

Overview of the Preliminary Design of the Optical Communication Demonstration and High-Rate Link Facility

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ABSTRACT

This paper presents an overview of the preliminary design of both the flight and ground systems of the Optical Communication Demonstration and High-Rate Link Facility which will demonstrate optical communication from the International Space Station to ground after its deployment in October 2002. The overview of the preliminary design of the Flight System proceeds by contrasting it with the design of the laboratory-model unit, emphasizing key changes and the rationale behind the design choices. After presenting the preliminary design of the Ground System, the timetable for the construction and deployment of the flight and ground systems is outlined.

Keywords: optical communication, International Space Station, lasercomm

1. INTRODUCTION

Motivated by demands for faster, better, cheaper spacecraft, NASA is developing optical communication technology which promises reduced mass, volume, and power consumption compared to radio-frequency technology¹. As part of that technology development, the International Space Station (ISS) Engineering Research and Technology Development program (ISSERT) has sponsored the Jet Propulsion Laboratory (JPL) to create the Optical Communication Demonstration and High-Rate Link Facility (OCDHRLF)² which will demonstrate a 2.5 Gbps optical downlink from the ISS to JPL's Optical Communication Telescope Laboratory (OCTL)³. This demonstration will gather statistics on the space-to-ground optical communication link and quantify the performance of the OCDHRLF as a system. Following successful demonstration, the high-rate downlink capability will be available as a facility experiment for the downlink of high-rate science data from the ISS.

In this paper presents an overview of the preliminary design of the OCDHRLF. The overview begins with Section 2 which summarizes the link in a design table and the performance of the end-to-end system. Section 3 contrasts the preliminary design of the Flight System in terms of modulation rate, wavelength, output power, instrumentation, and interface to the host platform with the heritage design of the Optical Communication Demonstrator (OCD)^{4,6}. Section 4 presents the preliminary design of the Ground System and discusses operations. Finally, Section 5 summarizes the schedule for the development of the OCDHRLF.

Data Rate	1.244 Gbps	2.488 Gbps
Transmit Power, average	23 dBm	23 dBm
Transmit Gain & Optics Efficiency	100 dB	100 dB
Channel Mis-Pointing Allowance	-4 dB	-4 dB
Space Loss	-258 dB	-258 dB
Atmospheric Transmission Loss	-2 dB	-2 dB
Atmospheric-Induced-Fade Allowance	-6 dB	-6 dB
Receive Gain & Optics Efficiency	118 dB	118 dB
Received Signal	-29 dBm	-29 dBm
Required Signal Level at Receiver	-35.5 dBm	-31.9 dBm
Link Margin	+ 6.5 dB	+ 2.9 dB

Figure 1. This table summarizes, under pessimistic estimations, the gains and losses in the end-to-end optical link at 1.244 and 2.488 Gbps under the worst-case geometry for a clear day. The gains exceed the losses by approximately 6.5 dB at 1.244 Gbps and 2.9 dB at 2.488 Gbps.

2. END-TO-END SYSTEM

The end-to-end OCDHRLF design is capable of communicating a pseudorandom bit sequence (PRBS) to the Ground System at a data rate exceeding 1 Gbps and provides a User Input Port by which an externally-supplied, formatted binary data stream can be communicated to the Ground System at similar high data rates, supporting the facility experiment purpose of the OCDHRLF. In addition to these data rate performance goals, the design meets the NASA safety requirement that at the ISS both the intensity of the beacon beam and the intensity of the downlink beam be below the eye-safe limit. The design of the Flight System also includes instrumentation to measure the Flight System's performance in the ISS operating environment and to provide diagnostic capability.

The design of the flight and ground systems were guided by the link table shown in Figure 1. The table is tabulated for an on-off-keyed (OOK) bit stream with a bit-error-rate (BER) of 10^{-6} , clear weather with light high cirrus clouds, and the worst-case link geometry which occurs when the ISS is 985 km away from the Ground System. In this link geometry, the ISS is only 20 degrees above the horizon, maximizing the atmospheric transmission loss. The 200 mW of transmit power is produced by a 1550-nm erbium-doped fiber amplifier arranged in a master-oscillator power-amplifier configuration⁷. The power from this downlink laser is relayed through an optical system culminating in its collimation by a 10-cm-diameter Cassegrain telescope similar to the telescope used in the OCD. The allowance for 4 dB of pointing loss accounts for the anticipated worst-case residual pointing error associated with misalignments and the finite ability of the fine-steering control loop to compensate for the ISS vibration environment. The design table includes an allowance of 6 dB for expected intermittent signal reduction due to atmospheric fades. The receiver gain and optics efficiency is based on pessimistic performance estimates of the one-meter-aperture OCTL facility and the receiver sensitivity is as-specified for a commercial-off-the-shelf (COTS) fibercomm-standard receiver. Under these estimates and allowances, more than 6 dB of margin remains. The end-to-end system utilizes the Synchronous Optical Network (SONET) standard data rates 2.488 Gbps, 1.244 Gbps, 622 Mbps, and 155 Mbps. The link margin increases by approximately 3 dB with each factor-of-two decrease in data rate; approximately 3 dB of link margin remains at the highest data rate of 2.488 Gbps.

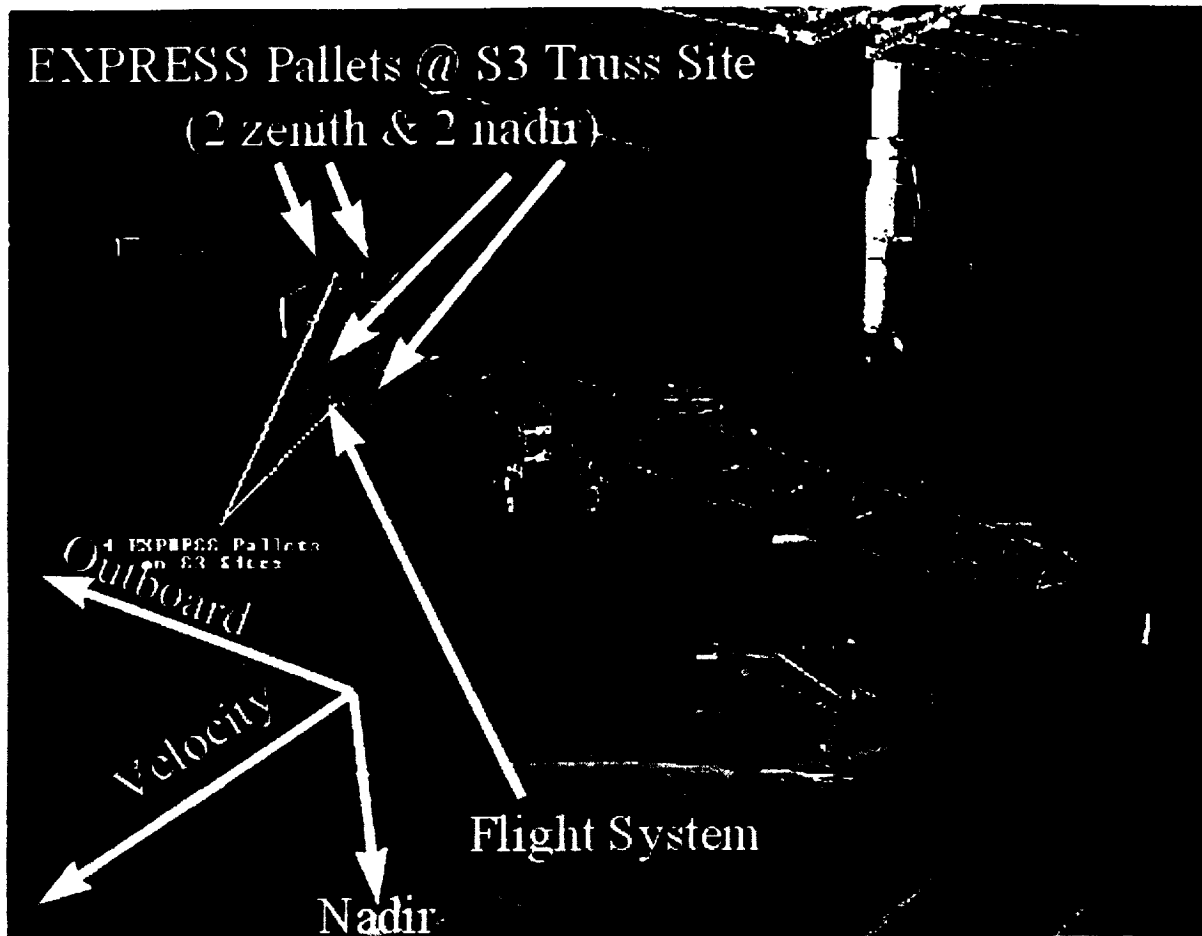


Figure 2 A conception of the International Space Station at assembly complete. The Flight System attaches to the nadir-facing outboard EXPRESS Pallet Adapter at the port forward position. This location permits the Flight System to have an unobstructed line-of-sight to the rising of the Ground System for particular passes.

3. FLIGHT SYSTEM

The Flight System of the OCDHRLF is manifested to be deployed to the ISS aboard Space Transportation System Utilization Flight 3 (STS-UF3), tentatively schedule for October 2002. The Flight System will be attached to a nadir outboard EXPedite the PROcessing of Experiments to the Space Station (EXPRESS) Pallet Adapter at the port forward position on the starboard truss as illustrated in Figure 2. This attach site permits the Flight System to have an unobstructed field of view as the ground station rises. Additional information about the EXPRESS Pallet Adapter, which is the electrical, electronic, and physical connection between the Flight System and the ISS, is contained in reference 2.

Figure 3 shows the layout of the Flight System on the EXPRESS Pallet Adapter. The Flight System telescope assembly mounts on an altitude / azimuth gimbal which provides rough pointing. The gimbal, in turn, is mounted on a pedestal which optimizes the height of its altitude axis of rotation to minimize line-of-sight blockages by experiments on neighboring EXPRESS Pallet Adapters. One electronics box houses the processing and control function of the flight terminal, one laser box houses the downlink laser and modulation assembly, and one electronics box houses the control electronics for the gimbal. The Flight System includes a retroreflector

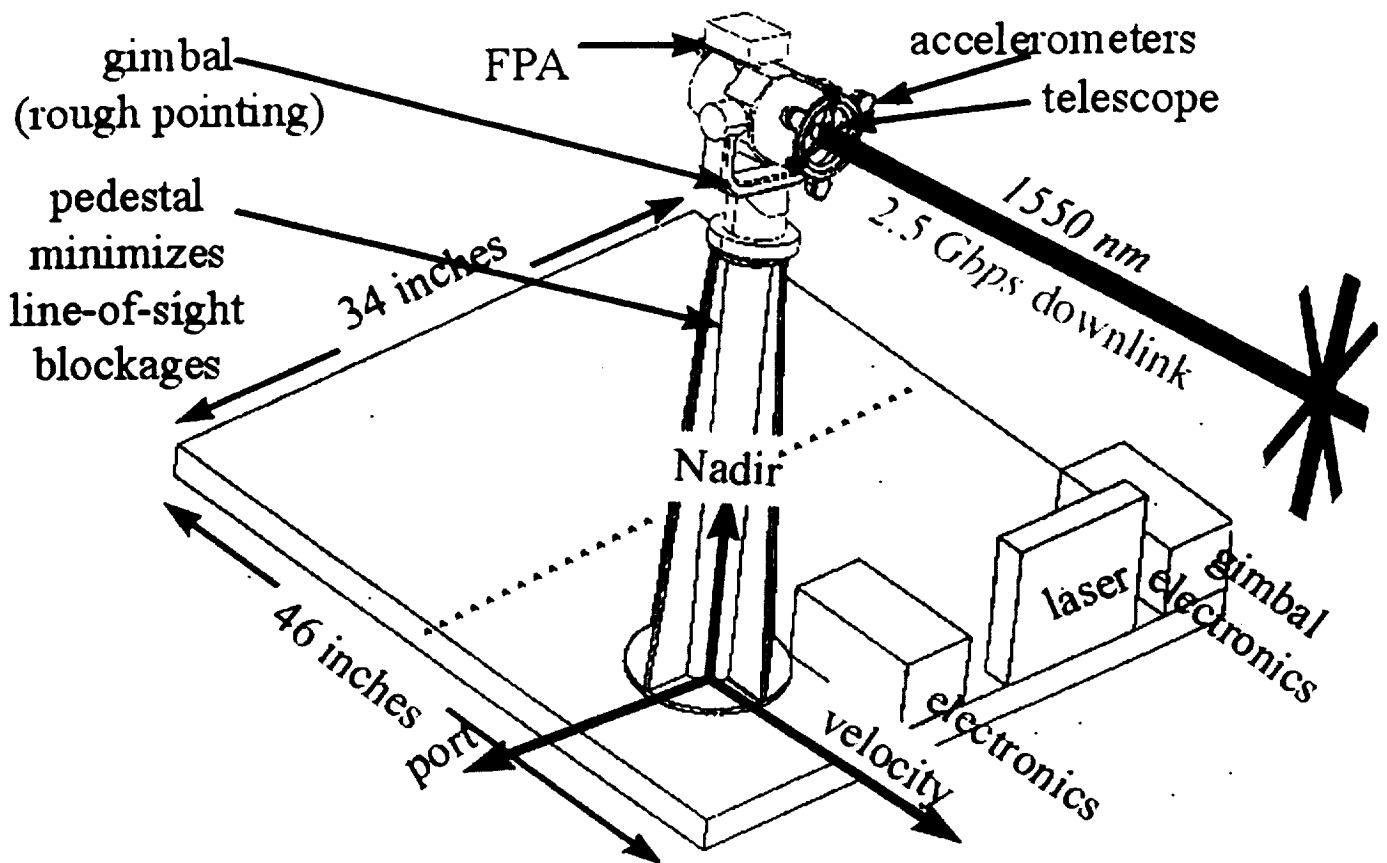


Figure 3. The Flight System integrated to an EXPRESS Pallet Adapter. The Flight System telescope assembly mounts on an altitude /azimuth gimbal which in turn mounts to a pedestal whose height minimizes line-of-sight blockages by neighboring payloads.

mounted on the floor of the EXPRESS Pallet Adapter which is designed to return the pulses at 1064 nm used by the ground station to verify that its telescope is correctly pointed at the Flight System. Three accelerometers mounted on the telescope assembly monitor telescope pointing changes induced by platform vibration.

The design of the Flight System retains the heritage architecture of the OCD laboratory-model form, fit, and function optical transmitter: fine tracking & point-ahead using one focal-plane-array & one fine steering mirror, and the downlink beam fiber-coupled to the telescope assembly. Since the design of the OCD has been discussed extensively in reference 5, it suffices to contrast the design of the Flight System with the design of the OCD. One key contrast is the operating wavelengths. The downlink beam of the Flight System is at the 'eye-safe' wavelength of 1550 nm and the beacon beam is at 980 nm. The 980-nm beacon wavelength choice allows the Ground System to utilize high-power commercially-produced lasers. Also, its long wavelength is favorable to scintillation effects yet remains visible to the FPA. The choice of 1550 nm for the downlink wavelength allows the Flight System to leverage the heavy investment that the fibercomm industry has made in the 1550-nm fiber laser system and at the same time makes the downlink beam eyesafe even directly in front of the Flight System aperture. The fibercomm industry investment in 1550-nm also allows the Ground System to minimize cost by utilizing a fibercomm COTS receiver package. Although the 1550-nm downlink beam is not visible to the Flight System Focal Plane Array (FPA), the laser assembly includes a 980-nm boresight reference beam co-propagating with the 1550-nm downlink. The FPA uses this boresight reference beam to perform tracking of the downlinked direction. This technique is further described in reference 7.

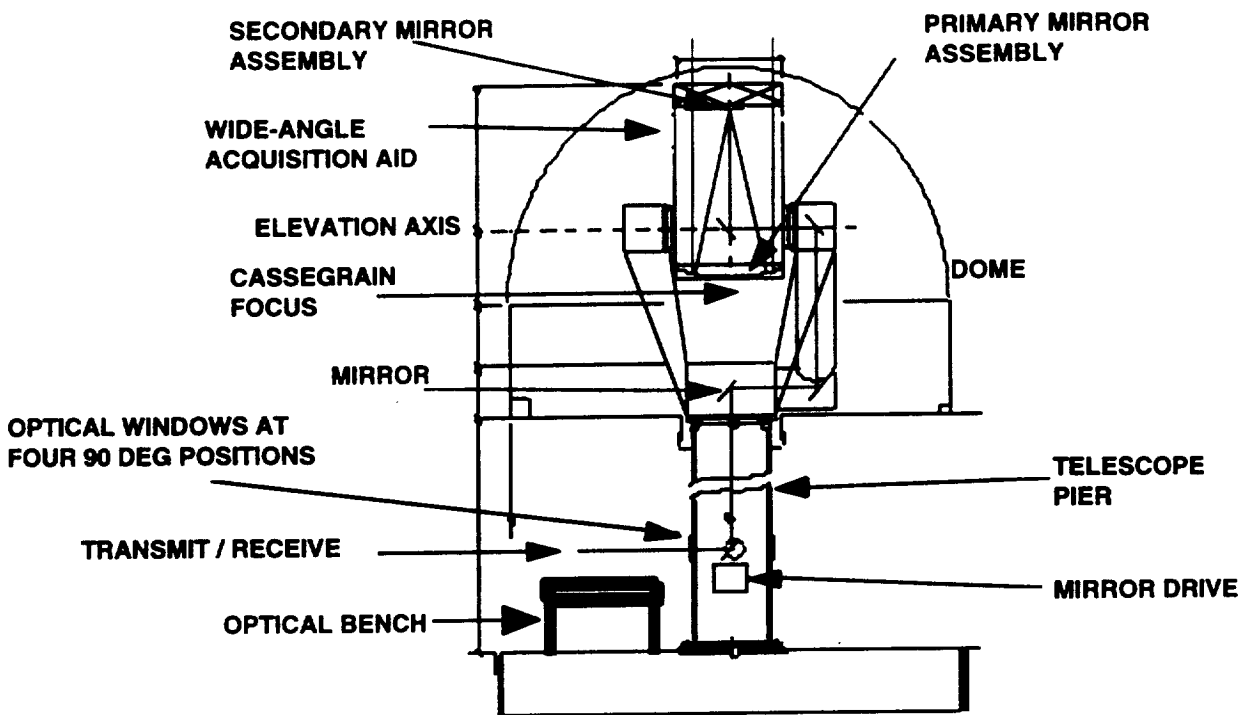


Figure 4. An illustration of the Optical Communication Telescope Laboratory to which the Ground System integrates.

Another key contrast between the design of the OCD and the preliminary design of the Flight System is the addition of a beacon monitor channel to the optical system. This channel splits off a portion of the beacon beam entering the telescope optical assembly and sends it to a detector which measures and digitizes the time-dependent intensity changes caused by atmospheric fluctuations. Analysis of these scintillation measurements will enable the accuracy of atmospheric scintillation models to be tested and quantify the effectiveness of beacon-beam scintillation-mitigation techniques.

The electronics interface is another key change. The Flight System electronics interface has been expanded to include, in addition to the 1553 B command and control data which receives ISS position, attitude, roll rate, and time, as well as commands from the Ground System, an Ethernet connection for relaying high-rate engineering data to the Ground System. This Ethernet connection enables measurements from the accelerometer array and scintillation monitor to be sent to the Ground System over the ExPA Ethernet link in near-real-time for recovery and analysis.

4. GROUND SYSTEM

The Ground System design draws heritage from the Ground-to-Orbit Lasercomm Demonstration⁸ and integrates to the OCTL, shown in Figure 4. The Ground System has three primary functions: maintain an illumination on the Flight System with the beacon beam, recover the downlink beam, and facilitate operations and planning.

The Ground System illuminates the Flight System with a beacon beam consisting of eight 1.25-W mutually-incoherent 980-nm laser beams broadcast from spatially separated locations on the primary mirror. The combination of these eight beams as they spatially overlap at the Flight System produces an irradiance whose scintillation is substantially reduced over the scintillation that an individual beam would possess. This spatial and

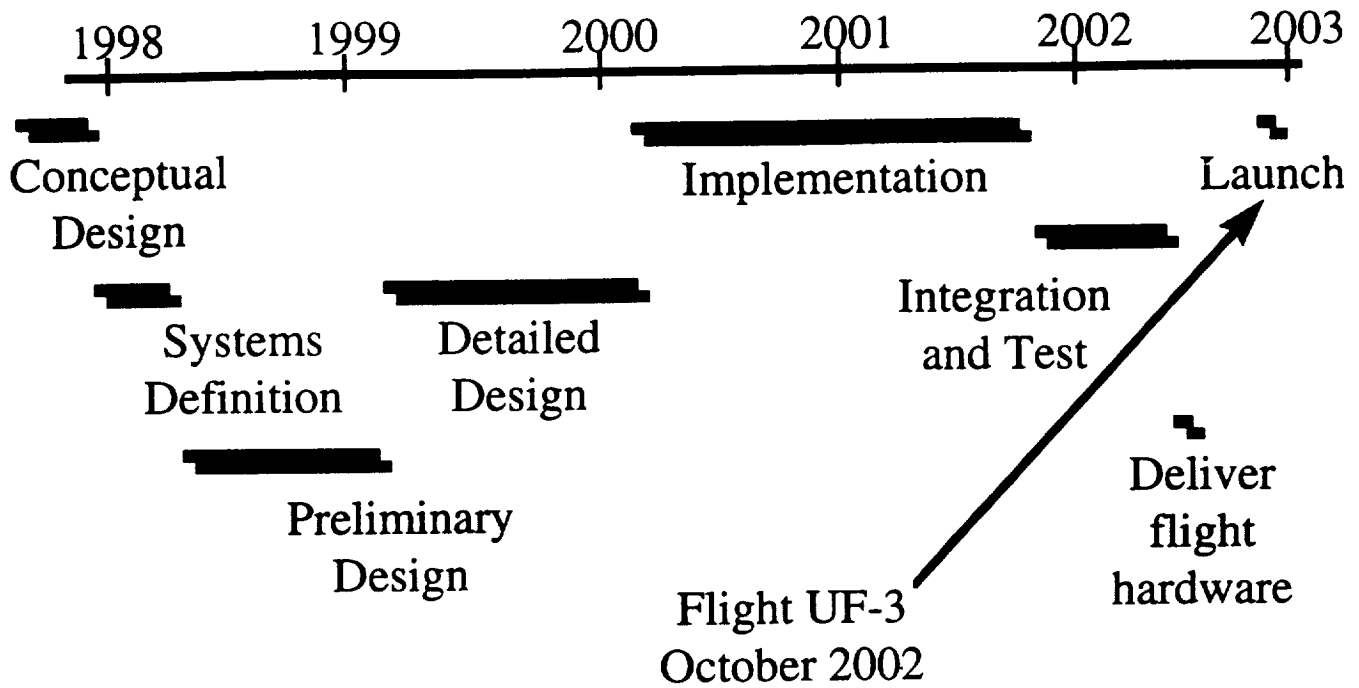


Figure 7. Schedule for the design and development of the flight terminal.

coherent separation technique, called beacon-beam averaging, was used successfully during the GOLD experiment to improve the signal quality received at the ETS-VI satellite. Each beacon laser has a divergence of 200 μ rad which is a compromise between the insensitivity to mispoint obtained with a broad beam and the beacon power required in a broad beam to maintain the required irradiance on the Flight System.

To ensure initial acquisition of the Flight System in the wide position uncertainty space defined by the 3000-ft 3-sigma position knowledge accuracy of the ISS, the Ground System is capable of transmitting a 1-mrad-divergence beacon boresight beam consisting of pulses from a YAG laser. Observing the arrival of retroreflected pulses assures that the telescope is correctly pointed at the Flight System.

To receive the downlink communication beam, the Ground System receive channel focuses the downlink beam onto a COTS receiver unit appropriate to the data rates which the Flight System transmits. The receiver is followed by a bit-error-rate tester (BERT) which measures link performance. A scintillation monitor attached to the detector measures the downlink scintillation statistics for later comparison to theory. Data from these monitors will be correlated with atmospheric transmission measurements made by the autonomous visibility monitoring (AVM)⁹ station located near OCTL, further increasing our understanding of the systems performance.

Operations which involve the Flight System pass through the United States Ground Segment of the International Space Station Payload Operations and Integration Center (POIC) to be located at Marshall Space Flight Center. An Internet connection allows commands for the Flight System to be sent from OCTL through POIC to the Flight System. High-rate engineering data flowing down from the ISS Ethernet link is processed through POIC and provided in near-real-time to the OCTL.

5. PLAN AND SCHEDULE

The schedule for the development of the flight terminal is shown in Figure 5. The conceptual design, systems definition, and preliminary design have been completed. The detailed design phase culminates in a Critical

Design Review (CDR) which will be followed by hardware fabrication and subsystem integration, leading to the integration and test of the Flight Terminal in early 2002. The complete flight terminal will be delivered to Kennedy Space Center six months before the October 2002 launch.

6. SUMMARY

In summary, the preliminary design of the Flight System of the Optical Communication Demonstrator and High-Rate Link Facility retains the heritage architecture of the Optical Communication Demonstrator while changing the downlink wavelength to 1550-nm, increasing the data rate to 2.488 Gbps, adding a beacon scintillation monitor and an accelerometer array, and changing the beacon-tracking wavelength to 980 nm. The preliminary design of the Ground System is matched to the requirements of the Flight System and uses multiple beacon beams to reduce scintillation. The Flight System of the OCDHRLF is scheduled to be deployed to the ISS in October 2002.

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