABLED          M-1415 RSD Op Status         D
   M-1400 FFT Status            DISABLED          M-1499 RSD Hdwr Status       GO
                                                  M-1458 CRC Lock              IDLE
                                                  M-1459 Pesudo-Deran Status   ENABLED

                                                  M-1451 Frame Syn Lock        IDLE
                                                  M-1417 Frame Syn Op Mode     ENABLED
                                                  M-1419 Frame Syn Word Lgth   32
                                                  M-1455 Total Frames          0
                                                  M-1456 Good Frames           0
                                                  M-1457 Bad Frames            0
                                                  M-1440 Frame Length          10112
```

Figure 5-5. Typical DMD page for station receiver/telemetry monitor data.

Table 5-3. "Point per pass" Dawn and station data for trending.

	A	B	FW	FX	FY	FZ	GA	GB	GC	GD	GE
1	**chan id**	**Report Date: June 8, 2009** **channel name**	2009-151 19:40 utc eot dss26 125000 dl & 2000 ul	2009-152 19:05 utc dss15 dor 125000 dl & 2000 ul	2009-153 19:15 utc eot dss25 125000 dl & 2000 ul	2009-156 04:00 eot dss45 PB 125000 dl & 2000 ul	2009-156 16:35 utc eot dss24 125000 dl & 2000 ul	2009-157 22:40 utc eot dss26 125000 dl & 2000 ul	2009-158 19:35 utc eot dss25 125000 dl & 2000 ul	2009-159 18:03 utc eot dss15 125000 dl & 2000 ul	2009-159 21:45 utc TV dss45 40 dl & 31 ul - thrust
2		**owlt_litime**	0:16:48	0:16:48	0:16:46	0:16:42	0:16:42	0:16:40	0:16:39	0:16:38	0:16:38
3	N-4043	WTS1 Position	2	2	2	2	2	2	2	2	1
4	N-4044	WTS2 Position	2	2	2	2	2	2	2	2	1
5	N-4045	WTS3 Position	2	2	2	2	2	2	2	2	1
6	N-4046	WTS4 Position	2	2	2	2	2	2	2	2	2
7	N-4047	WTS5 Position	2	2	2	2	2	2	2	2	2
8	N-4048	Selected antenna	HGA 0dn	HGA 0dn	HGA 0dn	HGA 0dn	HGA 0dn	HGA 0dn	HGA 0dn	HGA 0dn	pxlga 2dn
9	N-4049	RF path	bselin 17dn	bselin 17dn	bselin 17dn	bselin 17dn	bselin 17dn	bselin 17dn	bselin 17dn	bselin 17dn	bselin 17dn
12	N-4040	Powered SDST	1	1	1	1	1	1	1	1	1
13	N-4042	Powered TWTA	1	1	1	1	1	1	1	1	1
16	N-0145	1_cmd_data_rate	2000	2000	2000	2000	2000	2000	2000	2000	31.25
17	N-0125	1_coherency	enabled	enabled	enabled	enabled	enabled	enabled	enabled	enabled	n/a
18	N-0116	1_x_exciter	on	on	on	on	on	on	on	on	on
19	N-0120	1_x_ranging	on	on	on	on	on	on	on	on	off
20	N-0141	1_ranging_gain	1div4x_17.5	1div4x_17.5	1div4x_17.5	1div4x_17.5	1div4x_17.5	1div4x_17.5	1div4x_17.5	1div4x_17.5	n/a
21	N-0132	1_X_tlmMODindex	48 dn	48 dn	48 dn	48 dn	48 dn	48 dn	48 dn	48 dn	n/a
22	N-0111	1_carrier_lock	lock 12:10	lock 13:10	lock 12:05	lock 21:23	lock 13:24	lock 15:05	lock 12:00	lock 13:45	n/a tfr
23	N-0112	1_cdu_lock	unlocked	lock 13:18	unlocked	lock 22:04	unlocked	unlocked	unlocked	lock 13:57	unlocked
24	N-0147	1_sdstEVENTcntr	110	217	95	142	202	82	163	18	37
26		pass end (from query)	19:40	19:05	19:15	4:00	16:35	22:40	19:35	18:03	21:45
27	N-4035	SDST1 bus power	13.9	14.0	13.9	14.0	13.9	14.0	13.9	14.0	
28	E-0399	TEMP_PYPnl_3B	17.7	17.7	17.7	17.7	17.7	17.7	17.6	17.7	
29	N-0121	1_vcxo_temp	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	18.7
30	N-0122	1_aux_osc_temp	17.7	18.0	17.8	17.9	17.8	17.9	17.7	18.0	18.7
31	N-0146	1_rcvr_spe	-170	-168	-170	-167	-172	-171	-171	-166	
32	N-0175	1_wb_agc	-107.4	-106.0	-105.9	-104.9	-106.0	-106.0	-105.4	-105.7	
33	N-0178	1_pc_input_curr	433	436	433	436	433	436	433	436	
34	N-0179	1_pc5Vunswtch_V	4.97	4.97	4.97	4.97	4.97	4.97	4.97	4.97	
35	N-0170	1carrierLOCKaccm	-107.8	-115.2	-107.9	-113.9	-107.3	-107.0	-107.6	-114.8	-133.9
36	N-0169	1_nb_agc	-107.2	-113.1	-107.3	-111.5	-106.9	-106.6	-107.0	-112.7	
38	N-0431	TWTA1A_estBusPwr	220.1	190.3	190.1	190.2	190.1	190.1	190.2	190.5	
39	B-0262	TWTAAANODEV.anlg	0.626	0.626	0.626	0.626	0.626	0.626	0.627	0.627	0.626
40	B-0265	TWTAAHELIXCUR	0.662	0.662	0.662	0.662	0.662	0.662	0.663	0.662	0.657
41	N-0165	TEMP_TWT_TWTA1S1	23.6	23.6	23.6	23.6	23.6	23.6	23.6	23.6	
42	N-0167	TEMP_HVPS_TWTA1S1	22.6	22.7	22.6	22.6	22.6	22.6	22.5	22.6	
43	E-0404	LD1_TEMP	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	
46	M-0309	Conscan loop state	close12:28	close13:27	close12:22	close21:43	close13:53	close19:09	off-open	close14:02	off-open
47	M-1421	FS data rate	125000.0	125000.0	125000.0	125000.0	125000.0	125000.0	125000.0	125000.0	40.4
48	M-0042	Station (dss ID)	26	15	25	45	24	26	25	15	45
49	M-0304	Elevation, deg	49.8	54.0	50.0	35.7	52.7	46.4	50.8	57.9	27.4
50	M-1067	Txr_pwr, kW	16.2	20.8	19.7	17.8	18.7	19.9	20.2	20.9	17.5
51	M-1306	doppler freq (MON-2w)	1.91	2.04	2.17	2.51	2.56	2.70	2.82	2.18	2.33
52	M-1310	carrier power (MON)	-132.6	-133.2	-133.1	-132.9	-133.2	-132.5	-133.0	-133.2	-161.8
53	M-1315	Pc/No (MON)	52.3	50.8	50.8	50.1	50.5	51.9	50.9	50.9	21.2
54	M-1318	system noise temp (MON)	23.8	29.2	29.4	36.8	30.9	26.9	29.1	28.4	35.7
55	M-1393	tlm symbol SNR (MON)	2.7	1.3	1.2	0.6	0.9	2.2	1.3	1.6	-1.3
56	M-1512	ranging Pr/No (MON)	27.1	31.4	36.0	31.1	36.0	30.9	36.4	29.4	
57	M-1544	mean(DRVID)	-0.020	0.002	0.064	0.024	-0.017	0.000	-0.022	-0.023	
58	|M-1544|	abs(DRVID)	0.90	1.08	1.06	1.22	0.75	0.95	1.09	1.27	
59	M-1604	turbo_confid	661	559	538	526	532	708	549	578	365
60	M-1510	rng_confid	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
61	M-1306	doppler freq (MON-1w)	203	336	210	332	203	334	154	380	n/a tfr
62	SEP angle	(or day of week)	Sun 5/31	Mon 6/1	Tue 6/2	Fri 6/5	Fri 6/5	Sat 6/6	Sun 6/7	Mon 6/8	Mon 6/8
64	**Extremes**	**Special / Summary**	txr pwr avg 16.2 kW, eot snt 2 dB	OK, on dciuA at 17:03 utc scet	OK	OK, snt to 57K after 03:00 (rain?)	OK	OK, snt to 40K after 19:20 (thunder?)	OK	OK, dc027 hga then pxLGA for thrust	OK
65		cmd bit-1 utc ett		13:01:19		21:47:04				13:38:01	
66		utc scet		13:18:07		22:03:46				13:54:39	
67		utc ert		13:34:55		22:20:28				14:11:17	
68		cmd mod off utc ett		18:36:16		3:50:00				17:25:00	
69		utc scet		18:53:04		4:06:42				17:41:38	
70		utc ert		19:09:52		4:23:24				17:58:16	
71		degradation in AGC (bit_1)		on -0.2 dB		on -0.3 dB				on -0.3 dB	
72		degradation in AGC (md mod off)		off > ddor		off > eot				off 0.2 dB	
73		recent noticeable change									
74		data not in PSP_40 DMd									
75		value during special config									
76	MAX anodeV	0.627									
77	MAX helix I	0.680									

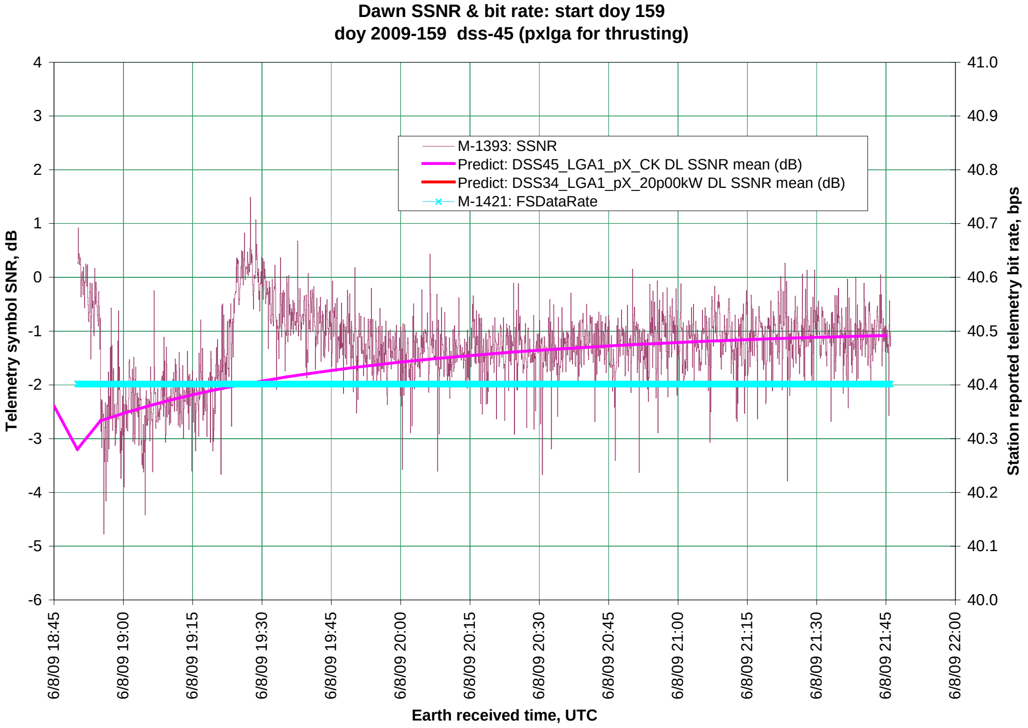


Figure 5-6. Typical station data plot from data queried during a Dawn pass.

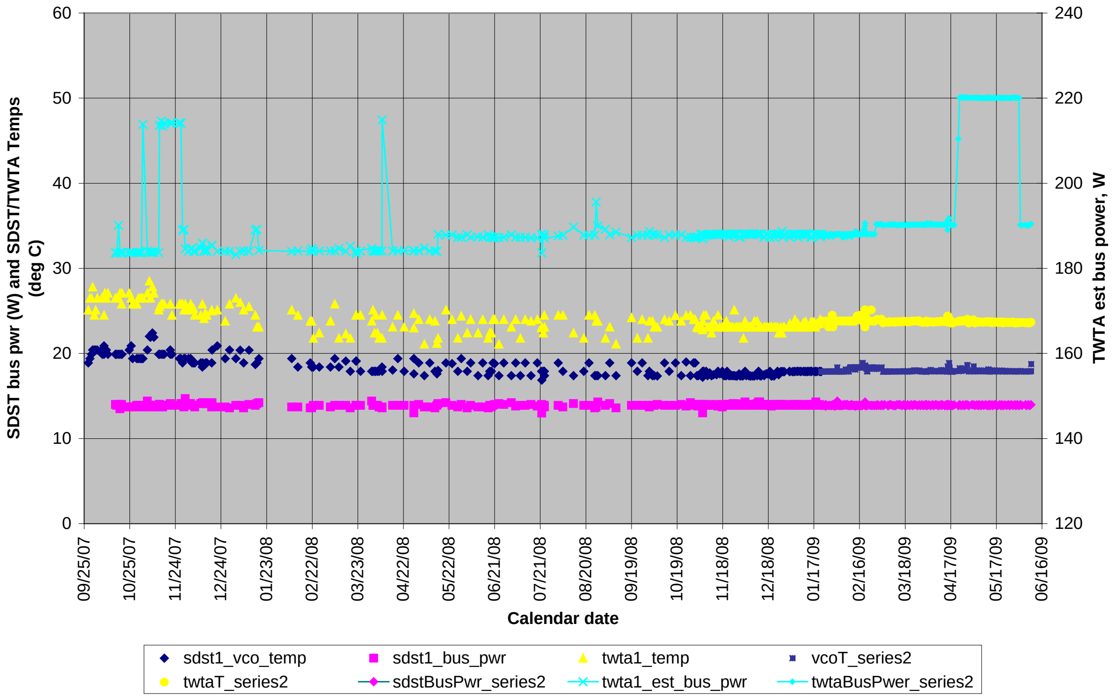


Figure 5-7. Trended Dawn SDST and TWTA telecom telemetry data through June 2009.

6 Telecom Lessons Learned

Dawn telecom has been fortunate that through August 2009 the on-board subsystems have worked well since launch, and there have been few surprises in terms of performance. The following lessons-learned are offered as an expression of good practices that have evolved over Deep Space missions in the last dozen or so years.

1. Characterize important parameters by test so that accurate and precise predictions can be made. Dawn example: the 2-dimensional pattern for the pXLGA, the one most used.
2. Utilize standard equipment, whose characteristics become better known with each project. Dawn example: the SDST, which was first used on Deep Space1 (1998) and on more than a half dozen projects since.
3. Adapt standard software from project to project, which results in cost effectiveness and well understood behavior. Dawn example: Telecom Forecaster Predictor, first used on Cassini (1997).
4. Automate routine operations whenever possible, both for cost-effectiveness and standardization. Dawn examples: (1) reusable communications blocks, (2) query tools such as dawn_tuna, (3) telecom analysis tools such as the templates for monitor, SDST, and TWTA daily assessment.

7 Abbreviations and Acronyms

1553	(MIL-STD-1553) a military standard for digital communications
ACE	attitude and control electronics
ACE	Call sign (not an acronym) for the project mission controller
ACS`	attitude control system
AGC	automatic gain control
Ahr	ampere hour
AOS	acquisition of signal
AOS/LOS	acquisition of signal/loss of signal
ASIC	application-specific integrated circuit
AT	attenuator
ATLO	assembly, test launch, and launch operations
AU	astronomical unit (150*10^6 km)
BCH	Bose-Chaudhari- Hocquenghem (code)
BGO	bismuth germinate
BLF	best lock frequency
bps	bits per second
BPSK	binary phase shift key
BPSK/PM	binary phase shift key
BWG	beam waveguide
CADU	channel access data unit
CCD	charge coupled device
CCSDS	Consultative Committee for Space Data Systems
CDH	command and data handling
C&DH	command and data handling
CDSCC	Canberra Deep Space Communications Complex
CDU	command detector unit
CdZnTe	cadmium-zinc-telluride
CEU	central electronics unit
CH	camera head
CLA	carrier lock accumulator

CMD	command
CSS	coarse Sun sensor
DAC	digital to analog
dB	decibel
DC	direct current
DCIU	digital control interface unit
DDOR	delta differential one-way ranging
deg	degree
DL	downlink
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DMD	Data Monitor and Display
DN	data number, digital number
DOD	depth of discharge
DOR	differential one-way ranging
DPM	digital processor module
DRO	dynamic resonance oscillator
DRAM	dynamic random access memory
DS1	Deep Space 1 spacecraft
DSN	Deep Space Network
DSS	Deep Space Station
DST	deep space transponder
EDD	Electron Dynamic Devices division of Boeing
EEPROM	electrically erasable programmable read-only memory
EPA	electrical power subsystem
EPC	electronic power converter
EPS	electrical power subsystem
ESA	European Space Agency
ESOC	European Space Operations Centre
Exc	exciter
F	filter
FC	framing camera
f/D	ratio of focal distance and diameter
FD&C	fault detection and correction

FP	fault protection
FPGA	field-programmable gate array
ESTRACK	European Space Tracking
FP	fault protection
FPA	fuse protection assembly
FPGA	field programmable gate array
FRO	frequency reference offset
FS	flight system
FSW	flight software
FT	flight thruster
GaAs	gallium arsenide
GALEX	Galaxy Evolution Explorer
GDE	gimbal-drive electronics
GUI	graphical user interface
GRaND	gamma ray and neutron detector (GRaND)
GS20	lithiated-glass
HAMO	high altitude mapping orbit
HCD	hardware command decoder
HDRM	hold-down and release mechanism
HGA	high-gain antenna
HVEA	high voltage electronics assembly
ICO	initial checkout
IAP	ion propulsion system
IDA	Institut fur Datentechnik und Kommunikationsnetze
IF	Intermediate frequency
IFMS	Integrated Facilities Management System
I/F	interface
IFSI	Istituto di fisica dello Spazio Interplanetario
IPS	Ion propulsion subsystem
I/Q	in phase/quadrature
IFSI	Istituto di Pisica dello Spazio Interplanetario
IRU	inertial reference unit

JPL	Jet Propulsion Laboratory
kbps	kilobits per second
KHz	kilohertz
L	launch
LAMO	low altitude mapping orbit
LCP	left circular polarization
LGA	low gain antenna mZLGA: LGA aligned with the minus-Z spacecraft axis pXLGA: LGA aligned with the plus-X spacecraft axis pZLGA: LGA aligned with the plus-Z spacecraft axis
LOS	loss of signal
LOX	liquid oxygen
LTTT	low-thrust trajectory tools
LVPS	low voltage power supply
M & C	monitor & control
MAQ	Magellan acquisition
ME	(VIR) Main Electronics
MER	Mars Exploration Rover
MGA	Mars gravity assist
MHz	megahertz
minute	min
MPAe	Max Planck Institute for Aeronomy
N_2H_4	hydrazine
Nb	narrow band
NiH_2	nickel hydride
NOOP	NO OPeration
NRZ-L	non return to zero – level
NSTAR	NASA Solar electric propulsion Technology Applications Readiness
OBC	on board computer
OCM	orbit correction maneuver
OpNav	optical navigation

OS	operating system
OSC	Orbital Sciences Corporation
PC	power converter
PCM	pulse code modulation
PDU	power distribution unit
PEM	proximity electronics module
pXLGA	plus X_low-gain antenna
pZLGA	plus Z low-gain antenna
PMD	propellant management device
PMT	photo multipler tube
PPU	power processing unit
Pt	total power
PVCDU	partial virtual channel data unit
PXLGA	LGA aligned with the plus-X spacecraft axis
pZLGA	LGA aligned with the plus-Z spacecraft axis
RCS	reaction control subsystem
RCP	right circular polarization
REA	rocket engine assembly
RF	radio frequency
RIU	remote interface unit
RP	rocket propellant or refined petroleum (kerosene)
RT	remote terminal
RTS	relative timed sequence
RWA	reaction wheel assembly
Rx	receive
S1	state 1
S/A	solar array
SADA	solar array drive assembly
SADE	solar array drive electronics
S/C	spacecraft
SDC	static/dynamic optimal control
SDST	small deep space transponder
seqgen	sequence generation

SFTP	secure file transfer protocol
SIT	select in test (attenuator)
SMA	coaxial connector using a 4.2-mm diameter outer coaxial
s/n	serial number
SNR	signal to noise ratio
SORCE	SOlar Radiation Climate Experiment
SR	sweep range
SRM	solid rocket motor
SPE	static phase error
SPE	Sun–probe–Earth angle
SR	sweep range
SRM	solid rocket motor
STE	system test equipment
SW	switch
TCM	trajectory correction maneuver
TCS	thermal control subsystem
TFP	telecom forecaster predictor
TGA	thruster gimbal assembly
TLM	telemetry
TMU	telemetry modulation unit
TR	tuning rate
Tx	transmitter
TV	thrust verification
TWTA	traveling wave tube amplifier
UL	uplink
USO	ultra stable oscillator
UTC	Universal Time Coordinated
VCO	voltage controlled oscillator
VCXO	voltage controlled crystal oscillator
VIR	visible and infrared mapping spectrometer (VIR)
VML	virtual machine language
VoIP	voice over internet protocol
VR	virtual recorder

Wb	wideband
WG	waveguide
WR-112	waveguide with inside dimensions 1.122 x 0.497 inches
WTS	Waveguide transfer switch
X-band	RF frequencies from 7 to 12.5 GHz
XCA	xenon control assembly
Xe	xenon
XFS	xenon feed system

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