A COMPACT, RAPIDLY TUNABLE Ce:LiCAF DIAL TRANSMITTER FOR AIRBORNE OZONE MEASUREMENTS

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ABSTRACT

An extensive effort has been made to create an Ozone DIAL transmitter that can be run autonomously in an UAV and the resulting design has considerably departed from the conventional design of a laser source used for LIDAR. Instead of the standard approach wherein the laser has to provide high energy pulses (on the order of 100mJ/pulse) at low pulse repetition frequency (on the order of 10 Hz), we have built a laser operating at a high PRF of 1 kHz but with a much lower output energy (~ 1mJ/pulse). Using this method we achieve the same average power but are able to more easily adapt the system to airborne applications due to the significant reduction in size. Another innovation of this system is that the tunable UV output is generated directly by a widely tunable Ce:LiCAF solid state laser source, which can be pumped by one of the most mature and robust commercial lasers available, the Nd:YLF. A high speed laser tuner permits the wavelength to be changed with every pulse and provisions have been made to operate with 1, 2, 3, or 6 different wavelengths in the range from 282 nm to 313 nm. The Ozone DIAL system has a master clock that is the basis for synchronizing all of the timing sequences created by the FPGA. The data acquisition system has been set up to eliminate data loss by using a ping-pong technique with two data acquisition boards. All of these innovative ideas have culminated in the successful production of an autonomous Ozone DIAL system ready for deployment in an UAV.

1. INTRODUCTION

A schematic of the ozone DIAL system is shown in Fig. 1. This system involves many complex components and thus it will be described as four subsystems: the transmitter, the receiver, the data acquisition system and the control system. Each of these will be described in detail in the sections below.

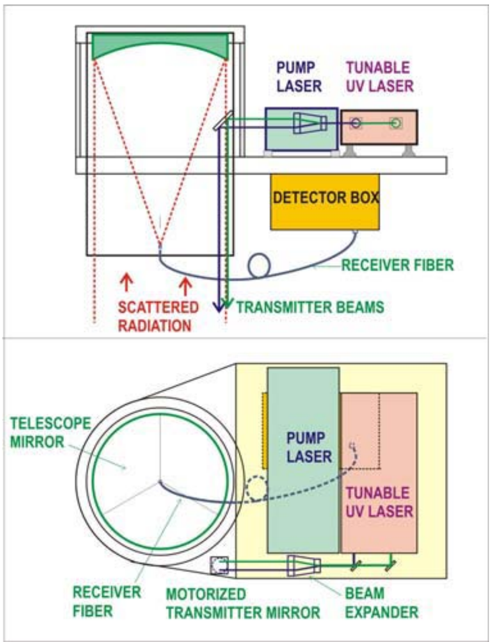

Fig. 1: Ozone DIAL system schematic

2. TRANSMITTER SYSTEM

The transmitter for the ozone DIAL system is a Ce:LiCAF laser which is optically pumped by a Nd:YLF laser at a PRF of 1 kHz (Fig. 2). The pump laser produces a TEM_{00} beam with ~ 11mJ/pulse at 527nm. This beam is then frequency doubled by a CLBO FHG to provide about 2.8 mJ/pulse at 263nm.

Fig. 2: Nd:YLF Pump Laser & Ce:LiCAF Laser

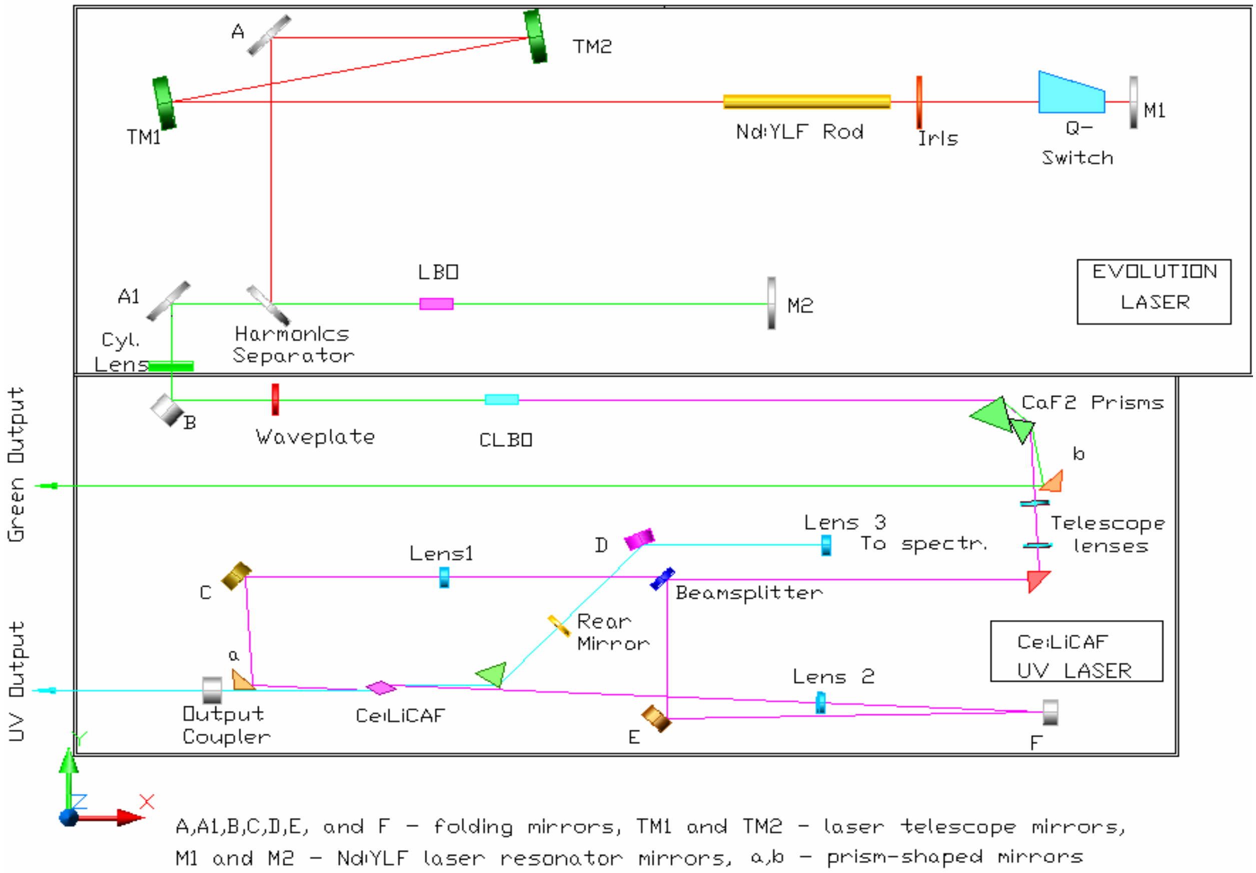

Fig. 3: Nd:YLF and Ce:LiCAF laser optical schematic

Fig. 3 is a schematic of the optical layout for the Ce:LiCAF laser transmitter. The 527 nm pump light is first quadrupled using a CLBO crystal. The residual 2nd and the 4th harmonics are separated with a dispersive prism, and the UV beam is split to pump the Ce:LiCAF from opposite ends for a more uniform pumped volume. The residual green light from the pump laser is later recombined with the tunable UV output prior to atmospheric transmission. In the Ce:LiCAF optical cavity, a HR mirror has been mounted to a servo controlled galvanometric motor to allow rapid tuning of the output wavelength. The resulting output beam has a tuning range of 282 nm to 313 nm and has an average power of ≥ 200mW for each wavelength. This system is not limited to creating a pair of wavelengths for a conventional "on-line" / "off-line" analysis. We have provisions for up to six different wavelengths to be generated by this laser.

The amplitude, phase and DC offset of the input sine wave to the galvanometric motor are adjusted to control the output wavelength selection, according to Fig. 4. Also, the frequency of this sine wave can be changed to create 1, 2, 3, or 6 wavelengths.

The final output consists of the tunable UV beam (~290 nm) and a visible beam (527 nm) which are expanded by a 5x beam expander and a 3x beam expander, respectively (not shown in Fig. 3). These beam expansions are utilized to keep the transmitted beams to diameter ~ 0.5 mm with beam divergence < 0.3 mrad. Operation from the ground or from the sky is possible since the transmitter mirror and the telescope can be directed in either vertical direction.

3. RECEIVER SYSTEM

A 40 cm diameter (F/1.8) primary mirror having a focal length of 731.5 mm is used as the receiver telescope. A negative lens was added to decrease the telescope speed (F/2.46) and obtain a 1 m effective focal length. A UV fiber with NA 0.22 is used to transmit the received signal to the detectors. The detector system consists of two photomultiplier tubes (PMTs) and one avalanche photodiode (APD), with provisions for two additional PMTs. The APD (PerkinElmer C30954) is used for detecting the visible return signals. One PMT (Hamamatsu R7400-U03) is used as a far-field UV detector for a Licel Transient Recorder (TR 20-40) that can acquire both analog and photon-counting signals from one detector, while the other PMT is used as the near-field UV detector.

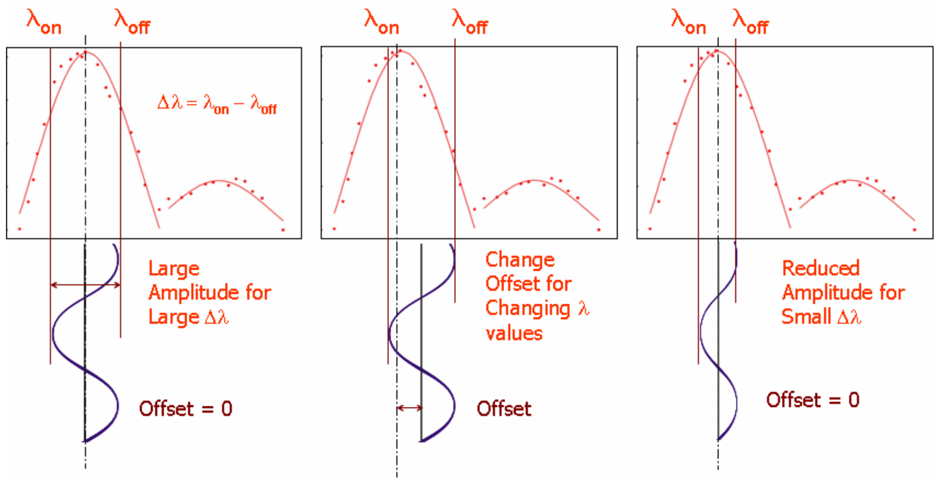

Fig. 4: Wavelength selection diagram

4. DATA ACQUISITION SYSTEM

The data system consists of two separate parts: a Licel Transient Digitizer and high speed data acquisition (DAQ) boards from National Instruments (NI). The combination of a powerful analog to digital converter (12 - bits at 40 MHz) with a 250 MHz fast photon counting system in the Licel digitizer increases the dynamic range of the acquired signal substantially compared to conventional systems. The Licel digitizer can be triggered by two inputs which allow acquisitions of two repetitive channels (on-line, off-line). The two separate onboard RAM modules allow the individual signals to be added sequentially. About 10 acquisition data files can be saved every second.

The high speed data acquisition consists of two NI-DAQ boards (NI 6115) with 4 channels, 12 bit resolution and 10 MS/s per channel. In order to record the signals without losing any data, the two NI-DAQ's are used in a ping-pong mode. An FPGA produces alternating triggers and clock signals for the NI-DAQ boards. While one of the boards acquires data, the other one saves the acquired data and then waits for its trigger before resuming acquisition. Every board acquires 4 seconds of data (4x1000 shots with 267 bins per channel) and then processes the data in the following 4 seconds. The data is saved sequentially as a 10 shot average. Fig. 5 is a pictorial view of the DAQ timing sequence.

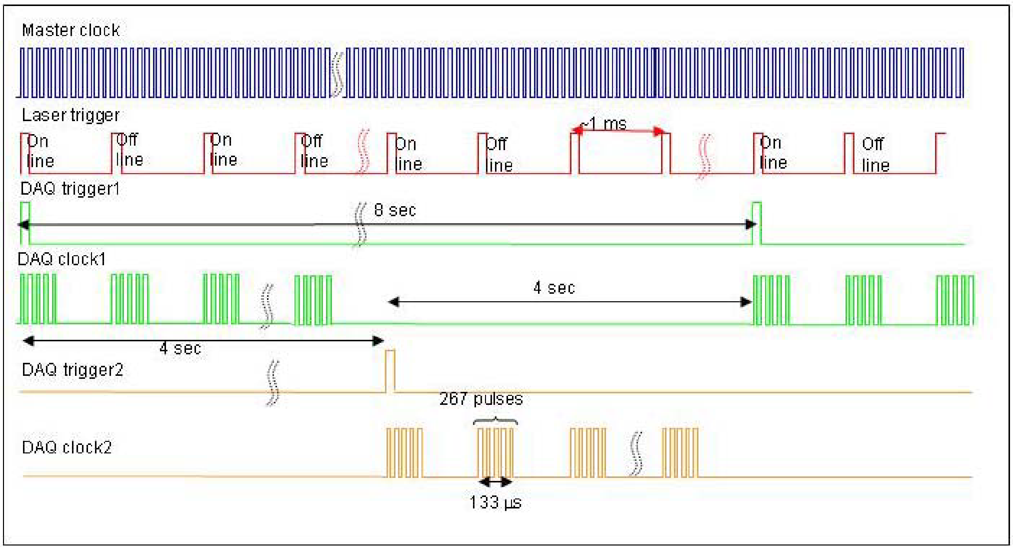

Fig. 5: Data acquisition sequence

5. CONTROL SYSTEM

The control system is designed around a master clock and a marker signal, which are produced by a sine wave generator. The marker signal is a series of single pulses that are generated at the onset of every sine wave cycle. The timing board (FPGA) utilizes these signals from the sine wave generator to synchronize all of the necessary triggers for the laser, the energy monitors, and the data acquisition system. The amplitude, offset and frequency of the sine wave are programmable, and so are the timings of laser triggers. Wavelength selection is achieved by means of tuning these parameters. A high resolution UV spectrometer (Ocean Optics HR2000) is used to monitor the output wavelengths. There are motorized stages for the CLBO and Ce:LiCAF crystals and the transmitter mirror, which are controlled by individual motor controllers for increased stability. Fig. 6 is a detailed control system design schematic of the Ozone DIAL system.

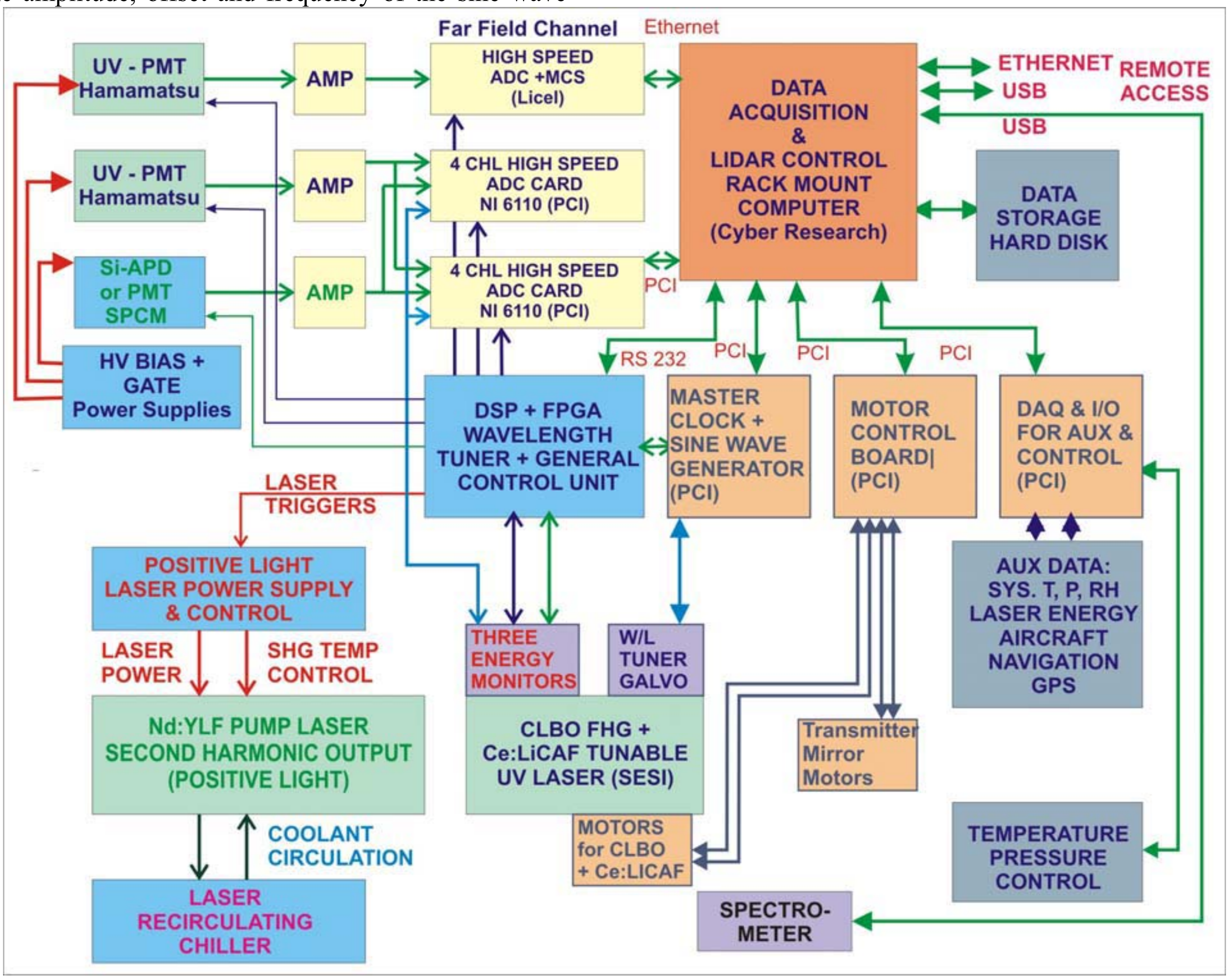

Fig. 6: Control system schematic.

6. CONCLUSION

We have created a versatile, rapidly tunable Ce:LiCAF DIAL transmitter for ozone measurements. This system incorporates many new techniques and technologies in order to operate autonomously in an UAV. We have designed the system in such a way that it can be easily adapted for different applications requiring rapid wavelength switching between several wavelengths, high rep-rate loss-less data acquisition involving photon counting and/or analog to digital conversion.