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PULSE-SHAPE CONTROL IN AN ALL FIBER MULTI-WAVELENGTH DOPPLER LIDAR

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ABSTRACT

Pulse distortion during amplification in fiber amplifiers due to gain saturation and cross talk in a multi-wavelength Doppler lidar are discussed. We present a feedback control technique which is capable of adjusting any predefined pulse shape and show some examples of feedback controlled pulse shapes.

1. INTRODUCTION

Using fiber amplifiers in MOPA configuration in all-fiber coherent Doppler lidar systems has become more attractive due to many advantages of such configurations. [1]

Erbium doped fiber amplifiers (EDFA) are pumped with laser diodes to achieve the population inversion which is needed for amplification of the injected seed pulses. During the amplification of the seed pulses the population inversion decreases as the pump process is rather slow compared to the pulse duration. This leads to a drop in gain along the pulse duration and characteristic pulse shapes with a large spike on the leading edge of the output pulses are generated. Therefore, all-fiber lidar systems show strong pulse distortion due to gain saturation at typical pulse lengths and repetition frequencies. [2]

The main pulse energy limiting effect is the stimulated Brillouin scattering (SBS). Due to the large spike on the leading edge of the output pulse, the SBS threshold is reached at very low possible pulse energy. Therefore, a certain preshaping of the seed pulse is necessary to prevent SBS at very low energy. [3]

In this multi-wavelength lidar system four pulses with different wavelengths are simultaneously amplified in one EDFA. Every wavelength reduces the density of excited Erbium ions in its specific sublevel. By means of fast phononic relaxation processes between energy sublevels the reduction of population inversion is balanced. This leads to a mutual gain dependence of simultaneously amplified wavelengths due to crosstalk between those wavelength-channels. [4]

Furthermore, pulse shape and peak power strongly depend on pump power, temperature changes, and ageing of the EDFA.

Due to pulse distortion caused by the mentioned processes, a careful control of pulse shapes is essential for stable and reliable lidar system operation. One important advantage of fiber amplifiers is that the output shape can be affected by the shape of the seed pulse. Different compensation techniques were presented in [5,6]. In this work we present a pulse shape feedback control technique which is capable of adjusting any given pulse shape for each channel of the four-wavelength Doppler lidar system.

2. METHODOLOGY

The schematic setup of the four-wavelength Doppler lidar system with a feedback controlled pulse shaping unit is shown in figure 1. The four-wavelength lidar consists of five overall units: Master oscillator unit (MO), pulse-shaping unit, amplifier and transceiver unit, detector unit, and signal processing unit. The MO unit consists of four external cavity diode lasers. The wavelengths are chosen from the ITU-grid near 1.55 µm. All four channels are multiplexed by a wavelength division multiplexer (WDM) and amplified by one EDFA. 80% of the MO laser light is directed to the pulse shaping unit, where the laser light is demultiplexed, in order to shape the pulses of each channel with electro-optic modulators (EOM) separately. Then all of the pulses are frequency shifted and preshaped by an acousto-optic modulator (AOM). The shifted and shaped pulses are amplified with a two-stage EDFA. Via a circulator the amplified pulses are directed to the telescope. In the detection unit the wavelengths of the local oscillator and the backscattered light are demultiplexed, thus, every channel can be coupled separately to the balanced detector. The amplified differential signal eliminates the DC and amplifies the AC component of the heterodyne signal. The signal processing unit extracts the information about wind velocity and signal strength. More detailed information about the four-wavelength Doppler-lidar is found in [7], including advantages using multiple wavelengths.

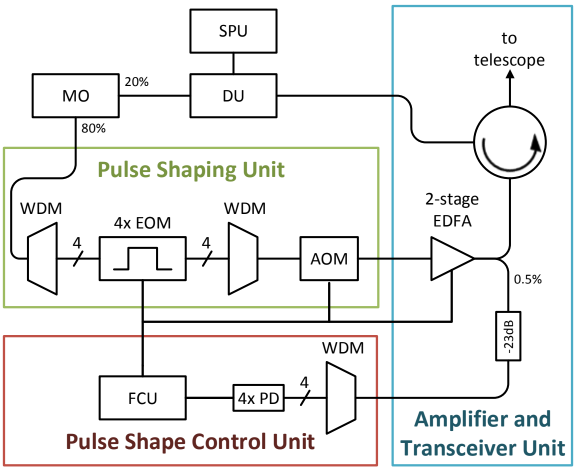

Figure 1: Schematic setup of the four-wavelength lidar system with feedback controlled pulse shaping (WDM – wavelength division multiplexer; EDFA – erbium doped fiber amplifier; EOM – electro-optical modulator; AOM – acousto-optical modulator; MO – master oscillator, DU – detector unit; SPU – signal processing unit; FCU – feedback control unit)

The system described in [7] was extended by a pulse shape control unit (PSCU). 0.5 % of the output pulse power of the EDFA is used to monitor the pulse shape. After attenuation, the wavelength-channels are demultiplexed. Four fast photodiodes measure the shape of the pulses for each wavelength separately. The pulses are digitized with a sampling rate of 100 MHz by an analog-to-digital converter within the feedback control unit (FCU). The FCU is connected to a personal computer (PC), where the pulse shape and the SBS threshold can be predefined. By means of a digital-to-analog converter, the FCU controls the EOMs, the AOM, and the pump power of the EDFA. To achieve a larger control range it is useful to preshape the pulses with the AOM.

Starting the PSCU, the EDFA is turned on at low pump power to avoid excess of the SBS level. Then the feedback control unit calculates the correction needed with an integral controller and it changes the seed pulse shape with the EOMs for each channel. Simultaneously, the EDFA pump power is controlled to adjust the output power of the EDFA close to SBS threshold.

The pulse control is performed by a PC software and consists of two nested control loops as illustrated in figure 2.

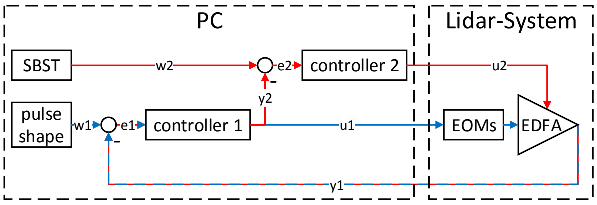

Figure 2: Schematic layout of the pulse control loops (EDFA – erbium doped fiber amplifier; EOM – electro-optical modulator; SBST – stimulated Brillouin scattering threshold)

Control loop one (blue) is responsible for pulse shape control. It stabilizes user defined pulse shapes by regulating the value for each sample of the pulses. The EOMs represent the actuator of this control loop, while the EDFA is the control path.

Control loop two (red) controls the pump power of the EDFA. The pump power is automatically adjusted to the lowest level at which the pulses can be completely developed, depending on the preset pulse amplitude. In most cases this amplitude is chosen close to the SBS threshold. There are two benefits resulting from this approach. On the one hand the amplified spontaneous emission (ASE) of the EDFA is reduced. On the other hand the amplitude resolution of the pulses is maximized by using the full dynamic range of the EOMs.

The controlled variable of control loop two is the maximum amplitude value of the EOMs used for pulse shaping. The EDFA is used as an actuator by manipulating the pump power, which affects control loop one as a disturbance variable. Furthermore, control loop one acts as a control path for control loop two. For those reasons the regulation of the pump power is designed to work much slower than the regulation of the pulse

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shape. This enables an adjustment of the pump power and pulse shape at the same time.

3. RESULTS

Amplifying four shifted pulses simultaneously by one EDFA, all pulses are distorted through gain saturation without preshaping and feedback control (figure 3). The first pulse (green) is much stronger than the following pulses. The dip following the leading edge of the green pulse shows that the SBS threshold is already reached at very low pulse energy due to the large spike.

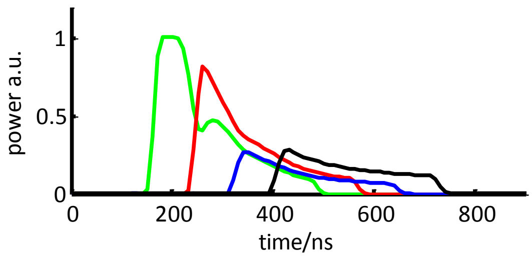

Figure 3: Four shifted pulses simultaneously amplified without preshaping and feedback control

For best preshaping using the AOM, a second degree polynomial input signal was chosen. Figure 4a shows the preshaped seed pulses. As the square pulses created by the EOMs pass a single AOM, as shown in figure 1, they are all affected in the same manner.

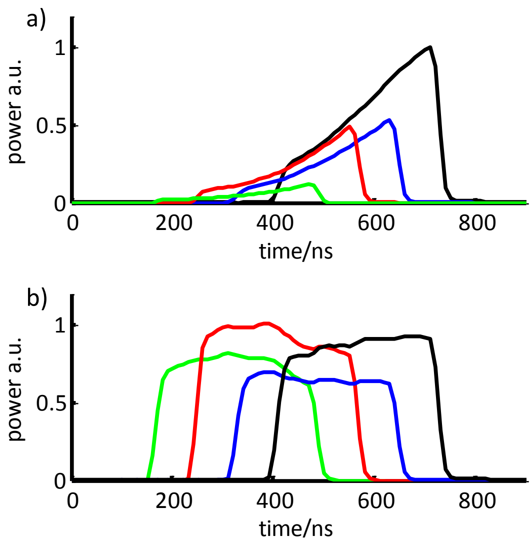

Figure 4: a) AOM preshaped seed pulses; b) Output pulse shape with preshaping

Using this preshaping with the AOM, the effect of gain saturation is significantly reduced. Figure 4b demonstrates the positive effect of preshaping. However, the pulse shapes of the wavelength-channels are disturbed by crosstalk between those pulses.

To achieve user defined and long-term stable pulse shapes, preshaping is not sufficient. The remaining distortions can be compensated by feedback controlling of pulse shapes using the EOMs. Figure 5 shows four shifted square pulses which are amplified in one EDFA with preshaping and feedback control by the PSCU. The corrected seed pulses by the EOMs and AOM can be seen in figure 5a. These corrections were necessary to generate a pulse train of four delayed square pulses (figure 5b). Obviously, all distortions are well regulated. To work stable at the falling and rising edge, the control algorithm needs at least two or three points on the edges. Since the sampling rate is 100 MHz the rise-time and trailing-edge time of the controlled pulses is limited to the range of 20 ns to 30 ns. This limitation can be avoided by applying a higher sampling rate. However, in general the main limitation is due to the rise-time and trailing-edge time of the AOM and EOMs, these are in the range of 20 ns in this system.

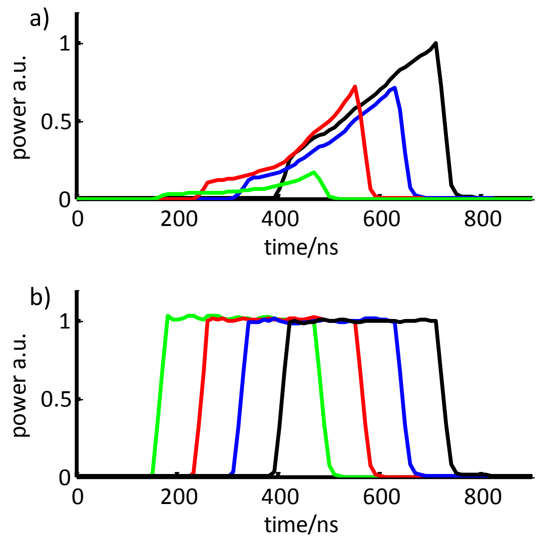

Figure 5: a) Seed pulses with feedback control; b) Output pulse shape of four simultaneously amplified and shifted pulses

Another advantage of the feedback control is that the chosen pulse shapes can be different on each channel as every channel is controlled separately. As an example, a Gauß-shaped and a square pulse are controlled at the same time. This capability enables us to compare the response of both pulse shapes under the same atmospheric conditions with the four-wavelength lidar system. Both regulated pulse shapes with a full-width half-maximum (FWHM) of 300 ns are shown with their corresponding seed pulse in figure 6.

Due to the stronger gain applied to the leading edge of the pulses, the output pulse (figure 6b) seems to rise earlier than the seed pulse.

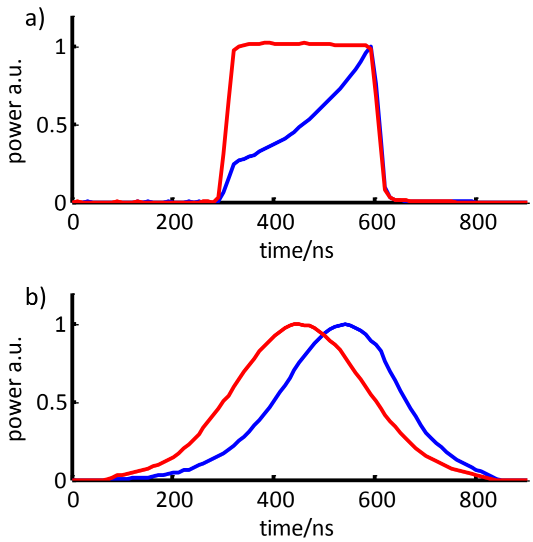

Figure 6: a) Channel with square pulse; b) Channel with Gauß-shaped pulse (blue: seed pulse, red: output pulse)

This system is capable of adjusting any given pulse shapes with a pulse duration from 100 ns to 1200 ns. The only limitation for the sake of stability is the rise-time and falling-edge time of at least 20 ns.

In general, the feedback control unit needs about five minutes from start-up to completely adjusting the predefined pulse shapes. Short disturbances are compensated within seconds by control loop one. Long term changes like temperature influences are compensated mainly by control loop two.

4. CONCLUSIONS

We present a feedback control technique which is capable of adjusting any given pulse shape for each channel of a multi-wavelength Doppler lidar system.

In future we will increase the control speed by applying models for gain saturation. In addition, we will use the backscattered SBS-Stokes wave to detect the SBS threshold for each wavelength-channel.

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