High rate delivery of AirSAR data using an in-flight free space optical communication link

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Abstract – NASA's AirSAR instrument is a key resource for the remote sensing community. An upgraded data acquisition capability is currently being developed which will enable data collection and storage at rates greater than 1 Gbps. Access to this data has been limited to post-flight analysis. A high data rate free space optical communications experiment is proposed to downlink the AirSAR data during the flight at specific ground locations. The stored data can then be disseminated in near real-time or analyzed for rapid turn around. Applications that would benefit from this technology include disaster management, natural hazard monitoring as well as military tactical operations.

In this paper we will discuss the technology for a 1 Gbps optical communication link from the DC-8 aircraft to a ground receiving system and overview the proposed experiment. The technology leverages commercially available fiber optic components and JPL's expertise in free space communications. Such a demonstration serves as a valuable precursor and risk mitigation to an autonomously operated UAV platform as well as to the development of a space based system. Scalability to multi-Gbps data rates is also possible along with multiplexing several science instruments such as HDTV and thermal and IR imagers.

1. Introduction

The AirSAR instrument is in the process of being upgraded with a new state-of-the-art acquisition system to handle an increased data collection and analysis capability [1]. Current data storage devices allow data transfer rates of greater than 1 Gbps using technology based on Fiber Channel (FC) protocol. However, access to the AirSAR data has traditionally relied on recovery of the backup tapes following the flight. Some in-flight processing of data is also possible through a quick look analysis scheme of the reduced data set. With the upgraded data acquisition system, access to the full data set during operations is also desired. If this data can be relayed to a ground station during the flight, upgraded mission operations can be made possible without compromising the integrity of the stored data onboard. To enable this transfer of data, a high rate communications system is required. Optical or laser communications technology is uniquely positioned to relay the data from the airborne platform at the rate of multi-Gbps to a ground based receiving station largely due to the following features:

- Availability of very large and unregulated bandwidth at optical frequencies
- Fiberoptic communication system technologies now routinely operate in the field at 1-10 Gbps data-rates. Much of their technology is directly pertinent to free-space laser comm systems.

The downlinked data can then be further stored or made available to other processing centers over a high speed ethernet connection.

This paper discusses the technology for such a high-rate free space optical communication system and a proposed demonstration opportunity through a BMDO and NASA funded program. This is in line with AirSAR's directive to act as technology demonstration test-bed. The technology leverages JPL's investment over the last several years and is a prime precursor and risk mitigation for the deployment of a space based system [2]. The goal of the Optical Comm Experiment is to demonstrate an end-end return of AirSAR science date from the airborne platform at nominally 1 Gbps through a optical link in the 20 km range. The key technologies to be investigated are acquisition and tracking of the aircraft and ground terminal and assessing the effects of atmospheric induced fading of the channel and mitigation strategies to ensure a data quality of service. Section II discusses the optical communications technology while Section III addresses the mission scenario specific to the AirSAR DC-8 platform and science requirements.

II - TECHNOLOGY

A free space optical communications system can be broken down into several sub-systems: the acquisition, tracking and pointing system (ATP), the laser transmitter and optical receiver system and the data interface or relay system. The former two systems are generic to any laser communication system whereas the latter is specific to the AirSAR instrument and contains the protocol to mitigate loss of data due to atmospheric induced fades in the optical channel. A flight system level block diagram is shown in Figure 1; the ground system has similar functions.

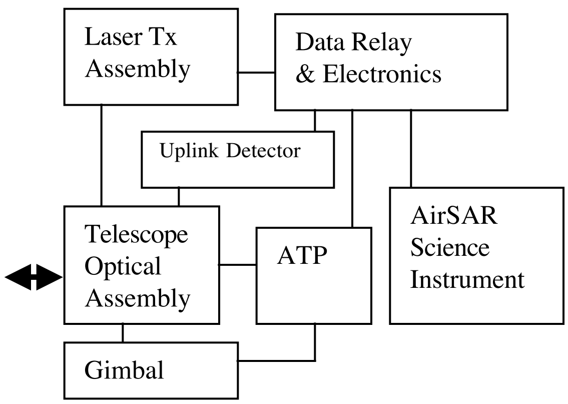

Fig. 1. Schematic layout of the free space optical communications flight system.

The system architecture involves a 1550 nm 200 mW average output power Erbium-doped fiber amplifier laser transmitter fiber coupled to a 10 cm telescope. Besides the mature fiber optic based technology centered around this wavelength, other properties associated with free-space communication use is eye-safety and lower levels of background sunlight. Coarse pointing is performed by gimbaling the telescope with a co-aligned wide field-of-view camera. Once acquired, hand-off is then made to the narrow field-of-view camera through the receive channel of the main telescope. Final acquisition is determined by the detection on this Si based CCD receive camera of an uplink beacon laser source propagated from the ground station. The acquisition, tracking and pointing (ATP) control is based on the JPL-developed OCD (Optical Communication Demonstrator) shown in Figure 2. The camera has a sub-windowing capability that can be read out at 1 kHz repetition rates with low pixel read noise. This is necessary to account for platform jitter along with the input of accelerometer based inertial sensors. The transmit laser source is propagated through a fast steering mirror (FSM) for either full or sub-aperture transmission depending on the coupling optics and required beam divergence. Fine pointing of the transmit beam is possible by feedback control of the FSM with the ATP camera. A 980 nm beam is also coaligned through the 1550 nm single mode fiber and is used as a reference for the transmit laser on the Si based CCD tracking sub-window.

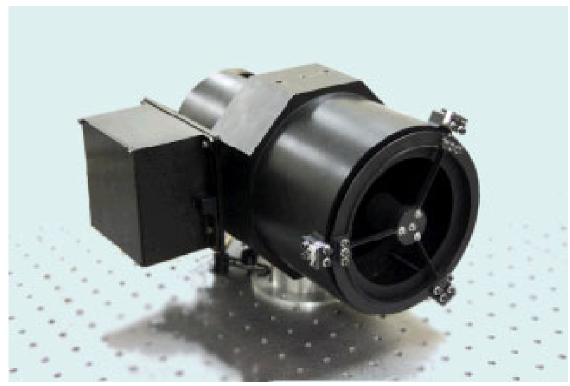

Fig. 2. Picture of the JPL-developed Laser-Communication Terminal

The ground stations involve a 1m or 3.5m optical telescope capable of tracking LEO objects. A laser is propagated through the coude path of the telescope and uplinked towards the airborne terminal to serve as the beacon source for acquisition and tracking. Beam divergences are from 300 to 500 μrad with multiple beams overlapping in the far field to mitigate the effects of atmospheric induced scintillation. Acquisition and tracking of the aircraft is performed either visually on a CCD camera or via GPS updates over an RF channel. A dichroic mirror is used in the optical train to allow simultaneous transmission of the eight beacon lasers at 809 nm and receipt of the downlinked signal on an InGaAs APD. A quad detector and FSM is used for stabilizing the received spot on the high speed data detector.

Some of the key parameters for communications are: required data rate, bit-error-rate (BER) and the probability of burst error (PBE). BER is typically driven by the average/ peak signal power and rms noise power during a bit interval. The burst error occurs when the signal irradiance at the distant receiver falls below the level required for maintaining an average BER. A typical link budget is given in the following table. The above parameters were assumed with a BER of 10^{-9} at a data rate of 1 Gbps and on-off keyed modulation. Sufficient link margin is carried to account for large atmospheric fades as well as extended data rate and range opportunities.

Parameter	Value	
Transmit power	200 mW avg	26 dBm
Transmit losses	56 % trans.	-2.5 dB
Transmitter gain	200 urad beam	87 dB
Pointing losses		-7 dB
Space loss		-224.2 dB
Atmos. Losses		-
Receiver gain	1 m	2.2dB
Receiver losses	44% transmis.	125.7 dB
		-3.5 dB
Received signal	0.86 mW	
Background	0.14 nW	-0.7 dBm
Required signal	1 uW	
		-30 dBm
Link Margin		
		29 dB

The data relay boards also represent critical parts of the system. On the flight side one accesses the stored AirSAR data via a Fiber Channel interface and on the ground it returns the serial data stream for processing or further storage. It provides the ability to overlay the physical link layer with protocol to ensure a quality of service to the data. An ARQ scheme has been chosen for the packetized data stream wherein any lost packets due to fades can be automatically resent. This fade tolerant link is robust to outages on the order of msec with onboard buffering of the data. Any larger loss of signal, such as clouds or weather related, requires re-establishment of the link and connection to the RAID storage system.

III. DC-8 OPTICAL COMM EXPERIMENT

The DC-8 optical communications experiment is seen as the risk mitigation for a Phase II experiment from an Unmanned Aerial Vehicle (UAV). Autonomous operation is hence desired and will be built into the flight system. In order to deliver meaningful data not only on the performance of the optical communication link but also that is scientifically interesting, several mission scenarios are planned. The ground stations are located at JPL's Table Mountain Facility in the San Gabriel mountains and the AFRL's Mauii Optical System in Hawaii. For the California operation, flights will be based out of Edwards AFB and data collected over several geologically interesting sites including Cima volcanic region, San Andreas fault, China Lake bed, Mammoth Lakes region and the Blackhawk landslide. The Hawaii operation will focus on the Kilauea and Mauna Loa volcanic region on the big island [3].

A typical mission scenario will involve the successive collection of AirSAR data over the designated site and then return to the ground station location. Operation will begin during nighttime to when the background and turbulent effects are more benign. The flight path will circle the telescope facility to enable the line of sight link of the two optical terminals. Initial acquisition of the aircraft is possible through real-time GPS updates from the aircraft using a differential system with sub-meter position accuracy. Once visually acquired and tracked the data channel is validated by sending a pseudo random bit sequence (PRBS). The corresponding BERs are measured for a variety of data rates and operational parameters. The science data is then sent in buffered packets of appropriate size to maximize the channel integrity. Real-time collection and transmission of data is also possible for flights within the line of sight and range, typically <30 km for the 35,000 altitude, of the ground station.

IV. CONCLUSION

The DC-8 based AirSAR instrument provides a unique system for demonstration of a high speed air-ground optical communication link. The technology is being developed for integration into a flight experiment planned for 2004 based in California and Hawaii.

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