International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

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icso proceedings

International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 111801U · © 2018 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2535985

LIDAR echo emulator

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ABSTRACT

The LIDAR Echo Emulator (LEE) emulates the returned signals from a Lidar system. As the return signal of a Lidar system depends on the target, this implies the capability of shaping the lasers returns. In brief, long echo corresponds to a natural or diffusive object (canopy, clouds) and short echoes to a hard object like roofs, ground, etc. Such signals are necessary to be simulated to study and validate new detectors and detection systems without developing/procuring entire Lidar system. LEE consists of pulse shaping electronics to drive independently the lasers for each echo and internal detection system to monitor the pulses. The short echoes can be in the range from 5 ns to hundreds of ns and the long echoes from 1 µs up to hundreds of µs. The repetition rates of the developed emulator are from 100 Hz to 10 kHz with limitation that the longest pulse does not exceed 10% of the duty cycle. The power difference between both echoes can be set and is as high as 60 dB. The dynamics of the echoes is better than 50 dB within the 8 ns in the rising/falling edge of the pulse (echo). The output power can be tuned by means of variable attenuators giving a range of the incoming echoes from -35 dBm to -100 dBm. The LEE can also emulate multiple returns with aforementioned dynamics.

Keywords: LIDAR, lidar echo, multiple returns, high dynamic, lidar emulator

1. INTRODUCTION

Nowadays, Lidar is a powerful tool in a wide field of applications like: remote sensing study of the atmosphere, temperature profiling, wind velocity probing, 3D imaging, mapping, etc. Many more will appear with increasing level of the technological maturity of the components used for its development. The most critical parts are emitters and receivers, and recently, also the computing power becomes more important for real time automotive lidar applications. To work comfortably and safely with lidar system some limitation on the emitter side has been established, namely the maximum laser power must be limited to the levels safe for human eyes. This implies the necessity of development nearly perfect detectors, able to exploit every useful photon, to design lidars with smaller energy lasers, smaller telescopes, leading to a compact, reliable, affordable solutions, especially for space applications. Promising candidate is a HgCdTe avalanche photodiode (APD) which can be used in application demanding detection of low number of photons within the observation time. The basis is its low excess noise factor and high, close to deterministic, avalanche gain leading down to single photon detection in the linear regime for wavelengths reaching into medium wavelength infrared (MWIR). With combination to other outstanding parameters like high quantum efficiency, large electrical bandwidth and its capability to extend its performance to visible or even UV light it becomes close solution to the demanded perfect detector. First such detectors have been developed under ESA [1], NASA [2], and CNES founding [3]. The detector module developed by CEA-Leti for CNES is currently used for CO_2 differential absorption lidar (DIAL) set-up. Since the results were positive [4] a consortium was found and a HOLDON project was granted by EC within the program H2020, where further improvements of the detector will be performed targeting space applications. The performance parameters are very challenging and need to be tested prior to the lidar setup development. Therefore, one of the task is a development of Lidar echo emulator (LEE) which will be used to characterize the dynamics and efficiency of the new detector from NIR to UV light.

In this paper we will present a LEE developed for HgCdTe characterization at 1064 nm. First, we will present the requirements of the characterization setup and possible approaches in the section 2. Then in the section 3 we will show the design and realization. In section 4 we will present obtained results concerning performance and we will summarize the work in the section 5.

2. REQUIREMENTS AND POSSIBLE SOLUTIONS

2.1 Requirements

A Lidar detection chain based on the new HgCdTe detector developed within HOLDON project will allow detecting a signal with photon noise limited signal to noise ration (SNR) over the optical dynamic range of 60 dB (dynamic range of space lidars) which is a substantial improvement of the existing state-of-the-art of 46 dB reported by Sun [2]. To characterize correctly the performance of this APD following requirements were chosen: two echoes (returns) had to be produced by a light source (i) long echo with the width of 270 µs (equivalent to a 40 km atmospheric path) and adjustable pulse power from 0.1 to 25 pW, besides the shape of the long echo should also be adjustable (parameters p1 and p2 in the Figure 1); (ii) short echo with the width up to 10 ns which can be superimposed to the long echo, the power level should be selected within 0.2 to 200 nW range. Hence, the combination of both echoes allows characterizing the APD over the full dynamic range of the space lidars (60 dB). The repetition rate is in the range from 100 Hz to 500 Hz. There is another important parameter, namely a short echo falling edge tail with respect to the peak which should have dynamics of 50 dB within 10 ns. The relative position of the echoes should be adjustable with the step of 2 ns. The temporal jitters should be whitin 2 and 10 ns for short (10 s) and long (1 h) operation time. Requirements are depicted in the Figure 1, to visualize the problem.

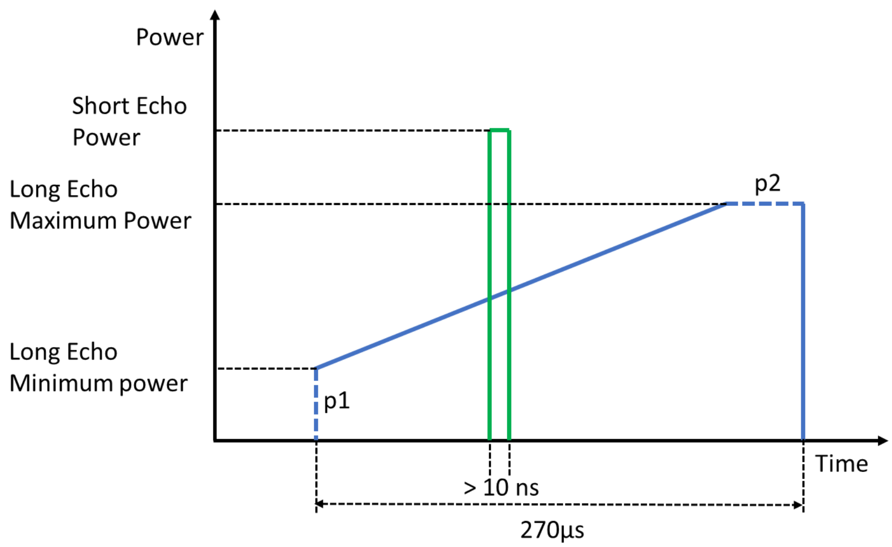

Figure 1. Superposition of a long and short echo. Parameter p1 describes the initial amplitude and p2 the flat part of the pulse with maximum power. Both parameters are given in %.

2.2 Approaches to Lidar echo emulator and final solution

In principle the task seems quite easy but looking at the requirements concerning the short echo – the dynamics of the falling edge of 50 dB within 10 ns with repetition rate of 100 Hz – there are two problems (i) generation of light – limitations of the light source or driving electronics, (ii) verification of the dynamics in the detected signal.

Considering the light source there are several possibilities at the emission wavelength of 1064 nm. First one is the laser diode (LD) – it characterizes by fast response to electrical pulses (ps) in the large or small signal modulation, possible short pulses in the gain or Q-swiching (high power short pulses – ps) sometimes called pulsed lasers, or it can be driven in on-off modulation. Other choice could be a diode pumped solid-state (DPSS) laser – since it is pumped by LD, it follows LD behaviour, but it is more complicated approach due to non-linear optics which is necessary. There are two other approaches where the laser is operating in the continuous wave and the light is modulated by optical switches or acusto-optical modulator (AOM). From the preliminary tests on the available options considering compactness, robustness, complexity, and limited budget we have made following conclusions:

- AOMs can reach necessary On/Off extinction ratio within 10 ns but they have to high modulation ratio and are out of the budget limits for this application.

- Optical switches – LiNbO3 modulators or fast electro-optical switches (EOS). There is no single optical switch that could reach necessary dynamics therefore a cascade with 2 switches was considered. In the case of the LiNbO3 modulators a temperature stabilization was main issue in realization of the stable pulses in power level and width. In the case of the EOS, after cascade the switches reached 45 dB dynamics, but the falling edge tail was about 25 ns.

- LD – after several trials we have found solution that allows for 50 dB dynamics within 10 ns of the falling tail and it is more compact and less complex from all tested solutions even including driving electronics. This result was achieved by means of large signal modulation and also by means of gain switching (the LD used was a single section device).

Visualization of at least 50 dB optical signal: from the beginning of the optical pulses produced by means of high power lasers there was a problem to visualize the pedestal of the peak which could include the remnants of the spontaneous emission or amplified spontaneous emission. Several techniques have been developed for different applications:

- High dynamic range pulse-contrast measurement [5] based on the third-order correlation system, which enables the contrast ratio of high-intensity ultra-short laser pulses to be measured on a single shot, with a dynamic range of better than 80 dB.

- Single-shot measurement of the temporal pulse contrast of ultra-short pulse lasers, based on the self-referenced spectral interferometry (SRSI) approach [6]. The introduction of the spatial equivalent of a temporal delay by tilted beams analysed with a high-quality imaging spectrometer, enables unprecedented performance in dynamic, temporal range and resolution simultaneously. The full range of the ps temporal contrast defining the quality of relativistic laser-solid interaction could be measured with almost 80 dB dynamic range, 18 ps temporal window, and 18 fs temporal resolution.

- Direct observation with the oscilloscopes allows measuring up to 20 dB in the difference between high and low-level signals in the same scale. In principle, the dynamic range could be increased in the following manner: high level signal can be measured at high level scale (e.g. 5V) and then changing the scale (e.g. 1mV) the low-level part of the signal can be measured. Unfortunately, it has disadvantage that the measurement is not taken at the same time.

- Logarithmic Amplifier (LA) which amplifies several orders of magnitude the low signals whereas the high signal remains almost unchanged. Fast PD is connected directly to LA and then the signal is observed at the oscilloscope.

After all the tests a LD was chosen as a light source and LA for visualization. Concerning the visualization, a double check was used. Since LA did not reach necessary bandwidth (minimum pulse width of 200 ns) it was used for dynamics observation and the direct monitoring with fast PD for pulse shape control.

3. DESIGN AND MANUFACTURING

The scheme of the design is shown in Figure 2. The light generation subsystem consists of two LDs: one for short echo and second for long echo, driven by means of commercially available electronics OPM-LD-ps (laser driver and arbitrary waveguide generator). Each laser is controlled separately. Generated optical signal is divided into two branches: monitoring branch to control the signal shapes and levels and output branch where the signal is attenuated to the desired values. The output power level is controlled by means of electrical variable attenuators, which allows tuning over 42 dB within 0-5 V range. Finally, both channels are combined with an optical coupler and the output is available from the front panel of this elegant breadboard. The realization is shown in Figure 3. The visualization subsystem consists of a fast PD and a LA with the same PD which is used for direct monitoring for each of the echoes. The electrical signals are then delivered to the USB oscilloscope integrated into the LEE. To ensure fast acquisition USB 3.0 was used. The PDs are reverse biased, and a battery is used to minimize the noise level.

The control software is written in the LabView. First, the laser setup is defined, which includes built-in safety controls to not overdrive the LDs and set-up correctly the triggers. Then the pulses can be specified with following data: short pulse height and width, long pulse height, width, the shape of the ramp, and the position of the short pulse regards to the long pulse. Finally, the monitoring screen is available with direct PDs and LAs to see the dynamics of the pulses. The screenshots are presented in the Figure 4. The top picture shows the simulation of the desired pulses, the height of the pulses is normalized to see clearly the shape of the long echo pulse (in the case of the short pulse it is a square pulse). The bottom picture shows the measured pulses: up the direct monitoring and down the response after amplification with LA. In this version of the software, the Y-axes were not scaled to the real values of the output power. In the case of the short echo the LA does not depict correctly the pulse shape, because its bandwidth (5 MHz) is too low for such short pulse. Nevertheless, it shows correctly the amplitude, it was checked by stretching the short echo to hundreds of ns, and the amplitude did not change.

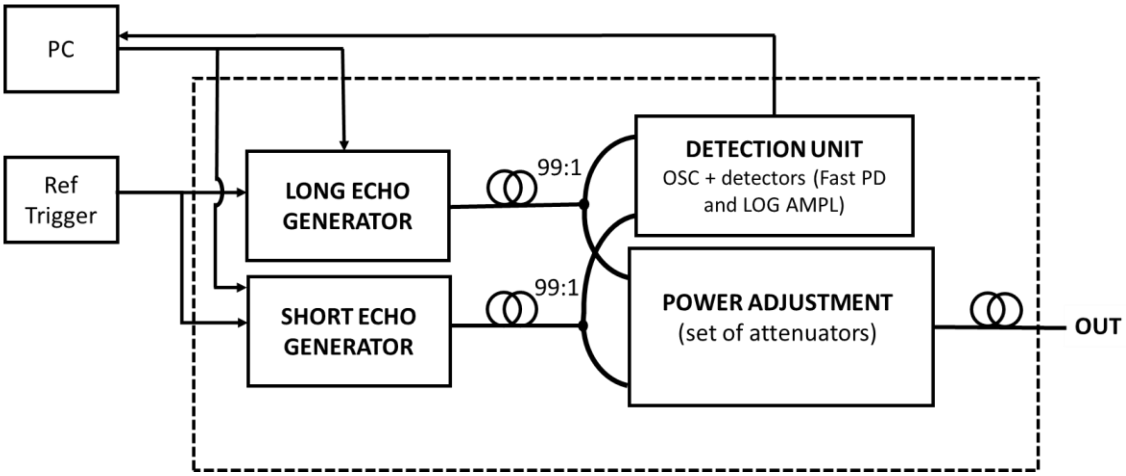

Figure 2. Main design of the LEE.

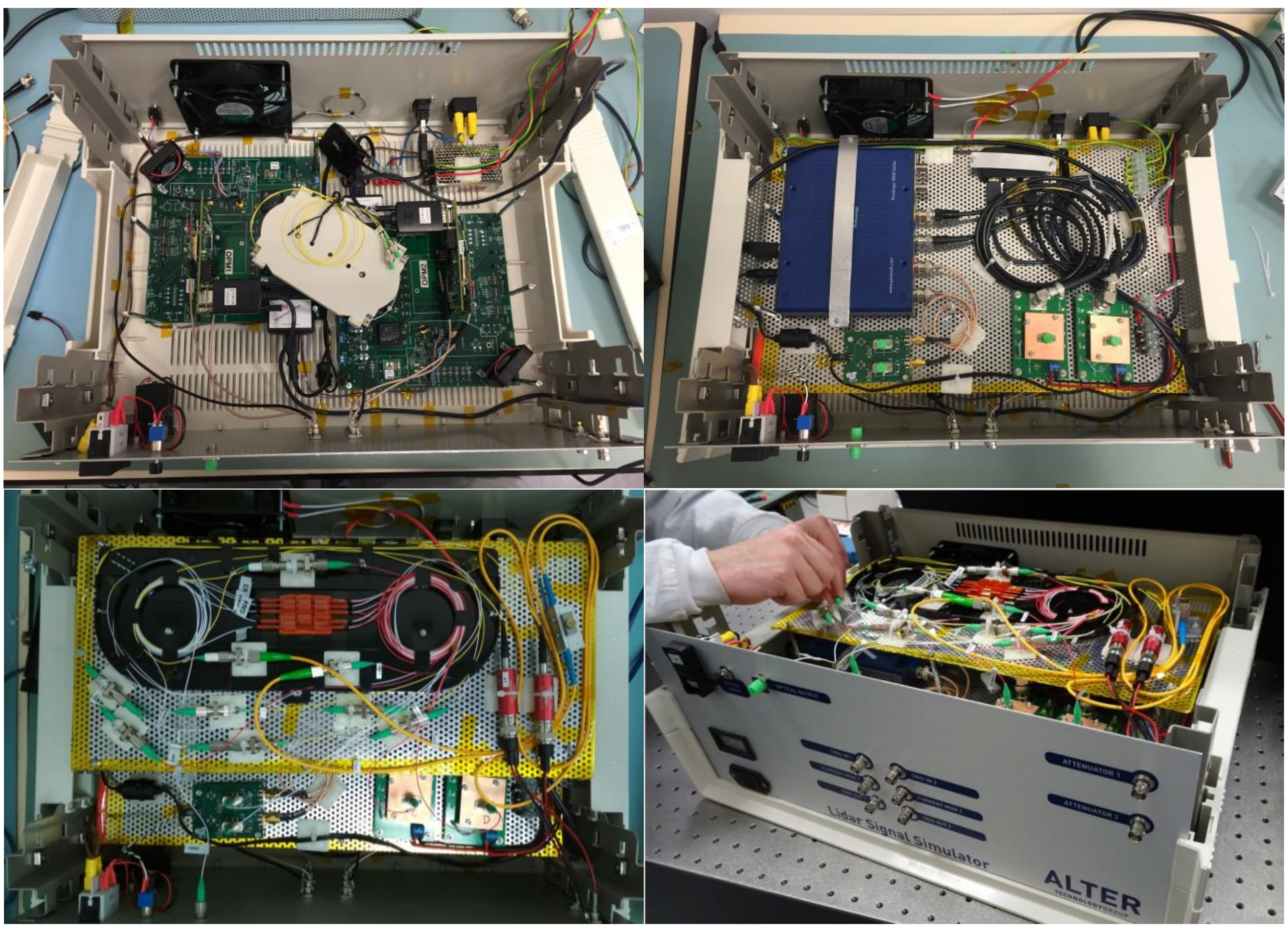

Figure 3. Realization of the LEE as an elegant breadboard. From the left top: the lower level of the LEE with light generation subsystem, right top: the medium level with detection subsystem. The bottom part shows the upper level with optical subsystem and the front panel with inputs and outputs is also visible.

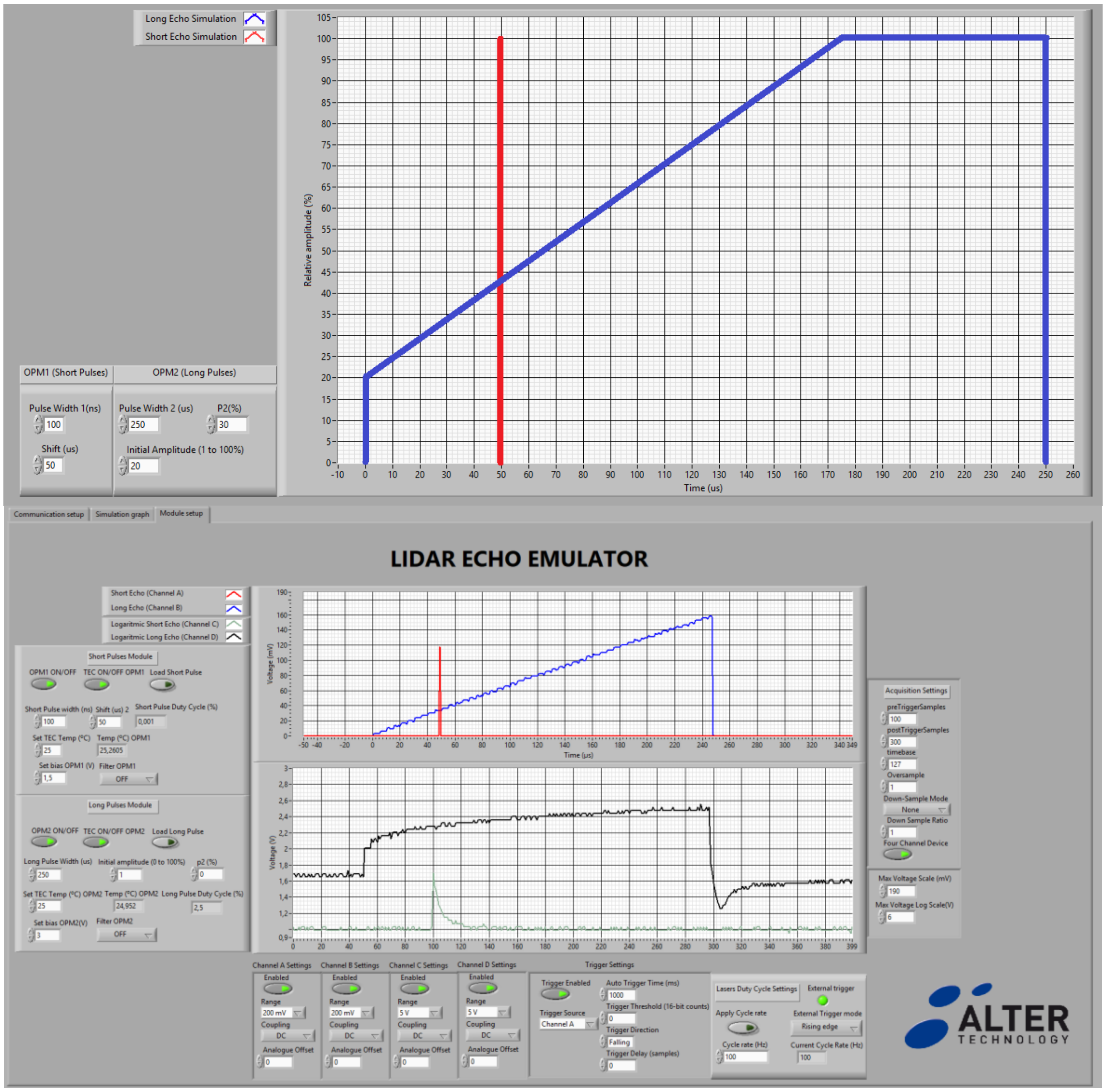

Figure 4. Screenshots of the LEE software. The upper screenshot shows a simulation example where short pulse have 100 ns pulse width and is shifted 50 µs with respect to the long pulse; the long pulse is 250 µs long, it has 20% of the initial amplitude (p1) and last 30% of the pulse is at maximum value (p2). The bottom screenshot shows the realization of the pulses with following data: short pulse 100 ns with 50 µs shift with respect to the long pulse; long pulse with 250 µs with a sawtooth shape. Upper part shows the direct detection and bottom part the response after logarithmic amplifier.

4. RESULTS

LEE can produce the light pulses which emulates the real lidar returns. It can emulate single returns as well as the multiple returns. In the next figures there are examples of the long and short echoes. To see both pulses correctly the long echo was set to only 1 µs. In the Figure 5 (a) the short echo has a width of 10 ns, whereas in Figure 5 (b) of about 40 ns. The only difference in the long echoes is the initial amplitude (p1) which is 1% and 50% for the Figure 5 (a) and (b), respectively. In both cases the flat part of the pulse (p2) is set to 50% of the pulse width. Setting the initial amplitude to 1% and the flat part to 0% the results in a sawtooth shape of the long echo. The square echo can be set with 100% of the initial pulse or flat part. The inset shows a short pulse and the falling edge is less than 8 ns. Both echoes have about 80 ns delay to incoming external trigger signal. As it was already stated there is a possibility to monitor the currents used to driving both lasers. We have checked that there were no delays in optical pulse in comparison to the current pulse (at least within the bandwidth of the oscilloscope – 1 GHz) and that the optical pulses reproduced the current pulses with 98% confidence level.

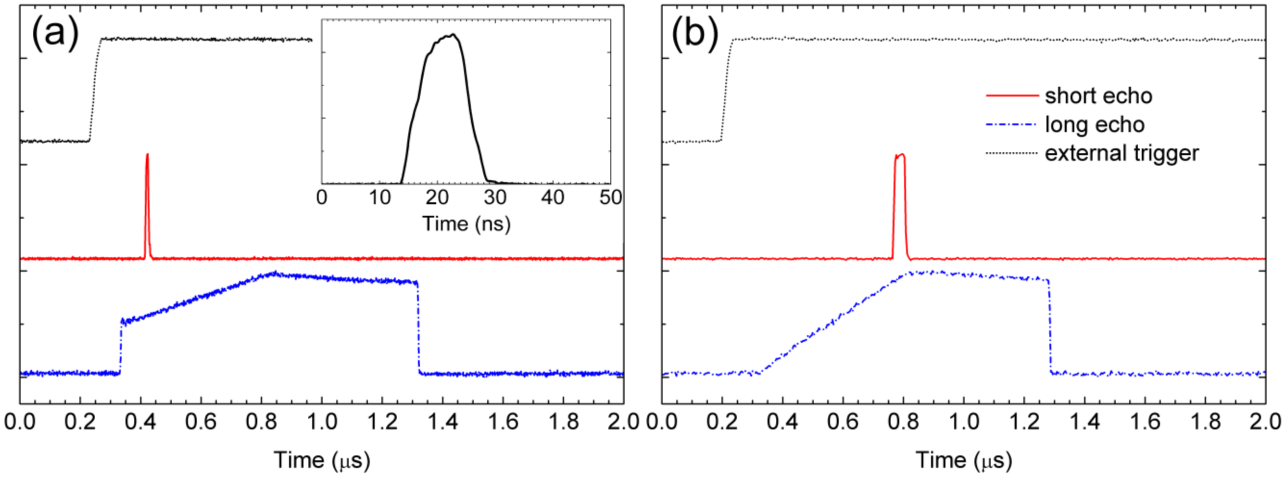

Figure 5. (a) Short pulse: 10 ns, shift 80 ns, long pulse: 1000 ns, initial amplitude p1 = 50%, flat part p2 = 50% of the pulse width, external trigger with 10 kHz repetition rate. Inset shows the short pulse. (b) Short pulse: 40 ns, shift 500 ns, long pulse: 1000 ns, initial amplitude p1 = 1%, flat part p2 = 50% of the pulse width, external trigger with 10 kHz repetition rate.

Figure 6 left shows the response of the logarithmic amplifier for the squared long pulse with 270 µs width (upper trace) and its direct measurement (bottom trace). The low level in the upper trace of about 1.16 V corresponds to the current of 10 nA incoming from the PD. The high level of 2.46 V corresponds to the current of about 6 mA, resulting in almost six orders of magnitude between the high and low levels, thus more than 50 dB dynamics in the current (power) is observed. The tail at lower currents (nA – levels) corresponds to the decreased bandwidth of the LA (down to hundreds of Hz).

The right-hand side of the Figure 6 presents an echo with multiple returns with a length of 2 µs. The maximum size of an echo could be set up to 1 ms in the current design of the LEE. Although only single or multiple returns were presented and tested, it would be possible to prepare a full-waveform lidar return and emulate it with LEE.

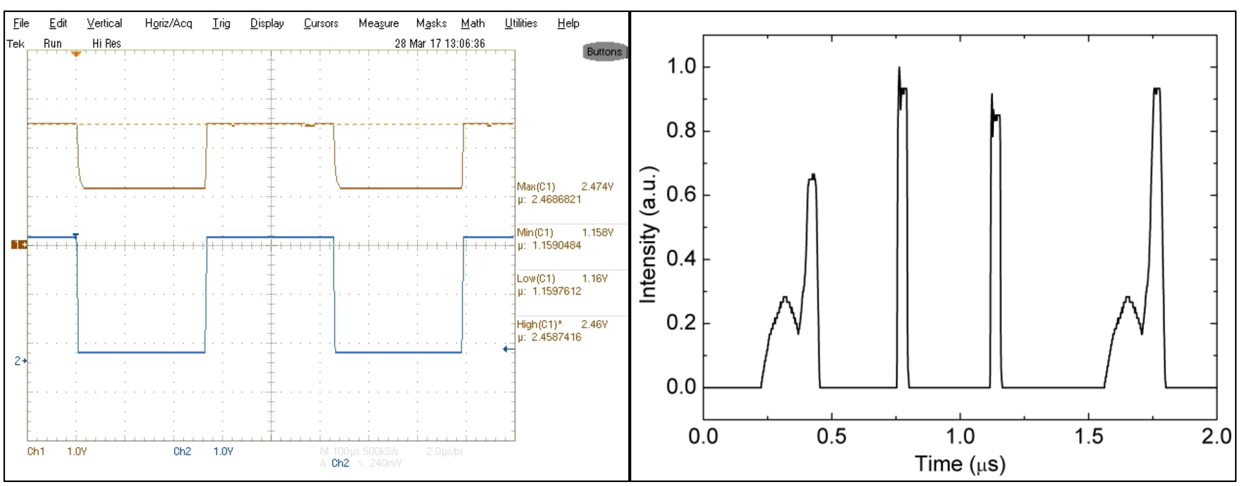

Figure 6. Left: Long pulse: 270 µs, top – after logarithmic amplifier, bottom – direct measurement. Right: Example of an echo realization with multiple returns.

5. SUMMARY AND FUTURE WORK

The Lidar echo emulator was designed and developed as a compact and standalone elegant breadboard. It delivers two echoes, short and long one to emulate the returns of the lidar system as the output into the optical fiber (FC/APC).

Multiple returns could be emulated too. It is easy configurable with the delivered software. It was successfully used in the preliminary characterization of the APD detector. The parameters of the Lidar echo emulator can be customized, and they are summarized in the Table 1. Besides, it has two 5 V input for variable attenuator for the long pulse and for the short pulse and the external trigger input for long pulse and for short pulse. Additionally, LEE allows monitoring of the laser current for short and long pulse and the internal trigger output for both pulses can be used to trigger another device to synchronize with LEE.

Table 1. Basic performance parameters.

Item	Value
Peak wavelength	1064 nm ± 5 nm
Pulse width	5 ns – 1 µs (short echo) 1 µs – 1 ms (long echo)
Pulsed output power	100 fW – 1100 mW
Repetition rate	from 10% of Duty Cycle to 1 Hz
Short echo falling tail	50 dB within 8 ns
Optical power difference between both pulses	from 0 dB to 100 dB

In the HOLDON project operation of this device will be extended to the visual (532 nm) and UV (355 nm) range. Since there is no laser diode emitting at room temperature at these wavelengths the most probable scenario is to develop a DPSS laser for both wavelengths. It is challenging task especially in the UV range considering that the short echo falling tail should be 50 dB within 10 ns and that the optical fibers have strong attenuation in this wavelength range.

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