Design of a 2.5 Gbps Optical Transmitter for the International Space Station

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ABSTRACT

A high data rate laser transmitter assembly (LTA) has been designed as the source for an optical free-space communication link between the International Space Station and the 1-meter Optical Communication Telescope Laboratory (OCTL) to be built at the Table Mountain Facility (TMF, Wrightwood, CA). The transmitter design concept uses a fiber-based master oscillator power amplifier (MOPA) configuration with an average output power of 200 mW at a 1550 nm transmit wavelength. This transmitter source is also designed to provide a signal at 980 nm to the Silicon-based focal plane array for the point-ahead beam control function. This novel integration of a 980 nm boresight signal allows the use of Silicon based imagers for the acquisition/tracking and point-ahead functions, yet permits the transmit signal to be at any wavelength outside the Silicon sensitivity. The LTA, a sub-system of the Flight Terminal, has been designed to have a selectable data rate from 155 - 2500 Mbps in discrete steps. It also incorporates a 2.5 Gbps pseudo-random bit sequence (PRBS) generator for complete link testing and diagnostics. The design emphasizes using commercial off the shelf components (COTS).

Keywords: Optical communications, MOPA, laser transmitter, high data rate, PRBS generator.

1. INTRODUCTION

The Jet Propulsion Laboratory is developing the deployment of a Gbps-class optical communications downlink for the International Space Station[1] (ISS). In order to provide this communication link a preliminary design of the laser transmitter to be used has been performed. This article will present and describe the key components and characteristics of the laser transmitter assembly subsystem design.

The communication link planned is composed of two segments, the flight system terminal and the ground system receiver. The receiver system to be used is the 1-meter Optical Communication Telescope Laboratory (OCTL)[2] being built at the Table Mountain Facility (TMF, Wrightwood, CA). The flight system is composed of a number of subsystems which include the gimbal, telescope, optics, pointing, acquisition and tracking subsystem, electronics and the laser transmitter assembly (LTA). Further description of the communication link including link budget, description of the flight and ground segments are given in another publication[3]. In order to complete the communication link the flight system has derived three key functional requirements for the LTA. These are discussed further in the following paragraphs and are summarized in Table 1.

For the demonstrations planned, the link design calls out for the LTA to provide a 200 mW average power optical transmit signal that is modulated at up to 2.488 Gbps. The wavelength selection for the laser source was driven by the need to be eye-safe at ISS, the desire to mitigate atmospheric effects, the availability of high-power, high-speed lasers, and the availability of sensitive high-speed detectors. From these drivers the two primary wavelength contenders were 1064 and 1550 nm lasers in a master oscillator power amplifier (MOPA) configuration. Figure 1 plots out the wavelength dependence of atmospheric transmittance,

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atmospheric radiance on the ground and maximum permissible ocular exposure (MEP). The transmittance and radiance data are obtained from MODTRAN simulations while the MEP values are calculated from data available in the literature[4]. Figure 1a graphically demonstrate the optical windows of low transmittance at 800-920, 1000-1100, 1080-1320, and 1500-1600. From figure 1b, the radiance, that contributes to background noise, is seen to decrease for longer wavelengths. The advantage of using longer wavelengths is also pointed out in figure 1c, where the allowed exposure for eye-safety increases for longer wavelengths. Therefore, based on its eye-safety advantage, better atmospheric transmission, its multiple vendor commercial availability, and excellent integrated receivers, the 1550 nm MOPA is baselined as the laser source.
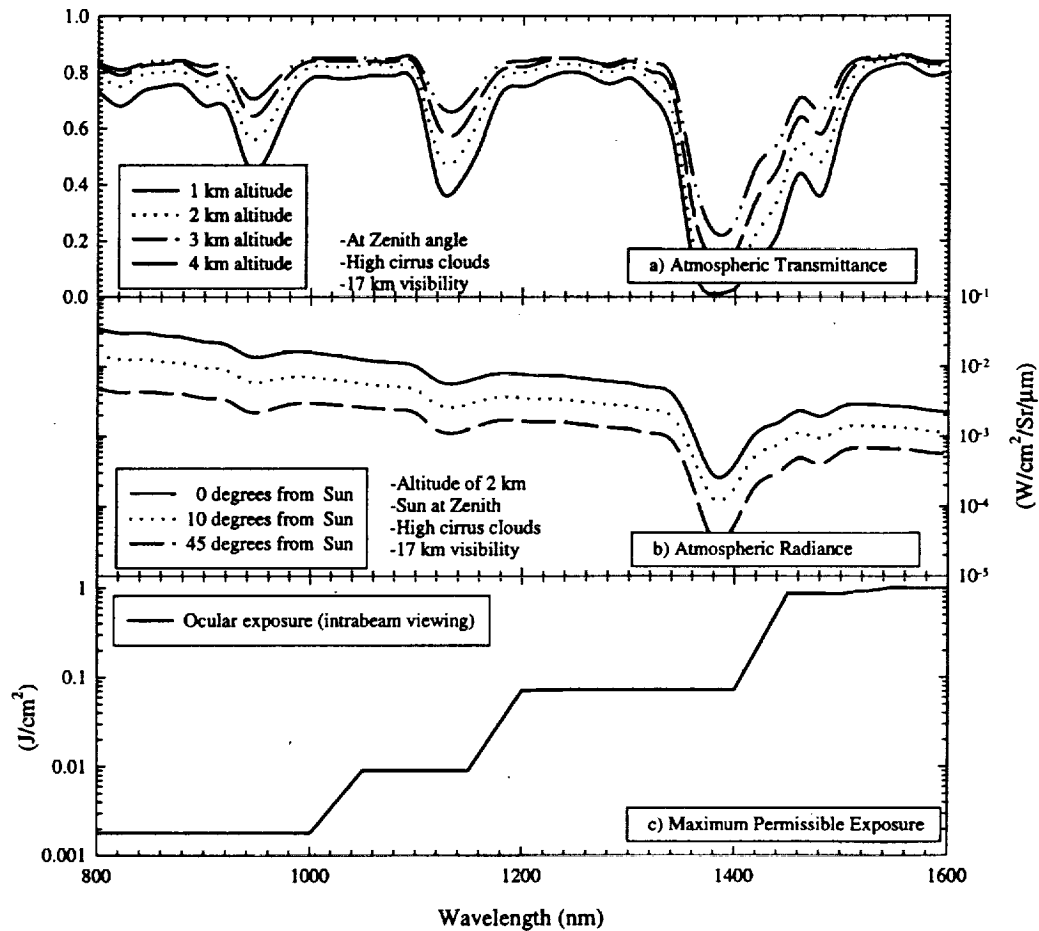

Figure 1. a) Atmospheric transmittance, b) atmospheric radiance, and c) maximum permissible exposure[4] as a function of wavelength.

The optical communication demonstration also desires to perform diagnostic measurement and characterization of the Bit Error Rate (BER) for the entire link. Therefore a second function for the LTA to perform is to provide a pseudo-random bit-sequence (PRBS) pattern generator capable of modulating the transmit beam at data rates up to 2.5 Gbps.

The third functional requirement is that the LTA provide a reference beam to perform the pointing, acquisition and tracking (PAT) function. The PAT architecture for the flight terminal is based on the OCD design[5]. This architecture uses only one focal plane array (FPA) and one steering mirror for implementation of the beam control system. In the OCD implementation[6] of this PAT architecture, part of the transmit signal (at 844 nm) is split to provide the boresight signal to the Silicon based. But, in the design presented here the transmit wavelength has been selected at 1550 nm and therefore it is not possible to use part of the transmit

signal as the boresight reference, unless the FPA is not made from Silicon but out of a material sensitive to the near-IR wavelengths (eg. HgCdTe). In order to keep the versatility of a Silicon based FPA, a novel concept has been developed to provide the boresight signal at a wavelength sensitive to Silicon yet allow for the transmit wavelength to be selected in the near-IR region.

Provide a transmit signal with	
Output power, average	200 mW
Wavelength	1550 nm
Data Rate, selectable	155 - 2500 Mbps
Provide a PRBS Generator with	
Data Rate, selectable	155 - 2500 Mbps
Sequence lengths	2^7-1 to 2^{31}-1
Provide a reference boresight signal with	
Output power	1 - 10 mW
Wavelength	980 nm
Beam mode quality	Symmetric

Table 1. Laser transmitter assembly functional requirements.

2. LASER TRANSMITTER ASSEMBLY DESIGN

The block diagram of a design that meets the functional requirements is shown in figure 2. The LTA is composed of five modules: the data converter module (DCM), the laser oscillator module (LOM), the optical amplifier module (OAM), the boresight signal module (BSM) and the power conditioning module (PCM). The DCM's primary function is to receive, format, and route the data to the modulator, but it also contains the PRBS generator and all the LTA sub-system command/control and interface electronics. From the DCM the formatted data is sent to the LOM, where the data is modulated onto the master oscillator optical signal. This modulated signal is then amplified by the fiber amplifier in the OAM and multiplexed with the boresight signal from the BSM before being delivered to the telescope assembly.

In this section the design of each of the modules will be discussed. Emphasis will be placed in describing the design of the DCM because of its special functions and detailing the novel use of the BSM in the architecture of the pointing, acquisition and tracking functions.

2.1 DATA CONVERTER MODULE

The DCM's primary function is to receive, format and route the input data to the modulator. It also contains the PRBS generator and all the LTA sub-system command/control and interface electronics. Due to its special functions the DCM requires its specific design. Electronics for all control, status and health monitoring is contained in this module. The LTA subsystem receives commands, which include, power up, PRBS Mode ON, By-pass mode ON, Stand-by, and Shut-down from the host PC through a serial communication port.

Part of the optical communication demonstration includes a bit error rate (BER) characterization of the complete link[1]. In order to accomplish this characterization, the DCM incorporates a PRBS generator chip. Current commercial vendors are able to provide PRBS chips that can operate over a wide temperature range, with ECL signal levels for the input and the output signals. There are semiconductor chips with available data rates up to 10 Gbps, but this LTA design only needs the 2.5 Gbps capability. This same chip is able to provide sequence lengths of 2^7-1 to 2^{31}-1.
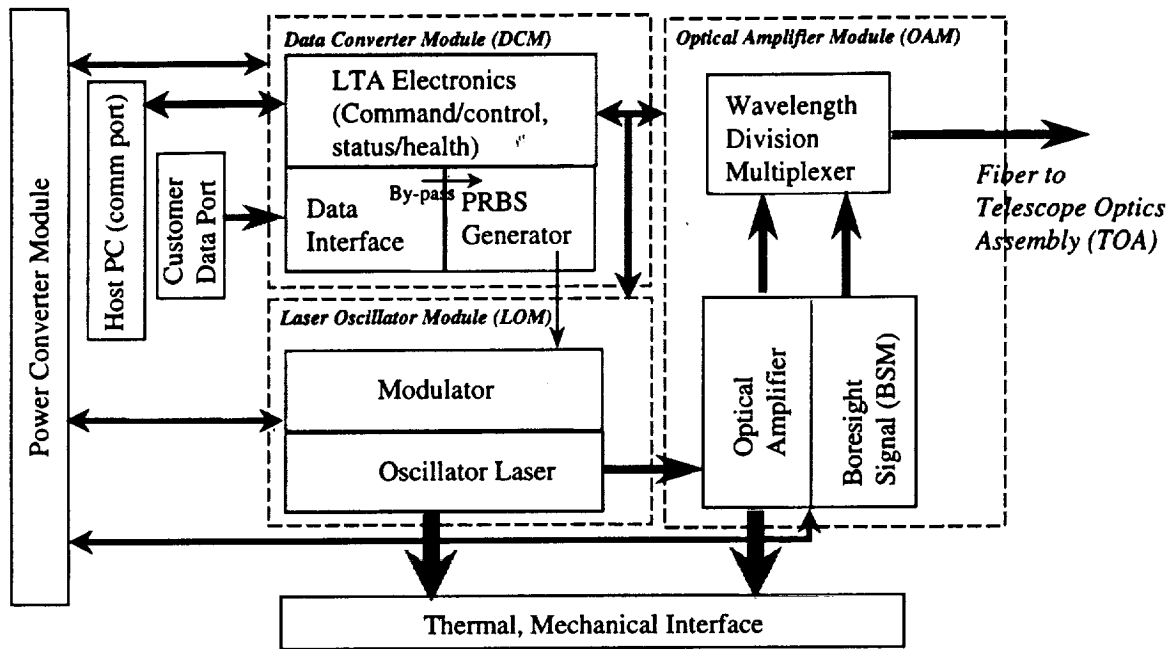
Figure 2. Laser Transmitter Assembly Block Diagram.

The block diagram for the DCM is shown in figure 2. The DCM receives instructions from the host PC to either modulate the oscillator laser with the PRBS pattern or with the data coming from the input port. The command signal from the LTA electronics to the PRBS generator includes the data rate, sequence length and PRBS mode of operation. The PRBS can be electronically selected to operate in the by-pass mode, which allows the capability to have an electronic switch between the data input port and the PRBS data. When the by-pass mode is selected, data from the data input port is de-multiplexed into the sixteen channels of the PRBS chip. These signals are regenerated by the PRBS chip and the sixteen channels are multiplexed to an aggregate data rate up to 2.5 Gpbs. Different data rates can be selected by commands to the clock and clock divide circuitry. If the PRBS mode is selected, the generator creates a pseudo-random bit-sequence in its sixteen channels at data rates of up to 155 Mbps. These sixteen channels are then multiplexed to obtain a PRBS pattern of up to 2.5 Gbps.
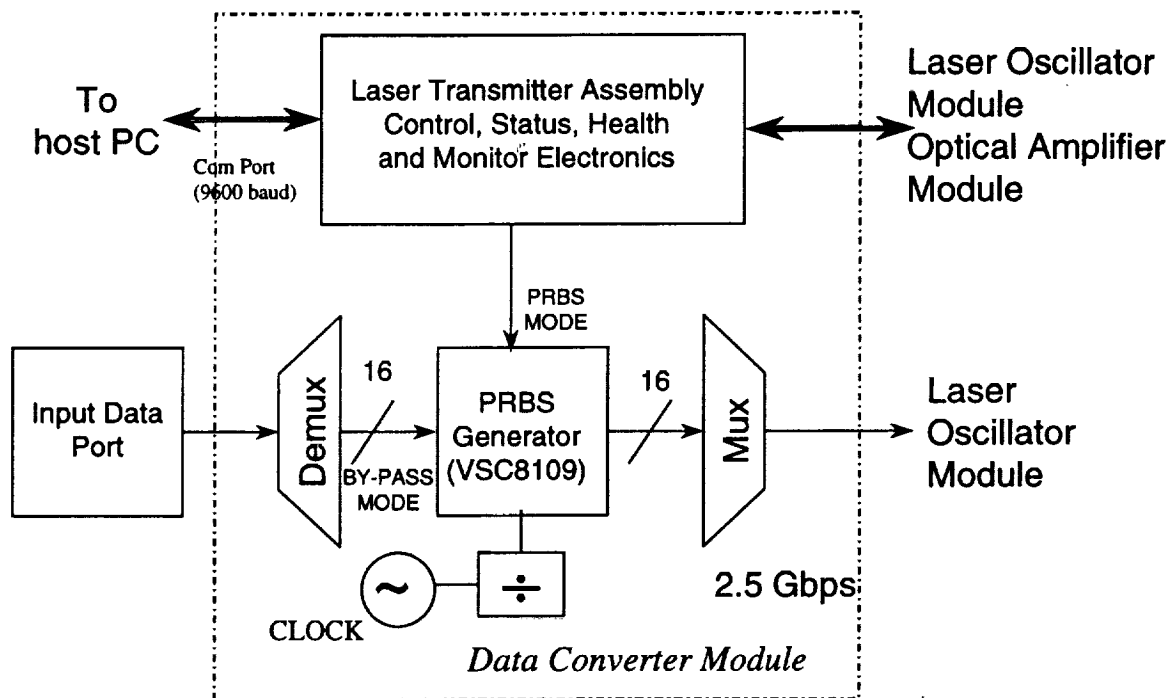
Figure 3. Data Converter Module Block Diagram.

The data from the DCM is routed to the modulating electronics in the LOM which drive the bias of an InGaAs DFB semiconductor laser diode. The laser diode is temperature controlled with a TEC that is monitored by the DCM electronics.

2.2 BORESIGHT SIGNAL MODULE

The pointing, acquisition and tracking (PAT) architecture for the flight terminal is based on the OCD design[7]. This architecture requires the use of only one focal plane array (FPA) for centroiding calculations of the beacon and boresight signals. In the OCD implementation[8] of this PAT architecture, part of the transmit signal -at 844 nm- is split to provide the boresight signal to the Silicon based FPA. But, in the design presented here the transmit wavelength has been selected at 1550 nm and therefore it is not possible to use part of the transmit signal as the boresight reference, unless the FPA is not made from Silicon but out of a material sensitive to the near-IR wavelengths (eg. HgCdTe). In order to keep the versatility of a Silicon based FPA, a novel concept has been developed to provide the boresight signal at a wavelength sensitive to Silicon yet allow for the transmit wavelength to be as selected by the link design. This design concept is illustrated in figure 3. The 1550 nm fiber-coupled output of the fiber amplifier transmit signal propagates through a single mode fiber which is fused to a wavelength division multiplexer (WDM) coupler. A low power 980 nm laser diode is also fused to the WDM to reduce coupling losses. The output fiber of the WDM coupler then delivers the single mode 1550 nm signal and the 980 nm signal to the telescope assembly. Both signals are automatically co-aligned after traveling in the same fiber. The beam quality of the 980 nm signal is required to be circularly symmetric at the focal plane array in order to minimize error in the centroiding algorithm. Preliminary analysis and experimental results of the beam quality indicate that the 980 nm beam is circularly symmetric[9].

The implementation of this novel concept to provide for the boresight signal of the PAT function offers a number of advantages. First, it allows the use of near-IR transmit wavelengths (such as 1064, 1330 and 1550) with readily available Silicon based FPA's (such as CCD's, APS', CID's and Silicon based Hybrids). Secondly, it provides for an independent control of the boresight signal power level delivered to the FPA, which was found to be difficult to control in the OCD implementation[10]. The signal power level can now be controlled by varying the current to the 980 nm laser diode, which allows for optimization of the signal level delivered to the FPA.
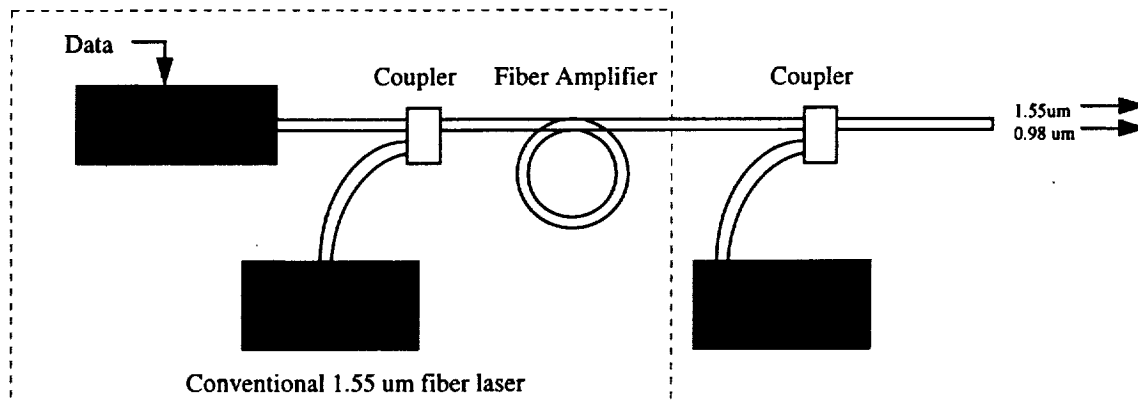
Figure 4. Novel implementation of boresight signal for centroiding.

3. SUMMARY

In summary, this article has presented the design of the 2.5 Gbps optical transmitter for the ISS optical communications demonstration. The transmitter incorporates a fiber-based optical amplifier at 1550 nm to amplify the modulated signal from the DFB-based master oscillator. PRBS circuitry has been incorporated into the design at all design data rates to provide for characterization of the BER of the complete link during operation at ISS. Furthermore, a novel implementation of the boresight signal for PAT has been demonstrated, which allows the flexibility to use commercially available and lower cost silicon based FPAs.

ACKNOWLEDGMENTS

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