Fiber-Based Laser Transmitter at 1.57 μm for Remote Sensing of Atmospheric Carbon Dioxide from Satellites

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Abstract: We review progress in developing laser technology and improving the technical readiness of a fiber-based laser transmitter operating at 1.57 μm for use in lidar remote sensing of atmospheric carbon dioxide (CO_2) from satellites

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1. Introduction

Over the past 20 years, NASA Goddard has successfully developed space-based lidar for remote sensing studies of the Earth and planets [1-4]. The lidar in all missions to date have used diode pumped Nd:YAG laser transmitters. Recently we have been concentrating work on developing integrated path differential absorption (IPDA) lidar to measure greenhouse gases, with the goal of measurements from space [5]. Due to the absorption spectrum of CO_2 a fiber-based master oscillator power amplifier (MOPA) laser with a tunable seed source is an attractive laser choice. Fiber-based lasers offer a number of potential advantages for space, but since they are relatively new, challenges exist in developing them. In order to reduce risks for new missions using fiber-based lasers, we developed a 30-month plan to mature the technology of a candidate laser transmitter for space-based CO_2 measurements to TRL-6. This work is also intended to reduce development time and costs and increase confidence in future mission success.

2. APPLICABILITY TO NASA ASCENDS MISSION

In 2007 Decadal Survey for Earth Science, the US National Research Council recommended that NASA develop 10 future satellite missions. One mission was the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) to accurately measure column CO_2 concentrations using the IPDA lidar technique. NASA's present plans show the launch date as 2023. NASA's ASCENDS mission definition activities have progressed through a parallel set of science studies, technology developments, and airborne campaigns [6]. Given the ASCENDS timeframe, its also logical to consider demonstrating a CO_2 IPDA lidar in space earlier, possibly as an ASCENDS precursor. This approach could serve as an intermediate step toward the ASCENDS mission while providing some earlier science and technology benefits.

We have developed and successfully demonstrated an airborne demonstrator CO_2 lidar (called the CO_2 Sounder), which uses the same lidar approach as planned for space. With successful airborne CO_2 lidar demonstrations and detector development [7-9], the primary remaining hurdle for measuring CO_2 from space with this approach is the laser. Demonstrating a laser transmitter with the power and optical performance required for space should enable a faster development for an active CO_2 sensing mission. Although this work targets the laser requirements for the CO_2 Sounder approach for ASCENDS, the laser development also serves as a pathfinder for other high peak power fiber lasers for space. A set of laser transmitter requirements for space-based CO_2 Sounder instrument is summarized in Table 1.

Table 1. Laser transmitter performance requirements.

Performance Parameters	8-Channel Combined Transmitter
Center Wavelength	Nominally centered at 1572.335 nm (Center wavelength anywhere between 1570.5 and 1574 nm)
Wavelength Span	Span for 1572.335 nm line center: from 1572.23 to 1572.43 (in 8 wavelength steps, TBR)
Tuning speed	~100 μs
Linewidth (each channel)	< 100 MHz
Side-mode suppression ratio (spectral)	>30 dB
Wavelength stability (each channel) fast	Locked to < 3 MHz
Wavelength stability (each channel) slow	Locked to <0.3 MHz
Wavelength locking reliability	Define acceptable mean time to loss of lock (TBD)
Pulse repetition frequency	7.5 KHz
Pulse period (derived)	133 μs
Pulse Width	100 ns – 1 μs (assume 1 μs for all derived parameters)
Duty Cycle	0.75 % (Derived from Pulse period & pulse width)
Pulse energy	Sum at Farfield: >3.2 mJ/pulse (goal), >2.5 mJ/pulse (operating, 18% derating)
Average power (informational derived)	Sum at Far Field: >24 W (goal); 20 W (op)
Peak power	3.2 kW goal, 2.5 kW operating
Pulse Extinction ratio (timing)	> 30 dB
% of power in the pulses (derived)	90%
ASE	<1% of average power
Margin to SBS threshold	> 2X
Pulse energy stability (short term – 1 min)	< 1%
Pulse energy stability (long term – 1 hr)	< 5%
Trigger (format – TTL?)	External trigger
Optical Output	Free space, PM, ~100 μrad divergence, beams co-aligned to better than ~20 μrad
Beam quality	$M^2 < 1.5$ per channel
PER [TBR]	20 dB
Environmental	GEVS (TBR)
Mech. Package (size, ICD)	TBD
Wall-plug Efficiency	> 10% (goal)

3. LASER TRANSMITTER ARCHITECTURE

The CO_2 Sounder approach rapidly steps its pulsed laser in wavelength across the selected atmospheric CO_2 absorption line near 1572 nm [10, 11]. Previous airborne measurements have used 30 wavelength samples to oversample the absorption line [5], however the space approach plans to use either 8 or 16 wavelength samples. The seed laser is rapidly switched from fixed locked wavelengths points, producing a repeating wavelength-stepped pulse train. The lasers repeatedly cycle through their wavelength steps every ~1 or ~ 2 msec. The 1 μsec-wide laser pulses are separated by ~133 μsec, which permits them to completely clear the lowest 20 km of the atmosphere before the next pulse enters, eliminating crosstalk from high altitude clouds. Stepping the laser wavelength across the absorption line also allows information to correct for any lidar drifts and minimizes systematic errors. The lidar receiver detects the time-resolved laser backscatter and range resolution is used to isolate the echo pulses from the scattering surface. Our technique provides information to measure the range and CO_2 line shape, as well as any Doppler shifts and wavelength dependent optical transmission. This added information makes the measurement robust against bias errors. At a spacecraft velocity of 7 km/sec the ~50 m diameter laser spot advances ~7-14 m for each wavelength scan. In a 10 second averaging time, the highly overlapped laser sampling minimizes any variability caused by changing surface reflectivity.

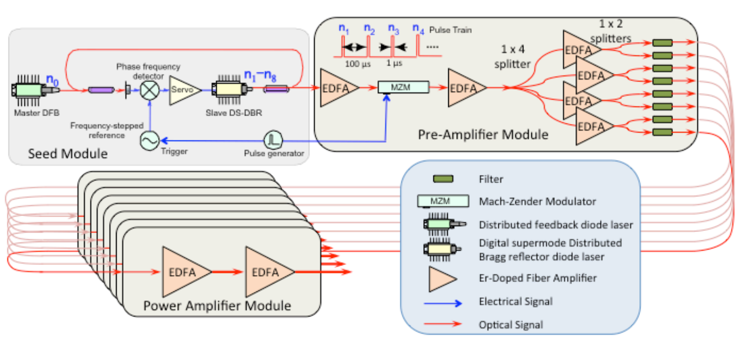

Figure 1. Block Diagram of the fiber-based laser transmitter

The laser architecture is based on a MOPA approach. It uses a tunable diode seed laser, several fiber preamplifiers, and then several fiber power amplifier stages as shown in Figure 1. This modular approach is quite flexible and has a number of advantages for space.

The overall design is comprised of three modules: a seed laser module, a pre-amplifier module and eight parallel power amplifier modules. The seed module is a diode source producing wavelength-stepped, constant-wave (CW) output. The preamplifier module consists of multiple erbium-doped fiber amplifier (EDFA) stages, amplitude modulation to form pulses, and a signal divider that splits the signal into 8 different output fibers. Each of the preamplifier output fibers feeds a power amplifier (PA) module. We split the signal into parallel channels because the fiber power amplifiers' peak power (and therefore pulse energy) is limited by stimulated Brillouin scattering (SBS). The output of the power amplifier modules are collimated output beams, which are co-aligned in angle. Their laser spots will overlap in the far-field and so achieve the required pulse energy on the scattering surface.

The baseline design uses eight parallel PA modules to reach the needed pulse energy. This number will be refined as the performance and margins of the amplifiers are better understood. We are working on two PA architectures: the first is being developed at Fibertek, Inc. and uses commercial Nufern PM large mode area (LMA) fiber pumped near 970 nm. The second is being developed at OFS laboratories and uses a custom designed PM very large mode area (VLMA) fiber. To date both approaches show promise for meeting all performance objectives of the laser transmitter. Ongoing work is addressing optimization involving SBS threshold, wall-plug efficiency, ASE and fiber length. Pulse shaping by the preamplifier is being tailored to achieve the desired quasi-rectangular output pulse. The goal is to develop a ruggedized, compact package that will survive typical environmental requirements for launch, space vacuum and radiation.

CONCLUSIONS

In February 2015, we began a 30-month effort to mature the required fiber-based laser technology for the ASCENDS Mission. The objective of this work is to reduce risk, development time and costs and demonstrate the required laser performance.

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