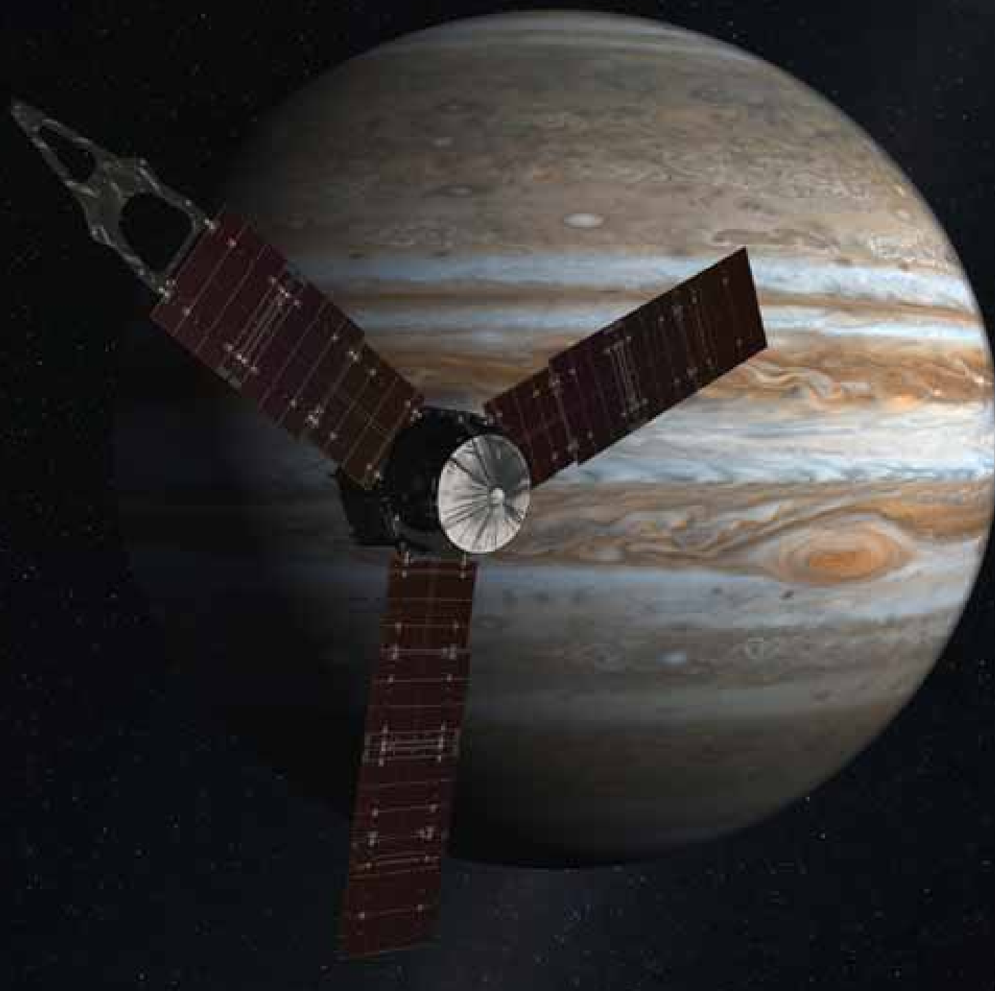
Juno Telecommunications

*Ryan Mukai, David Hansen, Anthony Mittskus,
Jim Taylor, and Monika Danos*

October 2012



Jet Propulsion Laboratory
California Institute of Technology

DESCANSO
Deep Space Communications and Navigation Systems
Center of Excellence

Design and Performance Summary Series

The cover

The cover is an artist's conception of Juno in orbit around Jupiter.[1] The photovoltaic panels are extended and pointed within a few degrees of the Sun while the high-gain antenna is pointed at the Earth.

[1] The picture is titled Juno Mission to Jupiter. See http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA13087 for the cover art and an accompanying mission overview.

DESCANSO Design and Performance Summary Series

Article 16

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DESCANSO DESIGN AND PERFORMANCE SUMMARY SERIES

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Center of Excellence
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Joseph H. Yuen, Editor-in-Chief

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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 of 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, the series collectively provides readers with a broad overview of the mission systems described.

Joseph H. Yuen

DESCANSO Leader

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Preface

Launched from Earth in 2011, the Juno spacecraft will arrive at Jupiter in 2016 to study the giant planet from an elliptical, polar orbit. Juno will repeatedly dive between the planet and its intense belts of charged particle radiation, coming only 5,000 kilometers (about 3,000 miles) from the cloud tops at closest approach.

Juno’s primary goal is to improve our understanding of Jupiter’s formation and evolution. The spacecraft will spend a year investigating the planet's origins, interior structure, deep atmosphere and magnetosphere. Juno’s study of Jupiter will help us to understand the history of our own solar system and provide new insight into how planetary systems form and develop in our galaxy and beyond.

This article is current as of September 14, 2012. As of that date, Juno had completed both parts of the Deep Space Maneuver.

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Acknowledgements

This article is a compilation of data from many sources. Much of the telecom information in this article was directly obtained from the *Juno Mission Plan* [1], the *Juno Project Telecommunications Design Control Documen*t [2], the *Juno Ka-Band Translator (KaTS) User Manual* [3], the *DSN Telecommunications Link Design Handbook*, 810-005 [4], the *Juno Project Navigation Plan* [5], the *Dawn Telecommunications* article in the DESCANSO series [6], the *Deep Space Network* (DSN) web site [7], the *DSN-Juno Operations Interface Control Document* (OICD) [8], the Juno Launch and Early Orbit Phase (LEOP) Implementing Agreement [9], and the *Small Deep Space Transponder (SDST) Functional Specification and Interface Control Document* [10].

Susan Kurtik, Padma Varanasi, and Wolfgang Heil are the authors of Ref. [9], and large amounts of this document were incorporated into Section 4 directly. Moreover, the Juno OICD is the product of the hard work of many individuals, and we gratefully acknowledge Susan Kurtik and Padma Varanasi again for their efforts here as OICD material has been incorporated into this document as well. Stuart Stephens is the author of Ref. [1], and we have also incorporated a great deal of his material, especially in Section 5 but also in other important parts of this article. We have also used material supplied by Matt Johnson, including his Cruise phase Baseline Reference Mission (BRM) spreadsheet, in the process of writing this article, and his help, knowledge, and materials are also gratefully acknowledged. We thank Entry, Descent, and Landing (EDL) Data Analysis (EDA) tones detection engineer Melissa Soriano for her review and for her feedback on this article.

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1 Mission Phases and Orbit Summary

1.1 Mission Overview

The Juno Project has the primary objective of delivering an orbiter with a specific science payload into polar orbit at Jupiter for a nominal duration of one Earth year. The remote sensing, in situ, and gravity science measurements will characterize Jupiter's interior, atmosphere, and polar magnetosphere with the primary science goal of understanding Jupiter's origin and evolution. The investigations will study the present state of Jupiter, not necessarily the time variability of the system, with the exception of the investigation of Jovian dynamics as it applies to understanding Jupiter's atmosphere and polar magnetosphere. The investigations will be enabled by measurements from observations of the polar region and from close perijove vantage points at Jupiter.

The spinning solar-powered spacecraft will carry a unique payload consisting of:

1. Microwave Radiometer (MWR) to measure the microwave brightness temperature of Jupiter.
2. Fluxgate Magnetometers (FGMs) to measure the Jovian magnetic field and Advanced Stellar Compass (ASC) to measure the orientation of the magnetometers. The abbreviation (MAG) for magnetometer is used to refer to the complete magnetometer instrument consisting of the ASC and the FGMs.
3. Gravity Science (Grav), which is part of the Telecom Subsystem as described in Section 2, to perform gravity measurements that will map Jupiter's interior structure.
4. Jovian Auroral Distributions Experiment (JADE) to resolve the plasma structure of the Jovian aurora by measuring the angular, energy and compositional distributions of particles in the polar magnetosphere of Jupiter.[2]
5. Jupiter Energetic-particle Detector Instrument (JEDI) to measure the energy and angular distribution of hydrogen, helium, oxygen, sulfur, and other ions in the polar magnetosphere of Jupiter using the time of flight versus energy technique.
6. Ultraviolet Spectrograph (UVS) to record the wavelength, position, and arrival time of detected ultraviolet photons during the time when the spectrograph slit views Jupiter during each turn of the spacecraft. It will provide spectral images of the UV auroral emissions in the polar magnetosphere.
7. The Waves (plasma waves/radio) instrument, using electric and magnetic antennas, will identify the regions of auroral currents that define Jovian radio emissions and acceleration of the auroral particles by measuring the radio and plasma spectra in the auroral region. Waves is the name of the investigation and the instrument, not an acronym.
8. JunoCam to provide visible color images to aid education and public outreach. It will provide the first pictures of Jupiter's poles.[3]

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[2] Grav, JADE, JEDI, UVS and Waves are defined in http://juno.wisc.edu/spacecraft_instruments_PMS.html.
[3] The JunoCam and JIRAM are defined in http://www.lockheedmartin.com/us/products/juno.html.

9. Jovian Infrared Auroral Mapper (JIRAM) is an infrared camera that acquires infrared images and spectra to provide atmospheric sounding and observations of the auroral structure and the troposphere structure.

These instruments are illustrated in Figures 1-1 and 1-2 below.

The observations will be obtained through orientation of the spin plane (approximately parallel to the orbit plane) and simple operations (no scan platform or instrument pointing). Gravity science will require communication antenna pointing to Earth, while microwave sounding of the atmosphere will require nadir pointing through the center of Jupiter. These two pointing/spin plane settings (gravity or microwave) will provide for all science measurements as all other experiments utilize ride-along pointing and will work in all orbits.

Primary science observations will be obtained within 3 hours of closest approach to Jupiter during each orbit. Calibrations, occasional remote sensing, and magnetospheric science observations are planned throughout the orbits. JunoCam will provide visible-light three-color images for educational and public outreach purposes.

1.2 The Juno Spacecraft

The primary systems of the Juno Project consist of a flight system, a launch vehicle, and the terrestrial ground data processing stations. The flight system consists of a spacecraft (S/C) with an integrated instrument package. Figure 1-2 shows a depiction of the spacecraft.

In Figure 1-2, the FLGA and MGA are antennas (forward low-gain antenna and medium-gain antenna, respectively. The SA is the solar array with its restraint and release mechanisms, and the RCS REMs are the reaction control system thrusters for attitude control.

Figure 1-3 shows the Juno S/C coordinate system that is used throughout this document. The flight system spins about the +Z axis with a positive rate, in a right-handed sense. In Figure 1-3, the +Z axis is toward the reader, and the HGA is pointing toward the reader.

The Magnetometer (MAG) consists of the FGM and ASC sensors, and it is at the end of Solar Wing 1.

1.3 Mission Phases

1.3.1 Launch Phase

Table 1-1 summarizes the phases of the Juno mission. The Juno spacecraft was launched on August 5, 2011. The launch vehicle was an Atlas 551. The Launch phase began when the spacecraft transferred to internal power on the launch pad and ended when the spacecraft was declared stable, healthy, and ready to accept commands, and when the launch telemetry had been played back. The major activities in the Launch phase included the liftoff and boost phase of the launch vehicle, insertion into a circular parking orbit, a coast period, followed by additional launch vehicle upper stage burns necessary to inject the spacecraft onto a trajectory away from Earth, separation of the spacecraft from the launch vehicle, initial acquisition by the Deep Space Network (DSN), verification of the initial spacecraft health and operating conditions, and the verified execution of a minimal set of post-launch commands.

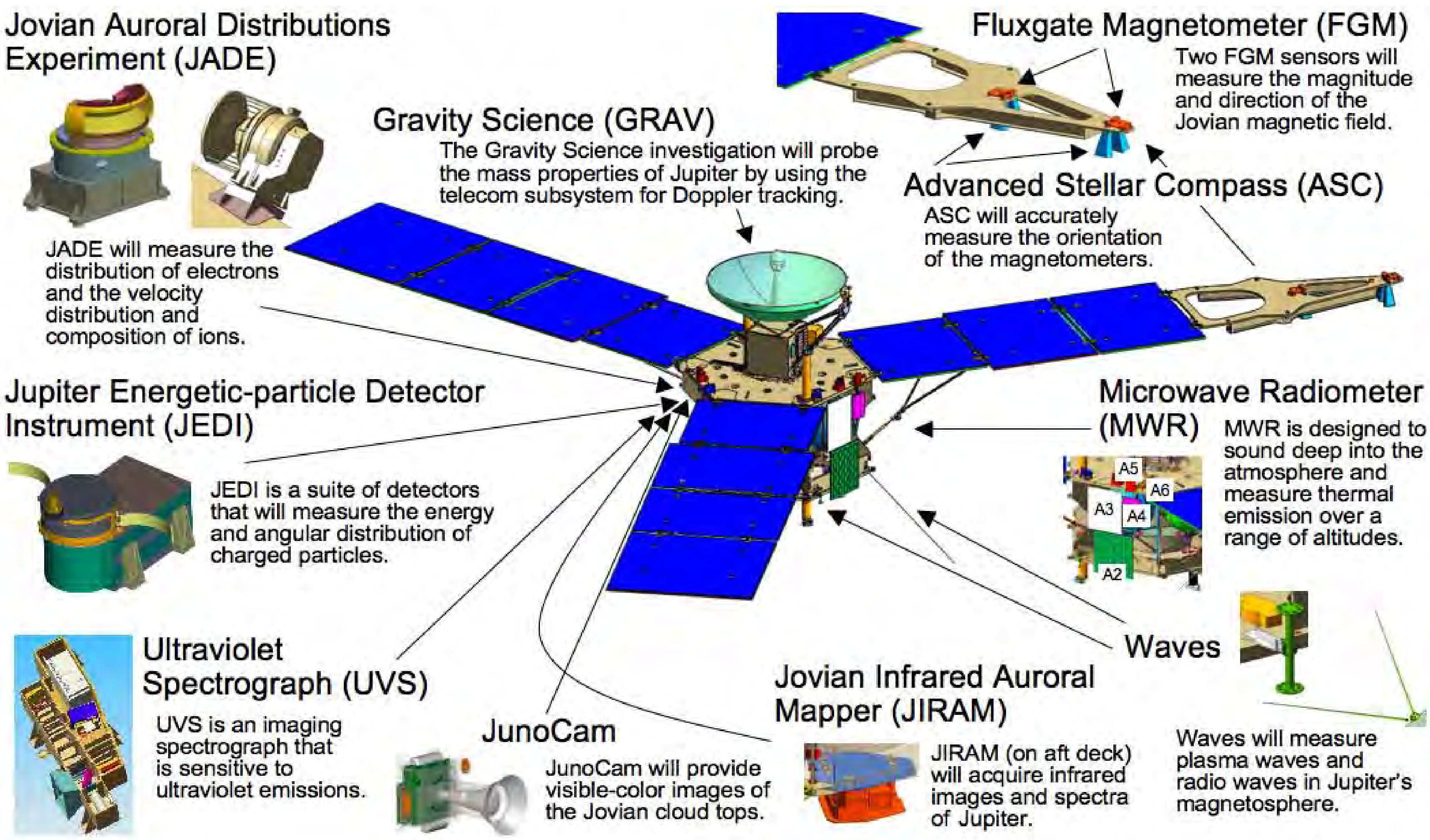


Figure 1-1: Juno science instruments.

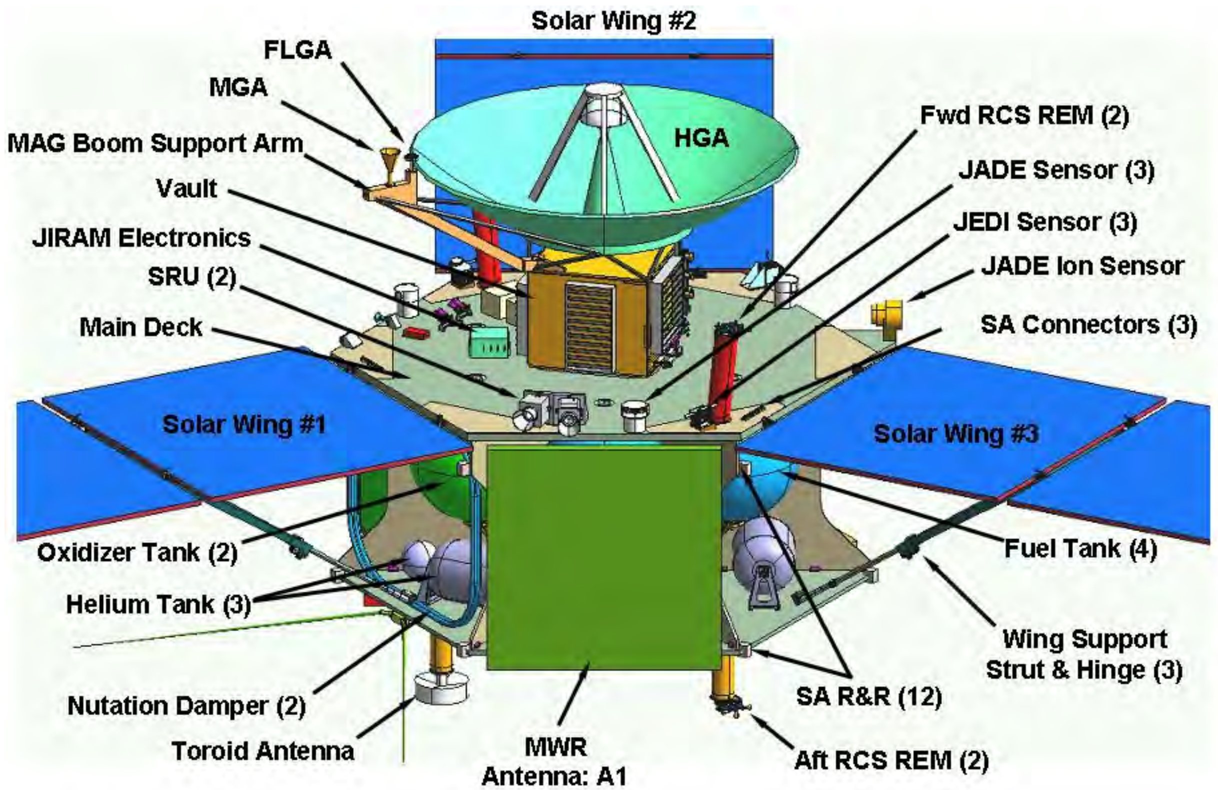


Figure 1-2: Juno spacecraft.

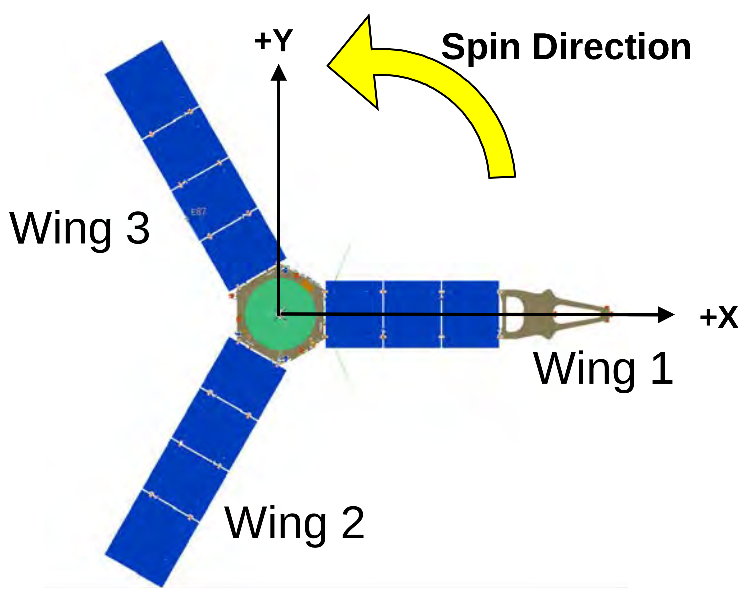


Figure 1-3: Juno S/C coordinate system.

Table 1-1: Juno mission phases.

Phase	Begin	Duration (days)	Rationale for Boundaries	Notes (times are in Universal Time, UTC)
Pre-Launch	L-3d 08/02/11	3	S/C power-up until final config	
Launch	L-0.75h 08/05/11	2.3	until cruise attitude control	Launch = 8/5/11 (16:11), at start of 22-day launch period: 8/5-26.
Inner Cruise 1	L+2.3d 08/08/11	61	until change to Earth-pointing	
Inner Cruise 2	L+63d 10/08/11	598	until change to off-Sun-pointing	DSM 1 = 8/30/12 (22:29), DSM 2 = 9/3/12 (22:29). DSM 1 varies from 6/20 to 8/30 over launch period.
Inner Cruise 3	L+661d 05/28/13	161	until change to Earth-pointing	EFB = 10/9/13 (14:12). Flyby times vary ~8 hours (from 7:14 to 15:08) over launch period.
Quiet Cruise	L+822d 11/05/13	791	until start of Approach science	
Jupiter Approach	JOI-182d 01/05/16	178	until JOI critical sequence	
JOI	JOI-4d 07/01/16	4	until end of critical sequence	JOI start = 7/5/16 (02:29). PJ0 = 7/5/16 (02:44). JOI cleanup OTM at JOI+7.6d.
Capture Orbit	JOI+1h 07/05/16	106	until PRM keepout zone	
PRM	PRM-18h 10/19/16	1	until end of keepout zone	PRM start = 10/19/16 (17:59). PJ1 = 10/19/16 (18:17).
Orbit 1-2	PRM+11h 10/20/16	20	until AP3 start	Orbit 2 includes PRM cleanup OTM 1 at PJ2+1h. Activity Period 2 is first AP (PJ-1d to PJ-1d).
Science Orbits	PJ3-1d 11/09/16	336	until before deorbit burn	Orbits 3-32 + most of (extra) Orbit 33. Orbit 3 includes PRM cleanup OTM 2 at PJ3+4h.
Deorbit	AJ33-1h 10/11/17	5.5	until Impact	Part of Orbit 33 + first half of Orbit 34. Impact = PJ34 = 10/16/17 (19:33).

Initial acquisition of the spacecraft used the Perth, Australia (primary) and New Norcia, Australia (backup) European Space Agency (ESA) sites along with the Canberra, Australia DSN site. The use of the ESA stations enabled reception of X-band telemetry from the Juno spacecraft approximately 1.3 minutes earlier than would have been possible using only the Canberra DSN site. This permitted a longer time margin for initial acquisition in order to monitor telemetry during solar array (SA) deployment [9]. The Telecom Subsystem transmitted at X-band shortly after separation through the combined forward and aft low-gain antennas (FLGA and ALGA).

After the launch and initial acquisition phase, Table 1-1 also includes the Cruise phase, the Approach and Jupiter Capture phases, and the Orbit phase described in the next sections. The cruise phase will include an Earth Flyby (EFB) in October 2013. The Orbit phase (following JOI) will include an orbit trim maneuver (OTM) after JOI as well as an OTM after the period reduction maneuver (PRM) and an OTM as part of the third orbit around Jupiter. The orbits are further divided into activity periods (APs) of science and mission operations.

Figure 1-4 shows the ground track of the spacecraft for the August 5, 2011 launch. Figure 1-5 shows initial ground-station coverage for launch on the same day, with the transmitter (TX) switched on showing the time the Canberra TX was switched on. In Figure 1-4, CAN, MAD, and GDS refer to the Canberra, Madrid, and Goldstone ground antenna sites, respectively, of the Deep Space Network. MES1 and MES2 indicate main engine start events, and MECO1 and MECO2 indicate main engine cutoff events. Perth refers to both Perth and New Norcia ground sites in Australia.

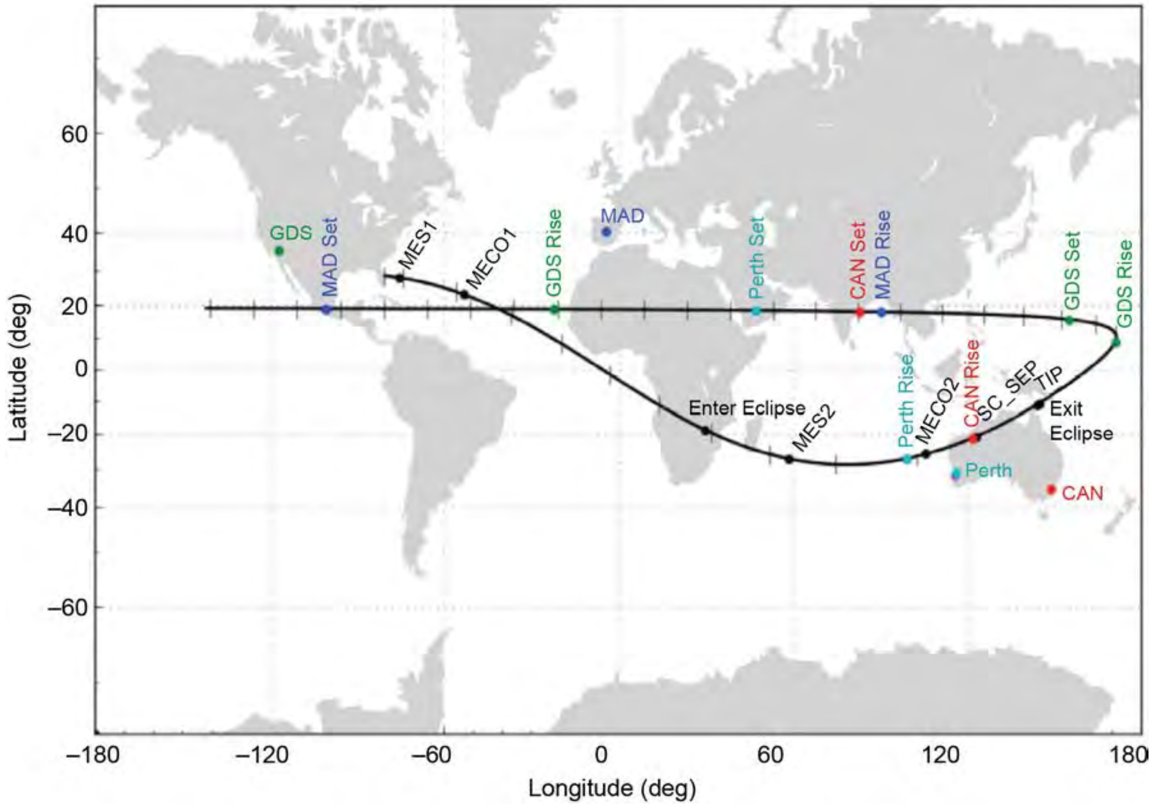


Figure 1-4: Juno launch ground track for 8/5/11 launch.

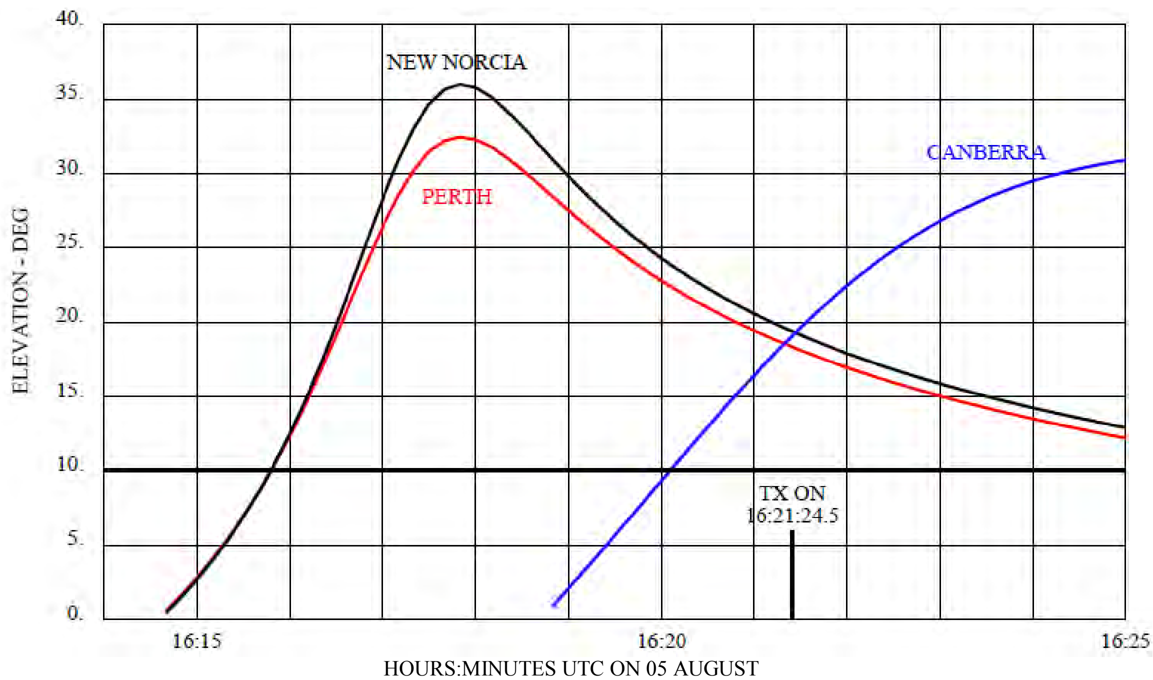


Figure 1-5: Juno ground station coverage following launch on 8/5/11 launch.

1.3.2 Cruise Phase

The Cruise phase began after the spacecraft completed the Launch phase.

The Juno spacecraft is spinning at 1 revolution per minute (rpm) during cruise except for the two major engine burns for the Deep Space Maneuver (DSM). Most of the antennas used during Cruise phase (a high-gain antenna [HGA], a medium-gain antenna [MGA], two low-gain antennas (LGAs, forward and aft) have their boresights co-aligned with the spin axis. The toroidal low-gain antenna (TLGA) is also used during Cruise. It is aligned normal to the spin axis on the aft end of the spacecraft.

The major activities in Cruise phase include:

- Checkout and maintenance of the spacecraft in its flight configuration,
- Monitoring and characterization/calibration of the spacecraft and payload subsystems (and associated parameter updates),
- Attitude maintenance turns,
- Navigation activities for determining and correcting the vehicle's flight path,
- Two major engine burns of the DSM,
- Preparations for Jupiter orbit insertion (JOI), Period Reduction Maneuver (PRM), and orbital operations.

The project planned 12 Trajectory Correction Maneuvers (TCMs) leading up to JOI, including the two DSM burns that were successfully executed on August 30 and September 14, 2012.

Figure 1-6 shows the spacecraft range for the 2011 launch opportunity.

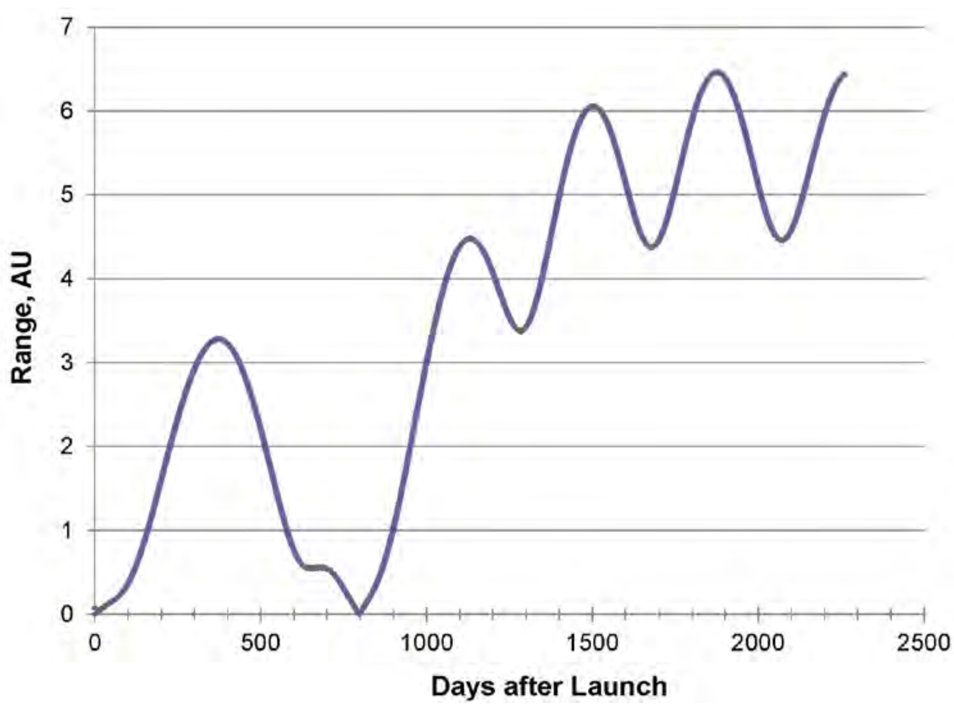


Figure 1-6: Spacecraft range from Earth vs. time after launch.

Figure 1-7 shows the Sun–Probe–Earth (SPE) and Sun–Earth–Probe (SEP) angles as a function of time for the full mission.

The spacecraft +Z axis is aligned with the high-gain antenna (HGA), medium-gain antenna (MGA) and forward low-gain antenna (FLGA) boresights. This axis is also normal to the solar arrays. The solar arrays may be slightly adjusted during the mission to realign the spin axis after the main engine burns. The antennas are fixed on the spacecraft body and are not gimbal mounted. Therefore antenna pointing, particularly with the MGA and with the HGA, is accomplished by orienting the spacecraft +Z-axis.

Note that the SPE angle is the angle from the forward antennas' boresights when the spacecraft is pointed at the Sun. As the spacecraft approaches Earth after the Deep Space Maneuver (DSM), the SPE angle exceeds 90 degrees (deg). This requires having an antenna on the backside of the spacecraft, i.e., the aft LGA (ALGA).

Figure 1-8 shows the originally planned spacecraft trajectory event dates during Cruise, based on the actual launch date of August 5, 2011. The two parts of the DSM took place on August 30 and September 14, 2012. Note that the second burn on September 14 had been originally planned for September 3, 2012.

Earth Fly-By (EFB) will occur on October 9, 2013. The target altitude is 500 km [5].

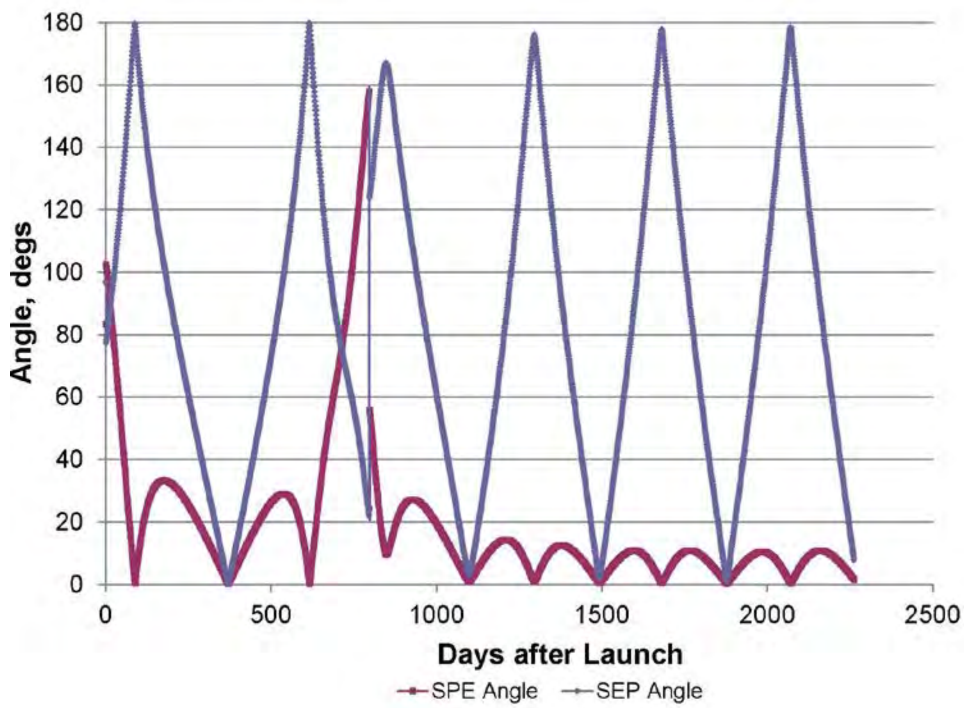


Figure 1-7: SEP and SPE angle vs. time.

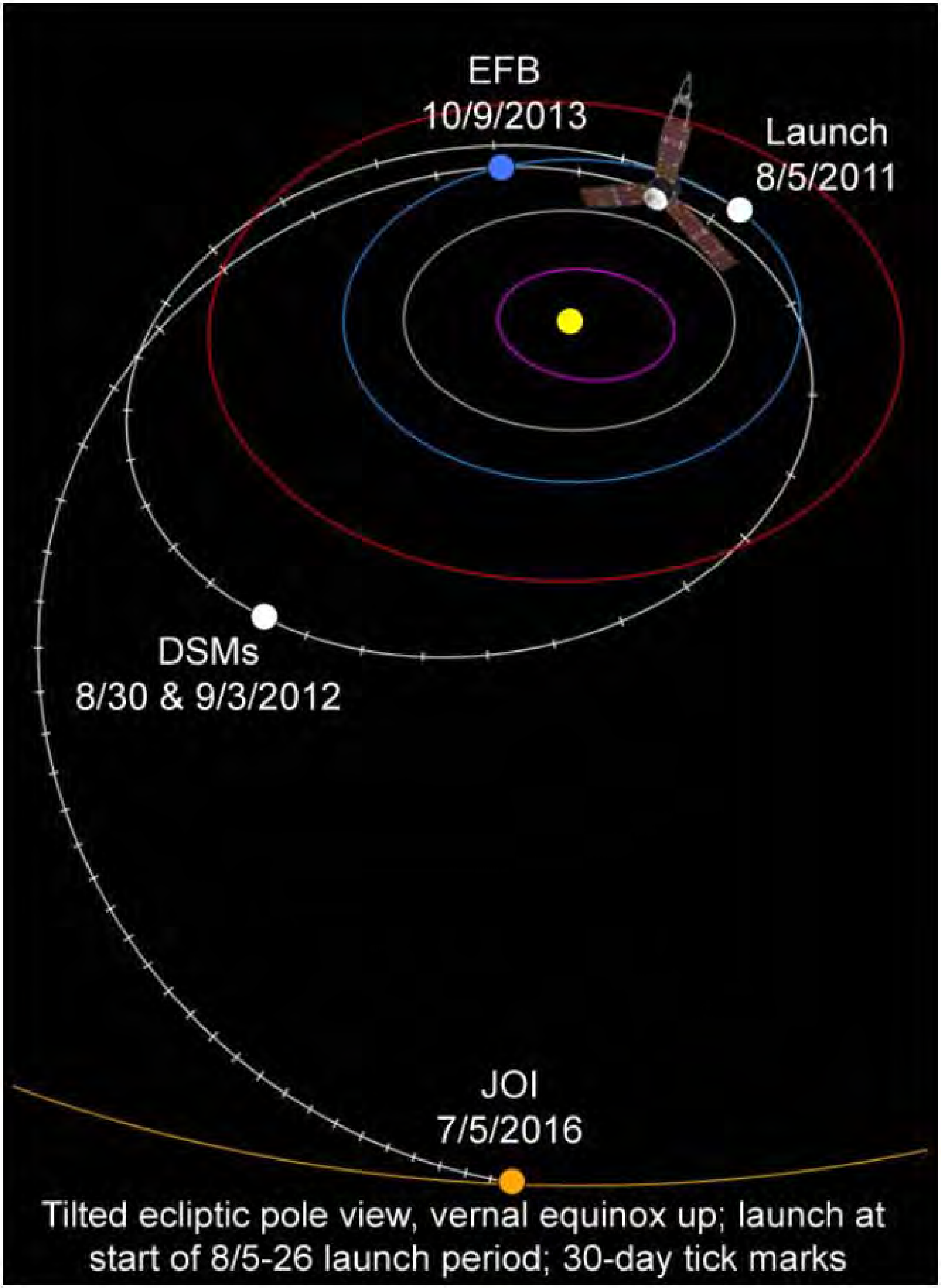


Figure 1-8: Planned activities from launch to Jupiter Orbit Insertion.

The Approach phase is defined to begin 182 days prior to JOI and to end 4 days prior to JOI, at which time the JOI phase commences. The principal activities during the Approach phase include the acquisition and processing of navigation data needed to support the development of the final three trajectory correction maneuvers (TCMs) and the spacecraft activities leading up to the JOI main engine burn.

1.3.3 JOI and PRM Phase

Two main engine burns are necessary to achieve the desired Jupiter orbit: Jupiter Orbit Insertion (JOI) and Period Reduction Maneuver (PRM). The first burn places the spacecraft into a 107-day orbit. The 2nd burn reduces the orbital period from 107 days to ~11 days. The 11-day orbit is required for sequencing perijove over Deep Space Station (DSS) 25 in Goldstone, California for gravity science tracking.

The timing of the JOI burn was done to reduce the magnetic field effects on spacecraft electronics. Also, the JOI burn is planned with dual 70-m antenna coverage, from the one 70-m antenna each at Goldstone and Canberra. This JOI timing results in the PRM burn being done just over Goldstone. JOI is scheduled for 7/5/2016. PRM is 10/19/2016. During both the JOI and PRM burns, the spacecraft will turn nearly normal to the Earth line. The spacecraft will transmit tones (subcarriers modulated onto the X-band carrier signal) through the TLGA to the ground for detection. After the PRM, the spacecraft will be in the 11-day science orbit.

1.3.4 Orbital Phase

The nominal lifetime requirement for Juno is thirty-three 11-day orbits around Jupiter. Figure 1-9 shows the trajectory for the spacecraft before JOI, the 107-day capture orbit, and the 33 science orbits. Figures 1-10 and 1-11 show the two types of science orbits during the science phase—Gravity Science and Microwave Radiometer. During the Gravity Science orbits the spacecraft is performing dual-band Doppler measurements with DSS-25 at Goldstone for 6 hours around perijove. During the MWR orbits, the MWR instrument is pointed at Jupiter during perijove, and there is no communication with Earth. There are six planned Deep Space Network (DSN) passes during each 11-day orbit to return science telemetry and perform navigation updates.

As Jupiter and the Earth travel in their orbits around the Sun, the Jupiter–Earth range varies between 4.46 and 6.43 astronomical units (AU) during the Orbit phase of the mission. Jupiter and the Earth are on opposite sides of the Sun as Juno starts and ends its 1-year orbital operations near maximum Earth range. Minimum range occurs with Jupiter and Earth on the same side of the Sun.

At the end of the mission, the spacecraft will perform a deorbit burn and impact Jupiter. This activity is to ensure the spacecraft does not later inadvertently contaminate a Galilean satellite with terrestrial organisms. Impact is scheduled for October 16, 2017.

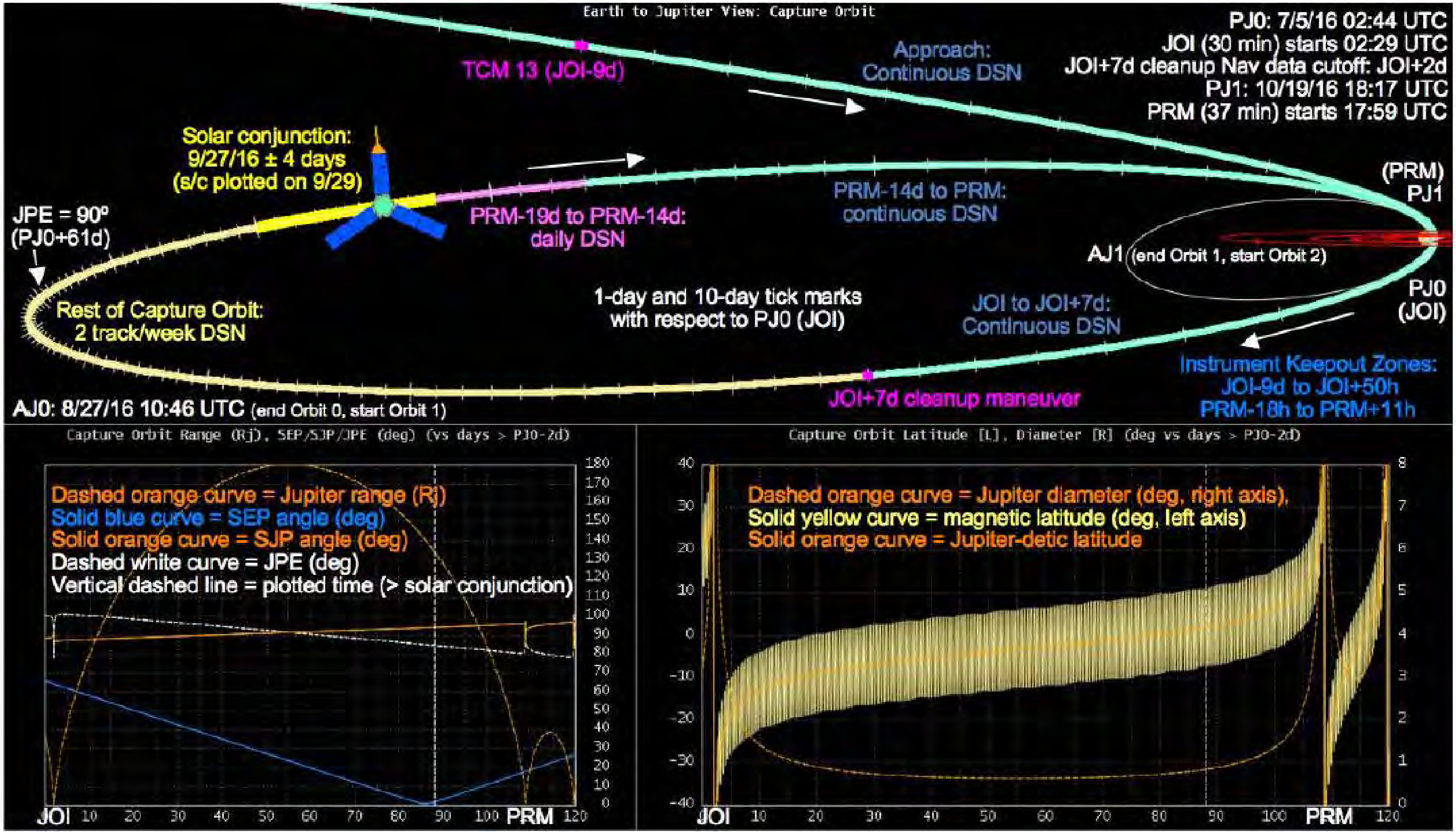


Figure 1-9: Juno during JOI, 107 day capture orbit and Orbital Operations.

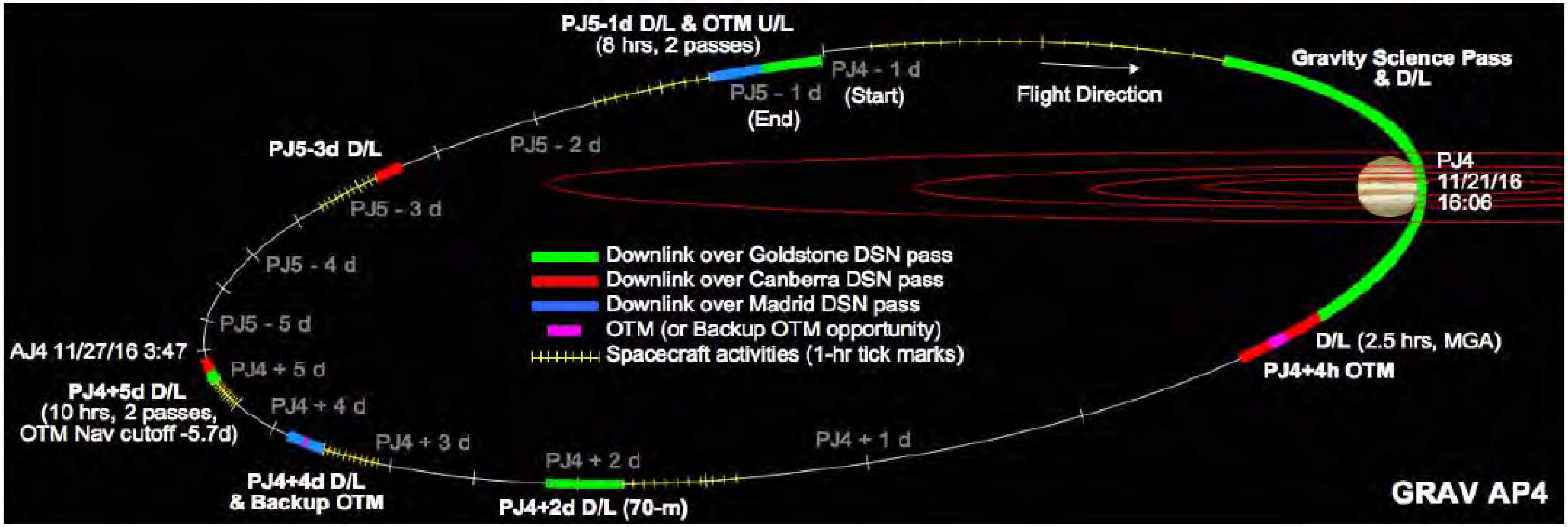


Figure 1-10: Gravity Science Orbit.

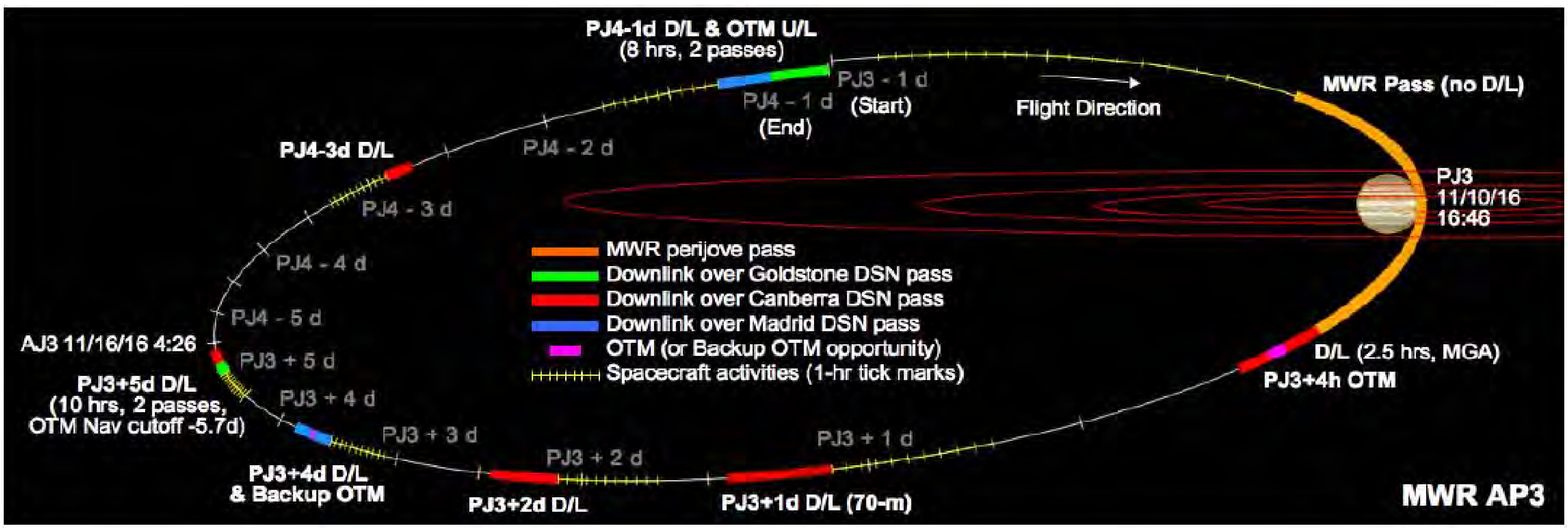


Figure 1-11: MWR Orbit.

2 Telecommunications Subsystem Overview

The Juno Telecom Subsystem operates at X-band for nominal two-way communications (command [CMD] uplink and telemetry [TLM] downlink), two-way tracking (Doppler and ranging), and changes in differential one-way ranging (delta-DOR), which is always performed in one-way mode. It also includes a Ka-band two-way carrier tracking capability for Gravity Science at Jupiter. These are the high-level functions, with the details explained in the following sections.

- During Cruise, X-band provides uplink, downlink, and radiometric measurements in support of navigation (ranging, Doppler, and delta-DOR).
- During portions of the DSM, JOI, and PRM maneuvers, with low signal levels due to antenna off-point, the X-band carrier is modulated with subcarrier tones that can be used for real-time observation and fault reconstruction.
- During the orbital phase of the mission:
  - o X-band will be used for uplink for commanding and downlink for telemetry return and tracking.
  - o X-Band (up and down) and Ka-band (up and down) will be used during Gravity Science passes on selected orbits at Jupiter perijove.

Figure 2-1 shows the telecom components mounted in the spacecraft radiation vault.[4] The vault is a titanium box designed to protect the 20+ electronic assemblies inside it against a total integrated dose (TID) of 25 krad or less. The mass of the whole vault is about 200 kg. The wall thicknesses are optimized for the minimum mass needed to attenuate the mix of electrons and protons at Juno over the Orbit phase mission duration.

2.1 X-Band

The Telecom Subsystem block diagram is presented in Figure 2-2.

For the most part, the Juno telecom subsystem operates on DSN X-band channel 6, as defined in [4]. As defined subsequently in Table 2-9, the KaTS also includes operations on channel 5.

- Receive frequency: 7153.065586 megahertz (MHz)
- Transmit frequency: 8404.135802 MHz

The X-band part of the Telecom Subsystem is designed to perform the following functions:

- Receive an X-band uplink carrier from the DSN. This carrier may be modulated by command data, by a ranging signal, or both. Then the system must demodulate the command data and the ranging signal.

[4] The vault is shown and described in http://opfm.jpl.nasa.gov/files/Y-McAlpine-Lessons%20Learned1.pdf and http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA13260.

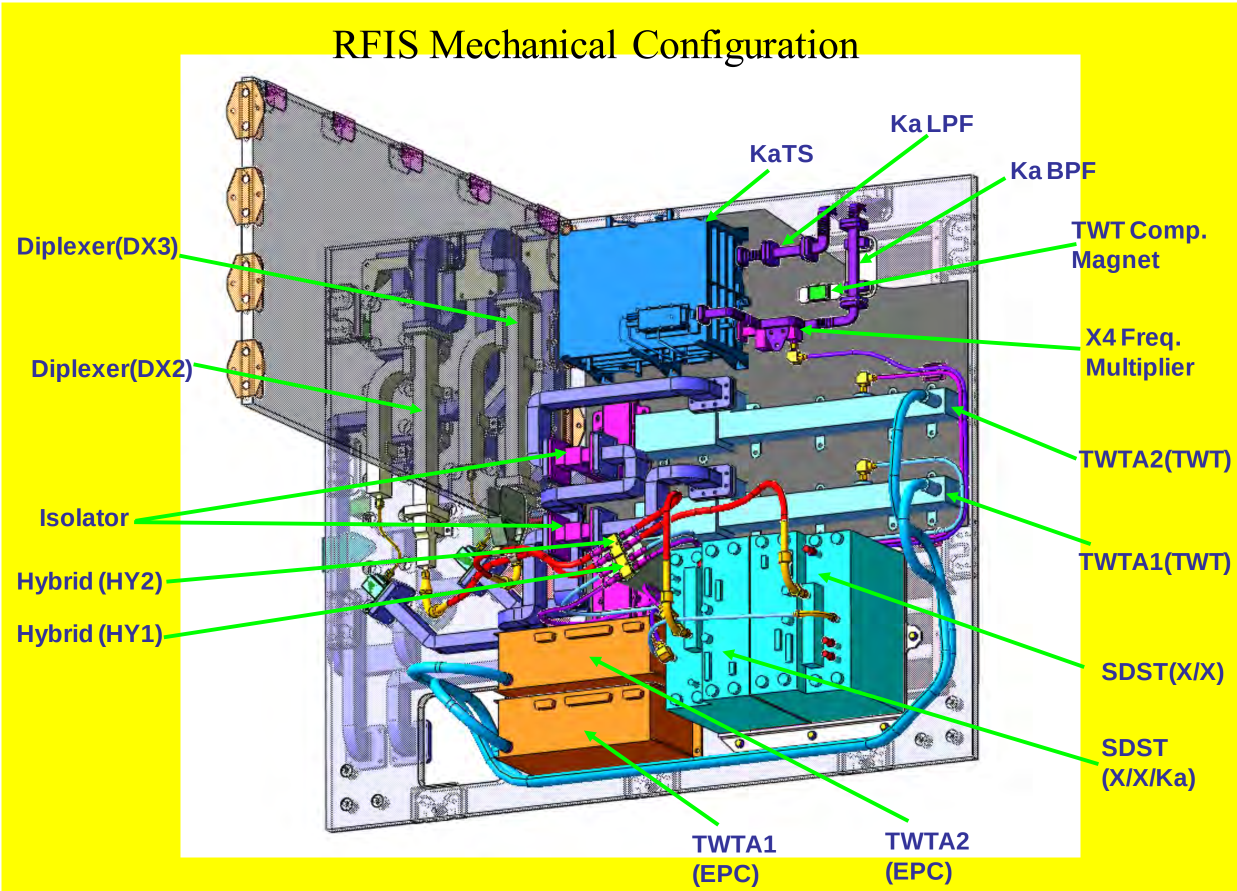


Figure 2-1: Juno telecom components (Radio Frequency Instrument Subsystem, RFIS) mounted in the S/C vault.

- Generate an X-band downlink carrier either by coherently multiplying the frequency of the uplink carrier by the turn-around ratio 880/749, or by utilizing an auxiliary crystal oscillator (Aux Osc).
- Phase-modulate the downlink carrier with either of three signals (or a combination of these signals):
  - A composite telemetry binary phase shift keying (BPSK) signal, either direct modulated or data modulated onto a squarewave subcarrier (25 or 281.25 kilohertz, kHz)
  - A tone series, a tone being a telemetry subcarrier frequency with no modulation on the tones
  - Differential one-way ranging (DOR) signal
  - The ranging signal that was demodulated from the uplink (this signal is referred to as two-way or turn-around ranging)

  Note: the planned data downlink configuration includes either telemetry or tones, but not both simultaneously. The radiometric configuration is either the DOR signal or the ranging signal, but not both simultaneously.

- Permit control of the subsystem through commands to select signal routing (i.e., which antenna should be used) and the operational mode of the subsystem (i.e., the configuration of the elements of the subsystem; examples are command data rate, telemetry subcarrier, convolutional code, downlink ranging modulation index). This commanding can be done either directly from the ground (i.e., with real-time commands) or through the initiation of sequences of commands that were previously loaded on the spacecraft.
- Provide status telemetry (to the Avionics Subsystem) for monitoring the operating conditions of the subsystem. Examples are: Aux Osc temperature, Small Deep Space Transponder (SDST) current, subcarrier frequency, state of ranging channel (ON or OFF), coherent/non-coherent operation, and receiver lock state (IN or OUT of lock).
- For all radio frequency (RF) transmitters, provide ON/OFF power control to permit the conservation of power.
- Upon a power-on-reset (POR), the system is placed into a single, well-defined operating mode; this provides a "known baseline state" from which the ground can command the Telecom Subsystem during safe-mode (emergency) operations
- All of the antennas are used during Cruise: They are:
    - FLGA: forward low-gain antenna
    - ALGA: aft low-gain antenna
    - MGA: medium-gain antenna
    - HGA: high-gain antenna
    - TLGA: toroidal low-gain antenna
- The DSM, JOI, and PRM maneuvers include transitions from the HGA to the MGA and then to the TLGA. Times of the switches are based on an internal timeline of maneuver events in flight software (FSW). The FSW switches back to the MGA from the TLGA after the burn. When HGA pointing has been refined after the burn, the spacecraft is sequenced to return to the HGA.
- During the orbital phase, the antenna that will be used nominally is the HGA (The MGA may be used after post-perijove orbit trim maneuvers (OTMs) depending on the HGA pointing capability.

Other names and acronyms in Figure 2-2 not explained so far are: LPF for low-pass filters, BPF for bandpass filters, HY for hybrid, AT for attenuator, DX for diplexer, WG for waveguide, WTS for waveguide transfer switch, Iso For isolator, and standard waveguide sizes for X-band (WR-112) and Ka-band (WR-28 and WR-34).

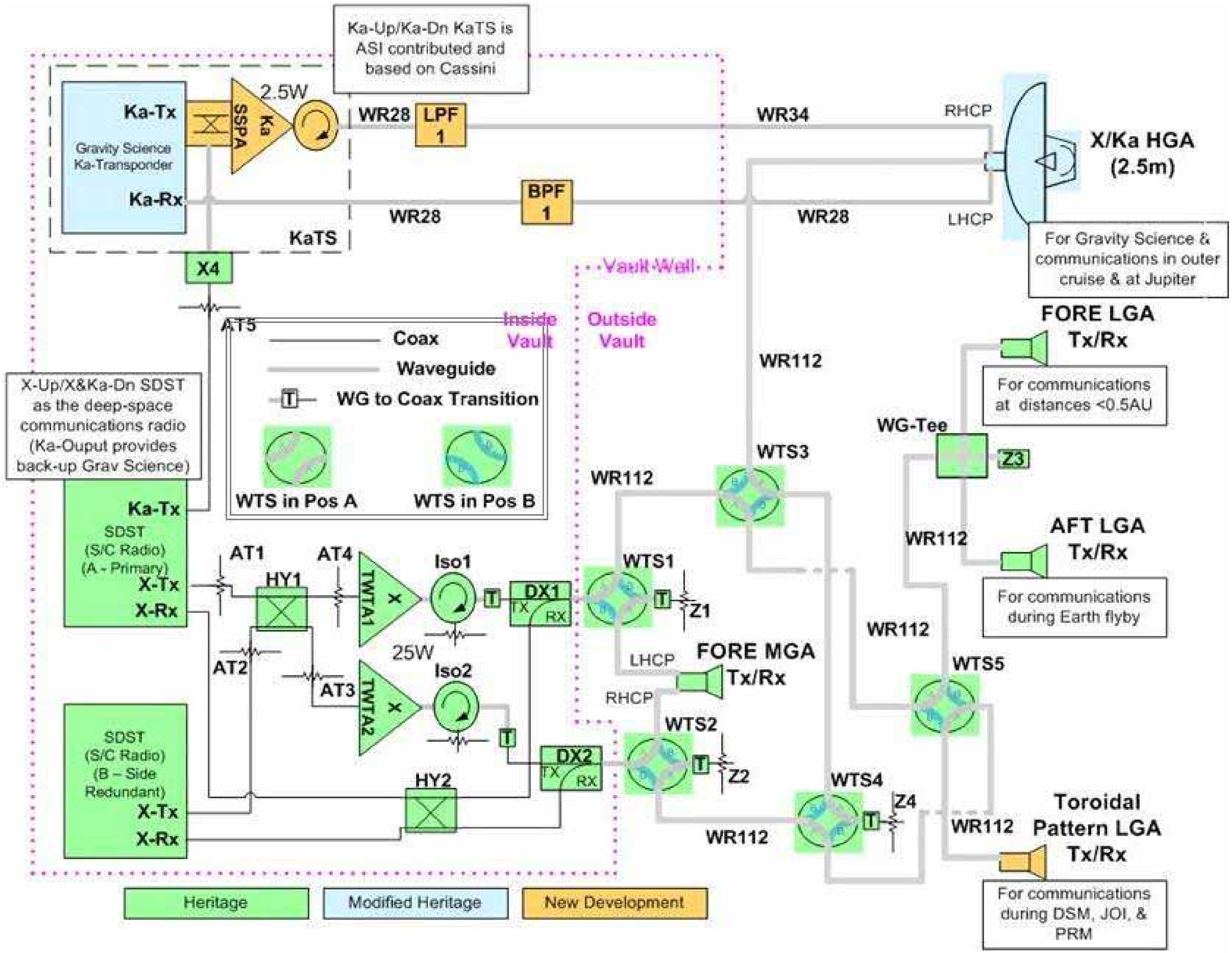


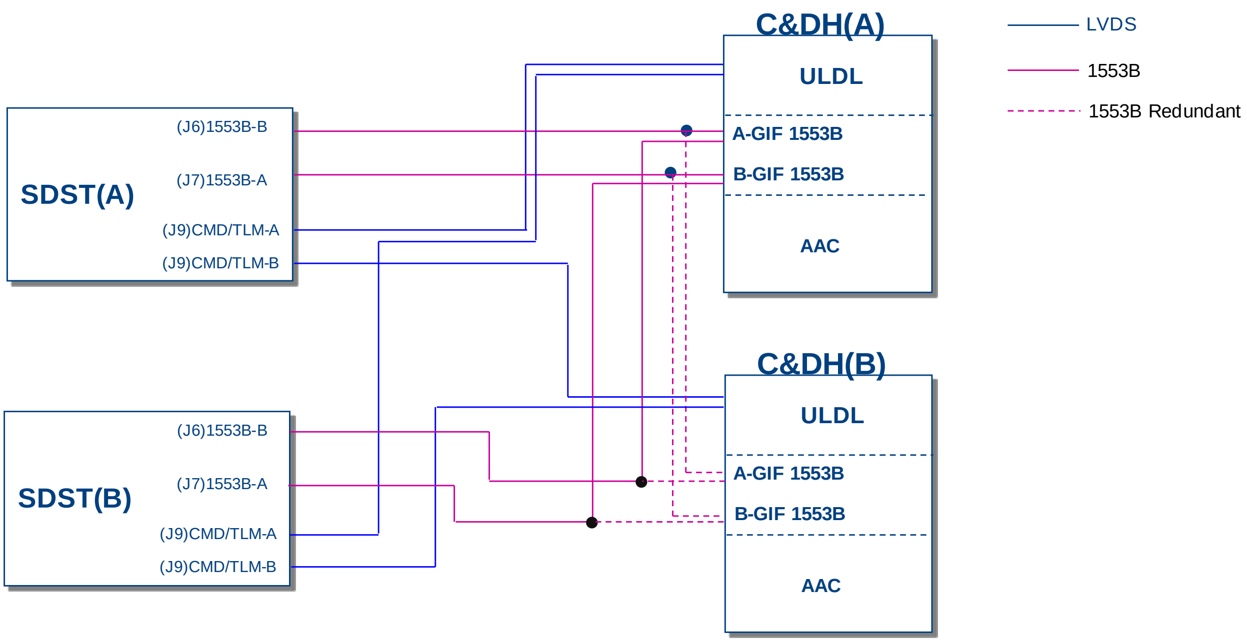
Figure 2-2: Juno telecom block diagram.

2.1.1 Interfaces

Figure 2-3 shows the interface between the SDSTs and the CD&H. The main interface to the SDST radios is the uplink/downlink (ULDL) card and the Command & Data Handling Subsystem (C&DH). The C&DH provides the following data transfer functions, including:

- Turbo code rate 1/6 with large (8920 bits) frame size, which is the baseline for high rate X-band downlink.
- Reed–Solomon encoding (interleave depth 1) that can be used for X-band downlink (in concatenation with convolutional (7,1/2) performed by the SDST) for low rate X-band downlink at 10 or at 40 bits per second (bps).
- Reed–Solomon encoding (interleave depth 5) that was used for X-band downlink (in concatenation with convolutional (7,1/2) performed by the SDST) at 1745 bps during launch.

The SDSTs provide redundant uplink (command) and downlink (telemetry) low-voltage differential signaling (LVDS) interfaces which are cross-strapped to the two ULDL cards. The active downlink port on the telecom side must be selected by the C&DH by issuing a command on the 1553 bus [13].[5] Both uplink ports in the SDST are always active.



ULDL = Up Link Down Link
AAC = Analog Acquisition Card
DTCI = Data Command Telemetry Interface Card
GIF = Guidance Navigation & Control Interface

Figure 2-3: LVDS and 1553B cross-strapping to flight system.

[5] MIL-STD 1553 is a standard published by the United States Department of Defense that defines the mechanical, electrical and functional characteristics of a serial data bus.

2.1.2 Small Deep Space Transponder (SDST)

Juno has two SDSTs, of two different types. The prime unit is an X/X/Ka unit that provides a backup Gravity Science function. The redundant unit is an X/X unit.

The SDST is composed of four different modules: the digital processing module (DPM), the downconverter module, the power converter module, and the exciter module. The DPM is responsible for convolutionally encoding the data, for providing X-band baseband telemetry and ranging signals to the exciter module, and for converting the analog output of the downconverter module into binary data.

The downconverter module takes the 7.153-GHz RF signal received from the ground station and converts it to an intermediate frequency (IF) signal at 4/3 F1. In SDST nomenclature, F1 is the fundamental frequency from which the uplink and downlink frequencies are derived. For example, the X-band downlink is 880F1 and the X-band uplink is 749F1. For Juno, F1 will be approximately 9.55 MHz. The voltage-controlled oscillator (VCO) output is at 8 F1. The uplink signal (with command and ranging modulation) gets sampled by an analog-to digital (A/D) converter at the input of the digital processor module. These samples are provided to three "channels" to use the old analog terminology:

a) The command channel

b) The carrier channel (for uplink carrier tracking)

c) The ranging channel

The ranging samples of the baseband uplink are put through a digital-to analog (D/A) converter to get an analog signal (to modulate the downlink with this 'turn-around' ranging).

The exciter module takes any combination of three inputs:

- Telemetry (from the DPM; this is a BPSK-modulated square-wave subcarrier or direct modulated symbol stream);
- DOR (differential one-way ranging; analog, a 2 F1 [~ 19 MHz] sinewave signal; internal to the exciter module) and
- Ranging (analog, from the DPM, after its D/A converter)

and phase-modulates the downlink carrier.

The power converter module is responsible for supplying steady voltages to the other SDST modules.

The SDST functional specifications summarized here are detailed in the *SDST Functional Specification & Interface Control Document* [10]. Tables 2-1 and 2-2 list some of the SDST requirements relevant to the telecom link performance.

Table 2-1: SDST receive functional specifications.

SDST Receive Parameter	Functional Requirement
Receive signal maximum power	–70 decibels referenced to milliwatts (dBm) (to meet performance specs) +10 dBm (no damage)
Carrier loop threshold bandwidth (BW)	2 settings: 20 ± 2 hertz (Hz) at receiver threshold (varies with carrier loop SNR; max BW is ~ 120 Hz at strong signal, 100 dB SNR) 50 Hz ± 5 Hz at receiver threshold
Noise	< 3.2 dB over temperature, aging, and radiation, 2.0 dB typical at beginning of life, at 25 ºC
Carrier tracking threshold @ best-lock frequency (BLF) and 0 dB loop S/N (20 Hz loop bandwidth)	–157.7 dBm typical –155.0 dBm worst case
Command rates	7.8125 to 4000 bps (SDST capability) 7.8125 to 2000 bps used operationally
Telemetry modulation index	0 to 135 degrees angle peak (3 degree maximum steps)

Table 2-2: SDST 880f1 exciter functional specifications.

X-band 880F1 Transmit Parameter	Functional Requirement
Output power level Of X-band exciter	13.0 + 3/–2 dBm over temperature, tolerance, end of life (EOL), radiation
Phase Noise	< –20 decibels below carrier (dBc)/Hz @ 1 Hz (Aux Osc mode)
Aux Osc short term frequency stability	0.06 ppm at any constant temp from 10°C to 40°C (1 sec integration measured at 5-minute intervals over a 30 min span)
Numerically controlled oscillator (NCO) subcarrier tone short term stability	30 ppm
NCO subcarrier tone long-term stability	20 ppm
Harmonics	< –50 dBc
In-band and Out-of-band Spurious	< –50 dBc
Minimum symbol rate	0 sps for subcarrier; 2000 sps for direct modulation
Maximum symbol rate	Filtered mode: 10 Msps Wideband (unfiltered) mode: 100 Msps

X-band 880F1 Transmit Parameter	Functional Requirement
Modulation index accuracy	± 10%
Ranging modulation indices (peak)	4.375, 8.75, 17.5, 35, 70 deg peak
Ranging modulation index accuracy	± 10%
Ranging modulation index stability (over temp., radiation, and EOL)	< ±20%
Ranging delay variation over FA temperature range	< 20 ns typical
DOR Modulation Index (peak)	70 deg peak
DOR Modulation Index accuracy	± 10%
DOR Modulation Index stability (over temp., radiation, and EOL)	< ±25%

2.1.3 Traveling Wave Tube Amplifier

There are redundant X-Band traveling wave tube amplifiers (TWTAs) on Juno. The TWTAs are 25-W X-band units from Tesat/Thales. The required dc input power is 56 W. The units are fully flight qualified and are based on the design for the Mars Reconnaissance Orbiter (MRO) and Mars Science Laboratory (MSL) X-band TWTAs. The TWTA is comprised of the traveling wave tube (the RF amplifying element) and the electronic power converter (EPC).

A picture of the Juno EPC is shown below in Figure 2-4.

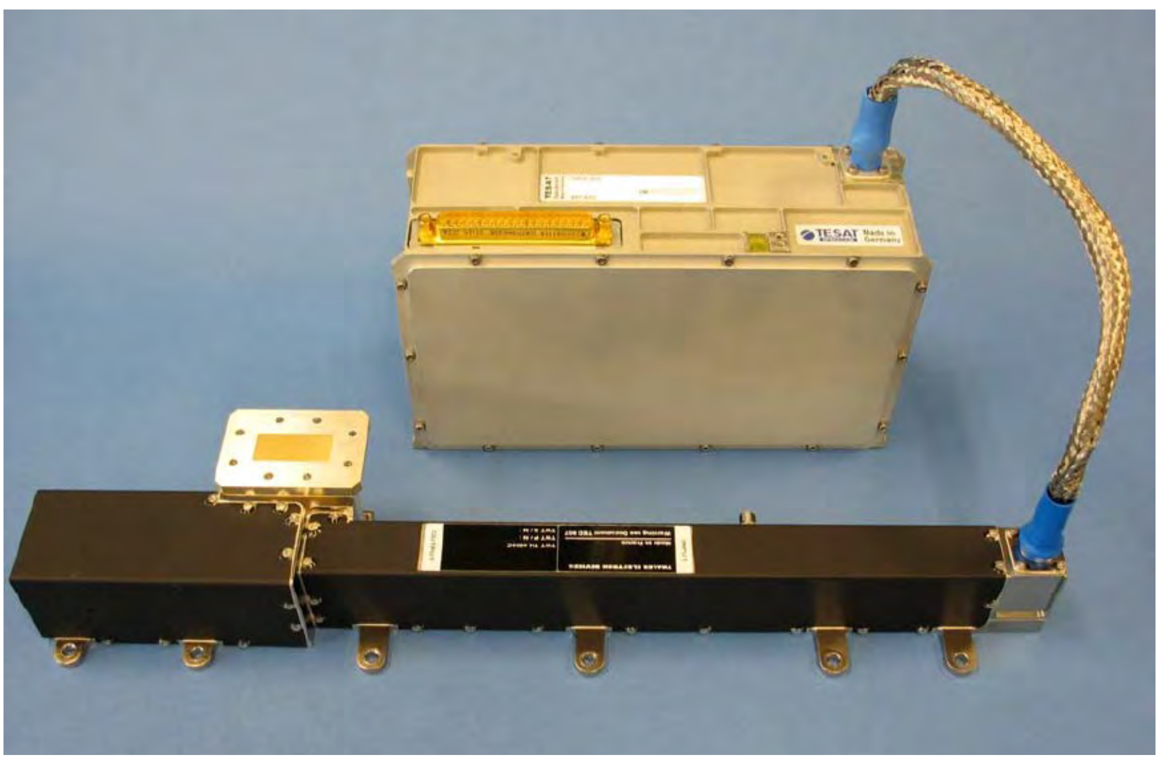


Figure 2-4: Juno TWTA with electrical power supply.

2.1.4 Antennas

There are five telecom antennas on Juno. They are the high-gain antenna (HGA), medium-gain antenna (MGA), toroidal low-gain antenna (LGA) and two low-gain antennas (LGAs), which are the forward LGA (FLGA) and the aft LGA (ALGA). The picture in Figure 2-5 shows the location of the antennas on the spacecraft.

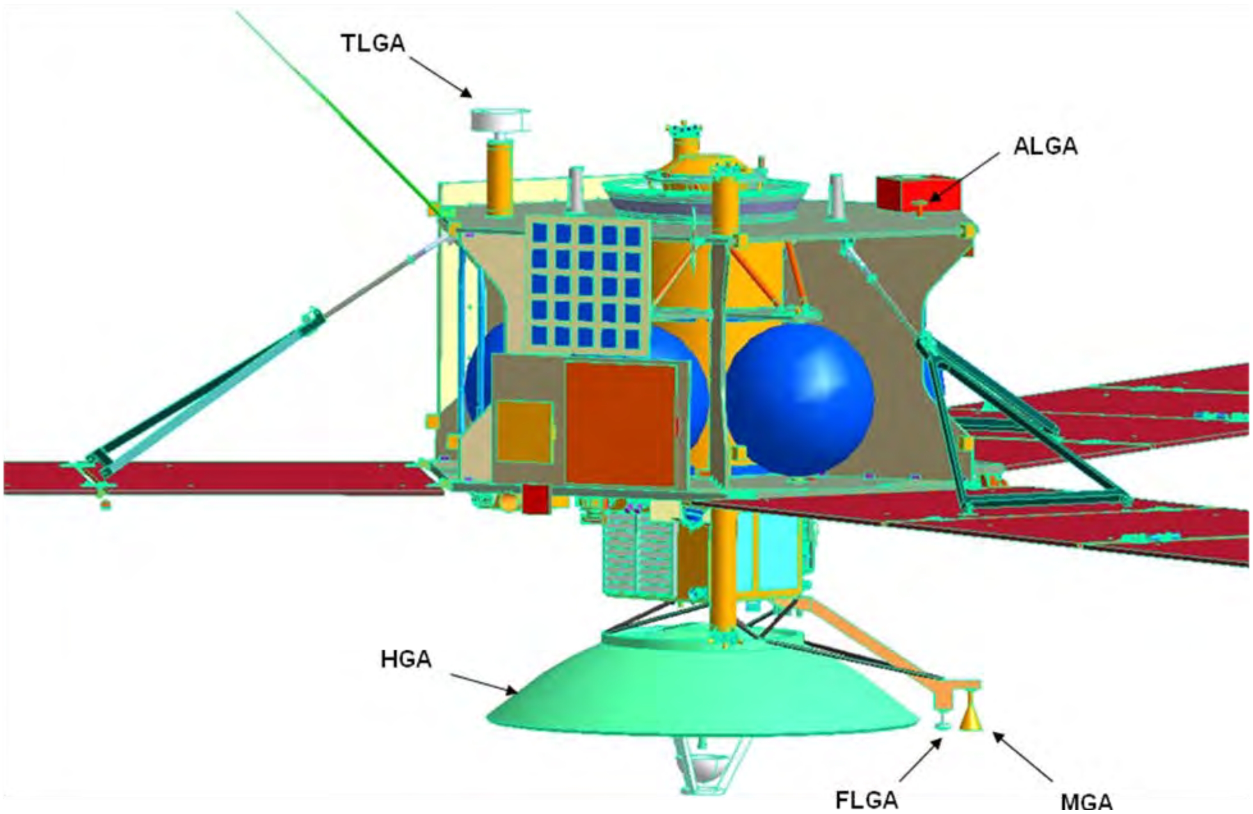


Figure 2-5: Location of antennas on the Juno spacecraft.

2.1.4.1 High-Gain Antenna (HGA)

The HGA is a 2.5-m dual-band (X and Ka) dual reflector. It is a similar design to the 3.0-m MRO HGA. Table 2-3 lists some of the key parameters of the HGA.

Table 2-3: HGA parameters.

Parameter	Value
Design	Dual reflector
Diameter	2.5 m
Required gain, transmit (X)	44.5 ± 0.5 dB
Required gain, receive (X)	43.0 ± 0.5 dB
Required gain, transmit (Ka)	47.5± 0.6 dB
Required gain, receive (Ka)	47.0± 0.6 dB
Polarization (X)	Right-hand circular polarization (RHCP) (uplink and downlink)
Polarization (Ka)	RHCP (downlink) and LHCP (uplink)
Axial ratio, receive and transmit (X, Ka)	2.0 dB
Beamwidth, receive and transmit (X)	± 0.25 deg
Beamwidth, receive and transmit (Ka)	± 0.25 deg

Figures 2-6 and 2-7 show the HGA gain patterns for downlink and uplink at X-band. Similar patterns for Ka-band are shown in Figures 2-8 and 2-9. The HGA patterns are expressed in dBiL, that is, dB relative to an isotropic linearly polarized antenna.

In these figures, the terms co-pol and cx-pol stand for co-polarization and cross-polarization, respectively. Because the HGA is RHCP, the term co-pol refers to the pattern measured with a test antenna that is also RHCP. The term cx-pol refers to the pattern measured by a LHCP test antenna.

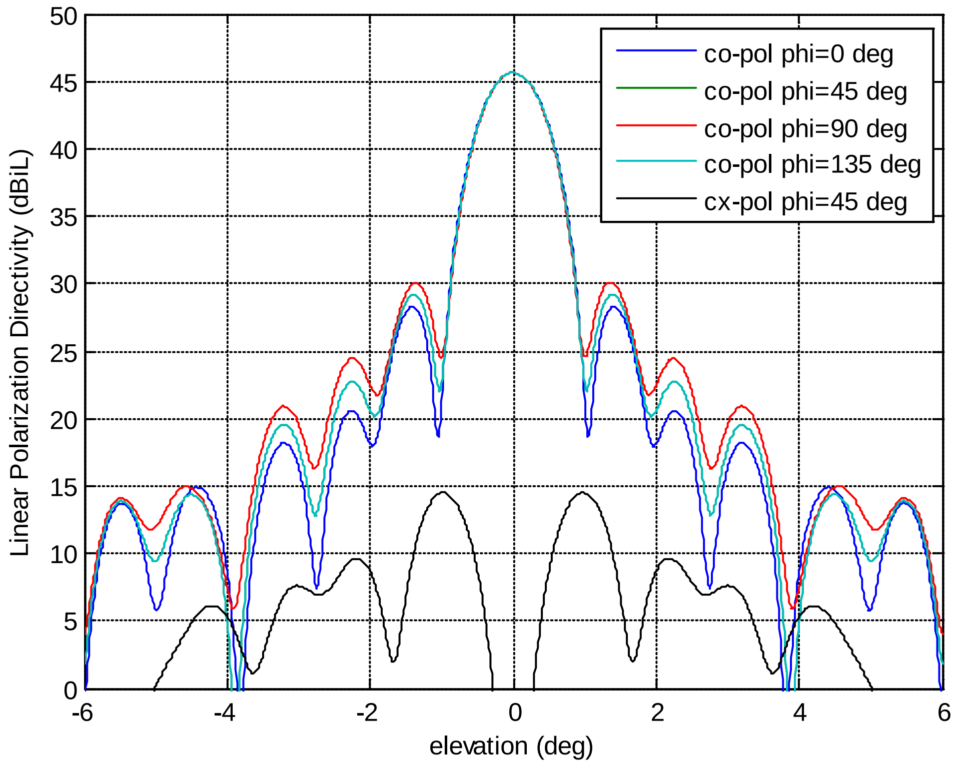


Figure 2-6: HGA X-band downlink pattern.

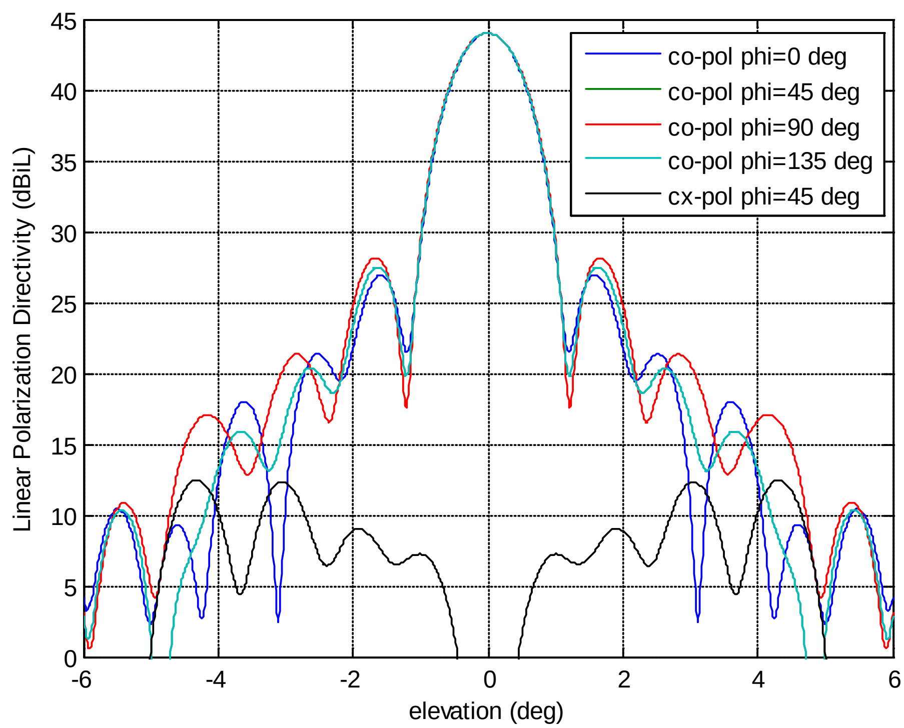


Figure 2-7: HGA X-band uplink gain.

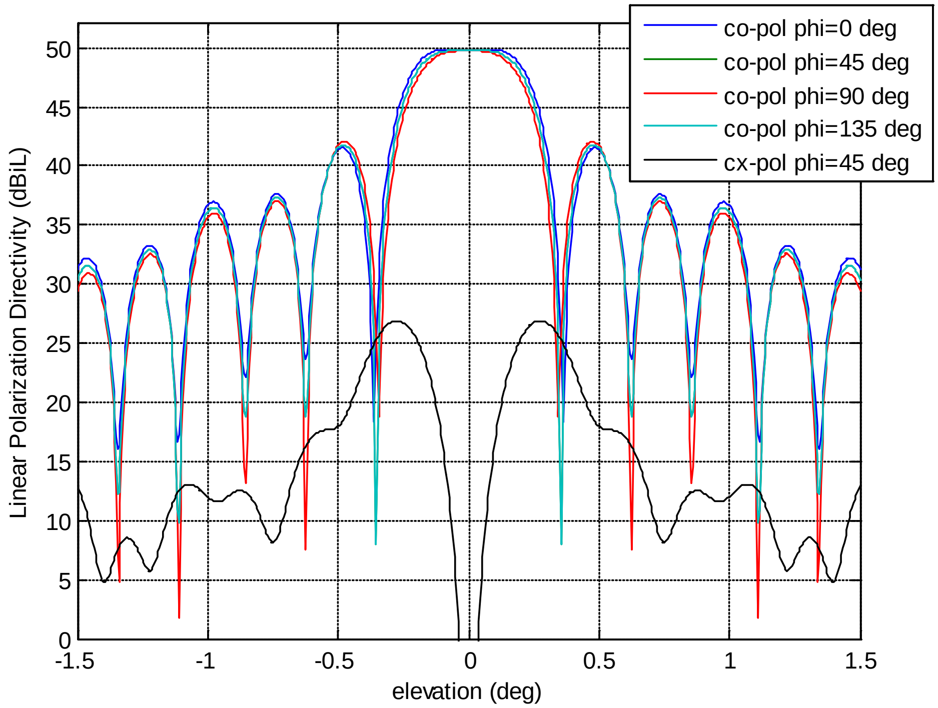


Figure 2-8: HGA Ka-band downlink gain.

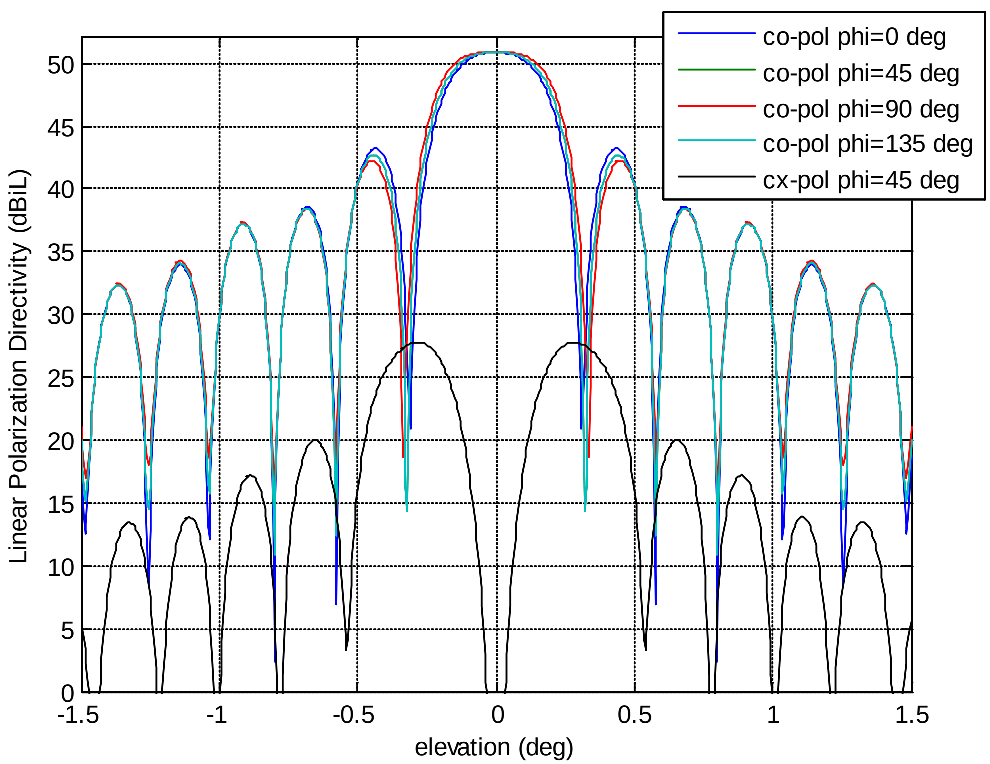


Figure 2-9: HGA Ka-band uplink gain.

2.1.4.2 Toroidal Low-Gain Antenna (TLGA)

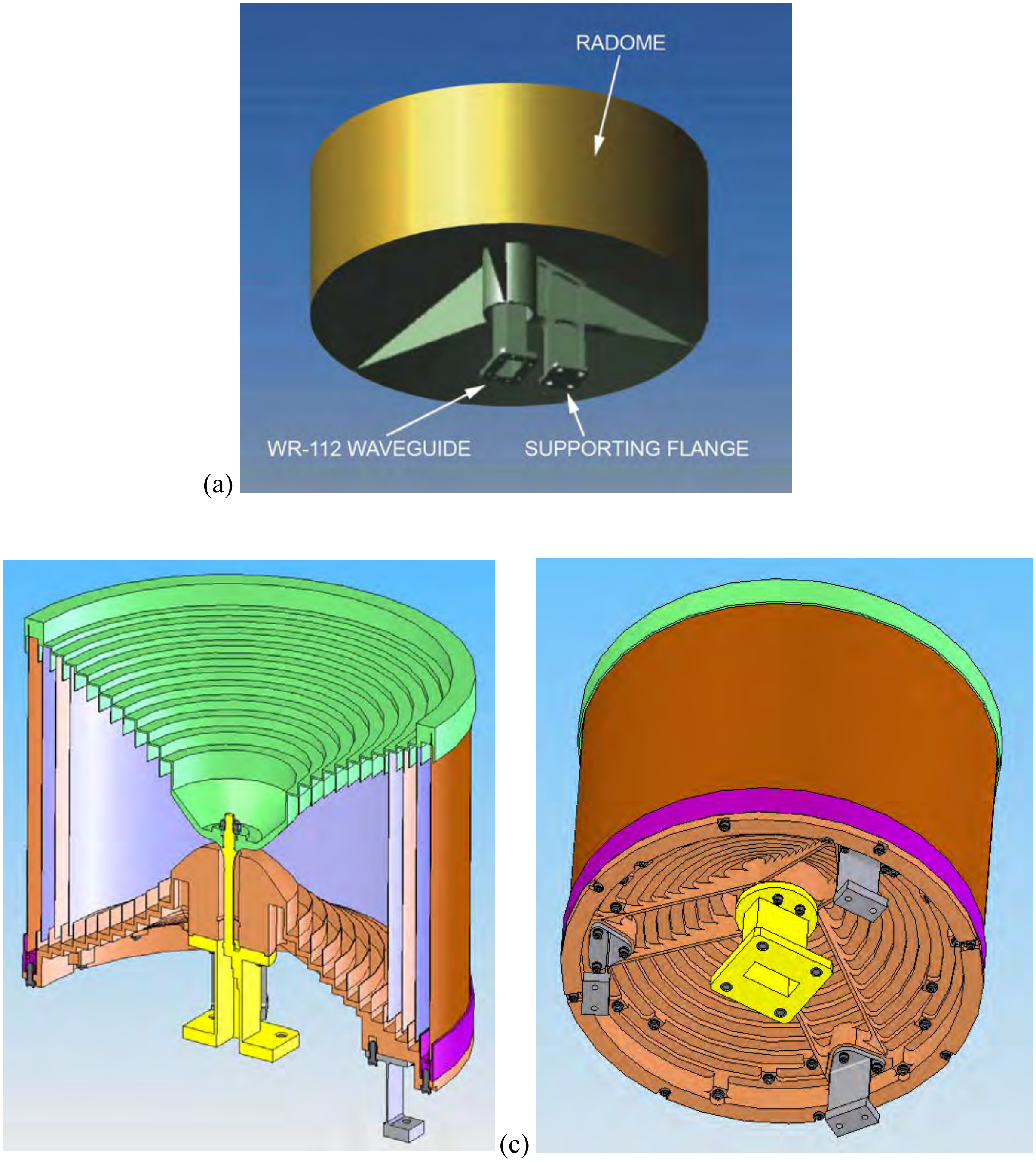
The toroidal LGA (TLGA) is a biconical design. It produces an RHCP pattern that is symmetrical about the spin axis. This antenna was added to the design for critical event coverage—the main engine burns for the two DSM burns, JOI and PRM. The antenna is located on the aft deck of the spacecraft. The uplink and downlink gain values will not vary by much. This is a broadband design and easily covers both the uplink and downlink frequency bands.

Table 2-4 lists some key parameters of the TLGA. Figure 2-10 shows three views of the antenna. Part (a) of the figure is a side view of the antenna covered with its protective radome; part (b) shows the inner pattern-forming biconical horn in green and orange; and part (c) is a bottom view of the antenna and the waveguide connector.

The transmit gain pattern of the TLGA is shown in Figure 2-11. The receive gain pattern is shown in Figure 2-12. The directivity patterns of the Juno LGAs and MGA are expressed in dBic, dB relative to an isotropic circularly polarized antenna. (As previously described, the Juno HGA directivity patterns are expressed in dBiL.)

Table 2-4: TLGA parameters

Parameter	Value
Design	Biconical horn
Receive frequency, MHz	7153.065586 channel 6
Transmit frequency, MHz	8404.135802 channel 6
Required gain, boresight, dBic	5.5 ± 0.5 receive 6.5 ± 0.5 transmit
Polarization	RHCP
Beamwidth, deg	± 10.0 receive ± 10.0 transmit
Axial ratio, on boresight, dB	<2.0 for ± 10 deg



(a) (b) (c)

Figure 2-10: External and internal views of TLGA: (a) side view under dome; (b) biconical horn; (c) bottom and waveguide connector.

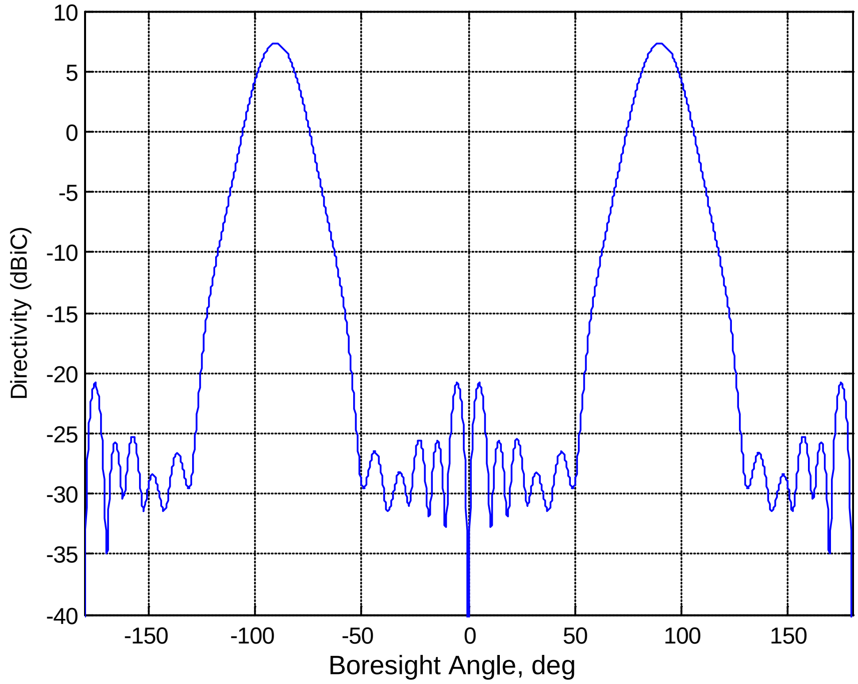


Figure 2-11: TLGA transmit gain pattern.

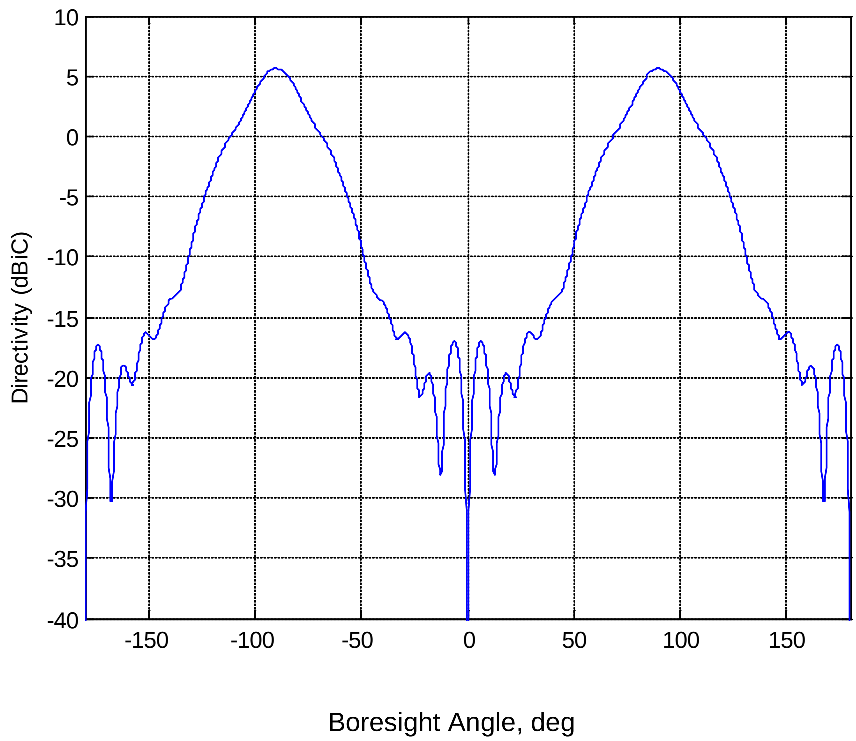


Figure 2-12: TLGA receive gain pattern.

2.1.4.3 Medium-Gain Antenna (MGA)

The medium-gain antenna (MGA) is used for communications during Cruise and for safe mode on orbit. It may also be used for the post-orbital trim maneuver (OTM) navigation passes. The Juno MGA is the same design as the Mars Exploration Rover (MER) MGA.

The MGA is attached adjacent to the HGA, aligned to the spacecraft spin axis (+Z). See Figure 2-5 for the MGA placement and size relative to the 2.5-m diameter HGA.

Figure 2-13 shows a photograph and a drawing to illustrate the MGA. The brick color in the drawing shows the antenna horn, and the pink and red colors show the mechanical support and the waveguide feed up to the horn.

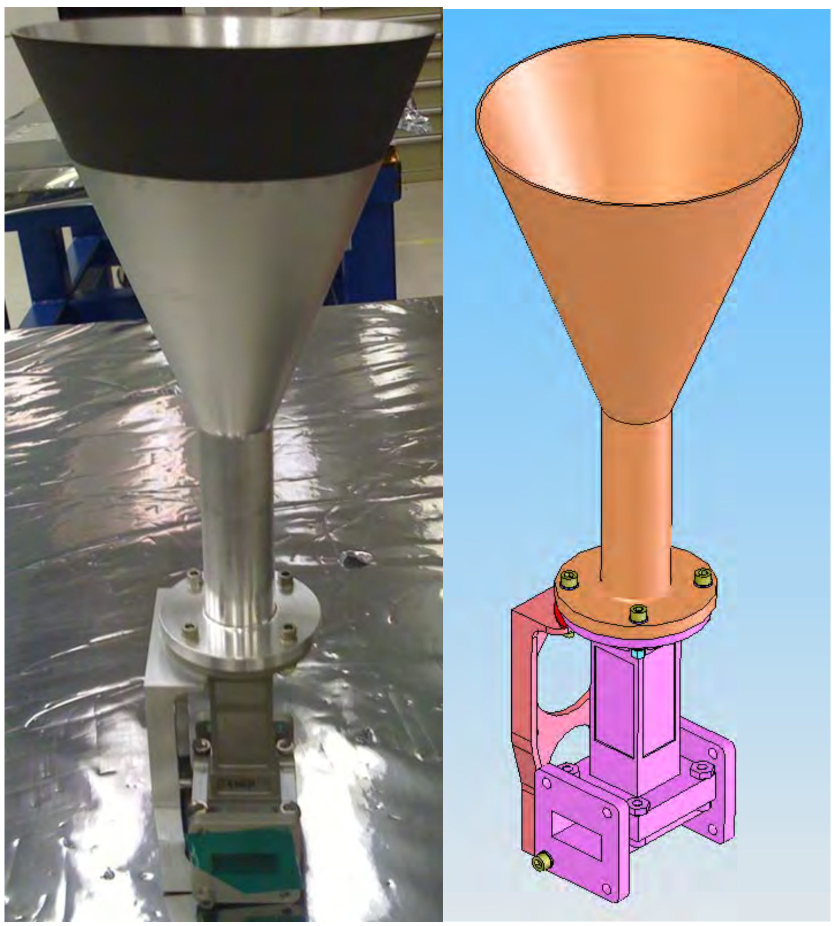


Figure 2-13: Photograph (left) and drawing (right) of the MGA.

Table 2-5 summarizes the main parameters. Figures 2-14 and 2-15 provide gain patterns, assuming an ideal polarizer. Each shows the co-polarized pattern in blue and the cross-polarized pattern in red. This results in the blue curve being the RHCP pattern when the RHCP port of the polarizer is in use and being the LHCP pattern when the LHCP port is in use. In these figures, gain is measured in dBic, and the term CP in the title stands for circular polarization.

Table 2-5: MGA parameters.

Parameter	Value
Design	RF conical horn
Receive frequency, MHz	7153.065586 channel 6
Transmit frequency, MHz	8404.135802 channel 6
Required gain, boresight, dBic	18.1 ± 0.4 receive 18.8 ± 0.4 transmit
Polarization	RHCP and LHCP
3 dB beamwidth, deg	± 10.3 receive ± 9.3 transmit
Axial Ratio, on boresight, dB	1.01 receive; 0.27 transmit
Axial Ratio, 20 deg off boresight, dB	6.29 receive; 7.53 transmit

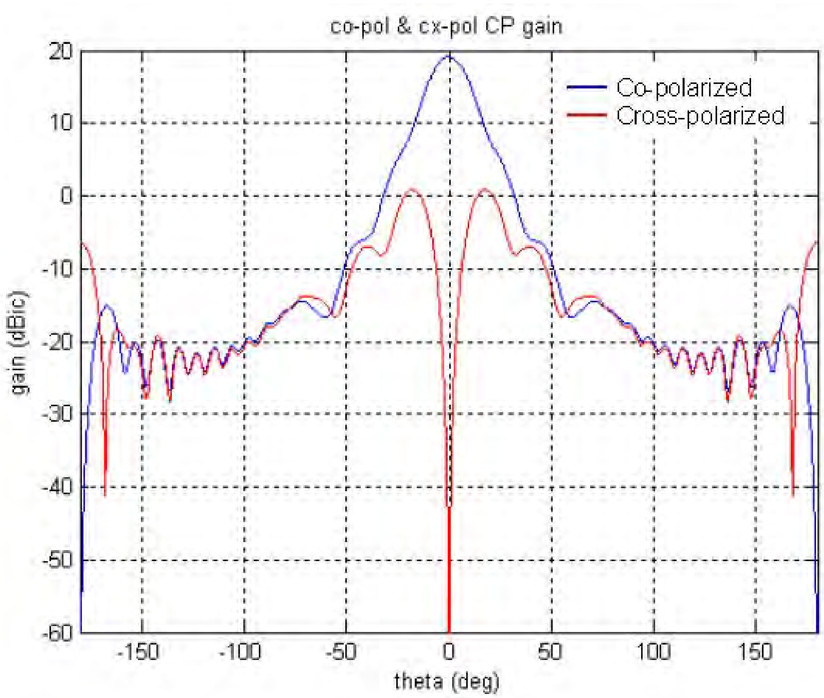


Figure 2-14: MGA downlink gain pattern.

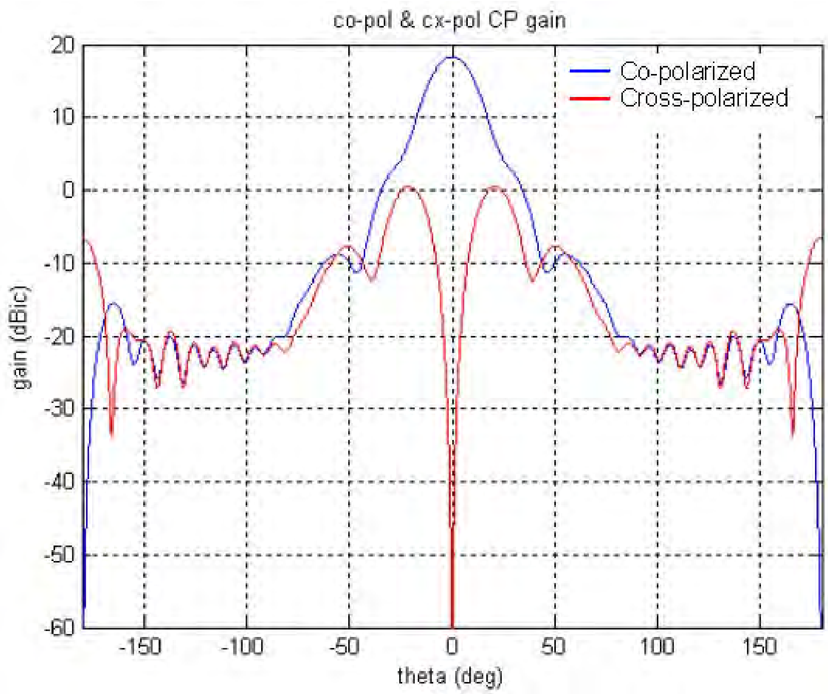


Figure 2-15: MGA uplink gain pattern.

2.1.4.4 Forward Low-Gain Antenna and Aft Low-Gain Antenna

The forward low-gain antenna and the aft low-gain antenna (FLGA and ALGA) were used during early Cruise, and they will be used for near-Earth communications (around Earth Flyby) and after fault responses. The FLGA boresight is aligned along the S/C +Z axis as shown in Figure 2-5.

The design for the antennas is the same as the MRO LGA. Figure 2-16 includes a color-coded drawing of the LGA, as well as photographs of the FLGA and ALGA. In the drawing, similar to the MGA, the red and pink show the mechanical support and the waveguide transition, respectively, while the yellow shows the antenna radiating element.

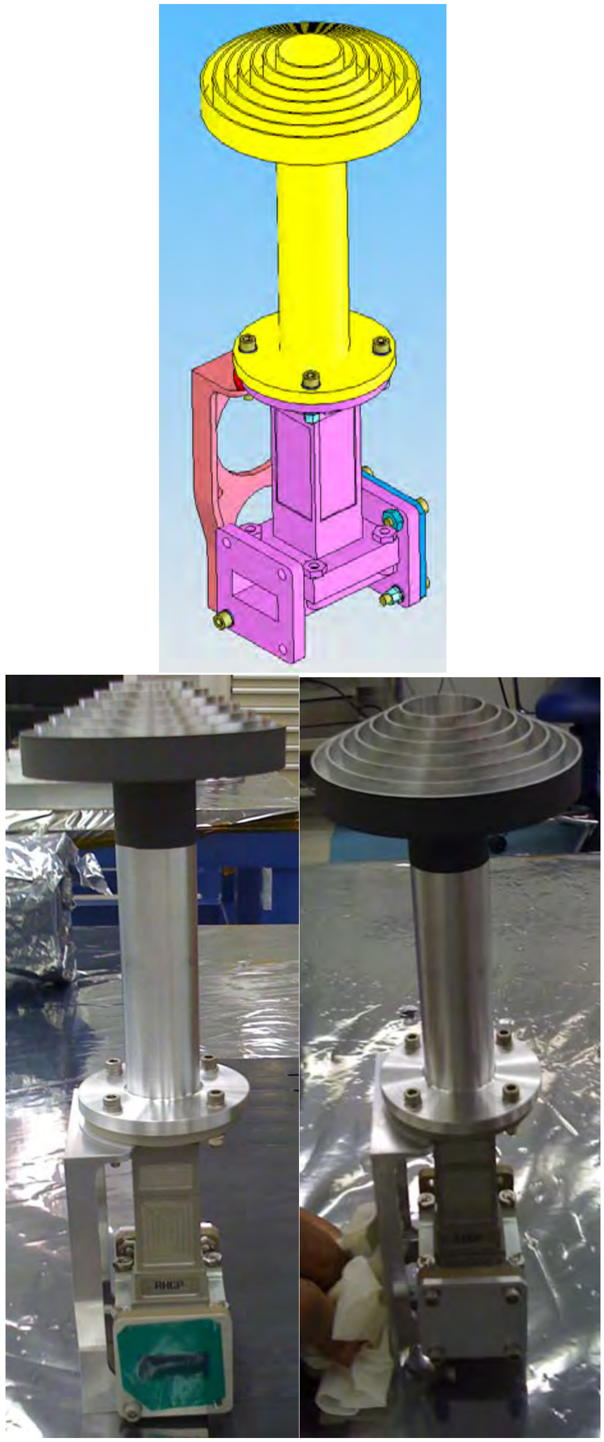


Figure 2-16: Forward (left) and Aft (right) LGAs with concept above.

Table 2-6 summarizes the main parameters, while Figures 2-17 and 2-18 present the antenna downlink and uplink patterns. Parameter values and patterns are considered identical for FLGA and ALGA for link modeling.

Table 2-6: LGA parameters.

Parameter	Value
Design	Choked horn
Receive frequency, MHz	7153.065586 channel 6
Transmit frequency, MHz	8404.135802 channel 6
Required gain, boresight, dBic	8.7 ± 0.4 dB receive 7.7 ± 0.4 dB transmit
Polarization	RHCP
3-dB beamwidth	± 40 deg receive ± 42 deg transmit
Axial ratio, on boresight	2.0 dB receive 2.0 dB transmit

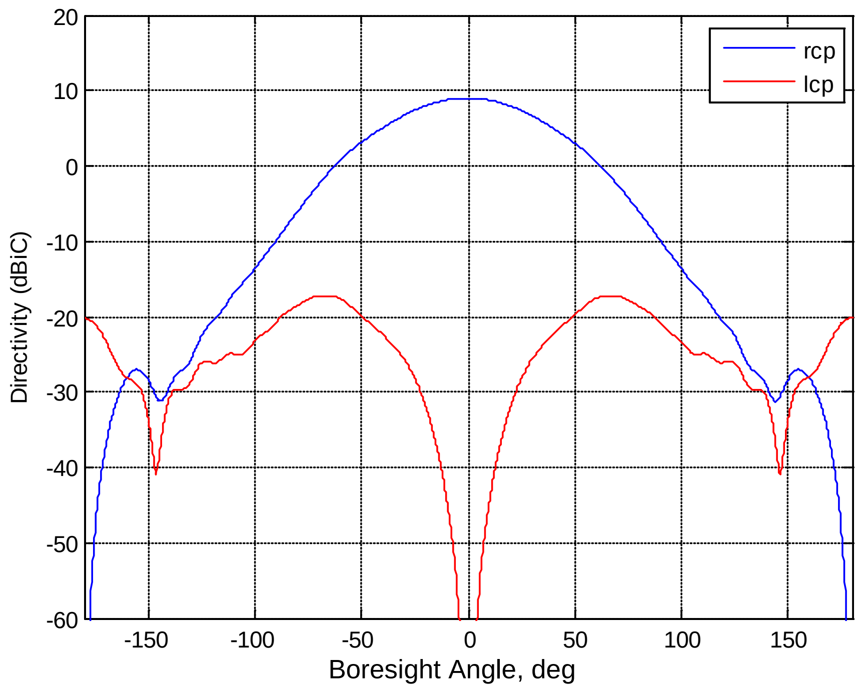


Figure 2-17: LGA downlink gain.

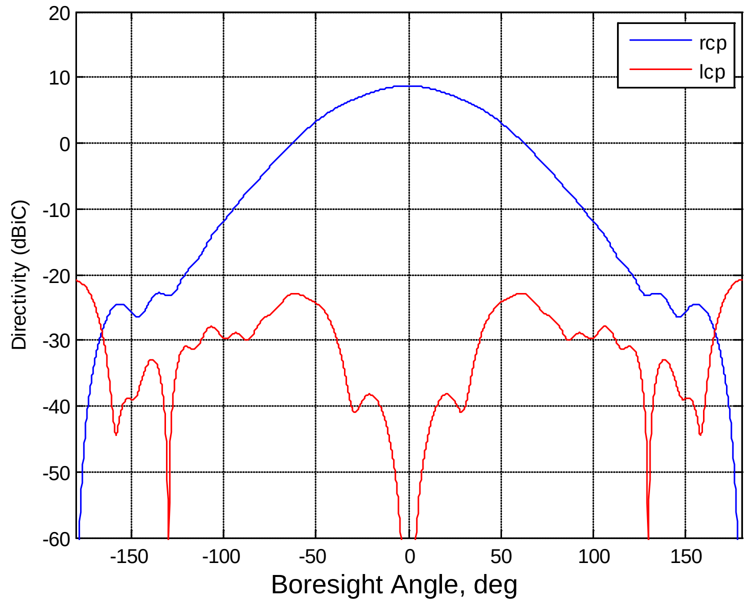


Figure 2-18: LGA uplink gain.

2.1.5 Waveguide Transfer Switch

The Waveguide Transfer Switches (WTSes) are MER heritage. Switches for both Juno and MSL are provided by Sector Microwave, with slight modifications based on MRO flight experience. Table 2-7 defines the top-level parameters for the switch, and Figure 2-19 shows a picture of a WTS.

Table 2-7: WTS parameters.

Parameter	Value
Insertion Loss	< 0.05 dB at 7.1 GHz and 8.4 GHz
Isolation between unconnected RF ports	> 55 dB

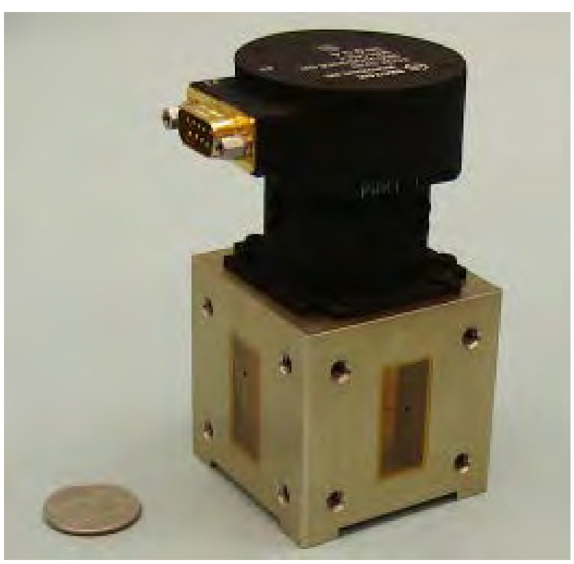


Figure 2-19: Picture of a WTS (quarter provided for scale).

2.1.6 X-Band Diplexer

The diplexer is a passive device connecting a receiver, a transmitter, and an antenna. The purpose of a diplexer's filters is to allow signals to be radiated by the antenna at one frequency while much weaker signals are received from the antenna at another frequency. On Juno, the diplexer reduces the TWTA output at the input of the SDST receiver to a safe and non-interfering level.

The Juno baseline design is MER residual hardware built by MCCI.

Table 2-8 defines the top-level parameters for the diplexer and Figure 2-20 is a photograph of several MER diplexers.

Table 2-8: X-band diplexer parameters.

Parameter	Condition	Value
Passband:	Transmit (TX)	8.29–8.545 GHz
	Receive (RX)	7.1–7.23 GHz
Insertion loss	TX	0.3 dB max
	RX	0.3 dB max
Passband voltage standing wave ratio (VSWR)	TX port, RX port, or Antenna Port	1.15:1 max (representative)
Isolation	TX/RX	> 120 dB (7.1 to 7.2 GHz) > 50 dB (8.4 to 8.5 GHz > 35 dB (2nd harmonic) > 35 dB (3rd harmonic) > 35 dB (4th harmonic)
Group delay variation		< 300 picoseconds (ps) in any 1-MHz range in the receive and transmit

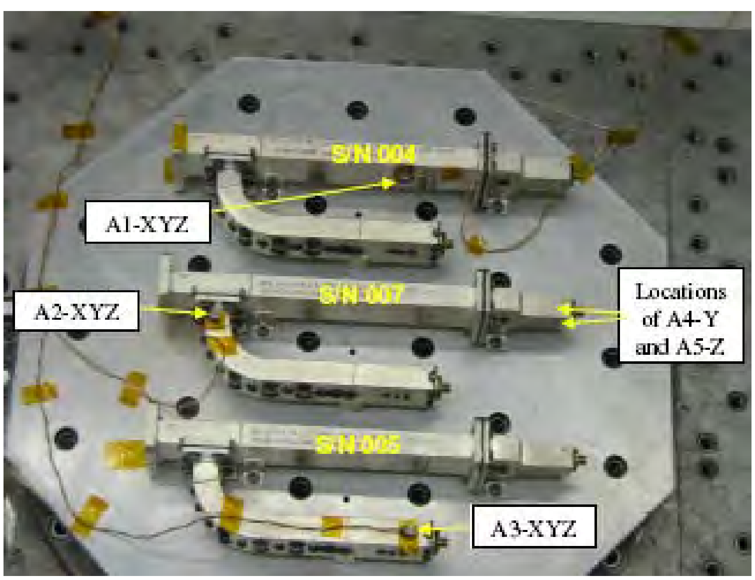


Figure 2-20: Photograph of several MER diplexers.

2.2 Ka-Band Radio Science

2.2.1 Ka-Band Translator – KaTS

The KaTS is a Ka/Ka translator (also sometimes called a transponder, analogous to the SDST) that is used for Gravity Science Doppler tracking at Jupiter. It is a science instrument provided to the Juno project by the Italian Space agency (ASI) and is built by Thales Alenia Space-Italy (TAS-I) It receives a Ka-band uplink carrier from DSS 25 at 34 GHz and returns a frequency-translated downlink carrier at 32 GHz, amplified to an output power of 2.5 W (34 dBm). The turn-around ratio is 3360/3599.

Figure 2-21 shows an illustration of the KaTS unit. Table 2-9 lists some of the KaTS parameters, and Figure 2-22 shows the KaTS software architecture. (For more detail, see Ref. [12].)

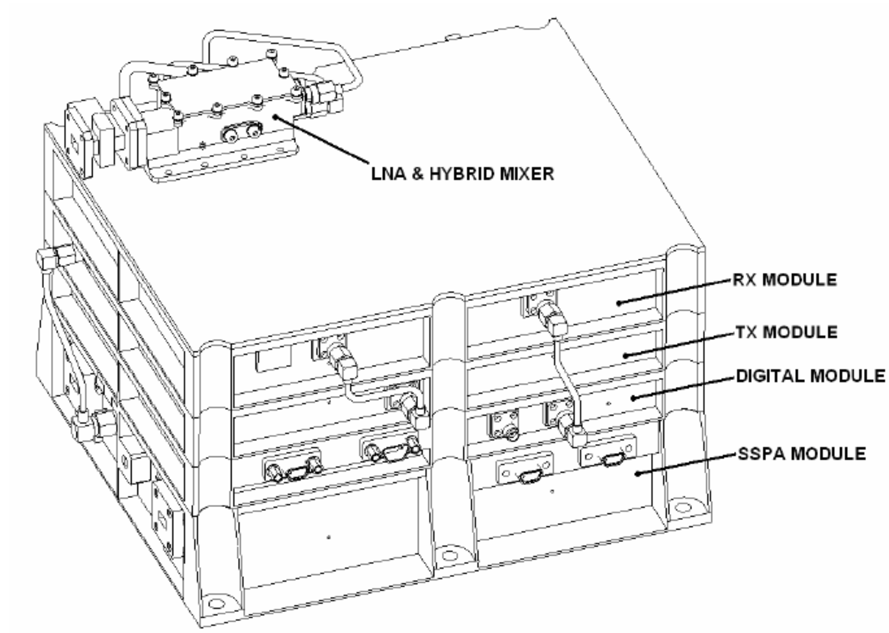


Figure 2-21: KaTS external view with labeled modules.

The Ka-band uplink and downlink are exclusively via the HGA.

Table 2-9: KaTS parameters from Ref. [3].

Parameter	Value	Comments
Receiver input frequency	34365.5 ± 3 MHz	DSN channel 5
Frequency output to SSPA	32088.5 ± 3 MHz	DSN channel 6
Downlink frequency	32083.3 MHz	Coherent or noncoherent
Downlink/uplink turnaround ratio	3360/3599	
Receiver input power range	–130 dBm to –90 dBm	
Receiver acquisition threshold	–130 dBm	With 4 kHz/s frequency rate
Receiver tracking threshold	–135 dBm	With 1.2 kHz/s frequency rate
SSPA RF input power	+2 dBm	
SSPA RF output power	+34 dBm	
Operating temperature	–31.5 C to +60 C	
Warm-up time	15 minutes	

The JUNO KaTS design is based on a combination of advanced signal processing algorithms and modern technological implementation [3]. The KaTS core, based on a digital architecture, led to the following advantages relative to an analog design:

1. Optimization of carrier acquisition and tracking performances.
2. Receiver tuning based on programmable constants.
3. Frequency plan based on direct digital frequency synthesis.

Names and acronyms in Figure 2-22 not defined elsewhere include: IFOC = IF-on-chip, OCXO = oven controlled quartz oscillator, μC = micro controller, NCO = numerically controlled oscillator, PFD = phase frequency detector, and SPD = sampling phase detector.

The KaTS is housed in a relatively small box composed of four stacked modules in aluminum alloy (AA6082 T6) with gold-over-nickel plating. The KaTS box has six type M4 fixing screws, allowing the contact surface to dissipate about 45 watts (W) through the S/C mounting panel, while the lateral wall thickness helps to protect the electronics against radiation. Also, as shown in Figure 2-1, the KaTS is inside the radiation-shielding vault.

The housing has 24 venting holes to reduce differential pressure between the interior and the exterior during the launch phase. The box is painted with Aeroglaze Z307 (black) to meet emissivity requirements.

Figure 2-23 is a top view photograph of the exterior of the KaTS. Figure 2-24 is a three-dimensional view of the KaTS with its modules.

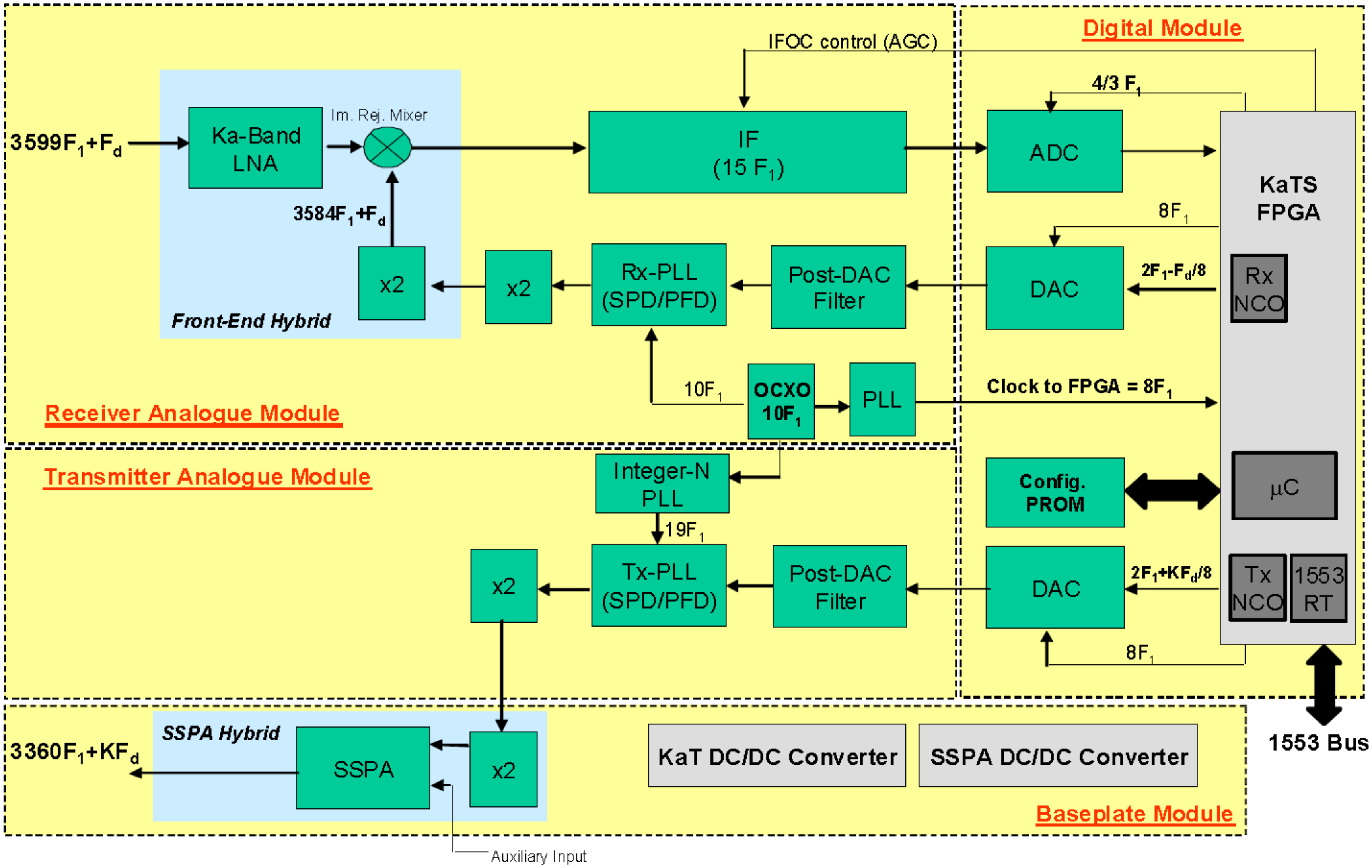


Figure 2-22: KaTS architecture block diagram (from Ref. [12]).

Figure 2-23: The KaTS manufacturer's photo.

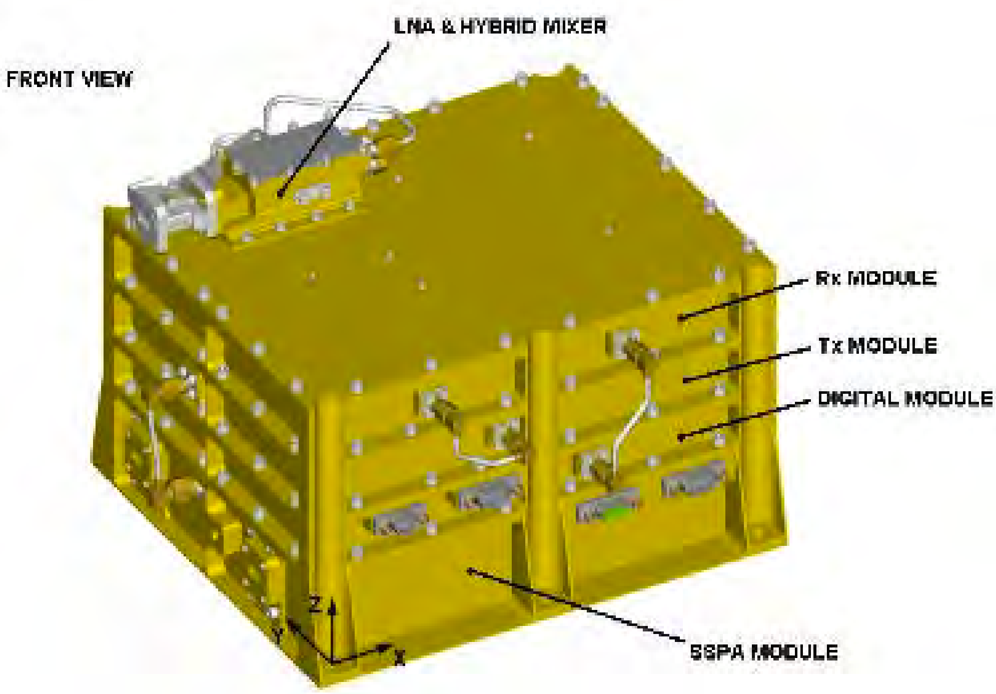


Figure 2-24: KaTS illustration with modules [3].

2.3 Subsystem Power and Mass Estimates

Table 2-10 shows the Juno Telecom Power and Mass Equipment List.

Note that the KaTS is powered off except during checkout and during gravity science operations.

Table 2-10: Juno telecommunications power and mass equipment list.

Component	Units	Input Power, W	Mass/Unit, kg	Component Masses, kg
SDST (X/X/Ka)	1	16.4		3.2
SDST (X/S)	1	15.7		3.0
TWTA	2	54.0	2.4	4.8
KaTS		46.2		3.1
HGA	1			21.3
MGA	1			0.5
TLGA	1			1.9
FLGA	1			0.5
ALGA	1			0.6
Diplexer	2		0.4	0.8
Isolator	2		0.55	1.1
WTS	5		0.44	2.2
X-band waveguide	1			6.3
X-band coax cable	1			0.9
Ka-band waveguide	1			0.2
Telecom panel	1			26.7
Miscellaneous microwave				1.0
Harness, fasteners, etc.				5.1
Total power (X-band)		70.4		
Total power (X/Ka)		116.6		
Total Mass				83.2

Blank

3 Link Performance

3.1 Summary of Link Performance

Below is a summary of the link performance for the different phases of the mission.

- Initial Acquisition
  - Juno performed initial acquisition over Canberra through the coupled LGAs. Because of the very strong downlink signal at initial acquisition, Juno planned the links the same as other recent deep space missions: (1) defining a prime and a backup station for downlink and for uplink, (2) scheduling 34-m stations, and (3) setting station downlink polarization to LHCP to reduce the received power from the RHCP downlink to prevent equipment damage. The data rate was 1745 bps with Reed–Solomon coding and an interleave depth of 5.
- Cruise
  - Cruise communications generally exceed requirements of 100 bps TLM rate and 7.8125 bps CMD rate.
  - It is assumed that ranging is on all of the time during Cruise.
  - There is one brief period before Earth flyby, when a switch from the toroidal antenna to the ALGA is made. The performance from either antenna has minimal margin due to large off-boresight angles.
  - The S/C will transition from use of the ALGA to use of the FLGA during Earth flyby—Note: no switching is required because the two antennas are coupled together.
- Orbital Operations
  - Juno is nominally on the HGA throughout orbital operations except for brief tracking periods after the orbit trim maneuvers (OTMs). The spacecraft will probably use the MGA for Doppler tracking during these periods.
  - The Telecom Subsystem is designed to support a minimum telemetry rate of 18 kbps into a DSN 34-m ground station for a nominal pass.
- Critical Event Coverage
  - Telecom coverage during the main engine burns is through the TLGA, downlink only.
  - At these times, there is no telemetry capability, but the link will support tones to a 70-m ground station.
- Safe Mode
  - In safe mode, a 70-m ground station is assumed for all support.
  - Minimum data rates are 7.8125 bps for command and 10 bps for telemetry.

Table 3-1 summarizes X-band uplink conditions (optimum modulation index and threshold signal level (uplink P_t/N_0)) as a function of command rate.

Table 3-1: Uplink thresholds and modulation indices.

		No Ranging	Ranging on (3 dB U/L suppr.)
CMD Rate	Mod Index (radians)	Req'd P_t/N_0	Req'd P_t/N_0
7.8125	0.94	25.44	28.44
15.625	1.2	26.95	29.95
31.25	1.3	29.72	32.72
62.5	1.5	32.35	35.35
125	1.5	33.97	36.97
250	1.5	37.11	40.11
500	1.5	39.93	42.93
1000	1.5	43.1	46.1
2000	1.5	46.13	49.13

Table 3-2 and Table 3-3 summarize X-band downlink conditions (optimum modulation index and threshold signal level (downlink P_t/N_0)) as a function of telemetry rate. Table 3-2 is for standard turnaround ranging on the downlink and Table 3-3 for no ranging.

Table 3-2: Telemetry modes and thresholds with turnaround ranging on.

Juno Downlink Telemetry Reference Table (With Ranging)						
Nominal Rate	Actual BPS	Symbol Rate	Coding	Mod Index (deg)	Subcarrier	Req'd P_t/N_0
10	12	23	RS+(7,1/2) short	46	25 kHz	19.15
40	47	93	RS+(7,1/2) short	60	25 kHz	22.08
100	100	602	Turbo-1/6	63.25	25 kHz	22.87
250	250	1,505	Turbo-1/6	70	25 kHz	26.21
1,000	1,000	6,018	Turbo-1/6	72	25 kHz	31.77
1,745	2,000	4,000	RS+(7,1/2) long	72	25 kHz	36.10
2,000	2,000	12,036	Turbo-1/6	72	281.25 kHz	34.69
4,000	4,002	24,088	Turbo-1/6	72	281.25 kHz	37.49
12,000	12,011	72,289	Turbo-1/6	72	281.25 kHz	42.04
18,000	18,036	108,553	Turbo-1/6	72	281.25 kHz	43.74
22,000	21,931	132,000	Turbo-1/6	72	281.25 kHz	44.59
26,000	25,893	155,844	Turbo-1/6	72	281.25 kHz	45.29
30,000	30,125	181,319	Turbo-1/6	72	281.25 kHz	45.90
35,000	34,978	210,526	Turbo-1/6	72	Direct BPSK	46.55
40,000	39,875	240,000	Turbo-1/6	72	Direct BPSK	47.12
50,000	49,844	300,000	Turbo-1/6	72	Direct BPSK	48.06
100,000	99,687	600,000	Turbo-1/6	72	Direct BPSK	51.00
120,000	119,191	717,391	Turbo-1/6	72	Direct BPSK	51.78
150,000	152,300	916,667	Turbo-1/6	72	Direct BPSK	52.73
200,000	199,375	1,200,000	Turbo-1/6	72	Direct BPSK	53.95

Table 3-3: Telemetry modes and thresholds with turnaround ranging off.

Juno Downlink Telemetry Reference Table (No Ranging)						
Nominal Rate	Actual BPS	Symbol Rate	Coding	Mod Index (deg)	Subcarrier	Req'd P_t/N_0
10	12	23	RS+(7,1/2) short	46	25 kHz	18.86
40	47	93	RS+(7,1/2) short	60	25 kHz	21.78
100	100	602	Turbo-1/6	63.25	25 kHz	22.57
250	250	1,505	Turbo-1/6	70	25 kHz	25.91
1,000	1,000	6,018	Turbo-1/6	72	25 kHz	31.47
1,745	2,000	4,000	RS+(7,1/2) long	72	25 kHz	35.80
2,000	2,000	12,036	Turbo-1/6	72	281.25 kHz	34.39
4,000	4,002	24,088	Turbo-1/6	74	281.25 kHz	37.19
12,000	12,011	72,289	Turbo-1/6	76	281.25 kHz	41.74
18,000	18,036	108,553	Turbo-1/6	76	281.25 kHz	43.44
22,000	21,931	132,000	Turbo-1/6	76	281.25 kHz	44.29
26,000	25,893	155,844	Turbo-1/6	77	281.25 kHz	44.99
30,000	30,125	181,319	Turbo-1/6	77	281.25 kHz	45.60
35,000	34,978	210,526	Turbo-1/6	77	Direct BPSK	46.25
40,000	39,875	240,000	Turbo-1/6	78	Direct BPSK	46.82
50,000	49,844	300,000	Turbo-1/6	78	Direct BPSK	47.76
100,000	99,687	600,000	Turbo-1/6	80	Direct BPSK	50.70
120,000	119,191	717,391	Turbo-1/6	80	Direct BPSK	51.48
150,000	152,300	916,667	Turbo-1/6	80	Direct BPSK	52.43
200,000	199,375	1,200,000	Turbo-1/6	80	Direct BPSK	53.65

In these tables, the first three columns indicate the nominal bit rate in bps, the actual information rate in bps, and the symbol rate in symbols/second on the RF channel between Juno and the ground station. The symbol rate is a function of the information rate and the coding. Note in the third column from the right that the telemetry modulation index values in the two tables differ for rates of 40 kbps and higher, depending on whether ranging is present on the downlink carrier. The rightmost column indicates the required P_t/N_0 for the combination of data rate, coding, modulation index, and absence or presence of simultaneous ranging modulation.

3.2 Detailed Link Performance

3.2.1 Link Performance Assumptions

Juno will primarily use the DSN 34-m subnet. For nominal communications with any 34-m station, the performance of DSS-34 is used to make long-range predictions. For Gravity Science planning, predictions are made specifically for DSS-25, the only station having Ka-band uplink. For Safe Mode, when a 70-m antenna is used, DSS-63 (Madrid, Spain) is assumed. For certain unique events (e.g., JOI), a specific DSN antenna is specified by the project.

A 90-percent weather model is used for all links. X-band links assume a 15-deg elevation angle while Ka-band links use a 20-deg elevation angle. The link capability plots assume free space antenna patterns. A 2-sigma statistical margin is kept for all link budgets. The required uplink bit error rate (BER) is 1×10^{-5}. The required downlink BER is 1×10^{-6}. In terms of downlink threshold signal level (specifically E_b/N_0), this downlink BER requirement is nearly identical to the frame error rate (FER) of 1×10^{-4}, that is shown in the design control tables (sometimes called link budgets) starting with Table 3-4.

Table 3-4 Juno Cruise HGA X-band downlink DCT.

Produced by JUNO V2.1 XML 5/5/2011

Predict	2012-187T19:12:00000 UTC
Up/down-link	Two-Way
RF band	X:X
Diplex mode	N/A
LNA selection	LNA-1
Telecom link	DSS26-HighGain-DSS26

TELEMETRY DOWN-LINK PARAMETER INPUTS

Encoding	Turbo (8920,1/6)
Carrier tracking	Residual
Oscillator	2 Way VCO
Subcarrier mode	Squarewave
PLL Bandwidth	3.00 Hz
Tlm usage	Engineering
Tlm data rate/mod index	120000 bps/ 72.00 deg
Tlm rng/DOR Mod Index	0.31 rad/ 0.00 deg

Operations mode	Nominal
Mission phase	Cruise
DSN site	Gold-Gold
DSN elevation	In view
Weather/CD	90
Attitude pointing	Earth pointed

EXTERNAL DATA
SPICE Kernels (in load order)
(omitted from this article)

Range	(km)	4.7456e+08
Range	(AU)	3.1722e+00
DL one-way light time (hh:mm:ss)		00:26:22
Station elevation (deg)		59.65
DL DOFF: Hga (deg)		0.25
DL Clk: Hga (deg)		0.36
Added S/C Pnt Offset (deg)		0.25

DSN site considered: DSS-26/DSS-26
At time: 2012-187T19:12:00.000 UTC

Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TRANSMITTER PARAMETERS						
1. S/C transmitter power	dBm	44.40	0.30	0.00	44.50	0.0050
2. S/C Xmit circuit loss	dB	-0.90	0.10	-0.10	-0.90	0.0033
3. S/C Antenna Gain	dBi	44.70	0.50	-0.50	44.70	0.0417
4. Degrees-off-boresight (DOFF) loss	dB	0.93	-0.00	-0.00	0.93	0.0000
5. S/C transmit pointing loss	dB	0.00	0.00	0.00	0.00	0.0000
6. EIRP (1+2+3-4+5)	dBm	87.37	0.67	-0.67	87.37	0.0500
PATH PARAMETERS						
7. Space loss	dB	-284.46	0.00	0.00	-284.46	0.0000
8. Atmospheric attenuation	dB	-0.06	0.00	0.00	-0.06	0.0000

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Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
RECEIVER PARAMETERS						
9. DSN antenna gain	dBi	68.26	0.10	-0.20	68.22	0.0039
10. DSN antenna pointing loss	dB	-0.10	0.10	-0.10	-0.10	0.0033
11. Polarization loss	dB	-0.05	0.10	-0.10	-0.05	0.0033
TOTAL POWER SUMMARY						
12. Tot Rcvd Pwr (6+7+8+9+10+11)	dBm	-129.08	-0.74	0.74	-129.08	0.0606
13. SNT due to Antenna-MW	K	16.33	-1.00	2.00	16.67	0.3889
14. SNT due to Atmosphere	K	3.68	0.00	0.00	3.68	0.0000
15. SNT due to Cosmic Backgnd	K	2.69	0.00	0.00	2.69	0.0000
16. SNT due to the Sun	K	0.00	0.00	0.00	0.00	0.0000
17. SNT due to other Hot Bodies	K	0.00	0.00	0.00	0.00	0.0000
18. SNT (13+14+15+16+17)	K	22.70	-1.00	2.00	23.03	0.3889
19. Noise Spectral Density	dBm/Hz	-185.04	-0.20	0.37	-184.98	0.0136
20. Received P_t/N_0 (12-19)	dB-Hz	55.90	0.82	-0.82	55.90	0.0741
21. Received P_t/N_0, mean-2 Sigma	dB-Hz	55.36	0.00	0.00	55.36	0.0000
22. Required P_t/N_0	dB-Hz	51.80	0.00	0.00	51.80	0.0000
23. P_t/N_0 Margin (20–22)	dB	4.10	0.82	-0.82	4.10	0.0741
24. P_t/N_0 Margin, mean-2 Sigma (21–22)	dB	3.55	0.00	-0.00	3.55	0.0000
CARRIER PERFORMANCE						
25. Recovered P_t/N_0 (20+[AGC+BPF])	dB-Hz	55.90	0.82	-0.82	55.90	0.0741
26. Telemetry Carrier Suppression	dB	-10.20	1.52	-1.89	-10.32	0.4854
27. Ranging Carrier Suppression	dB	-0.30	0.06	-0.06	-0.30	0.0006
28. DOR Carrier Suppression	dB	0.00	-0.00	-0.00	-0.00	0.0000
29. Carrier Power (AGC) (12+26+27+28)	dBm	-139.70	-2.22	2.22	-139.70	0.5466
30. Received P_c/N_0 (25+26+27+28)	dB-Hz	45.28	2.25	-2.25	45.28	0.5602
31. Carrier Loop Noise BW	dB-Hz	4.77	0.00	0.00	4.77	0.0000
32. Carrier Phase Error Var (from 30,31,xpond,solar)	rad^2	4.8e-03	0.00	0.00	4.8e-03	0.0000
33. Carrier Loop SNR (CNR) (from 32)	dB	23.19	2.25	-2.25	23.19	0.5602
34. CNR, mean-2 Sigma	dB	21.69	0.00	0.00	21.69	0.0000
35. Recommended CNR	dB	10.00	0.00	0.00	10.00	0.0000
36. CNR Margin (33–35)	dB	13.19	2.25	-2.25	13.19	0.5602
37. CNR Margin, mean-2 Sigma (34–35)	dB	11.69	0.00	-0.00	11.69	0.0000
TELEMETRY PERFORMANCE						
38. Telemetry Data Suppression	dB	-0.44	-0.20	0.16	-0.45	0.0053
39. Ranging Data Suppression	dB	-0.30	0.06	-0.06	-0.30	0.0006
40. DOR Data Suppression	dB	0.00	-0.00	-0.00	-0.00	0.0000
41. Received Pd/N_0 (25+38+39+40)	dB-Hz	55.15	0.85	-0.85	55.15	0.0800
42. Received Pd/N_0, mean-2 Sigma	dB-Hz	54.59	0.00	0.00	54.59	0.0000
43. Data Rate, Symbols (dB-Hz)	dB-Hz	50.79	0.00	0.00	50.79	0.0000
44. Available E_b/N_0 (41-43)	dB	4.36	0.85	-0.85	4.36	0.0800
45. Radio Loss	dB	0.30	0.00	0.00	0.30	0.0000
46. Subcarrier Demod Loss	dB	0.00	0.00	0.00	0.00	0.0000
47. Symbol Sync Loss	dB	0.00	0.00	0.00	0.00	0.0000
48. Decoder Loss	dB	-0.00	-0.00	-0.00	-0.00	0.0000
49. Waveform Distortion Loss	dB	0.10	-0.10	0.10	0.10	0.0017
50. SDST Filtering Loss	dB	-0.08	-0.00	-0.00	-0.08	0.0000
51. High Rate Ranging Loss	dB	-0.00	-0.00	-0.00	-0.00	0.0000
52. Output E_b/N_0 (44–51)	dB	4.04	0.86	-0.86	4.04	0.0817
53. Output E_b/N_0, mean-2 Sigma	dB	3.46	0.00	0.00	3.46	0.0000
54. Required E_b/N_0	dB	-0.10	0.00	0.00	-0.10	0.0000
55. E_b/N_0 Margin (52–54)	dB	4.14	0.86	-0.86	4.14	0.0817
56. E_b/N_0 Margin, mean-2 Sigma	dB	3.56	0.00	-0.00	3.56	0.0000
57. Down Data Rate Cap (21,22)	bps	2e+05				

The design control tables, Table 3-4 through Table 3-9, were generated by the Telecom Forecaster Predictor (TFP), a standard link analysis tool. While they have been lightly reformatted for this article, generally the computer outputs are left untouched. Acronyms, for example, may differ slightly from the style in the article.

The tables include the following acronyms not used elsewhere in the article.

Adv	adverse
CD	cumulative distribution (also called "percent weather")
Fav	favorable
MW	microwave
Pnt	pointing offset of spacecraft antenna (also called "DOFF")
Tol	tolerance
Var	variance

3.2.1.1 Pointing Errors Assumptions

For Cruise, we assume an antenna pointing error given by the Flight System based on thermal and power predicts for the spacecraft.

When the HGA is used, it is assumed that the antenna pointing is 4.4 milliradians (mrad) (0.25 deg).

3.2.1.2 Downlink Performance Assumptions

The current baseline is 20 downlink rates, between 10 and 200,000 bps.

Turbo encoding (rate 1/6, 8920 frame length) is the baseline for all downlink rates except 10, 40, and 1745 bps, and it is performed by the C&DH Subsystem. For 10, 40, and 1745 bps, a concatenated convolutional (7, 1/2) + Reed–Solomon (interleave depth 1 for 10 and 40 bps and interleave depth 5 for 1745 bps) outer code will be used.

The X-band downlink performance estimates assume a TWTA output power of 25 W.

3.2.1.3 Uplink Performance Assumptions

The uplink threshold estimates (see Table 3-1) are based on test results.

For uplink performance estimates, we make the same assumptions as in the downlink analyses section regarding the antenna patterns and path losses. For SDST noise we use the average (2.1 dB) of all SDST flight units for capabilities assessment, and the end of life estimate (2.8 dB) for requirements verification.

3.2.1.4 Ranging Performance Assumptions

The following formula gives the 1-sigma ranging uncertainty in meters due to thermal noise only (810-005 [4], Module 203) for sinewave operations:

$$\sigma(r) = \sqrt{\frac{285}{F_c^2(MHz)T_1 \dfrac{P_r}{N_0}}}$$

Where F_c is the clock frequency (approximately 1 MHz), P_r/N_0 is the downlink power to noise ratio in the ranging channel, and T_1 is the integration time for the clock component.

In order to resolve range ambiguity, lower-frequency components are used. The probability of acquisition, P_{acq}, is:

$$P_{acq} = \left\{ \frac{1}{2} + \frac{1}{2} erf \left[\sqrt{T_2 \times P_r / N_0} \right] \right\}^n$$

where n is the number of components and T_2 the integration time of each of them.

The values for T_1 and T_2 can then be used in the formula for the cycle time:

$$T_{cyc} = T_1 + 3 + n + nT_2$$

For a specified sigma and P_{acq}, the cycle time is a function of P_r/N_0 and n.

For a sigma of 5 m and a total cycle time of 1000 seconds, the received P_r/N_0 must be between –10 and –7 dB-Hz depending on the number of lower-frequency components the Juno navigation team determines are required to resolve the range ambiguity. Since telecom does not control how many components are needed, we assume a value of –9.0 dB-Hz as the threshold.

3.2.1.5 Differential One-way Ranging

Delta-DOR is a type of data complementary to turnaround ranging and Doppler. While ranging provides an estimate of the location of the spacecraft (in a radial sense, i.e., how far away the S/C is), delta-DOR gives very good angular location (relative to a known quasar; this is also referred to as "plane of sky location," or "tangential" motion). It requires the spacecraft to modulate the downlink carrier with a pair of DOR tones at approximately ±19 MHz. The telecom configuration for delta-DOR includes a telemetry subcarrier frequency of 281.25 kHz (with nothing modulating the subcarrier) that is also modulated onto the carrier during DOR measurements.

The DOR tone modulation index is selected to be 70 deg for the Juno SDST. This increases power in the DOR channel with respect to the value of 28 deg used on the MER SDSTs by about 6.5 dB.

3.2.2 Ka-Band Assumptions

The Ka-band part of the Radio Frequency Instrument Subsystem (RFIS), another name for the Telecom Subsystem) is to support dual-frequency Gravity Science. Ka-band is used only with the HGA and the DSS-25 ground station at Goldstone, California. The Ka-band signal is carrier only, no telemetry. During Ka-band operation, the HGA pointing accuracy is 4.4 mrad (0.25 deg). There is only one path for the uplink and downlink as the Ka-band equipment is single string.

3.2.3 Link Analysis

The link analyses below cover nominal Cruise phase, Jovian orbits, and safe mode. Link performance varies with station elevation angle. For Juno link planning, an elevation angle of 15 deg is assumed.

3.2.3.1 Cruise Phase

One basic requirement covering all of the antennas is that a minimum downlink bit rate of 100 bps must be supported throughout Cruise. It is assumed that ranging is on.

Another basic requirement covering all of the antennas is that a minimum uplink command rate of 7.8125 bps must be supported through Cruise. It is assumed that ranging is on.

Figure 3-1 shows the expected downlink performance throughout the mission. Note that the chosen antenna changes throughout the mission. As seen in Figure 3-1, most of the time the spacecraft is on the HGA. The also shows that throughout Cruise, the Telecom Subsystem can support a minimum of 100 bps. Figure 3-2 shows a similar curve for the uplink. This shows ample margin to support the 7.8125 bps command rate.

X-band performance on the HGA is illustrated by an example taken from the July 5, 2012 (day of year, DOY 187) X-band pass over DSS-26 (34-m beam waveguide antenna at Goldstone, California). Table 3-4 and Table 3-5 are design control tables to illustrate X-band predicted performance at 19:12 UTC on that day. The predictions are for DSS-26 (a 34-m station at Goldstone) which was actually performing this pass. The station elevation angle was nearly 60 deg. A comparison of predicted performance and actual performance follows in Figures 3-3 through 3-6.

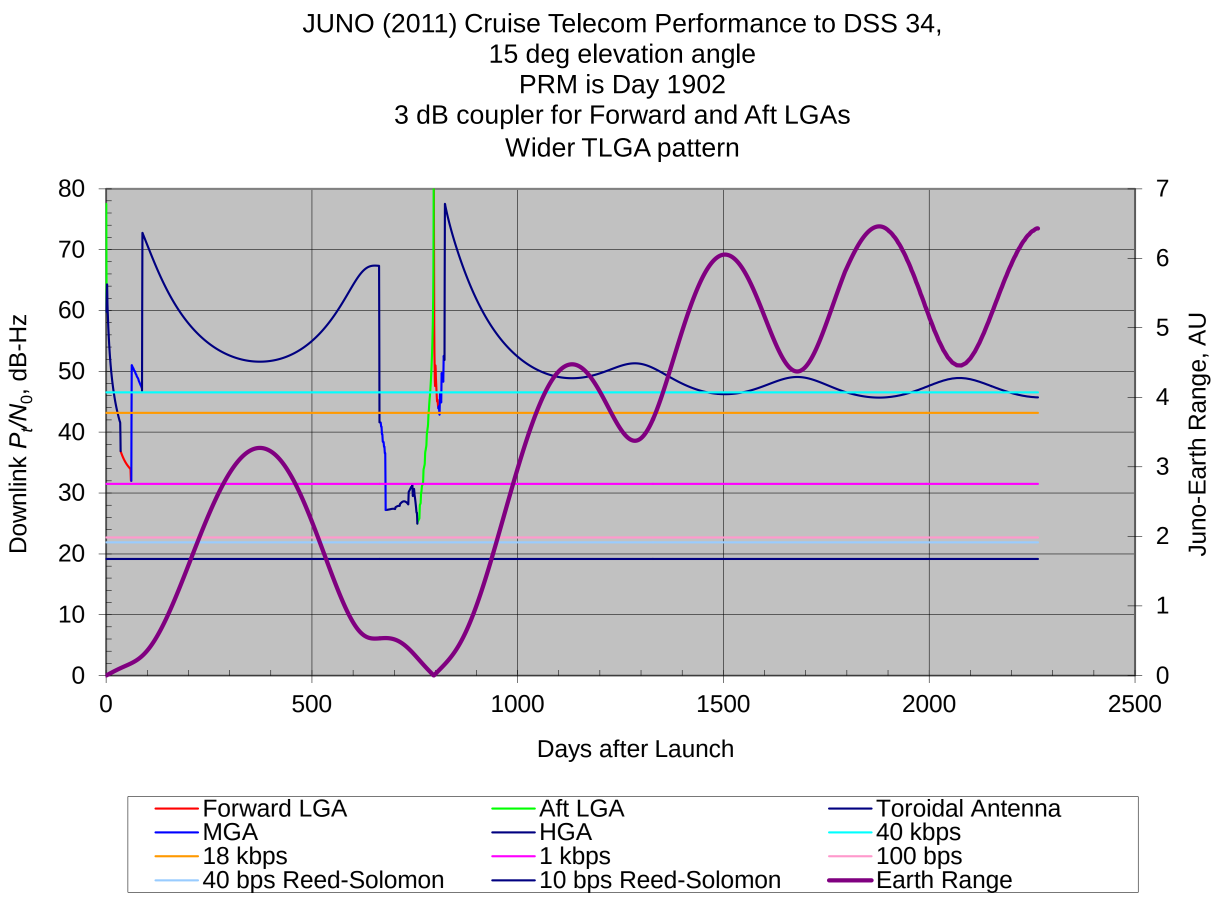

Figure 3-1: Juno predicted downlink performance.

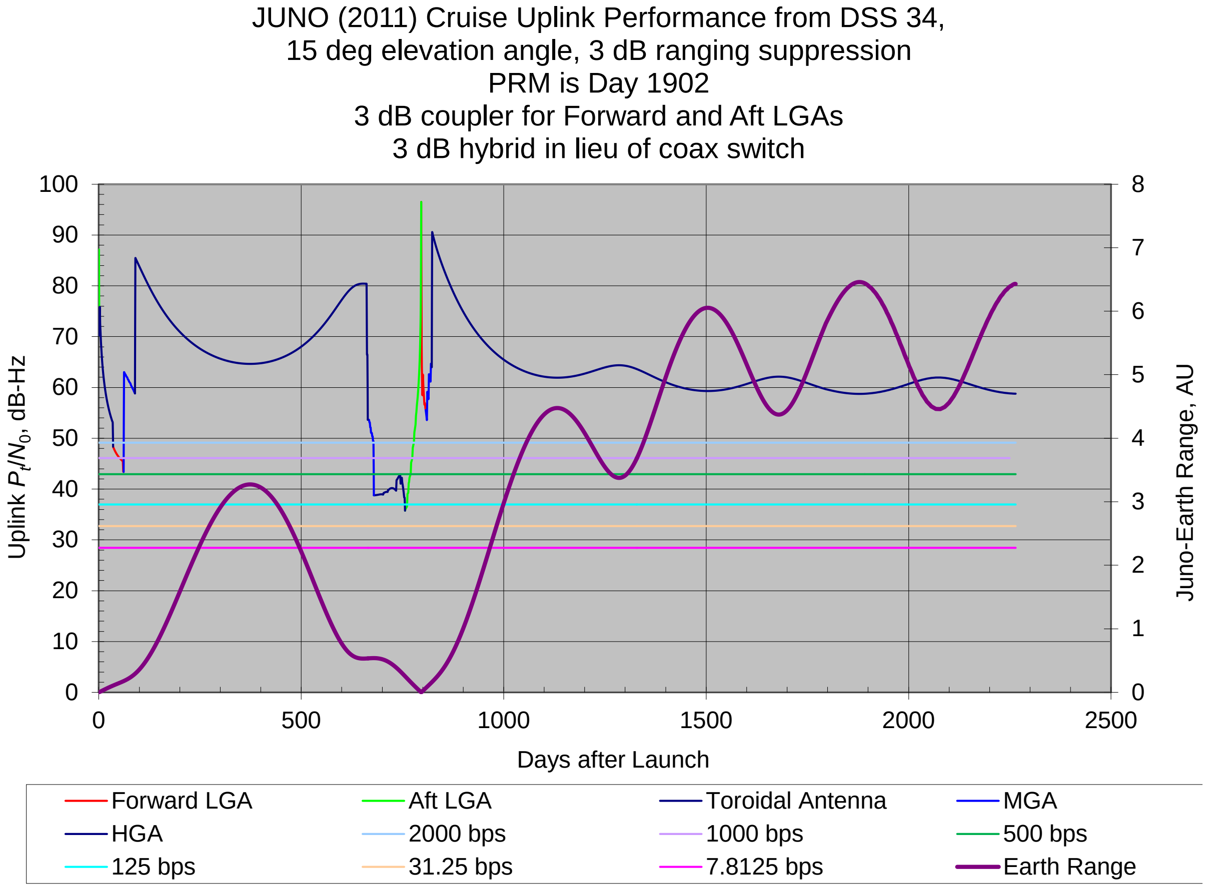

Figure 3-2: Juno predicted uplink performance.

Table 3-5: Juno Cruise HGA X-band uplink DCT.

Produced by JUNO V2.1 XML 5/5/2011

Predict 2012-187T19:12:00.000 UTC
Up/Down-Link Two-Way
RF Band X:X
Telecom Link DSS26-HighGain-DSS26

COMMAND UP-LINK PARAMETER INPUTS
Cmd Data Rate 2000.0000 bps
Cmd Mod Index 1.50 radians
Cmd RngMod Index 44.9 degrees

Operations Mode Nominal
Mission Phase Cruise
DSN Site Gold-Gold
DSN Elevation In View
Weather/CD 90
Attitude Pointing Earth Pointed

EXTERNAL DATA
SPICE Kernels (in load order)
(omitted from this article)

Range (km) 4.7459e+08
Range (AU) 3.1724e+00
One-Way Light Time (OWLT) (hh:mm:ss) 00:26:23
Station Elevation (deg) 59.65
UL DOFF: Hga (deg) 0.25
UL Clk: Hga (deg) 0.51
Added S/C Pnt Offset (deg) 0.25

DSN Site Considered: DSS-26/DSS-26
At Time: 2012-187T19:12:00.000 UTC

Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TRANSMITTER PARAMETERS						
1. Total Transmitter Power	dBm	73.01	0.50	-0.50	73.01	0.0417
2. Xmitter Waveguide Loss	dB	-0.60	0.10	-0.10	-0.60	0.0017
3. DSN Antenna Gain	dBi	66.92	0.20	-0.30	66.89	0.0106
4. Antenna Pointing Loss	dB	-0.10	0.10	-0.10	-0.10	0.0017
5. EIRP (1+2+3+4)	dBm	139.20	0.71	-0.71	139.20	0.0556
PATH PARAMETERS						
6. Space Loss	dB	-283.06	0.00	0.00	-283.06	0.0000
7. Atmospheric Attenuation	dB	-0.06	0.00	0.00	-0.06	0.0000
RECEIVER PARAMETERS						
8. Polarization Loss	dB	-0.07	0.10	-0.10	-0.07	0.0033
9. Degrees-off-boresight (DOFF) Loss	dB	0.71	-0.00	-0.00	0.71	0.0000
10. S/C Antenna Gain (at boresight)	dBi	42.84	0.50	-0.50	42.84	0.0417
11. S/C Receive Pointing Loss	dB	0.00	0.00	0.00	0.00	0.0000
12. Lumped Circuit Loss	dB	-4.00	0.50	-0.50	-4.00	0.0833

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Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TOTAL POWER SUMMARY						
13. Tot Rcvd Pwr (5+6+7+8-9+10+11+12)	dBm	-105.87	-1.29	1.29	-105.87	0.1839
14. Noise Spectral Density	dBm/Hz	-172.57	-1.40	0.75	-172.78	0.1979
15. System Noise Temperature	K	401.25	-110.49	75.37	389.54	1456.4778
16. Received P_t/N_0 (13–14)	dB-Hz	66.92	1.85	-1.85	66.92	0.3817
17. Received P_t/N_0, mean-3 Sigma	dB-Hz	65.06	0.00	0.00	65.06	0.0000
18. Required P_t/N_0	dB-Hz	49.13	0.00	0.00	49.13	0.0000
19. P_t/N_0 Margin (16-18)	dB	17.79	1.85	-1.85	17.79	0.3817
20. P_t/N_0 Margin, mean-3 Sigma (17–18)	dB	15.93	0.00	-0.00	15.93	0.0000
CARRIER PERFORMANCE						
21. Recovered P_t/N_0 (16+[AGC+BPF])	dB-Hz	66.92	1.85	-1.85	66.92	0.3817
22. Command Carrier Suppression	dB	-5.82	0.58	-0.58	-5.82	0.0564
23. Ranging Carrier Suppression	dB	-3.00	0.20	-0.21	-3.00	0.0069
24. Carrier Power (AGC)	dBm	-114.68	-1.49	1.49	-114.68	0.2472
25. Received P_c/N_0 (21+22+23)	dB-Hz	58.10	2.00	-2.00	58.10	0.4451
26. Carrier Loop Noise BW	dB-Hz	20.47	-0.20	0.15	20.45	0.0102
27. Carrier Loop SNR (CNR) (25–26)	dB	37.65	2.02	-2.02	37.65	0.4553
28. CNR, mean-3 Sigma	dB	35.63	0.00	0.00	35.63	0.0000
29. Recommended CNR	dB	12.00	0.00	0.00	12.00	0.0000
30. CNR Margin (27–29)	dB	25.65	2.02	-2.02	25.65	0.4553
31. CNR Margin, mean-3 Sigma (28–29)	dB	23.63	0.00	-0.00	23.63	0.0000
CHANNEL PERFORMANCE						
32. Command Data Suppression	dB	-2.06	-0.14	0.12	-2.07	0.0029
33. Ranging Data Suppression	dB	-3.00	0.20	-0.21	-3.00	0.0069
34. Received P_d/N_0 (21+32+33)	dB-Hz	61.85	1.88	-1.88	61.85	0.3915
35. Received P_d/N_0, mean-3 Sigma	dB-Hz	59.97	0.00	0.00	59.97	0.0000
36. Data Rate (dB-Hz)	dB-Hz	33.01	0.00	0.00	33.01	0.0000
37. Available E_b/N_0 (34–36)	dB	28.84	1.88	-1.88	28.84	0.3915
38. Implementation Loss	dB	1.48	-0.84	0.75	1.45	0.1054
39. Radio Loss	dB	0.00	0.00	0.00	0.00	0.0000
40. Output E_b/N_0 (37–39)	dB	27.39	2.11	-2.11	27.39	0.4970
41. Output E_b/N_0, mean-3 Sigma	dB	25.28	0.00	0.00	25.28	0.0000
42. Required E_b/N_0	dB	9.60	0.00	0.00	9.60	0.0000
43. E_b/N_0 Margin (40–42)	dB	17.79	2.11	-2.11	17.79	0.4970
44. E_b/N_0 Margin, mean-3 Sigma (41–42)	dB	15.68	0.00	-0.00	15.68	0.0000
45. BER (from 40)		none	7.8657e-241			

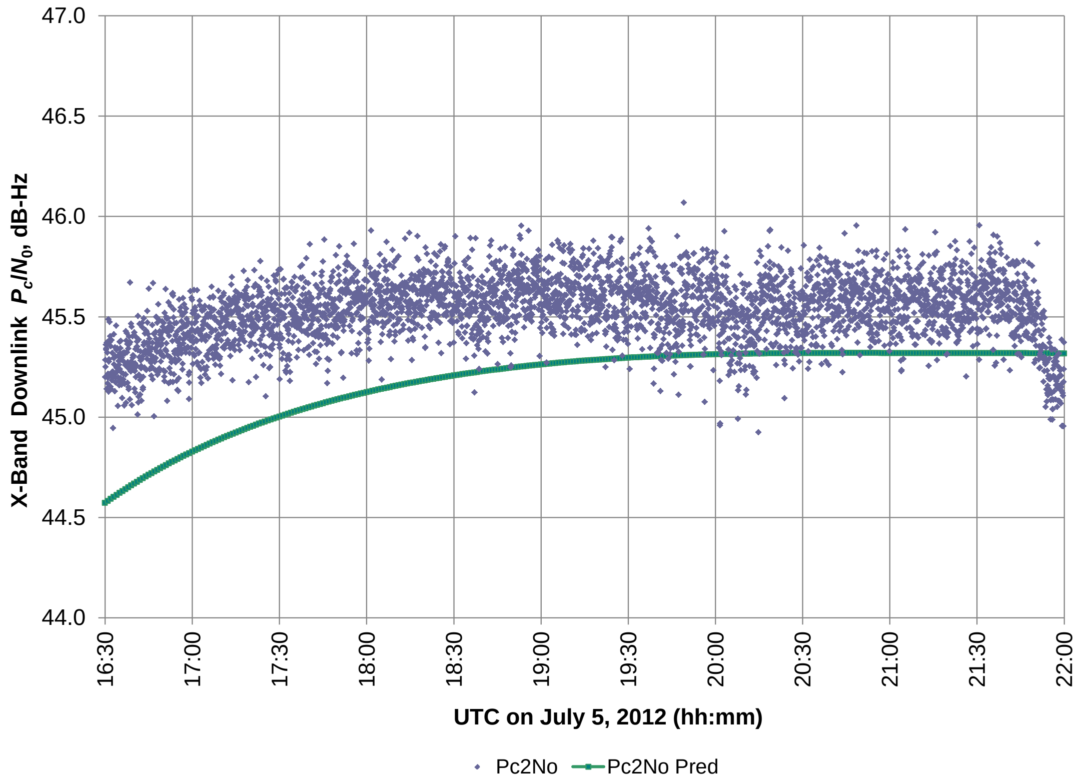

Figure 3-3: Predicted and actual carrier power to noise spectral density (P_c/N_0) on July 5, 2012.

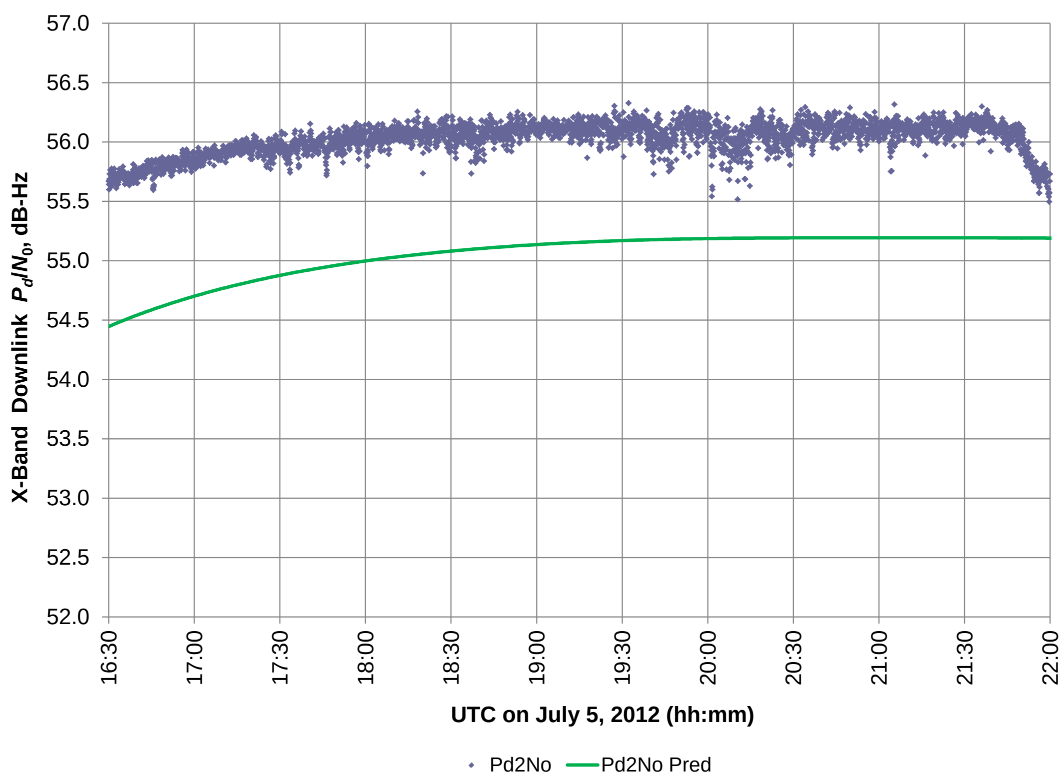

Figure 3-4: Predicted and actual data power to noise spectral density (P_d/N_0) on July 5, 2012.

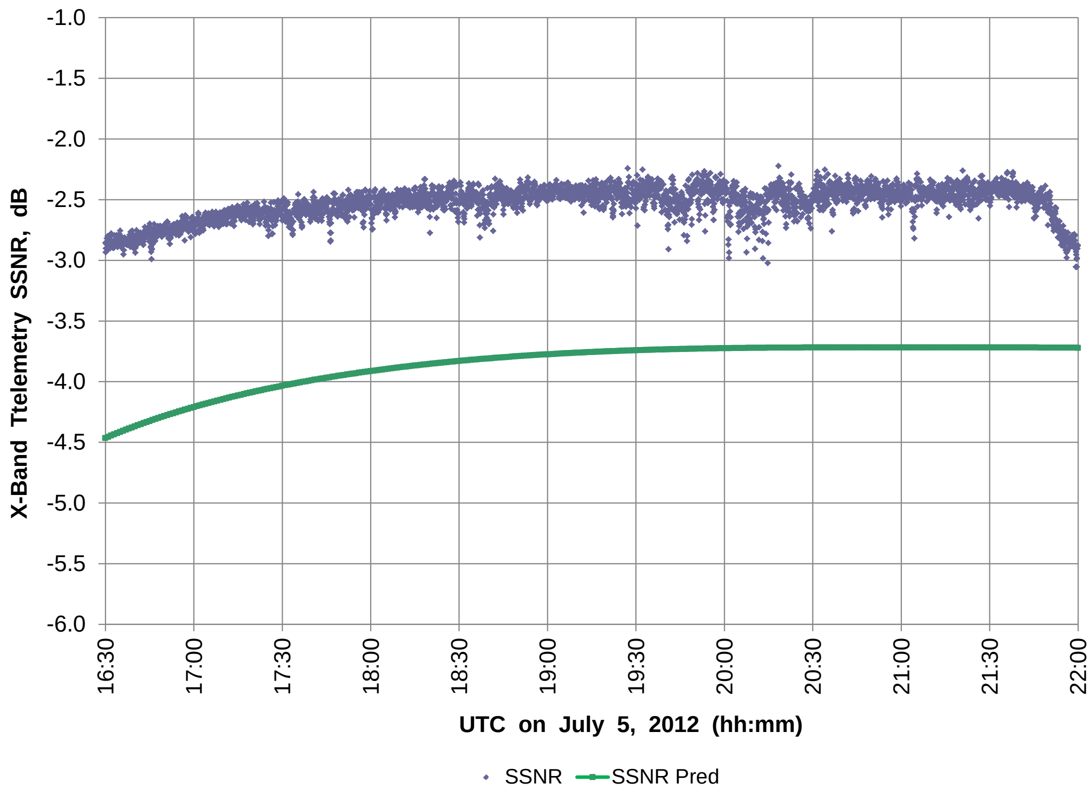

Figure 3-5: Predicted and actual symbol SNR on July 5, 2012.

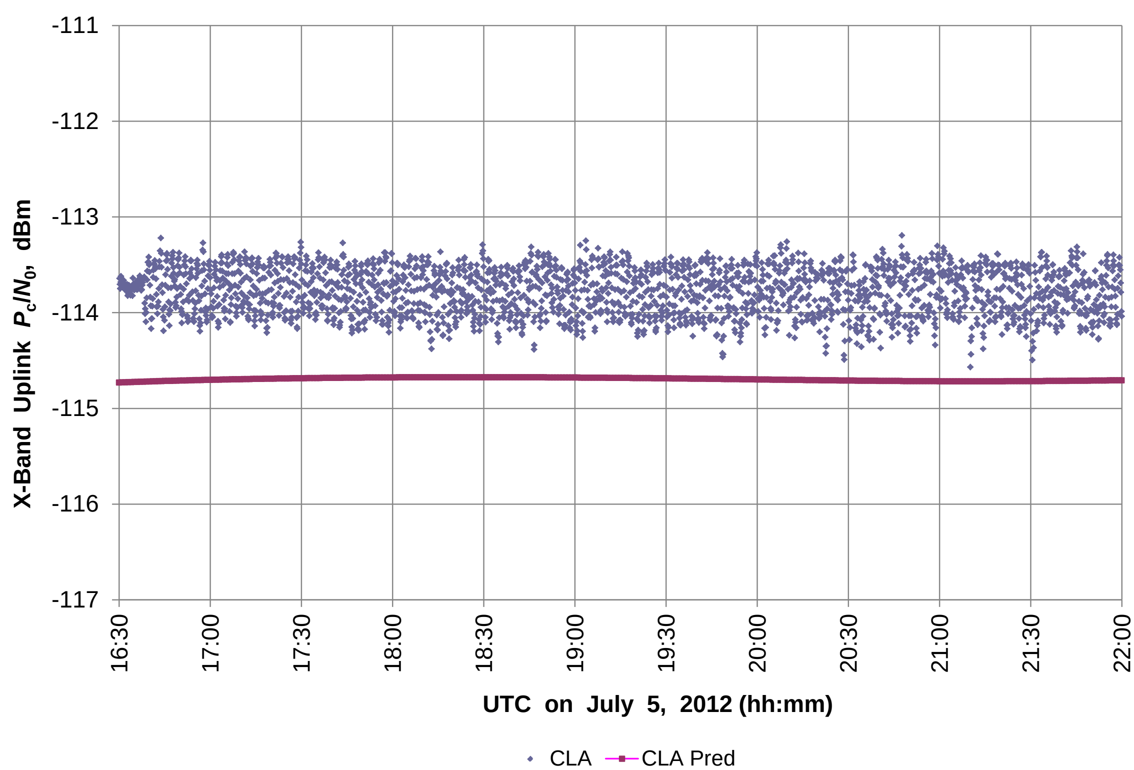

Figure 3-6: Predicted and actual uplink carrier (P_c) on July 5, 2012.

3.2.3.2 Orbital Phase

During the orbital phase, the flight system must be capable of receiving commands transmitted on X-band at 2000 bps via the HGA and of downlinking X-band telemetry to a 34-m beam waveguide antenna at no less than 18 kbps.

Table 3-6 and Table 3-7 are downlink and uplink design control tables (DCT) that illustrate predicted X-band telemetry and command performance, respectively, in orbit. Note that these DCTs are generated for DSS-34 (as representative of any 34-m station), at a fixed station elevation angle of 15 deg, and for doy 2016-270 (September 26, 2016).

Table 3-7 and Table 3-8 are design control tables for the Ka-band downlink and Ka-band uplink, respectively. They are carrier-only, and are generated for DSS-25 at a fixed 15-deg elevation angle.

These DCTs were done at the maximum orbital range. Most of the gravity science passes will be done at significantly shorter ranges, which will lead to larger margins.

Figure 3-7 shows the Ka-band downlink performance expected during the orbital phase. The performance is shown in three curves, assuming station elevation angle fixed at 25 deg (top curve), 20 deg, and 15 deg.

Table 3-6: Juno X-band downlink DCT at maximum range in 2016.

Predict	2016-270T07:00:00000 UTC
Up/Down-Link	Two-Way
RF Band	X:X
Diplex Mode	N/A
LNA Selection	LNA-1
Telecom Link	DSS34-HighGain-DSS34

TELEMETRY DOWN-LINK PARAMETER INPUTS

Encoding	Turbo (8920,1/6)
Carrier Tracking	Residual
Oscillator	2 Way VCO
Sub-Carrier Mode	Squarewave
PLL Bandwidth	3.00 Hz
Tlm Usage	Engineering
Tlm Data Rate/Mod Index	18000 bps/ 72.00 degrees
Tlm Rng/DOR Mod Index	0.31 Rad/ 0.00 degrees

Operations Mode	Nominal
Mission Phase	Cruise
DSN Site	Canb-Canb
DSN Elevation	Fixed Val Deg
Weather/CD	90
Attitude Pointing	Earth Pointed

EXTERNAL DATA
SPICE Kernels (in load order)
(omitted from this article)

Range	(km)	9.6625e+08
Range	(AU)	6.4590e+00
DL One-Way Light Time (hh:mm:ss)		00:53:43
Station Elevation (deg)		15.00
DL DOFF: Hga (deg)		0.25
DL Clk: Hga (deg)		4.45
Added S/C Pnt Offset (deg)		0.25

DSN Site Considered: DSS-34/DSS-34
At Time: 2016-270T07:00:00.000 UTC

Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TRANSMITTER PARAMETERS						
1. S/C Transmitter Power	dBm	44.40	0.30	0.00	44.50	0.0050
2. S/C Xmit Circuit Loss	dB	-0.90	0.10	-0.10	-0.90	0.0033
3. S/C Antenna Gain	dBi	44.70	0.50	-0.50	44.70	0.0417
4. Degrees-off-boresight (DOFF) Loss	dB	0.93	-0.00	-0.00	0.93	0.0000
5. S/C Transmit Pointing Loss	dB	0.00	0.00	0.00	0.00	0.0000
6. EIRP (1+2+3-4+5)	dBm	87.37	0.67	-0.67	87.37	0.0500
PATH PARAMETERS						
7. Space Loss	dB	-290.64	0.00	0.00	-290.64	0.0000
8. Atmospheric Attenuation	dB	-0.20	0.00	0.00	-0.20	0.0000
RECEIVER PARAMETERS						
9. DSN Antenna Gain	dBi	68.26	0.10	-0.20	68.23	0.0039
10. DSN Antenna Pnt Loss	dB	-0.10	0.10	-0.10	-0.10	0.0033
11. Polarization Loss	dB	-0.05	0.10	-0.10	-0.05	0.0033

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Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TOTAL POWER SUMMARY						
12. Tot Rcvd Pwr (6+7+8+9+10+11)	dBm	-135.40	-0.74	0.74	-135.40	0.0606
13. SNT due to Antenna-MW	K	16.81	-1.00	2.00	17.14	0.3889
14. SNT due to Atmosphere	K	12.78	0.00	0.00	12.78	0.0000
15. SNT due to Cosmic Backgnd	K	2.60	0.00	0.00	2.60	0.0000
16. SNT due to the Sun	K	17.54	0.00	0.00	17.54	0.0000
17. SNT due to other Hot Bodies	K	0.00	0.00	0.00	0.00	0.0000
18. SNT (13+14+15+16+17)	K	49.72	-1.00	2.00	50.06	0.3889
19. Noise Spectral Density	dBm/Hz	-181.63	-0.09	0.17	-181.61	0.0029
20. Received P_t/N_0 (12-19)	dB-Hz	46.21	0.76	-0.76	46.21	0.0635
21. Received P_t/N_0, mean-2 Sigma	dB-Hz	45.71	0.00	0.00	45.71	0.0000
22. Required P_t/N_0	dB-Hz	43.64	0.00	0.00	43.64	0.0000
23. P_t/N_0 Margin (20-22)	dB	2.57	0.76	-0.76	2.57	0.0635
24. P_t/N_0 Margin, mean-2 Sigma (21-22)	dB	2.06	0.00	-0.00	2.06	0.0000
CARRIER PERFORMANCE						
25. Recovered P_t/N_0 (20+[AGC+BPF])	dB-Hz	46.21	0.76	-0.76	46.21	0.0635
26. Telemetry Carrier Suppression	dB	-10.20	1.52	-1.89	-10.32	0.4854
27. Ranging Carrier Suppression	dB	-0.30	0.06	-0.06	-0.30	0.0006
28. DOR Carrier Suppression	dB	0.00	-0.00	-0.00	-0.00	0.0000
29. Carrier Power (AGC) (12+26+27+28)	dBm	-146.02	-2.22	2.22	-146.02	0.5466
30. Received Pc/N_0 (25+26+27+28)	dB-Hz	35.58	2.22	-2.22	35.58	0.5495
31. Carrier Loop Noise BW	dB-Hz	4.77	0.00	0.00	4.77	0.0000
32. Carrier Phase Error Var (from 30,31,xpond,solar)	rad^2	5.9e-03	0.00	0.00	5.9e-03	0.0000
33. Carrier Loop SNR (CNR) (from 32)	dB	22.31	2.22	-2.22	22.31	0.5495
34. CNR, mean-2 Sigma	dB	20.83	0.00	0.00	20.83	0.0000
35. Recommended CNR	dB	10.00	0.00	0.00	10.00	0.0000
36. CNR Margin (33-35)	dB	12.31	2.22	-2.22	12.31	0.5495
37. CNR Margin, mean-2 Sigma (34-35)	dB	10.83	0.00	-0.00	10.83	0.0000
TELEMETRY PERFORMANCE						
38. Telemetry Data Suppression	dB	-0.44	-0.20	0.16	-0.45	0.0053
39. Ranging Data Suppression	dB	-0.30	0.06	-0.06	-0.30	0.0006
40. DOR Data Suppression	dB	0.00	-0.00	-0.00	-0.00	0.0000
41. Received P_d/N_0 (25+38+39+40)	dB-Hz	45.46	0.79	-0.79	45.46	0.0693
42. Received P_d/N_0, mean-2 Sigma	dB-Hz	44.93	0.00	0.00	44.93	0.0000
43. Data Rate, Symbols (dB-Hz)	dB-Hz	42.55	0.00	0.00	42.55	0.0000
44. Available E_b/N_0 (41-43)	dB	2.91	0.79	-0.79	2.91	0.0693
45. Radio Loss	dB	0.30	0.00	0.00	0.30	0.0000
46. Subcarrier Demod Loss	dB	0.00	0.00	0.00	0.00	0.0000
47. Symbol Sync Loss	dB	0.00	0.00	0.00	0.00	0.0000
48. Decoder Loss	dB	-0.00	-0.00	-0.00	-0.00	0.0000
49. Waveform Distortion Loss	dB	0.10	-0.10	0.10	0.10	0.0017
50. SDST Filtering Loss	dB	-0.10	-0.00	-0.00	-0.10	0.0000
51. High Rate Ranging Loss	dB	-0.00	-0.00	-0.00	-0.00	0.0000
52. Output E_b/N_0 (44-45-46-47-48-49-50-51)	dB	2.60	0.80	-0.80	2.60	0.0710
53. Output E_b/N_0, mean-2 Sigma	dB	2.07	0.00	0.00	2.07	0.0000
54. Required E_b/N_0	dB	-0.10	0.00	0.00	-0.10	0.0000
55. E_b/N_0 Margin (52-54)	dB	2.70	0.80	-0.80	2.70	0.0710
56. E_b/N_0 Margin, mean-2 Sigma	dB	2.17	0.00	-0.00	2.17	0.0000
57. Down Data Rate Cap (21,22)	bps	30000				

Table 3-7: Juno X-band uplink DCT at maximum range in 2016.

Predict 2016-270T07:00:00.000 UTC
Up/Down-Link Two-Way
RF Band X:X
Telecom Link DSS34-HighGain-DSS34

COMMAND UP-LINK PARAMETER INPUTS
Cmd Data Rate 2000.0000 bps
Cmd Mod Index 1.50 radians
Cmd RngMod Index 44.9 degrees

Operations Mode Nominal
Mission Phase Cruise
DSN Site Canb-Canb
DSN Elevation Fixed Val Deg
Weather/CD 90
Attitude Pointing Earth Pointed

EXTERNAL DATA
SPICE Kernels (in load order)
(omitted from this article)

Range (km) 9.6625e+08
Range (AU) 6.4590e+00
One-Way Light Time (OWLT) (hh:mm:ss) 00:53:43
Station Elevation (deg) 15.00
UL DOFF: Hga (deg) 0.25
UL Clk: Hga, (deg) 4.43
Added S/C Pnt Offset (deg) 0.25

DSN Site Considered: DSS-34/DSS-34
At Time: 2016-270T07:00:00.000 UTC

Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TRANSMITTER PARAMETERS						
1. Total Transmitter Power	dBm	73.01	0.50	-0.50	73.01	0.0417
2. Xmitter Waveguide Loss	dB	-0.60	0.10	-0.10	-0.60	0.0017
3. DSN Antenna Gain	dBi	66.93	0.20	-0.30	66.90	0.0106
4. Antenna Pointing Loss	dB	-0.10	0.10	-0.10	-0.10	0.0017
5. EIRP (1+2+3+4)	dBm	139.21	0.71	-0.71	139.21	0.0556
PATH PARAMETERS						
6. Space Loss	dB	-289.24	0.00	0.00	-289.24	0.0000
7. Atmospheric Attenuation	dB	-0.20	0.00	0.00	-0.20	0.0000
RECEIVER PARAMETERS						
8. Polarization Loss	dB	-0.07	0.10	-0.10	-0.07	0.0033
9. Degrees-off-boresight (DOFF) Loss	dB	0.71	-0.00	-0.00	0.71	0.0000
10. S/C Antenna Gain (at boresight)	dBi	42.84	0.50	-0.50	42.84	0.0417
11. S/C Receive Pointing Loss	dB	0.00	0.00	0.00	0.00	0.0000
12. Lumped Circuit Loss	dB	-4.00	0.50	-0.50	-4.00	0.0833

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Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TOTAL POWER SUMMARY						
13. Tot Rcvd Pwr (5+6+7+8-9+10+11+12)	dBm	-112.18	-1.29	1.29	-112.18	0.1839
14. Noise Spectral Density	dBm/Hz	-172.57	-1.40	0.75	-172.78	0.1979
15. System Noise Temperature	K	401.25	-110.49	75.37	389.54	1456.4778
16. Received P_t/N_0 (13–14)	dB-Hz	60.60	1.85	-1.85	60.60	0.3817
17. Received P_t/N_0, mean-3 Sigma	dB-Hz	58.75	0.00	0.00	58.75	0.0000
18. Required P_t/N_0	dB-Hz	49.13	0.00	0.00	49.13	0.0000
19. P_t/N_0 Margin (16–18)	dB	11.47	1.85	-1.85	11.47	0.3817
20. P_t/N_0 Margin, mean-3 Sigma (17–18)	dB	9.62	0.00	-0.00	9.62	0.0000
CARRIER PERFORMANCE						
21. Recovered P_t/N_0 (16+[AGC+BPF])	dB-Hz	60.60	1.85	-1.85	60.60	0.3817
22. Command Carrier Suppression	dB	-5.82	0.58	-0.58	-5.82	0.0564
23. Ranging Carrier Suppression	dB	-3.00	0.20	-0.21	-3.00	0.0069
24. Carrier Power (AGC)	dBm	-121.00	-1.49	1.49	-121.00	0.2472
25. Received P_c/N_0 (21+22+23)	dB-Hz	51.79	2.00	-2.00	51.79	0.4451
26. Carrier Loop Noise BW	dB-Hz	20.31	-0.20	0.15	20.28	0.0102
27. Carrier Loop SNR (CNR) (25–26)	dB	31.50	2.02	-2.02	31.50	0.4553
28. CNR, mean-3 Sigma	dB	29.48	0.00	0.00	29.48	0.0000
29. Recommended CNR	dB	12.00	0.00	0.00	12.00	0.0000
30. CNR Margin (27–29)	dB	19.50	2.02	-2.02	19.50	0.4553
31. CNR Margin, mean-3 Sigma (28-29)	dB	17.48	0.00	-0.00	17.48	0.0000
CHANNEL PERFORMANCE						
32. Command Data Suppression	dB	-2.06	-0.14	0.12	-2.07	0.0029
33. Ranging Data Suppression	dB	-3.00	0.20	-0.21	-3.00	0.0069
34. Received P_d/N_0 (21+32+33)	dB-Hz	55.54	1.88	-1.88	55.54	0.3915
35. Received P_d/N_0, mean-3 Sigma	dB-Hz	53.66	0.00	0.00	53.66	0.0000
36. Data Rate (dB-Hz)	dB-Hz	33.01	0.00	0.00	33.01	0.0000
37. Available E_b/N_0 (34–36)	dB	22.53	1.88	-1.88	22.53	0.3915
38. Implementation Loss	dB	1.48	-0.84	0.75	1.45	0.1054
39. Radio Loss	dB	0.00	0.00	0.00	0.00	0.0000
40. Output E_b/N_0 (37-38-39)	dB	21.08	2.11	-2.11	21.08	0.4970
41. Output E_b/N_0, mean-3 Sigma	dB	18.96	0.00	0.00	18.96	0.0000
42. Required E_b/N_0	dB	9.60	0.00	0.00	9.60	0.0000
43. E_b/N_0 Margin (40–42)	dB	11.48	2.11	-2.11	11.48	0.4970
44. E_b/N_0 Margin, mean-3 Sigma (41–42)	dB	9.36	0.00	-0.00	9.36	0.0000
45. BER (from 40)	none	5.5332e-58				

Table 3-8: Juno HGA Ka-band carrier downlink at maximum range.

Produced by JUNO V2.1 XML 5/5/2011

Predict	2016-270T07:00:00000 UTC
Up/Down-Link	Two-Way
RF Band	Ka:Ka/X
LNA Selection	LNA-1
Telecom Link	DSS25-HighGain-DSS25

TELEMETRY DOWN-LINK PARAMETER INPUTS

Encoding	Turbo (8920,1/6)
Carrier Tracking	Residual
Oscillator	2 Way VCO
Sub-Carrier Mode	Squarewave
PLL Bandwidth	3.00 Hz
Tlm Usage	Engineering
Tlm Data Rate/Mod Index	0 bps/ 0.00 Degrees
Tlm Rng/DOR Mod Index	0.00 Rad/ 0.00 Degrees

Operations Mode	Nominal
Mission Phase	Cruise
DSN Site	Gold-Gold
DSN Elevation	Fixed Val Deg
Weather/CD	90
Attitude Pointing	Earth Pointed

Range	(km)	9.6626e+08
Range	(AU)	6.4590e+00
DL One-Way Light Time (hh:mm:ss)		00:53:43
Station Elevation (deg)		15.00
DL DOFF: Hga (deg)		0.25
DL Clk: Hga (deg)		2.74
Added S/C Pnt Offset (deg)		0.25

DSN Site Considered: DSS-25/DSS-25

At Time: 2016-270T07:00:00.000 UTC

Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TRANSMITTER PARAMETERS						
1. S/C Transmitter Power	dBm	34.31	0.50	-0.50	34.31	0.0417
2. S/C Xmit Circuit Loss	dB	-2.20	0.20	-0.20	-2.20	0.0133
3. S/C Antenna Gain	dBi	48.72	0.60	-0.60	48.72	0.0600
4. Degrees-off-boresight (DOFF) Loss	dB	3.65	-0.00	-0.00	3.65	0.0000
5. S/C Transmit Pointing Loss	dB	0.00	0.00	0.00	0.00	0.0000
6. EIRP (1+2+3-4+5)	dBm	77.18	1.02	-1.02	77.18	0.1150
PATH PARAMETERS						
7. Space Loss	dB	-302.28	0.00	0.00	-302.28	0.0000
8. Atmospheric Attenuation	dB	-1.09	0.00	0.00	-1.09	0.0000
RECEIVER PARAMETERS						
9. DSN Antenna Gain	dBi	78.41	0.30	-0.30	78.41	0.0150
10. DSN Antenna Pnt Loss	dB	-0.11	0.10	-0.10	-0.11	0.0033
11. Polarization Loss	dB	-0.07	0.10	-0.10	-0.07	0.0033

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Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TOTAL POWER SUMMARY						
12. Tot Rcvd Pwr (6+7+8+9+10+11)	dBm	-147.96	-1.11	1.11	-147.96	0.1367
13. SNT due to Antenna-MW	K	33.35	-1.00	2.00	33.68	0.3889
14. SNT due to Atmosphere	K	61.38	0.00	0.00	61.38	0.0000
15. SNT due to Cosmic Backgnd	K	2.12	0.00	0.00	2.12	0.0000
16. SNT due to the Sun	K	17.58	0.00	0.00	17.58	0.0000
17. SNT due to other Hot Bodies	K	0.00	0.00	0.00	0.00	0.0000
18. SNT (13+14+15+16+17)	K	114.43	-1.00	2.00	114.76	0.3889
19. Noise Spectral Density	dBm/Hz	-178.01	-0.04	0.08	-178.00	0.0006
20. Received P_t/N_0 o (12-19)	dB-Hz	30.04	1.11	-1.11	30.04	0.1372
21. Received P_t/N_0, mean-2 Sigma	dB-Hz	29.30	0.00	0.00	29.30	0.0000
CARRIER PERFORMANCE						
25. Recovered P_t/N_0 (20+[AGC+BPF])	dB-Hz	30.04	1.11	-1.11	30.04	0.1372
26. Telemetry Carrier Suppression	dB	0.00	0.00	0.00	0.00	0.0000
27. Ranging Carrier Suppression	dB	0.00	0.00	0.00	0.00	0.0000
28. DOR Carrier Suppression	dB	0.00	-0.00	-0.00	-0.00	0.0000
29. Carrier Power (AGC) (12+26+27+28)	dBm	-147.96	-1.11	1.11	-147.96	0.1367
30. Received P_c/N_0 (25+26+27+28)	dB-Hz	30.04	1.11	-1.11	30.04	0.1372
31. Carrier Loop Noise BW	dB-Hz	4.77	0.00	0.00	4.77	0.0000
32. Carrier Phase Error Var (from 30,31,xpond,solar)	rad^2	7.5e-03	0.00	0.00	7.5e-03	0.0000
33. Carrier Loop SNR (CNR) (from 32)	dB	21.26	1.11	-1.11	21.26	0.1372
34. CNR, mean-2 Sigma	dB	20.52	0.00	0.00	20.52	0.0000
35. Recommended CNR	dB	10.00	0.00	0.00	10.00	0.0000
36. CNR Margin (33-35)	dB	11.26	1.11	-1.11	11.26	0.1372
37. CNR Margin, mean-2 Sigma (34-35)	dB	10.52	0.00	-0.00	10.52	0.0000

Table 3-9: Juno HGA Ka-band carrier uplink at maximum range.

Produced by JUNO V2.1 XML 5/5/2011

Predict	2016-270T07:00:00.000 UTC
Up/Down-Link	Two-Way
RF Band	Ka:Ka/X
Telecom Link	DSS25-HighGain-DSS25

COMMAND UP-LINK PARAMETER INPUTS

Cmd Mod Index	0.00	Radians
Cmd RngMod Index	0.0	Degrees

Operations Mode	Nominal
Mission Phase	Cruise
DSN Site	Gold-Gold
DSN Elevation	Fixed Val Deg
Weather/CD	90
Attitude Pointing	Earth Pointed

Range	(km)	9.6626e+08
Range	(AU)	6.4590e+00
One-Way Light Time (OWLT) (hh:mm:ss)		00:53:43
Station Elevation (deg)		15.00
UL DOFF: Hga (deg)		0.25
UL Clk: Hga (deg)		2.17
Added S/C Pnt Offset (deg)		0.25

Continued from previous page

DSN Site Considered: DSS-25/DSS-25
At Time: 2016-270T07:00:00.000 UTC

Link Parameter	Unit	Design Value	Fav Tol	Adv Tol	Mean Value	Var
TRANSMITTER PARAMETERS						
1. Total Transmitter Power	dBm	59.00	0.50	-0.50	59.00	0.0417
2. Xmitter Waveguide Loss	dB	-0.25	0.10	-0.10	-0.25	0.0017
3. DSN Antenna Gain	dBi	79.52	0.20	-0.30	79.49	0.0106
4. Antenna Pointing Loss	dB	-0.12	0.00	0.00	-0.12	0.0000
5. EIRP (1+2+3+4)	dBm	138.12	0.70	-0.70	138.12	0.0539
PATH PARAMETERS						
6. Space Loss	dB	-302.87	0.00	0.00	-302.87	0.0000
7. Atmospheric Attenuation	dB	-1.09	0.00	0.00	-1.09	0.0000
RECEIVER PARAMETERS						
8. Polarization Loss	dB	-0.07	0.10	-0.10	-0.07	0.0033
9. Degrees-off-boresight (DOFF) Loss	dB	8.77	-0.00	-0.00	8.77	0.0000
10. S/C Antenna Gain (at boresight)	dBi	49.36	0.60	-0.60	49.36	0.0600
11. S/C Receive Pointing Loss	dB	0.00	0.00	0.00	0.00	0.0000
12. Lumped Circuit Loss	dB	-2.93	0.30	-0.30	-2.93	0.0300
TOTAL POWER SUMMARY						
13. Tot Rcvd Pwr (5+6+7+8-9+10+11+12)	dBm	-128.25	-1.15	1.15	-128.25	0.1472
14. Noise Spectral Density	dBm/Hz	-169.73	-1.17	0.64	-169.91	0.1401
15. System Noise Temperature	K	770.63	-182.12	121.67	750.48	3896.1095
16. Received P_t/N_0 (13-14)	dB-Hz	41.66	1.61	-1.61	41.66	0.2873
CARRIER PERFORMANCE						
21. Recovered P_t/N_0 (16+[AGC+BPF])	dB-Hz	41.66	1.61	-1.61	41.66	0.2873
22. Command Carrier Suppression	dB	0.00	-0.00	0.00	0.00	0.0000
23. Ranging Carrier Suppression	dB	0.00	0.00	0.00	0.00	0.0000
24. Carrier Power (AGC)	dBm	-128.25	-1.15	1.15	-128.25	0.1472
25. Received Pc/N_0 (21+22+23)	dB-Hz	41.66	1.61	-1.61	41.66	0.2873
26. Carrier Loop Noise BW	dB-Hz	19.18	-0.20	0.15	19.16	0.0102
27. Carrier Loop SNR (CNR) (25-26)	dB	22.50	1.64	-1.64	22.50	0.2975
28. CNR, mean-3 Sigma	dB	20.86	0.00	0.00	20.86	0.0000
29. Recommended CNR	dB	12.00	0.00	0.00	12.00	0.0000
30. CNR Margin (27-29)	dB	10.50	1.64	-1.64	10.50	0.2975
31. CNR Margin, mean-3 Sigma (28-29)	dB	8.86	0.00	-0.00	8.86	0.0000

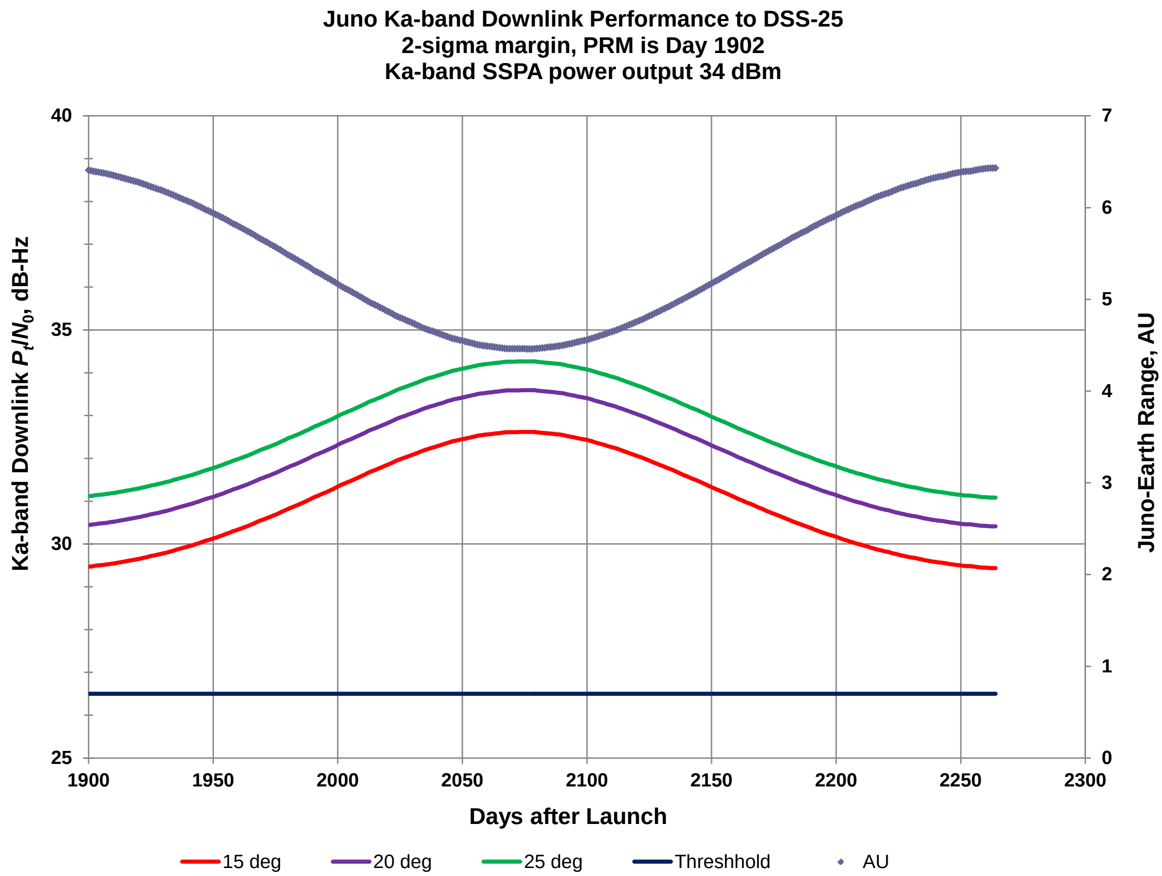

Figure 3-7: Juno Ka-band carrier downlink performance.

3.2.3.3 Telecom during Main Engine Burns

There are four main engine burns during the mission. The first two were the Deep Space Maneuver (DSM) Parts 1 and 2 in 2012. The next two will be the Jupiter Orbit Insertion (JOI) burn and the Period Reduction Maneuver (PRM) in 2016. Following the Orbit phase, there is also a deorbit burn planned to end the mission for planetary quarantine purposes. The JOI burn places the spacecraft into a 107-day orbit around Jupiter. The PRM puts the spacecraft into a roughly 11-day orbit around Jupiter. This 11-day final orbit is designed to place perijove over DSS-25 for the Gravity Science passes. During the main engine burns, the spacecraft will put the velocity vector close to normal to the Earth line.

The toroidal LGA (TLGA) supports communications during the burns. Because of the limited capability of an LGA and the distance to the Earth, the downlink will not support telemetry. Instead, the spacecraft will transmit tones, similar to MER Entry, Descent, and Landing (EDL) telecom, to a 70-m ground station. The two DSM burns were planned with dual 70-m coverage for redundancy, as will be the JOI burn. The PRM burn will be done over Goldstone to allow for orbit alignment with DSS-25. For JOI the off-Earth antenna angle will be 2 deg maximum, and for PRM it will be 4 deg maximum. PRM will be at a slightly longer range and wider angle so it will be a tougher requirement to meet than JOI.

During each burn sequence, the S/C will start on the HGA, switch to the MGA and then to the TLGA as the spacecraft turns to burn attitude. The station is not required to uplink during the main engine burns. Therefore, the tone downlinks are one-way. The S/C will go back to the MGA for navigation and engineering TLM downlink. After each burn, the S/C attitude will have to be adjusted to align the HGA with the spacecraft spin axis. It will need adjustment because the mass properties of the spacecraft will have changed due to propellant usage. After S/C alignment is complete, the S/C will return to using the HGA.

3.2.3.4 Safe Mode

In safe mode, the spacecraft goes into a configuration that is power positive, thermally stable, and commandable. Juno has two types of safe mode, depending on whether three-axis attitude knowledge is retained or not. If attitude knowledge is retained, the spacecraft pointing (including that of the antenna toward Earth) is not changed. If attitude knowledge is lost, the spacecraft will "cone" within 2 deg of the Sun. That is, the solar panel pointing to the Sun will describe a cone with 2-deg radius centered on the Sun.

The nominal safe mode data rates are 40 bps for downlink telemetry and 7.8125 bps for the uplink command. The downlink rate may be changed by flight software during phases of the mission when the range is short. Ranging is to be switched off for all safe mode telecom. Nominal and safe mode TWTA and antenna choices are mission phase dependent. In safing, the uplink loss executive (ULLE) and the downlink loss executive (DLLE) have the ability to swap hardware and to use the backup antenna paths if the primary antenna path to the given safe mode antenna were to fail [11].

Attitude knowledge not lost: Figures 3-8 and 3-9 show the safe mode capability (downlink and uplink, respectively) to a 70-m ground station throughout the mission. Both of these figures were plotted with two assumptions: (1) the spacecraft pointing attitude toward Earth does not change in going to safe mode and (2) the spacecraft ends up on the MGA.

Attitude knowledge is lost: Figures 3-10 and 3-11 show similar safe mode performance, but they assume that the spacecraft has lost spacecraft attitude knowledge and is coning 2 deg off of the Sun line. This would be worst case. Note that for these cases, safe mode might have to switch to an LGA to maintain communications.

In either case, the system can meet the safe mode communications requirements.

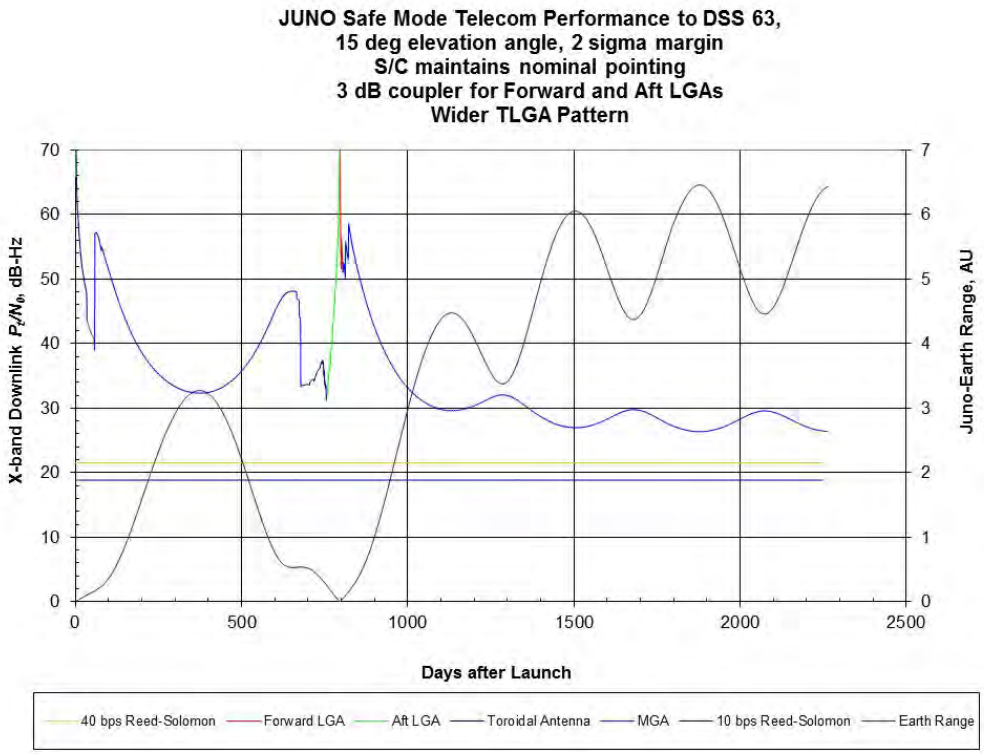

Figure 3-8: Safe mode downlink performance – no attitude change.

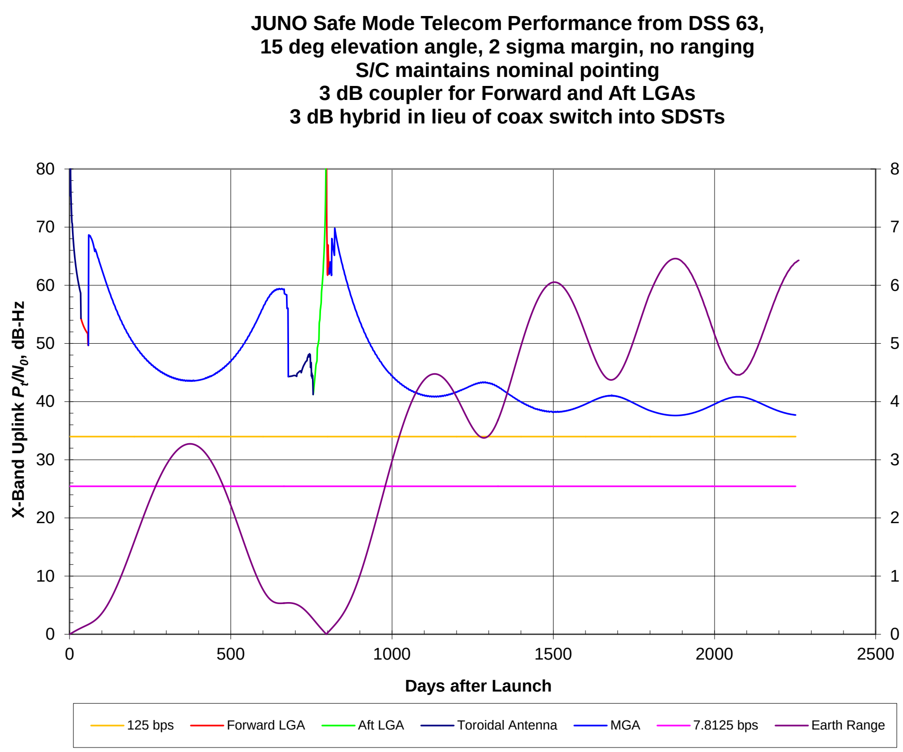

Figure 3-9: Safe mode uplink performance – no attitude change.

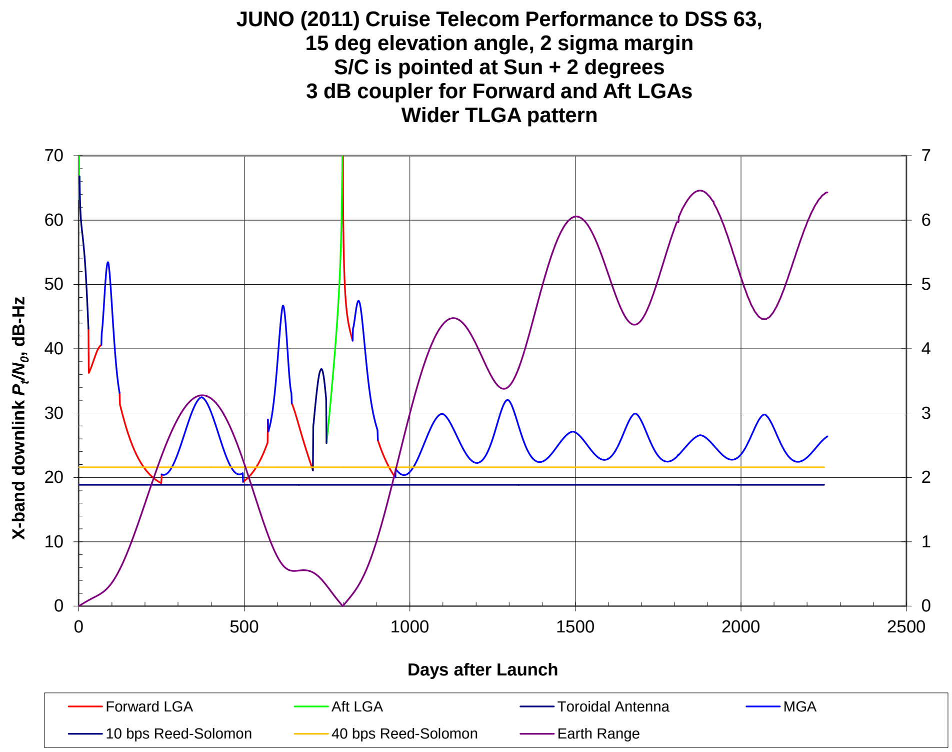

Figure 3-10: Safe mode downlink performance – Sun-pointed.

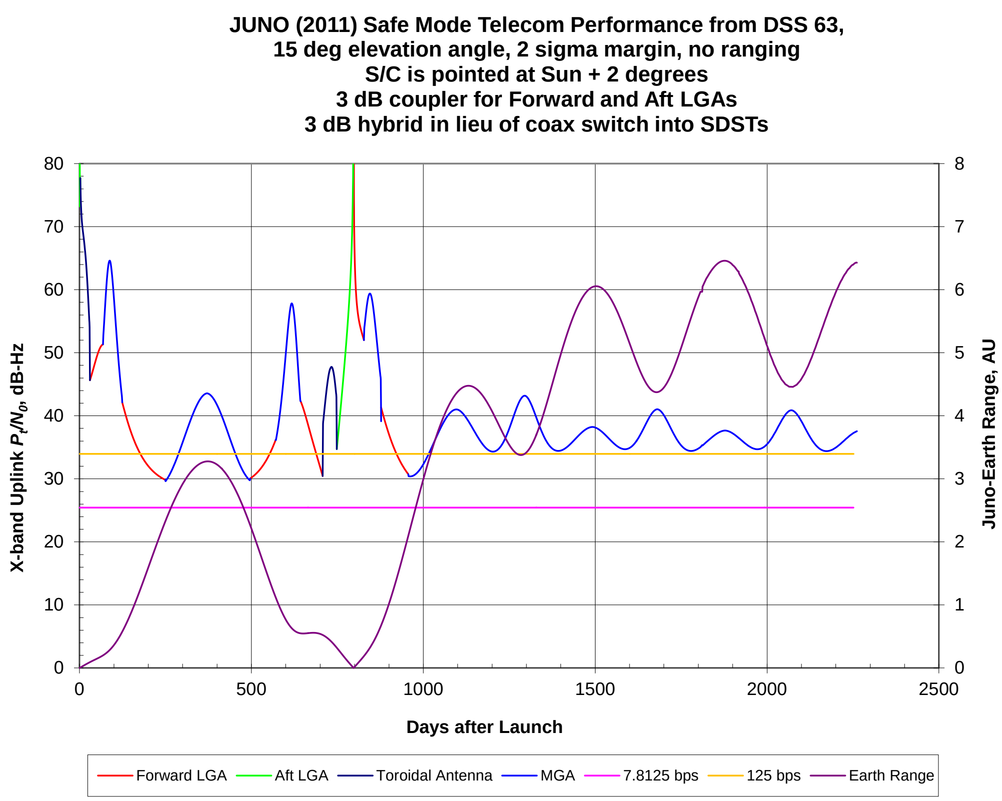

Figure 3-11: Safe mode uplink performance – Sun-pointed.

Blank

4 Ground Systems

4.1 Deep Space Network

As described in the Dawn article in this series [6] and in the Deep Space Network (DSN) web site [7], the National Aeronautics and Space Administration (NASA) DSN is a network of antennas at three deep space communications facilities that are located approximately 120 degrees (deg) apart around the world. One site is at Goldstone in the California Mojave Desert; another is near Madrid, Spain (Figure 4-1); and the third is near Canberra, Australia. These locations permit constant observation of spacecraft as the Earth rotates. Each complex contains one 70-meter (m) diameter antenna and a set of 34-m diameter antennas as well.

The Juno mission will often rely on 34-m antennas in nominal operations. However, in orbit around Jupiter, 70-m stations will be used if the spacecraft enters safe mode. Additionally, 70-m stations were used for tone detection during the Deep Space Maneuvers (DSM). They are planned for the same purpose during Jupiter Orbit Insertion (JOI) and during the Period Reduction Maneuver (PRM) as well as for increased science data return at Jupiter. Photographs of the antennas of the DSN are available at the DSN web site [7].

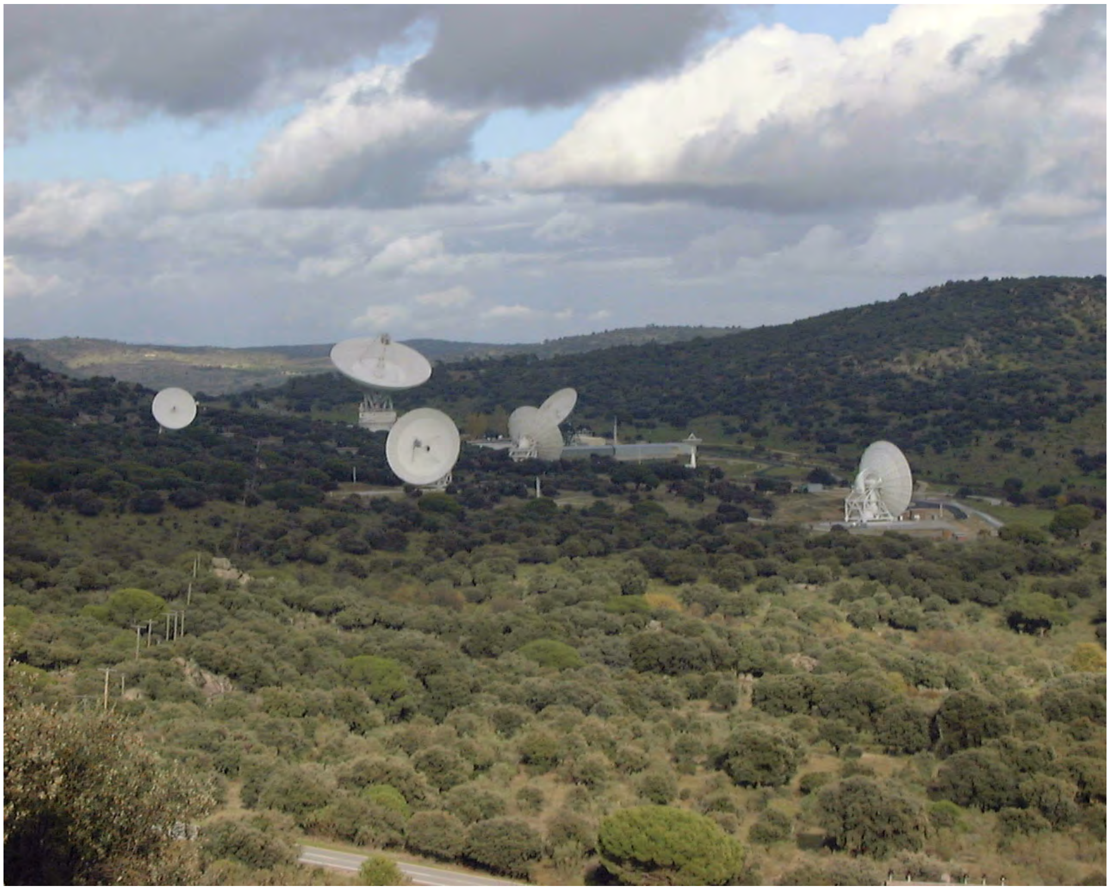

Figure 4-1: The Madrid DSN complex.

4.2 Initial Acquisition Support from the European Space Agency

Though DSN stations were prime for Juno initial acquisition, the European Space Agency (ESA) stations provided backup for initial capture of telemetry. The objective of the cross-support service from ESA's Perth and New Norcia stations was to mitigate the risk of critical data loss through the entire launch period. Without the ESA stations, the critical data period was subject to a short visibility gap between separation of the spacecraft from the launch vehicle and initial acquisition at the DSN Canberra Complex. Furthermore, because Perth is fitted with an X-band acquisition aid antenna with auto-track capability, acquisition and tracking of the spacecraft downlink signal could have been accomplished even in case of a non-nominal trajectory.

As stated in the *Juno Operations Interface Control Document* (OICD) [8] and chiefly in the Juno LEOP implementing agreement [9], during the latter portions of the launch period, the elevation angle at Canberra would have been low, sometimes close to or below 6 deg. The elevation angle in Northwest Australia is much higher and if launch had occurred later in the launch period, there would have been cases in which Canberra would not have been in view for separation.

For these cases, only ESA's Australia stations at Perth or New Norcia Stations would have been in view. Figures 4-2 and 4-3 show the spacecraft ground track, and site views for the actual August 5 launch date and for a launch-period closing date of August 26. The red line on each plot is the ground track of Juno on launch day. The dotted portion of the red curve (going generally from left to right as time increases) is before the Juno transmitter radiates a downlink, and is therefore before any station could receive a downlink. Starting with transmitter on (at 16:21 UTC on the actual launch date), the curve becomes solid, and has superimposed red markers on one-hour centers. The yellow areas originating at the Perth (or New Norcia), Canberra, Madrid and Goldstone sites depict the views (begin-of-track to end-of-track) from these sites. A station can receive the downlink when the solid red line is within that site's yellow view.

The difference in post-separation station elevation angle profiles for the early and late launch dates is shown in Figure 4-4 (actual August 5 launch) and Figure 4-5 (August 26). Similarly, the post-separation spacecraft-to-station slant range profiles for early and late launch dates are shown in Figures 4-6 and 4-7.

Critical operations, such as the deployment of the solar panels, could possibly have fallen into the period when the spacecraft had not yet been acquired by Canberra, and the data acquired at Perth would have become important for forensic purposes. To further mitigate the risk of having a visibility gap, ESA also acquired the signal at the New Norcia station. In addition to the normal telemetry acquisition at New Norcia, that station was configured to perform open-loop recording of the downlink signal to have a basis for analysis in the event that telemetry acquisition had failed.

As New Norcia has neither an acquisition-aid antenna nor auto-track, the pointing of the New Norcia antenna with respect to the predicts would have been corrected as needed on the basis of the actual pointing determined by the Perth station in auto-track mode. Furthermore, an along-track offset observed at Perth would have been communicated via the voice loop to the Canberra complex to aid initial acquisition there.

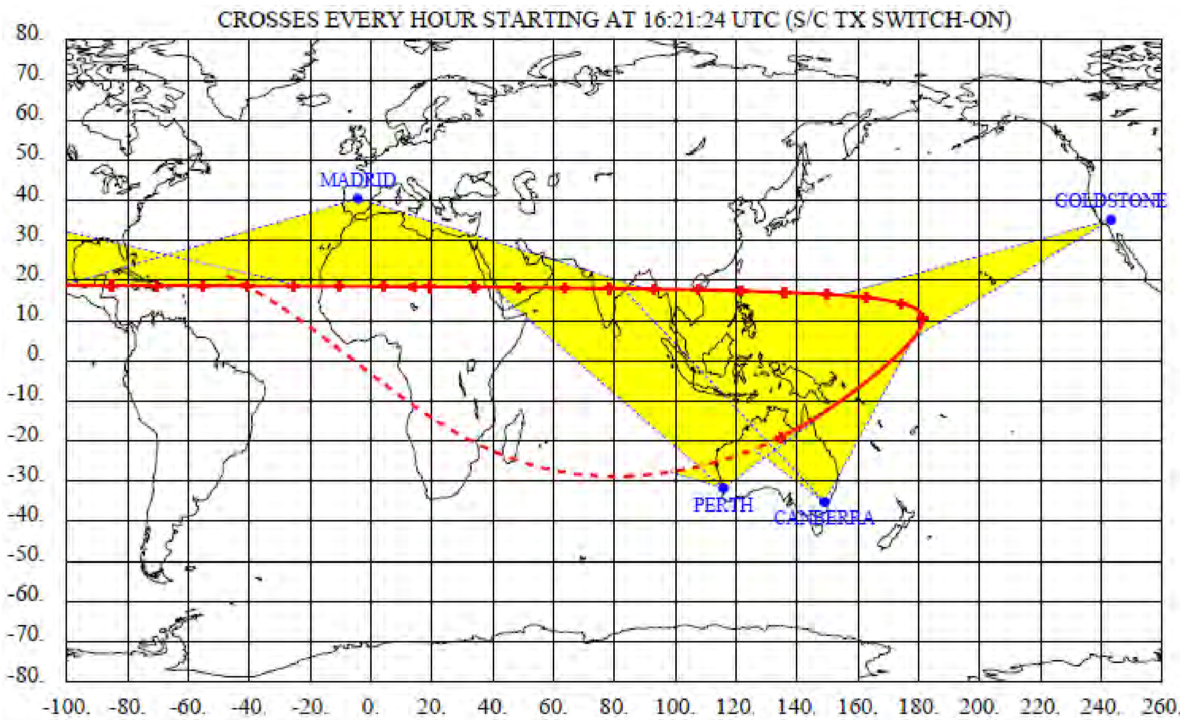

Figure 4-2: Juno ground track after separation (launch on August 5, 2011).

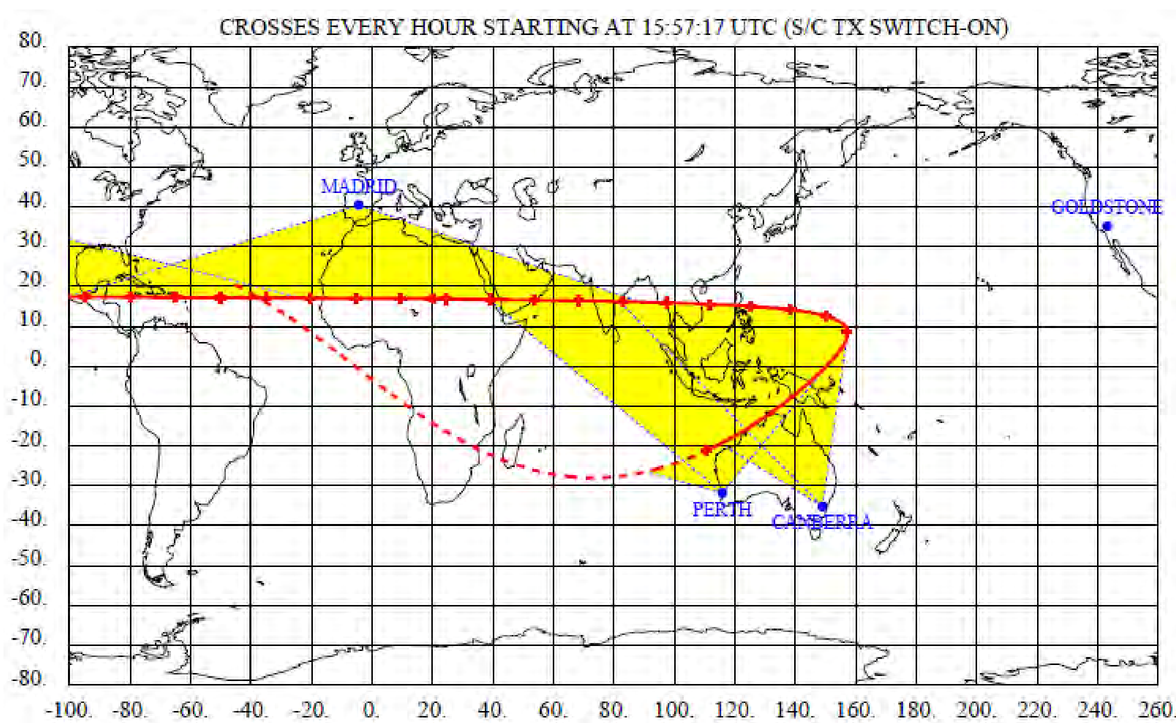

Figure 4-3: Juno ground track after separation (launch on August 26, 2011).

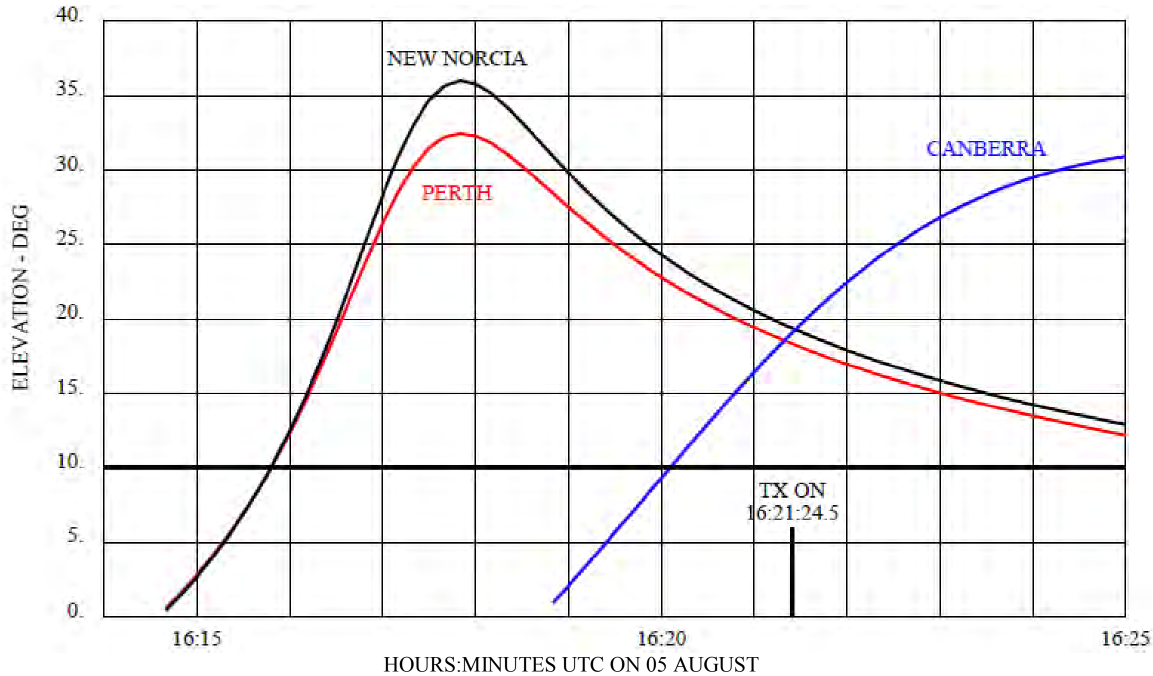

Figure 4-4: Elevation at the LEOP stations (launch on August 5, 2011).

A secondary objective for the ESA support was to acquire spacecraft telemetry and route it on a best-efforts basis to the Juno Project so that in case of a serious spacecraft problem as much telemetry as possible would have been available for offline diagnosis of the problem, although launch proved to be nominal on August 5, 2011. The signal from Perth was routed to a spectrum analyzer, and a live view of the spectrum analyzer display was projected to Astrotech[6] where Juno engineering personnel watched for the signal in real time, although the image from the webcam at Perth was delayed to a certain extent by Internet delays before reaching Astrotech.

The signal level emitted by the Juno spacecraft after separation in the direction of the antenna boresight was quite high (47.5 decibels referenced to milliwatts, dBm) while the slant range at acquisition (transmit ON, TX ON) could have been as low as 2000 km from Perth and from New Norcia had launch been delayed (see Figure 4-7). The low-noise amplifier (LNA) at each station would have received a signal comfortably below its compression point with the Juno LGA pointed at the station at a distance of 2000 km. With standard gain settings, however, the Intermediate Frequency Modem System (IFMS) would have been saturated and in its nonlinear operations range. Therefore, this support required temporary installation of attenuators (20 dB at Perth and 30 dB at New Norcia).

[6] Astrotech Space Operations at Titusville, Florida, readied the Juno spacecraft for launch as the payload aboard the Atlas V launch vehicle. The launch vehicle was the responsibility of the United Launch Alliance, a joint venture between Lockheed Martin Corporation and the Boeing Company.

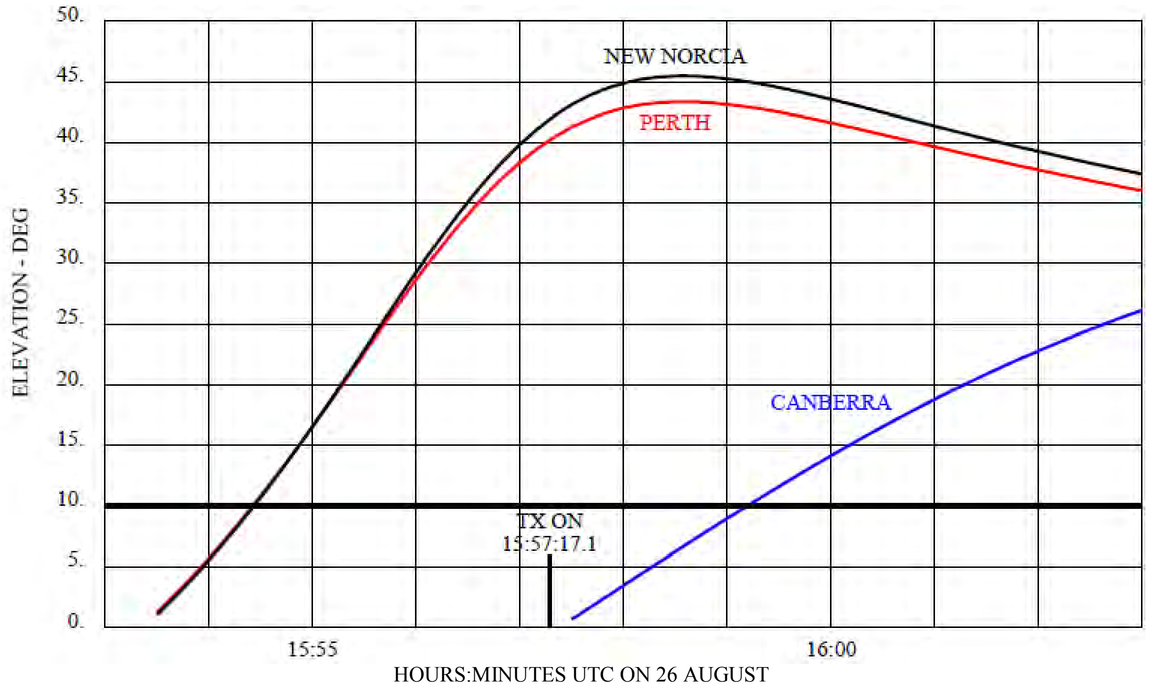

Figure 4-5: Elevation at the LEOP stations (launch on August 26, 2011).

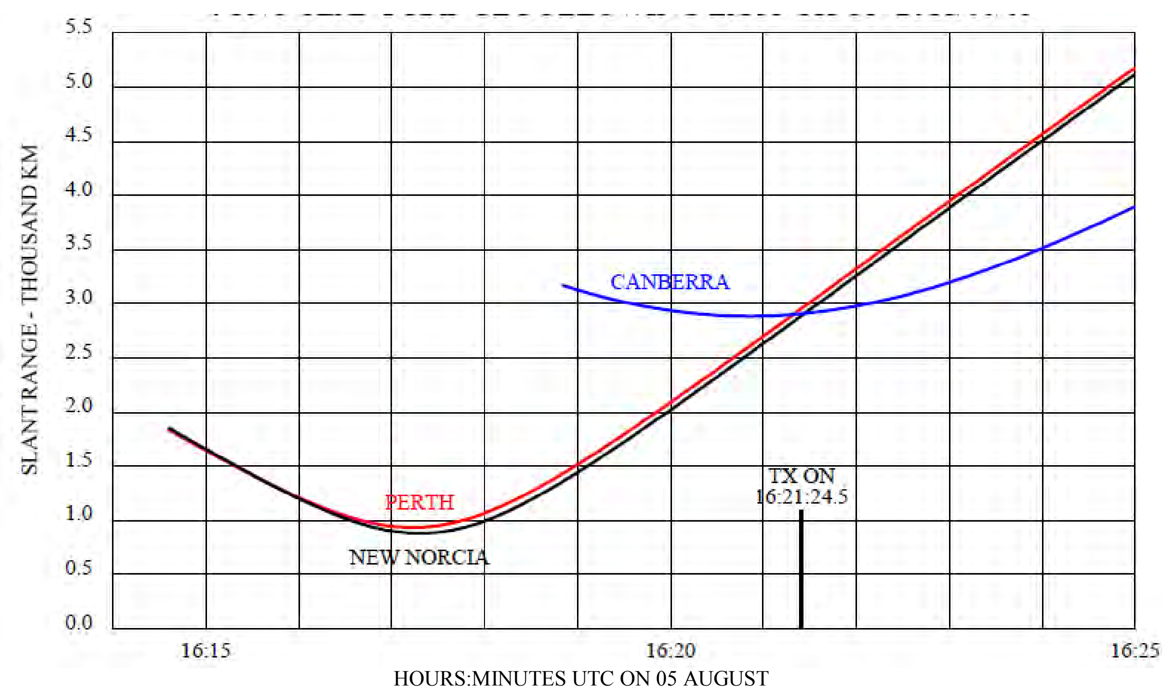

Figure 4-6: Slant range from the LEOP stations (launch on August 5, 2011).

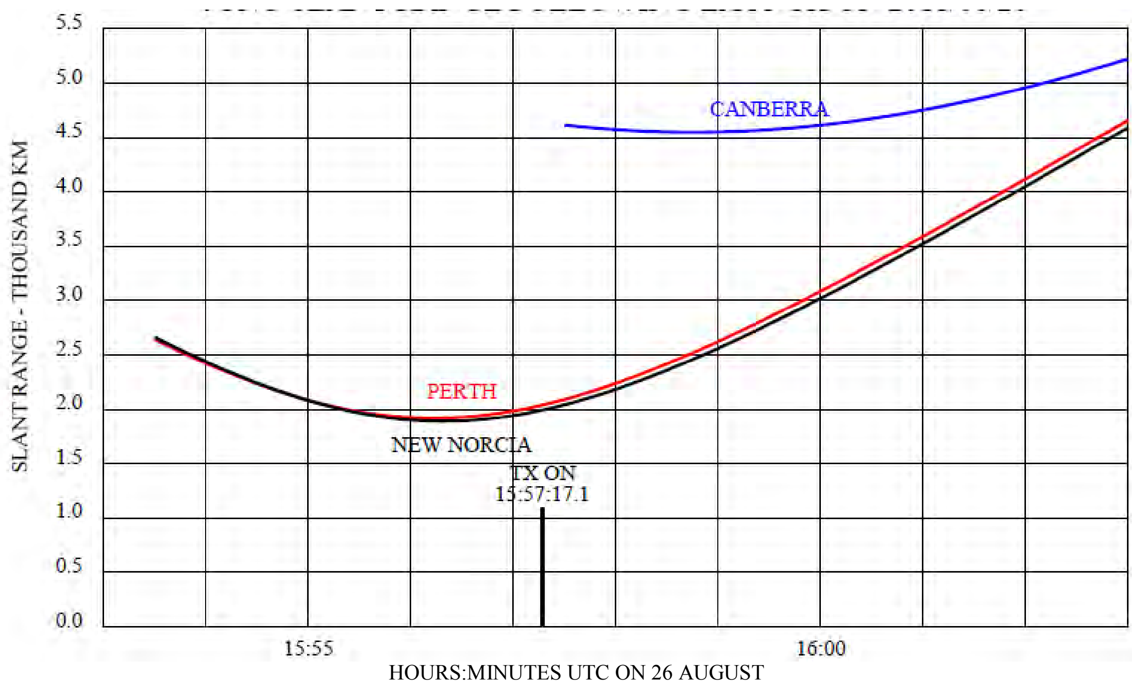

Figure 4-7: Slant range from the LEOP stations (Launch on August 26).

The European Space Tracking (ESTRACK) 15-m station at Perth supported Juno LEOP operations. A simplified block diagram of the station is provided in Figure 4-8. The antenna was initially pointed in accordance with the trajectory predicts provided in a file by Juno navigation. ESA's Flight Dynamics operational organization retrieved the file from the DSN Service Preparation System (SPS) and converted the contents to an internal format to forward via the station computer to the Front-End Controller (FEC) and to the IFMS. The FEC used the converted trajectory data to point the antenna, and the IFMS is used them to calculate the Doppler predicts. The above outlined process has been used with other non-ESA projects, e.g., for the SOlar Heliospheric Observatory (SOHO) test tracks at New Norcia.

Acronyms and names that appear in Figure 4-8 that are not previously defined are:

HPA	high power amplifier
LAN	local area network
M&C	monitor and control
MCM	monitoring and control module (subsystem controller)
TC	telecommand
TMTCS	telemetry and telecommand system

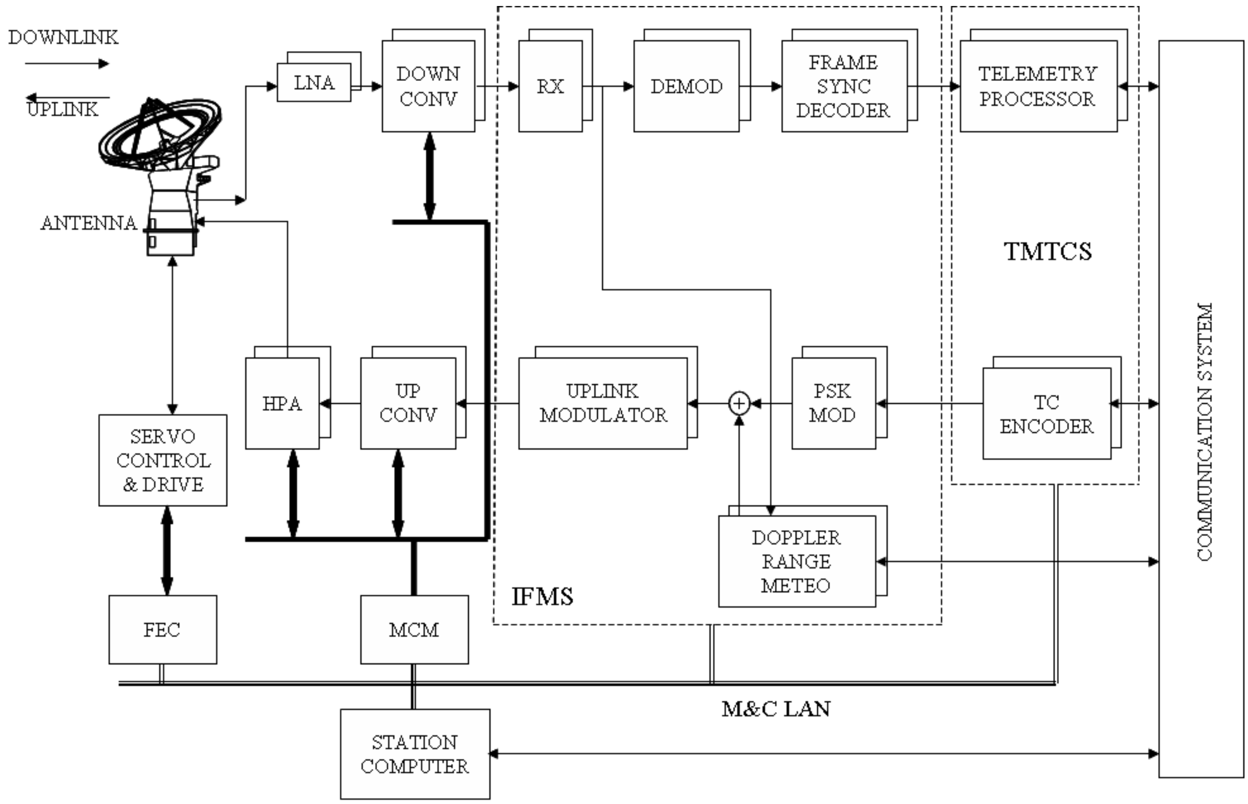

Figure 4-8: ESA ESTRACK station block diagram.

The key events that occurred after separation during the Perth and New Norcia view periods are listed below and are illustrated in Figure 4-9, taken from Ref. [9].

- The designated prime traveling wave tube amplifier (TWTA) was sequenced on by the flight software approximately 5 minutes before separation;
- The spacecraft was to start transmitting no earlier than 5 seconds after separation (safety constraint), which was 53:25 after launch;
- The TWTA began to radiate RF 11 seconds after separation when the TWTA transitioned from the warm-up mode to the high-power mode;
- The solar array deployment was planned to be initiated 3.5 minutes after separation and to be complete no later than 15 minutes after separation.

The pre-launch trade referred to in Figure 4-9 was to determine station coverage necessary to insure a downlink would be received before the pyro firing events.

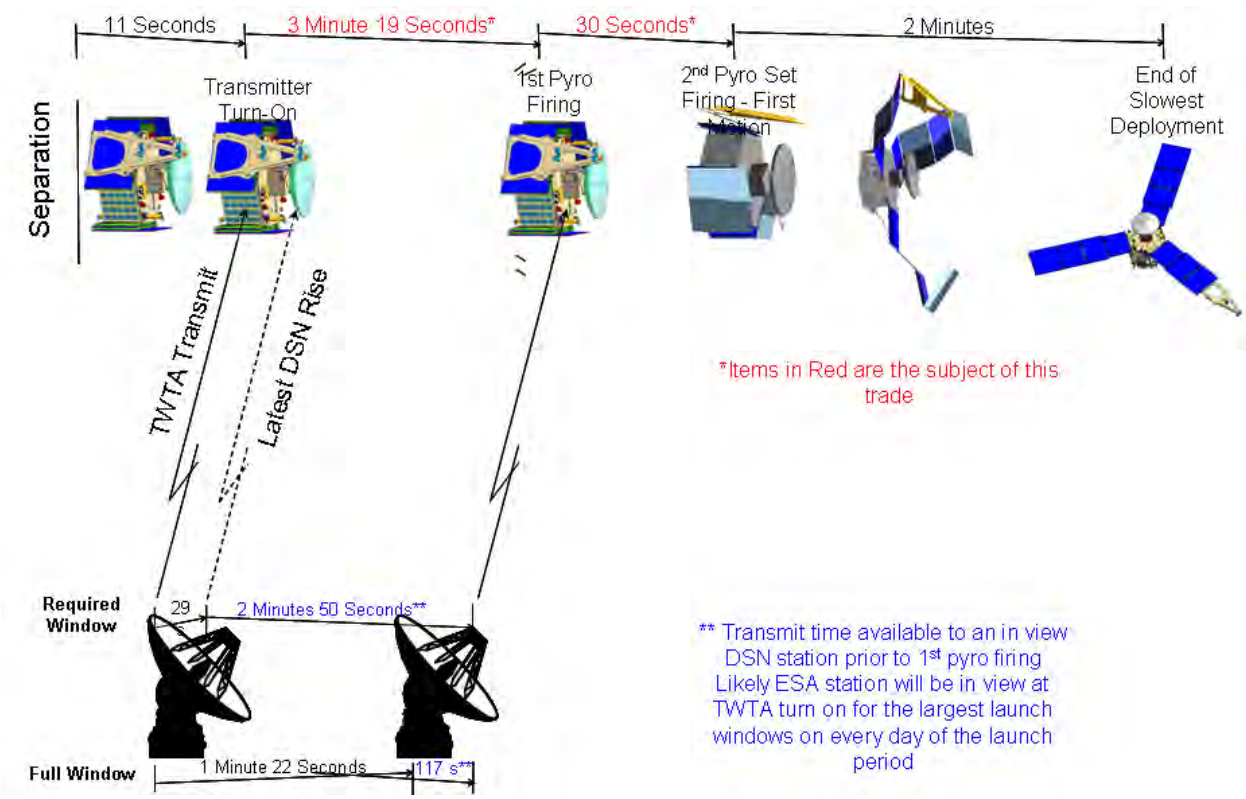

Figure 4-9: Key events after separation [9].

5 Gravity Science Operations

This section provides a summary of gravity science operations to be carried out during the science orbits phase. It provides an overview of how the Gravity Science orbits will be scheduled along with the other basic orbit type, the Microwave Radiometer (MWR) orbits. MWR orbits will be conducted earlier in the science orbits phase due to the limited lifetime of the MWR in the presence of radiation. The bulk of this material comes from the Juno Project Mission Plan, Jet Propulsion Laboratory (JPL) Document D-35556 [1].

5.1 Gravity Science Overview

The Juno Gravity Science (Grav) investigation will probe into the depths of Jupiter by precisely observing the Doppler Effect on the radio signal during close flybys. The quality of the experiment depends on a number of factors, including the phase stability of the radio links and minimizing the noise due to interplanetary plasma and the Earth's atmosphere. The contribution of dispersive noise sources is inversely proportional to wavelength, making Ka-band (32 GHz or 1 cm) an order of magnitude less susceptible than X-band (8.4 GHz or 3.6 cm). X-band is used for communications and navigation, and X-band and Ka-band are used together for the Gravity Science investigation.

When the X-band and Ka-band signals are received simultaneously on the ground, the dispersive noise contribution is differentially calibrated and removed. To accomplish this, Juno has an instrument called the Ka-band Translator (KaTS), which is separate from the X-band telecom subsystem (the SDST and the X-band TWTA). The KaTS receives a Ka-band uplink unmodulated carrier from the Deep Space Network (DSN) and generates a Ka-band downlink unmodulated carrier that is coherent with the uplink. The coherency maintains the uplink's excellent phase stability derived from hydrogen-maser atomic sources on the ground.

As described in Section 2 of this article, the KaTS includes a Ka-band receiver, digital signal processing, and a Ka-band solid-state power amplifier (SSPA). KaTS operations do not involve extensive commanding, sequencing, or flight software. The only commands affecting the KaTS are when the spacecraft power subsystem turns it on or off.

The Gravity Science investigation will make use of considerable ground infrastructure as well as the Telecom Subsystem on the spacecraft (Figure 5-1). The major ground operation is to generate a "sweep" uplink transmitter frequency profile to allow the KaTS to lock onto the uplink carrier.

The noise contribution due to the Earth's troposphere is calibrated via ground-based water-vapor radiometers.

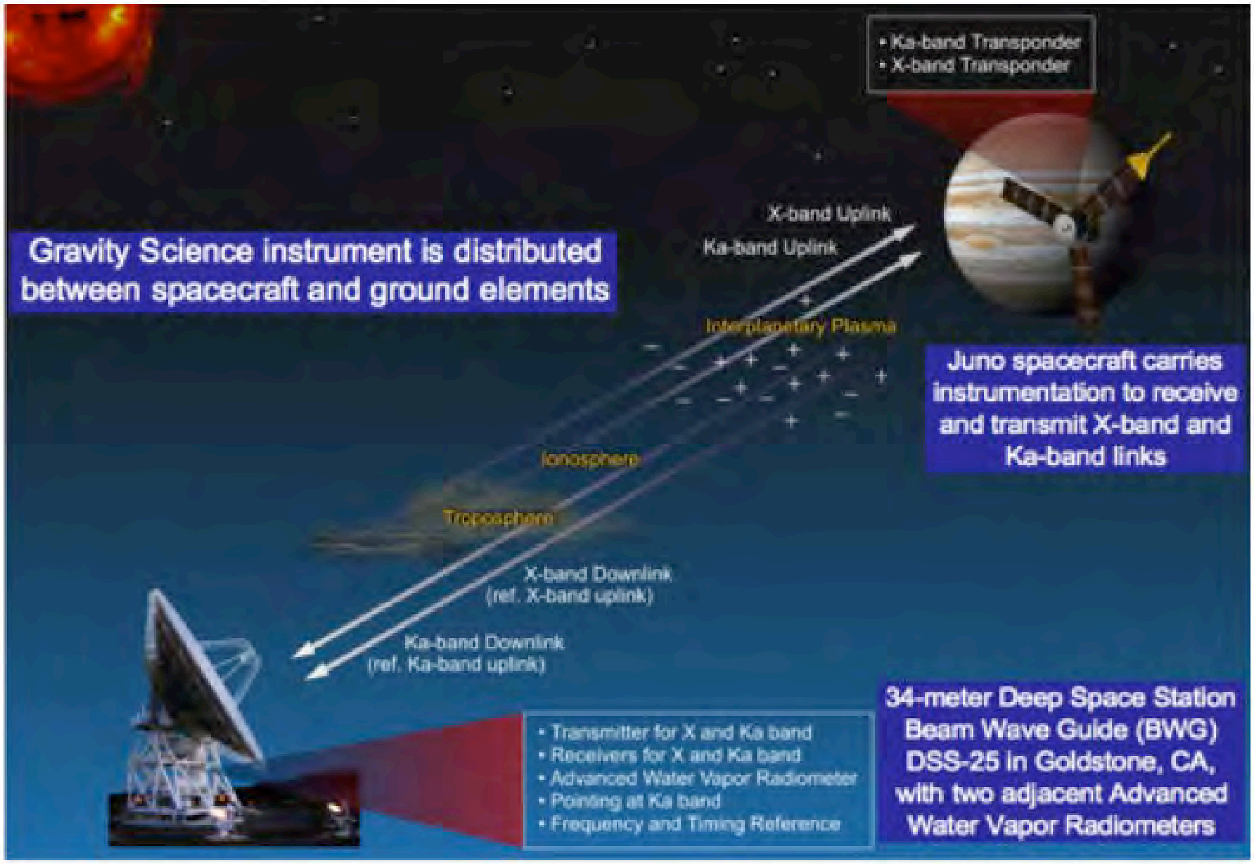

Figure 5-1: The Gravity Science instrument.

5.2 Science Orbits

We distinguish activity periods from orbits. Orbits are used to refer to the mission design and navigation strategy (for example, Nav data cutoffs, which occur near AJ orbit boundaries, and trajectory events), while activity periods are used to describe science and mission operations such as sequence generation and data flow from the stations to the scientists.

The Science Orbit phase includes Orbit 3 through Orbit 33 (Figure 5-2). Beginning with Orbit 1, Orbit N is defined from apojove (AJ) N-1 through apojove N, and includes perijove (PJ) N.

Orbit numbering begins with Orbit 0 at JOI. Orbit 0 lasts from Perijove 0 (PJ0) through Apojove 0 (AJ0). This orbit includes a JOI cleanup maneuver at JOI + 7.6 d). Orbit 1 includes PJ1 (and PRM at PJ1), and runs from AJ0 through AJ1. Orbit 2 includes PJ2 (and the PRM cleanup 1 maneuver at PJ2 + 1 h), and runs from AJ1 through AJ2. In the early orbits, science is currently baselined (except for JOI and PRM) in Orbit 0 and the first half of Orbit 1 (which together contain the 107-day capture orbit), and in Orbit 2, but not in the last half of Orbit 1 (PJ1 to AJ1).

Orbit 3 is the first science orbit. It includes PJ3 (and the PRM cleanup 2 maneuver at PJ3 + 4 h), and runs from AJ2 through AJ3. The last science orbit is Orbit 33. It will be bookkept as an extra science orbit, since the mission will use Orbits 3 through 32 to obtain 30 perijoves with MAG and other data that meet Level-1 baseline science requirements. Small (0.0–3.0 m/s) orbit trim

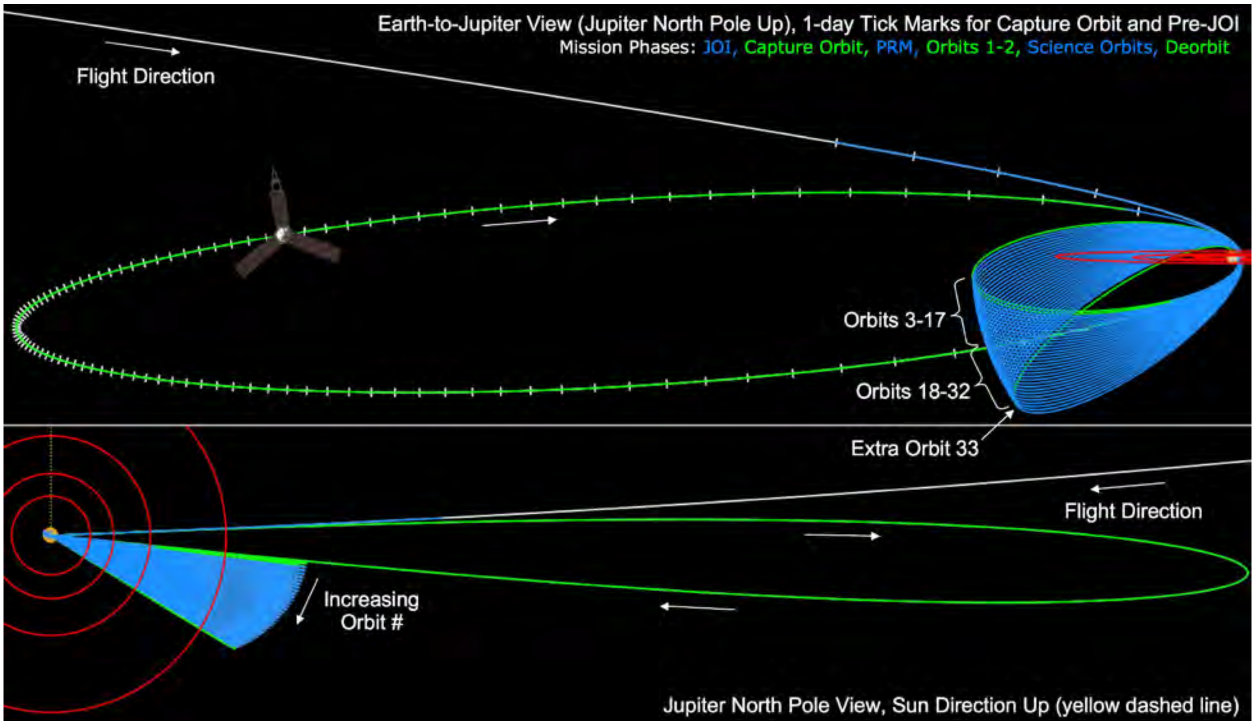

Figure 5-2: Juno orbital trajectory.

maneuvers (OTMs) are planned after each set of perijove science observations, at PJ + 4 h in Orbits 3 through 32, to target the perijove longitude required for science observations in the next orbit. There is no need for an OTM at PJ33 + 4 h. The deorbit maneuver (deterministic change in velocity (delta V, DV) = 74 m/s) is planned near AJ33.

An activity period (AP) runs from one PJ – 1 d to the next PJ -1 d. Each AP is defined by the number of the PJ science pass it contains, and the type (MWR or GRAV). AP2 is the first 11-day activity period (a special type in this case), and runs from PJ2 – 1 d through PJ3 – 1 d. It is followed by the first activity period during the Science Orbits, AP3 (an MWR type), from PJ3 – 1 d through PJ4 – 1 d. The Science Orbits phase begins at the start of AP3, and continues through AP33, which ends early, at AJ33 – 1 h, before the deorbit burn in the Deorbit phase.

Radiation accumulation will increase substantially as the orbital line of apsides rotates and perijove latitude increases from 3 deg at JOI to 34 deg at PJ33 (Figures 5-3 and 5-4), so there are no plans for an extended mission. One more orbit may be possible, but more than that is not likely. There is likely to be very little DV capability remaining after JOI, which will also limit extended mission options.

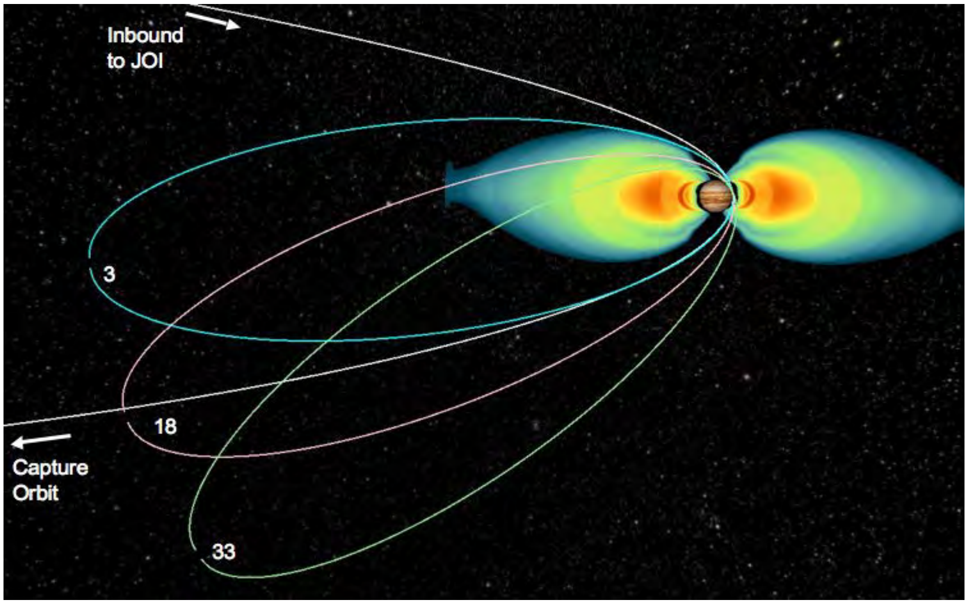

Figure 5-3: Juno orbital radiation environment.

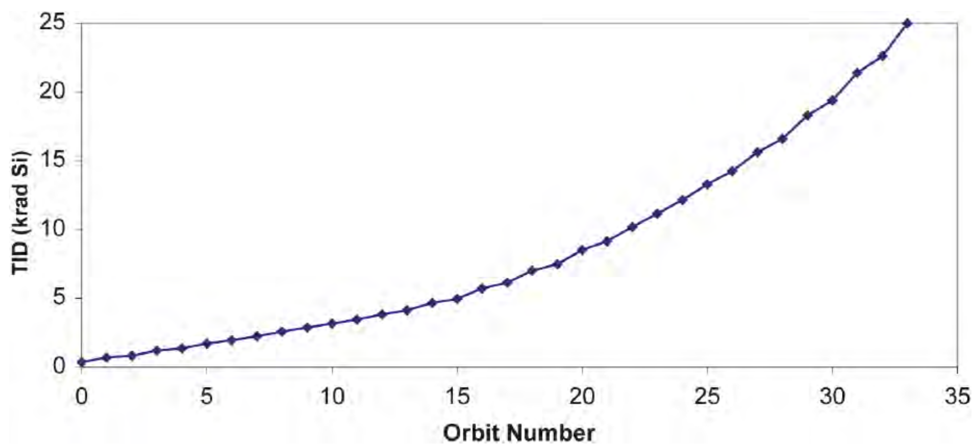

Figure 5-4: Juno orbital radiation accumulation (vault total ionizing dose vs. orbit).

Each orbit will be ~40 minutes less than ~11 days long (10.9725 days), to allow Juno to be viewable at every perijove from the same ground station (DSS-25 at Goldstone), which is the only DSN antenna capable of Ka-band uplink for Gravity Science. This timing, along with Jupiter's ~9.925-hour rotation period, is designed to shift the System-III longitudes at perijove so that the entire 360-deg longitude range is viewed with 24-deg spacing in the first 15 science orbits.[7]

[7] From Wikipedia, http://en.wikipedia.org/wiki/Jupiter. Definitions of System I, System II, and System III: Because Jupiter is not a solid body, its upper atmosphere undergoes differential rotation. The rotation of Jupiter's polar atmosphere is about 5 minutes longer than that of the equatorial atmosphere; three systems are used as frames of reference, particularly when graphing the motion of atmospheric features. System I applies from the latitudes 10 deg N to 10 deg S; its period is the planet's shortest, at 9h 50m 30.0s. System II applies at all latitudes north and south of these; its period is 9h 55m 40.6s. System III was first defined by radio astronomers, and corresponds to the rotation of the planet's magnetosphere; its period is Jupiter's official rotation.

The first 15 orbits (3 through 17) represent Juno's minimum mission. The PJ17 + 4 h OTM adjusts the timing so that PJ18 will begin to fill in the intermediate longitudes (with 24-deg spacing). Orbits 3 through 32 together will provide coverage of the entire longitude range with 12-deg spacing (Figure 5-5).

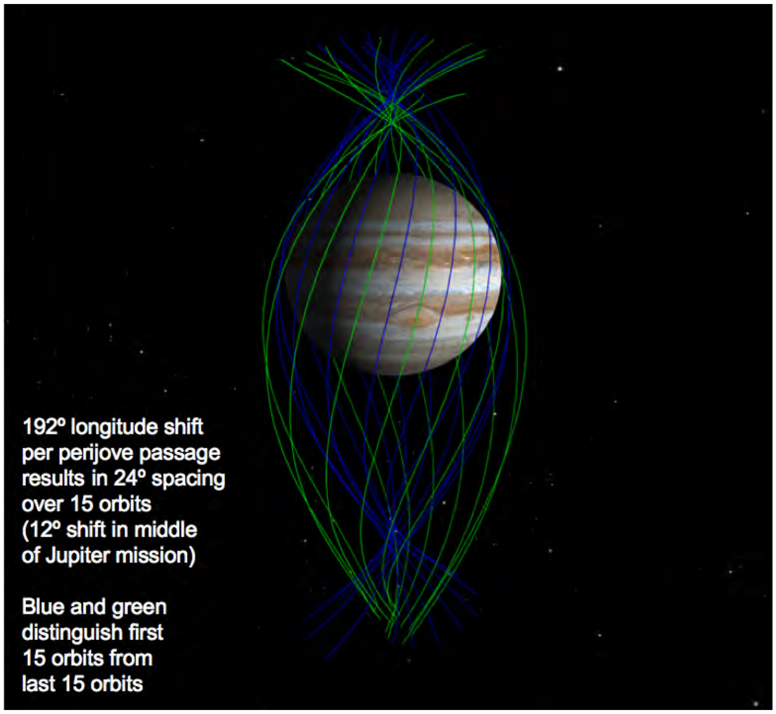

Figure 5-5: Global coverage resulting from a net of perijove science passes.

MWR is not designed to withstand radiation accumulation past the early orbits. Along with JIRAM and JunoCam, which also observe in the spin plane, MWR is only planned to be operated through Orbit 8 (although MWR is designed to survive until Orbit 11). Perijove passes in Orbits 3 and 5–8 will be dedicated to MWR, while the other perijove science passes (in Orbits 4 and 9–32, and probably Orbit 33) will be dedicated to Gravity Science (Grav). MWR, JIRAM, and JunoCam will be off during Grav passes, although we will consider using JIRAM and JunoCam as allowed by power, thermal, and other Flight System and mission operations constraints. Grav (the KaTS) will be off for MWR passes. UVS and the fields and particles instruments (JADE, JEDI, MAG, and Waves) are planned to observe during all science passes. To minimize operations costs, activities will be very repetitive from orbit to orbit. We will use two principal activity templates, one for MWR activity periods and one for Grav activity periods.

To understand mission requirements, capabilities, and constraints during the Science Orbits phase, we use representative activity periods as Mission Scenarios. Since early orbits are more constrained by data rate and volume than middle orbits (which are closer to the minimum Earth–spacecraft distance), we use Activity Periods 3 (MWR) and 4 (Grav) for Mission Scenarios. Later orbits are also constrained by data rate and volume, but we no longer expect to use MWR, JIRAM, and JunoCam.

The plots at the bottom of Figure 5-6 show how the individual science orbits vary. Earlier and later orbits occur when Juno is further from the Earth, while middle orbits occur near opposition when the Earth range is near minimum. The green curve shows how the angle between the Earth direction and the negative orbit normal direction varies, starting from its lowest value during Orbit 3. This geometry is important for Grav, which favors larger negative orbit normal to Earth angles for greater Doppler signal, and which also favors larger SEP angles for simultaneous X- and Ka-band observations (the closer to opposition the better since this means much less noise due to the solar corona at X-band, which is more susceptible than Ka-band). Finally, the negative orbit normal to Sun geometry (yellow curve) affects our ability to use Orbits 9-11 for MWR if needed, since larger angles mean less solar array power.

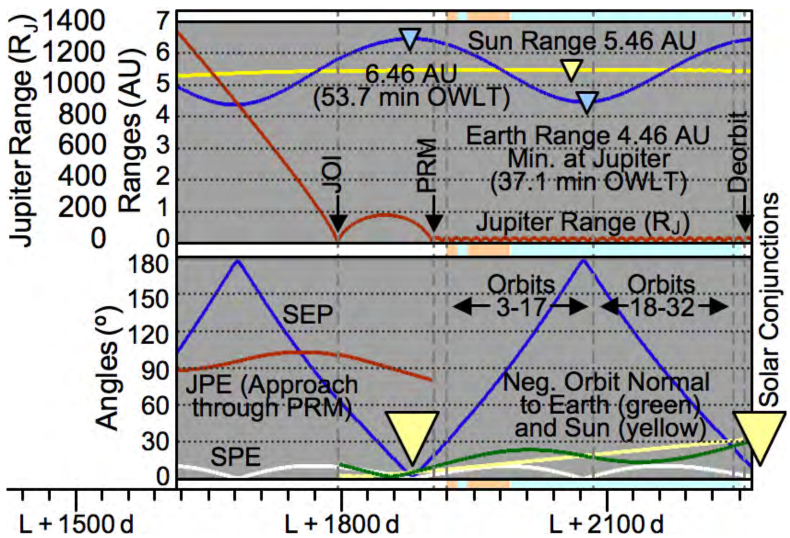

Figure 5-6: Science orbits geometry.

Figure 5-7 shows the spacecraft attitude during MWR and Grav perijove passes.

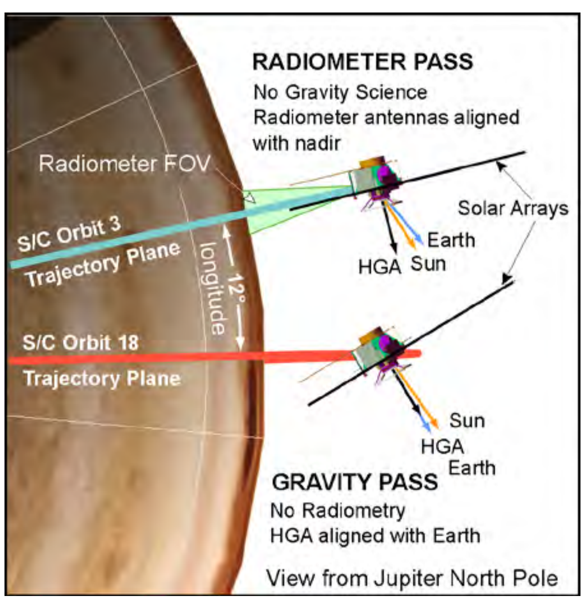

Figure 5-7: Spacecraft attitude during MWR and Grav perijove passes.

During the orbital mission, we will be Earth-pointed except for turn-burn-turn maneuvers (JOI, PRM, and deorbit), as well as MWR science passes and an MWR calibration. Other maneuvers (JOI and PRM cleanup maneuvers and all other OTMs) will be done in vector mode, unless a contingency arises which requires the DV efficiency of a turn-burn-turn maneuver (e.g., if the JOI+7.6d maneuver turns out to be greater than ~20 m/s, which is unlikely). Grav passes and most other DSN contacts require precise Earth-pointing; we will stay roughly Earth-pointed for most of the rest of the time when we are not in contact. Due to the changing position of the Earth with respect to the spacecraft, we will need to periodically reacquire Earth-point, mainly prior to DSN contacts. We will use the HGA for most DSN contacts. Due to the nutation of the spinning spacecraft following any maneuvers, we will need to allow several hours for nutation damping following Earth-point maneuvers before using the HGA.

Currently we allow 8 hours prior to most DSN tracks and 16 hours prior to the 6-hour MWR or Grav perijove science passes that start at PJ – 3 h. The one exception to using the HGA for DSN contacts is for the brief pass covering the PJ + 4 h OTM, in which case we currently plan to use the MGA. The reason is that after MWR passes, there is not enough time for nutation damping after a PJ + 3 h Earth-point maneuver, and for both MWR and Grav passes we do not expect to maintain precise pointing during the OTM to let us use the HGA (this is the subject of ongoing analysis; it may be possible to remain on the HGA at a rate that is still higher than on the MGA). There are 20 available downlink data rates: 10, 40, 100, 250, 1000, 1745, 2000, 4000, 12000, 18000, 22000, 26000, 30000, 35000, 40000, 50000, 100000, 120000, 150000, and 200000 bps. On the HGA we expect ≥18 kilobits per second (kbps) (≥12 kbps during Grav passes due to power required for carrier signal), and ≥10 bps on the MGA. We will use the MGA and ≥10 bps for Science Orbits safe mode communication (assuming a 34-m DSN pass).

Note: in Table 5-1, which is from a computer-generated Juno activity plan, the name “Grav” used elsewhere in the article is left as GRAV.

Table 5-1: Trajectory event times (UTC) for reference trajectory.

t	Event	Time
	L [1]	08/05/2011 16:11
	DSM1	09/07/2012 22:29
	DSM2	09/14/2012 22:29
	EFB	10/09/2013 15:29
0	PJ0 [2]	07/05/2016 02:44
JOI	AJ0	08/27/2016 10:46
1	AJ0	08/27/2016 10:46
PRM	PJ1 [2]	10/19/2016 18:17
	AJ1	10/25/2016 05:56
2	AJ1	10/25/2016 05:56
Cleanup	PJ2	10/30/2016 17:36
	AJ2	11/05/2016 05:11
3	AJ2	11/05/2016 05:11
MWR	PJ3	11/10/2016 16:46
	AJ3	11/16/2016 04:26
4	AJ3	11/16/2016 04:26
GRAV	PJ4	11/21/2016 16:06
	AJ4	11/27/2016 03:47
5	AJ4	11/27/2016 03:47
MWR	PJ5	12/02/2016 15:26
	AJ5	12/08/2016 03:07
6	AJ5	12/08/2016 03:07
MWR	PJ6	12/13/2016 14:47
	AJ6	12/19/2016 02:28
7	AJ6	12/19/2016 02:28
MWR	PJ7	12/24/2016 14:07
	AJ7	12/30/2016 01:46
8	AJ7	12/30/2016 01:46
MWR	PJ8	01/04/2017 13:27
	AJ8	01/10/2017 01:06
9	AJ8	01/10/2017 01:06
GRAV	PJ9	01/15/2017 12:47
	AJ9	01/21/2017 00:28
10	AJ9	01/21/2017 00:28
GRAV	PJ10	01/26/2017 12:07
	AJ10	01/31/2017 23:47

Orbit	Event	Time
11	AJ10	01/31/2017 23:47
GRAV	PJ11	02/06/2017 11:27
	AJ11	02/11/2017 23:08
12	AJ11	02/11/2017 23:08
GRAV	PJ12	02/17/2017 10:47
	AJ12	02/22/2017 22:26
13	AJ12	02/22/2017 22:26
GRAV	PJ13	02/28/2017 10:07
	AJ13	03/05/2017 21:47
14	AJ13	03/05/2017 21:47
GRAV	PJ14	03/11/2017 09:27
	AJ14	03/16/2017 21:07
15	AJ14	03/16/2017 21:07
GRAV	PJ15	03/22/2017 08:48
	AJ15	03/27/2017 20:30
16	AJ15	03/27/2017 20:30
GRAV	PJ16	04/02/2017 08:08
	AJ16	04/07/2017 19:48
17	AJ16	04/07/2017 19:48
GRAV	PJ17	04/13/2017 07:28
	AJ17	04/18/2017 18:59
18	AJ17	04/18/2017 18:59
GRAV	PJ18	04/24/2017 06:28
	AJ18	04/29/2017 18:08
19	AJ18	04/29/2017 18:08
GRAV	PJ19	05/05/2017 05:48
	AJ19	05/10/2017 17:29
20	AJ19	05/10/2017 17:29
GRAV	PJ20	05/16/2017 05:08
	AJ20	05/21/2017 16:49
21	AJ20	05/21/2017 16:49
GRAV	PJ21	05/27/2017 04:28
	AJ21	06/01/2017 16:09
22	AJ21	06/01/2017 16:09
GRAV	PJ22	06/07/2017 03:49
	AJ22	06/12/2017 15:28

Orbit	Event	Time
23	AJ22	06/12/2017 15:28
GRAV	PJ23	06/18/2017 03:09
	AJ23	06/23/2017 14:48
24	AJ23	06/23/2017 14:48
GRAV	PJ24	06/29/2017 02:29
	AJ24	07/04/2017 14:09
25	AJ24	07/04/2017 14:09
GRAV	PJ25	07/10/2017 01:49
	AJ25	07/15/2017 13:29
26	AJ25	07/15/2017 13:29
GRAV	PJ26	07/21/2017 01:09
	AJ26	07/26/2017 12:50
27	AJ26	07/26/2017 12:50
GRAV	PJ27	08/01/2017 00:29
	AJ27	08/06/2017 12:08
28	AJ27	08/06/2017 12:08
GRAV	PJ28	08/11/2017 23:49
	AJ28	08/17/2017 11:30
29	AJ28	08/17/2017 11:30
GRAV	PJ29	08/22/2017 23:09
	AJ29	08/28/2017 10:49
30	AJ29	08/28/2017 10:49
GRAV	PJ30	09/02/2017 22:29
	AJ30	09/08/2017 10:11
31	AJ30	09/08/2017 10:11
GRAV	PJ31	09/13/2017 21:49
	AJ31	09/19/2017 09:29
32	AJ31	09/19/2017 09:29
GRAV	PJ32	09/24/2017 21:09
	AJ32	09/30/2017 08:50
33	AJ32	09/30/2017 08:50
Extra	PJ33	10/05/2017 20:29
	AJ33	10/11/2017 08:15
34	AJ33	10/11/2017 08:15
Deorbit	PJ34	10/16/2017 19:33

[1] JOI starts 07/05/2016 02:29 (duration = 29:38 min = 1778 s).
[2] PRM starts 10/19/2016 17:59 (duration = 36:53 min = 2213 s).

Figure 5-8 shows the timing of PJ and OTM events with respect to the DSS-25 view period, and illustrates how science orbit perijove timing is optimized for Gravity Science, with perijove occurring about the middle of each pass.

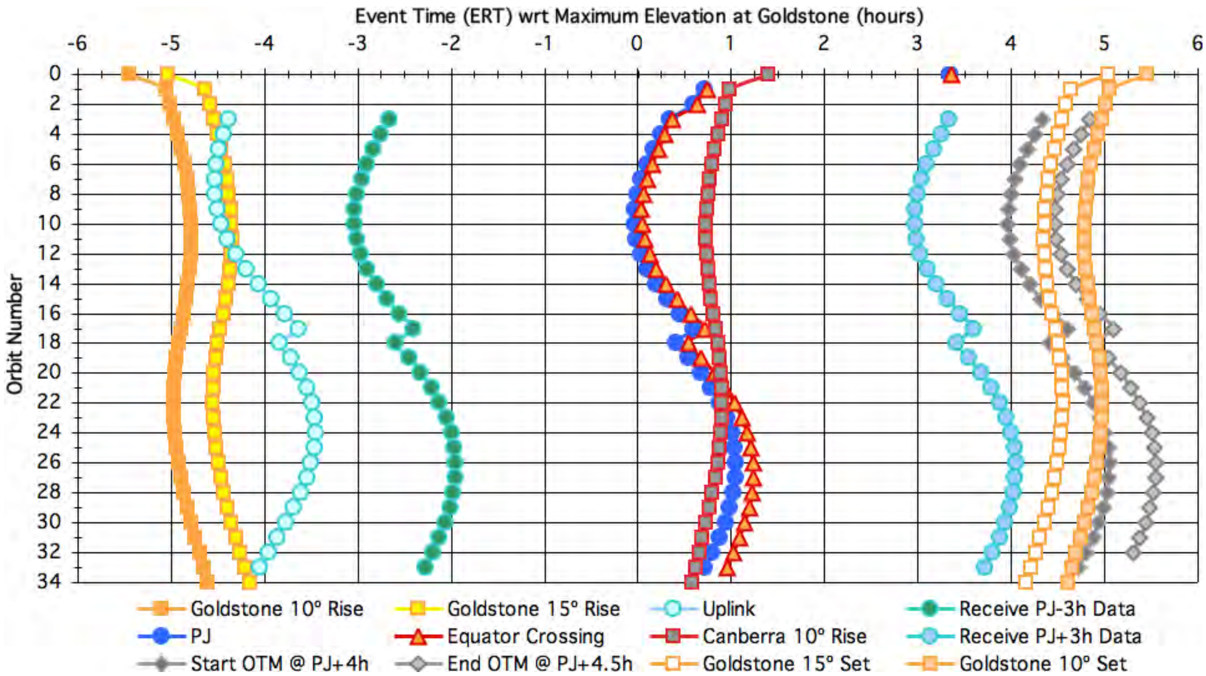

Figure 5-8: Timing of perijove events over DSS-25.

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7 Abbreviations and Acronyms

1553	(MIL-STD-1553) a standard for digital communications published by the United States Department of Defense
AAC	analog acquisition card
A/D, ADC	analog-to-digital (converter)
Adv	Adverse (tolerance)
AGC	automatic gain control
AJ	Jupiter apojove (analogous to Earth apogee)
ALGA	aft low-gain antenna
AOS	acquisition of signal
AP	activity period
ASC	advanced stellar compass
ASI	Italian Space Agency
AT	attenuator
AU	astronomical unit (149,597,871 meters (92,955,807 miles))
Aux Osc	auxiliary crystal oscillator
BER	bit error rate
BLF	best lock frequency
BPF	bandpass filter
bps	bits per second
BPSK	binary phase shift keying
BRM	Baseline Reference Mission
BW	bandwidth
CAN	Canberra Deep Space Communications Complex, CDSCC
CD	cumulative distribution (also called "percent weather")
C&DH	Command and Data Handling Subsystem
CMD	command
CNR	carrier-power-to-noise ratio
co-pol	co-polarization, co-polarized
CP	circular polarization
CW	continuous wave
cx-pol	cross polarization, cross polarized
D/A, DAC	digital to analog (converter)
dB	decibel
dBc	decibels below carrier
dBic, dBiC	decibels relative to an isotropic circularly polarized antenna
dBiL	decibels relative to a isotropic linearly polarized antenna
dBm	decibel referenced to milliwatts
DCT	design control table

deg	degree
DLLE	Downlink Loss Executive
DN	data number, digital number
DOFF	degrees off boresight
DOR	differential one-way ranging
DOY	day of year
DPM	digital processing module
DSM	Deep space maneuver
DSN	Deep Space Network
DSS	Deep Space Station
DSS-25	Deep Space Station 25 (34-meter beam waveguide antenna at Goldstone, California)
DSS-26	Deep Space Station 26 (34-meter beam waveguide antenna at Goldstone, California)
DSS-34	Deep Space Station 34 (34-meter beam waveguide antenna at Canberra, Australia
DSS-63	Deep Space Station 63 (70-meter antenna at Madrid, Spain)
DTCI	data command telemetry interface card
DV	delta-V, delta-velocity, change in velocity
DX	diplexer
E_b/N_0	Energy per bit to noise spectral density ratio
EDA	entry, descent, and landing (EDL) data analysis
EDL	entry, descent, and landing
EFB	Earth Fly-By
EIDP	End Item Data Package
EIRP	equivalent isotropically radiated power
EM	Engineering Model
EOL	end of life
EPC	electronic power converter
ESA	European Space Agency
ESTRACK	European Space Tracking (network)
Fav	favorable (tolerance)
F1	fundamental frequency from which uplink and downlink frequencies are derived
F_c	clock frequency
FEC	Front-End Controller
FER	frame error rate
FGM	Fluxgate Magnetometer
FLGA	forward low-gain antenna
FM	Flight Model
FOV	field of view
FPGA	field-programmable gate array
FSW	flight software

GDS	Goldstone Deep Space Communications Complex, GDSCC
GHz	gigahertz
GIF	guidance navigation and control interface
GOLD	Goldstone Deep Space Communications Complex, GDSCC
Grav	Gravity Science
h	hour
HGA	high-gain antenna
HPA	High power amplifier
hr	hour
HY	hybrid
ICD	Interface Control Document
ICO	initial checkout
IF	intermediate frequency
IFMS	Intermediate Frequency Modem System
IFOC	intermediate frequency-on-chip
JADE	Jovian Auroral Distributions Experiment
JEDI	Jupiter Energetic-particle Detector Instrument
JIRAM	Jovian Infrared Auroral Mapper
JOI	Jupiter Orbit Insertion
JPE	Jupiter–Probe–Earth (angle)
JPL	Jet Propulsion Laboratory
Ka-band	26.5–40 GHz
KaTS	Ka-Band Translator
kbps	kilobits per second
kHz	kilohertz
L	launch
LAN	local area network
LEOP	Launch and Early Orbit Phase
LGA	low-gain antenna
LHCP	left-hand circular polarization
LNA	low-noise amplifier
LOS	loss of signal
LPF	low-pass filter
LVDS	low-voltage differential signaling
MAD	Madrid Deep Space Communications Complex, MDSCC
MAG	Complete Magnetometer (flux gate magnetometers and advanced stellar compass)
M&C	Monitor and control
MCM	Monitoring and Control Module (of ESTRACK)

MDSCC	Madrid Deep Space Communications Complex, MAD
MECO	main engine cutoff
MER	Mars Exploration Rover
MES	main engine start
MGA	medium-gain antenna
MHz	megahertz
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
Msps	megasymbols per second
MW	Microwave
MWR	Microwave Radiometer
NaN	not a number (may appear in some link budgets)
NASA	National Aeronautics and Space Administration
NAV	Navigation
NCO	numerically controlled oscillator
NOP	Network Operations Plan
NRZ-L	non return to zero – level
ns	nanosecond
OCXO	oven controlled quartz oscillator
OICD	Operations Interface Control Document
OTM	Orbit Trim Maneuver
OWLT	one-way light time
PCM	pulse code modulation
PFD	phase frequency detector
PJ	Jupiter perijove (analogous to Earth perigee)
PJ 0, PJ1	J0 is the perijove at JOI
PLL	phase-locked loop
PM	phase modulation
Pnt	pointing (of spacecraft antenna in DCT, also called “doff”)
POR	power-on reset
PRM	period reduction maneuver
ps	picosecond
PSK	phase shift keying
P_c/N_0	carrier power to noise spectral density ratio
P_d/N_0	data power to noise spectral density ratio
P_r/N_0	ranging power to noise spectral density ratio
P_t/N_0	total power to noise spectral density ratio
RCS REM	Reaction Control System thrusters
RF	radio frequency
RFIS	Radio Frequency Instrument Subsystem
RFS	Radio Frequency Subsystem

RHCP	right-hand circular polarization
rpm	revolutions per minute
RS	Reed–Solomon
RX	receive
S	Separation
SA	solar array
SA R&R	solar array restraint and release (mechanisms)
S/C	Spacecraft
SDST	Small Deep Space Transponder
SEP	Sun–Earth–probe angle
S/N	serial number
SNR	signal-to-noise ratio
SNT	system noise temperature
SOHO	SOlar Heliospheric Observatory
SPD	sampling phase detector
SPE	Sun–probe–Earth angle
SPS	Service Preparation System (of the DSN)
Sps	symbols per second
SRU	Stellar Reference Unit
SSPA	solid state power amplifier
T_1	integration time for the clock component
T_2	integration time of each component
TAS-I	Thales Alenia Space-Italy
TC	Telecommand
TCM	Trajectory Correction Maneuver
TDL	Telecom Development Laboratory
Telecom	telecommunications
Telecom	Telecommunications (Subsystem)
TFP	Telecom Forecaster Predictor
TIP	target interface point
T-LGA	toroidal low-gain antenna
TLM	telemetry
TMTCS	Telemetry and Telecommand System
Tol	tolerance (in DCT parameter)
TWTA	traveling wave tube amplifier
TX	transmit
ULDL	uplink/downlink card
ULLE	Uplink Loss Executive
UTC	Universal Time Coordinated (Greenwich Mean Time)
UVS	Ultraviolet Spectrograph
μC	micro controller
Var	Variance (in DCT quantity)

VCO	voltage controlled oscillator
VSWR	voltage standing wave ratio
W	watt
Waves	an instrument to measure radio and plasma waves
WG	waveguide
WR-28, WR-34	waveguide sizes used for Juno Ka-band
WR-112	waveguide size used for Juno X-band
WTS	waveguide transfer switch
X-band	7.0 to 11.2 gigahertz