

COMPACT ENERGY MEASURING SYSTEM FOR SHORT PULSE LASERS

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Abstract

In experiments with short-pulse lasers the measurement control of the energy of the laser pulse is of crucial importance. Generally it is difficult to measure the amplitude of the pulses of short-pulse lasers using electronic devices, their response time being longer than the duration of the laser pulses. The electric response of the detector is still too fast to be directly digitized therefore a peak-hold unit can be used to allow data processing for the computer. In this paper we present a device which measures the energy of UV short (fs) pulses shot-by-shot, digitizes and sends the data to the PC across an USB interface. The circuit is based on an analog peak detect and hold unit and the use of fiber optical coupling between the PC and the device provides a significant improvement to eliminate potential ground loops and to reduce conductive and radiated noise as well. The full development is open source and has been made available to download from our web page (<http://www.noise.inf.u-szeged.hu/Instruments/PeakHold/>).

Keywords: laser energy, optical fiber, USB, peak-hold, UV short pulse, open-source

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1. Introduction

Laser-matter interactions as in industry, material processing [1], dentistry [2], microholography, photonuclear physics [3] rely on the use of short laser pulses for their interaction with matter. In recent decades more and more of these studies have been carried out by ultrashort laser pulses, i.e. shorter than 1 picosecond. Electronic circuits are too slow, therefore they are unable to follow, and thus, to measure the amplitude of the peak of the pulse. This is required for basics diagnostics as monitoring the energy of the laser beam. A peak-hold energy readout circuit was designed for using pyroelectric laser energy monitors [4]. Photodiodes – in general – may give a response linear with the absorbed laser energy. The problem with their direct application is that either they are slow and then with the direct integration of charge the background noise will be high or they have a fast response, faster than the analog-digital (AD) converters can follow. Additionally in case of direct integration the electrical noises from potential ground loops and EMP (electromagnetic pulses) noise originating from the discharge pumped excimer lasers and also from the high power laser-plasma interactions is a strong hindrance for accurate measurements. Therefore conventional cable connections are to be avoided and fiber optical coupling is preferred.

Smirl et al [5] presented an energy monitor for simple laser pulses including an integrating detector circuit, an amplifier and a peak detector and hold circuit. Kuroda [6] demonstrated a peak and hold circuit which consists of two basic units: peak and hold, and sample and hold circuits. Another application was an 8K pulse height analyzer with USB interface [7].

Peak-hold systems have the advantage that they are able to catch the charge of the first peak of a short electric pulse then to keep the output signal at a constant level.

For the laser-plasma experiments with an ultrashort pulse excimer laser we have designed a measuring system for energy monitoring, which can catch the pulse, digitize it and send the result to the computer for subsequent processing. The energy monitor contains the diode and all the electronics in a single box together with a microprocessor unit. It communicates with the external systems using only fiber optical connections.

2. Description of the hardware

Measuring the laser pulse energy of short-pulse lasers is not a trivial problem because of the short pulse duration. A solution for this problem was given by Vetrivel and Sivaram [8] who demonstrated a computer-controlled high-speed peak-hold detector applying two peak detectors in tandem. In our energy meter the diode, the analog peak-hold unit and the analog-digital converter are in a single metallic box which is connected to other units through fiber-optical coupling only, thus reducing electrical noise picked up during the measurements. The measuring system is shown in Fig. 1.

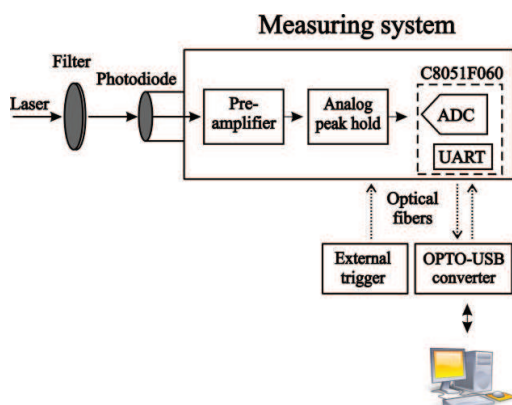


Fig. 1. Schematic drawing of the measuring system.

Two peak-hold units are used in tandem, the first is an analog one and the second is a digital peak hold (at software part). A photodiode (BPW21) detects the light pulse behind a grey filter and a scatter plate and it converts photons to charges. The photodiode is reverse biased to provide faster response. Due to the removal of the window in front of the photodiode the diode becomes sensitive enough at the wavelength of 248 nm. The typical photodiode preamplifier circuit utilizing a FET input operational amplifier – see Fig. 2 – is suitable for our measurements. The feedback capacitor of 8,2pF and the feedback resistor of 200k allow proper pulse response and gain.

This preamplifier outputs an electrical pulse to obtain a voltage value proportional to the energy of the laser. The analog peak-hold unit is used to keep the maximum voltage at a constant level. It includes two type OPA350 operational amplifiers. The analog peak-hold part corresponds to the electrical circuit demonstrated by Vetrivel and Sivaram [8] which is shown in Fig. 2. The first operational amplifier charges the capacitor ($C=1$ nF) through the diode (D). A resistor ($R=1$ M Ω) parallel to the capacitor was also used in case the discharge was too slow. Subsequently the signal is fed to a microcontroller – C8051F060 – in which the 16-bit analog digital converter (ADC) turns the analog signal to a digital format. The lowest

value of the width of the pulse that can be detected by the setup is about 300 ns (at a pulse level of 4V) and the highest value of the repetition rate is 1 ms.

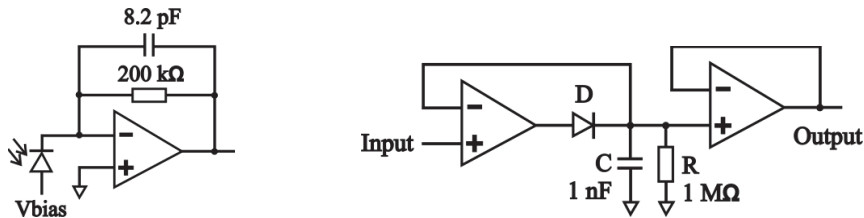


Fig. 2. Preamplifier with the photodiode (left) and analog peak hold circuit (right): self-discharge capacitor by the resistor.

The present system – as mentioned above – contains optical fibers, which are immune to electromagnetic interference and which also provide galvanic decoupling. Therefore we can avoid ground loops as sources of noise. An OPTO-USB converter (FT232RL) is used between the device and the computer. At the OPTO-USB converter there are two fibre optic connections: a high performance link receiver (HFBR 1521) and a transmitter (HFBR 2521). The type of the plastic fibre cable is HFBR-RUS100Z with fibre optic connectors (HFBR-4511Z, HFBR-4501Z).

Using the USB interface for data communication is an important step forward in contrast with former devices [9, 10]. The energy meter receives an external trigger shot by shot to measure the subsequent pulse of the laser. The trigger signal comes in a fibre optical cable, too.

3. Software

Separate programming of the microcontroller and the PC is necessary. The program for the microcontroller is based on the main requirement to sample the analog signal with an ADC at 100 kHz sampling frequency, as shown in Fig. 3. During the sampling of the analog signal the capacitor begins to discharge so a small decrease of the level of the signal is obtained. Due to the discharge of the capacitor and to the delay uncertainty between the laser pulse and the readout time, the statistical error of the pulse level is kept below 1 %.

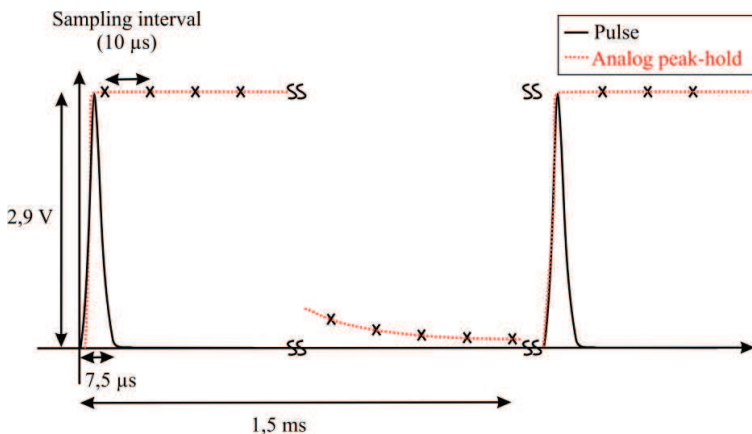


Fig. 3. Sampling of the short laser pulses with 100 kHz sampling frequency, the discharge time of the capacitor is 1.5 ms.

An external signal just before the incoming light signal provides a reset of the software peak detector for the microcontroller. Across an exclusive-or gate the polarity of the trigger pulse can be changed by software. This program was written in C.

On the PC side we receive the data via an USB interface and load it to a LabVIEW program that is waiting for the coming data and then displays it on the screen. Fig. 4 depicts the first test of the device using a function generator where the average of the peaks is 2946 ± 12.3 mV, i.e. the measurement has 0.42 % statistical error.

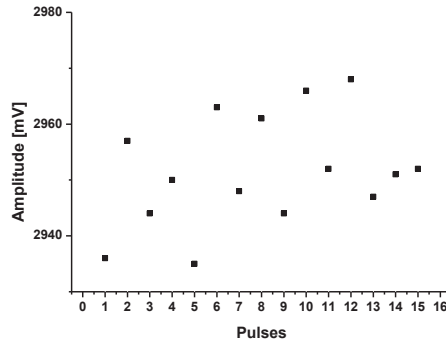


Fig. 4. Measured amplitude of the pulses, the average is 2946 ± 12.3 mV.

4. Experimental results

In our experiments we use an UV laser system which is based on a twin discharge EMG150 Lambda-Physik excimer laser [11]. The dye-laser chain is pumped by the XeCl laser, then the beam goes through the KrF preamplifier and the main amplifier. It has a 70 mJ pulse energy with 610 fs pulse duration and 248 nm wavelength. Focusing the beam the intensity can be as high as 10^{18} W/cm² with a spot size of ~2 μm diameter [12].

The second test of the energy monitor unit was carried out by putting different filters in the beam to attenuate it. Using filters the linearity of the photodiode was controlled and the electric circuit checked. Fig. 5 illustrates the test of the measuring system. The relative error of the fitting is 3.2 % originating from the error of the transmission of the grey filters because the statistical error is just 0.42 % when using a function generator.

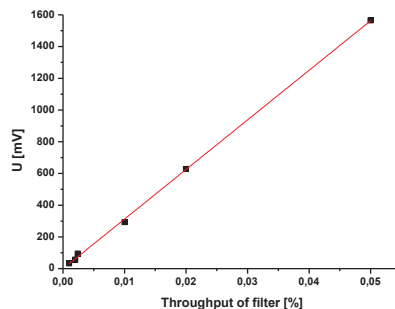


Fig. 5. Transfer test and calibration.

The energy monitor is essential in the investigations of laser-plasma interactions. In the case of laser plasmas generated on solid targets it reflects most of the radiation, i.e. it acts as a plasma-mirror. If initially the target is transparent, then only the light reflected from the target after the initiation of plasma will be used for the further experiments. Thus plasma mirrors can be used for cleaning the laser pulse from prepulses. In order to measure the reflectivity of the plasma for different angles of incidence, the energy was monitored at the input and the output side of the plasma mirror. Two measuring systems were used side-by-side. Fig. 6 shows the block diagram of the energy monitor. The measuring system of the plasma mirror experiment is shown Fig. 7.

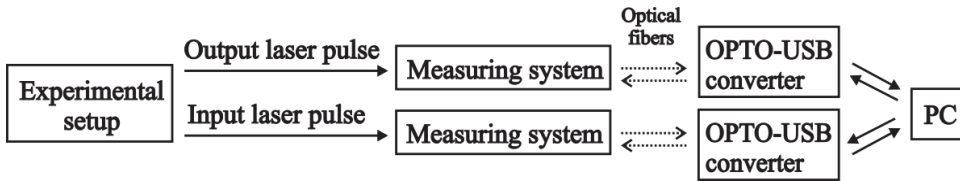


Fig. 6. Block diagram of energy monitoring.



Fig. 7. The measuring system for the plasma mirror experiment.

The experiments proved that plasma mirrors can be used for improving the contrast even for the ultraviolet KrF laser pulses[13]. Similarly to the earlier investigations with infrared systems in other laboratories, the reflectivity increases with increasing intensity up to a point where saturation and decrease of the reflected intensity occurs due to nonlinear interactions.

The Peak-Hold Energy Meter monitor was calibrated for measuring energy of the short pulse. For the calibration the total energy of the beam before and after the plasma mirror was measured by a linear, absolute calibrated Gentec Joulemeter (ED-500) thus calibrating the detector which detected a small part reflected out of the beam. Fig. 8 depicts the reflectivity (output energy/input energy) of the plasma as a function of laser intensity [13]. Nearly 50% reflectivity was obtained which means that in case of using an antireflection-coated target (for which the reflectivity of low intensity radiation is less than 1%) a contrast improvement larger than 50 can be obtained by using the plasma mirror arrangement.

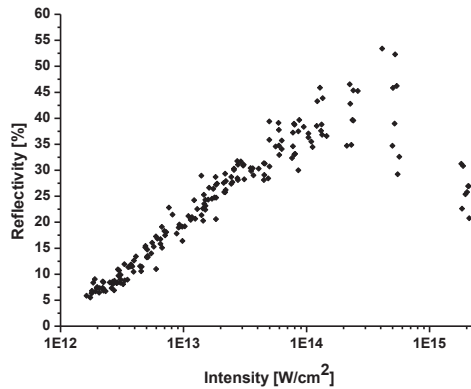


Fig. 8. Intensity dependence of the reflectivity for 620 fs KrF laser pulses.

Besides using it as an energy monitor in interaction experiments the device can be used in several other applications as investigating the fluctuation of the laser pulse, as it became a standard diagnostic means of the laser system. Further development of the device is possible to form an independent, faster and more precise instrument and it can be used in other laser systems, for instance in diode lasers.

5. Conclusion

A compact, cheap, small yet efficient and precise device is developed for short pulsed lasers. The measuring system is convenient for analog and digital data processing including an analog peak-hold unit and microprocessor-driven digitization. The system is separated from the computer side by optical fibers to reduce ground loops as sources of noise. Therefore besides measuring the energy of the short pulses, one of the main advantages of it is the reduction of high frequency noise for laser systems due to fibre optical coupling. Another important advantage is the USB interface between the computer and the instrument, allowing automatic data processing. After collecting the data there are additional opportunities on the computer side e.g. it is possible to make statistics or to calculate distribution functions without using expensive instruments as high-speed oscilloscopes. After designing and testing the device two measuring systems were used in a plasma-mirror experiment where the energy of the laser pulse was monitored. Besides using it in interaction experiments the instrument can be used in another laser system and developed to turn into an independent, more precise but at the same time very cheap device. The hardware and software development is fully open-source to support easy reproduction, to serve as a basis for further enhancements and to allow building it into a more complex system. The related documents are available on the following website: <http://www.noise.inf.u-szeged.hu/Instruments/PeakHold/>.

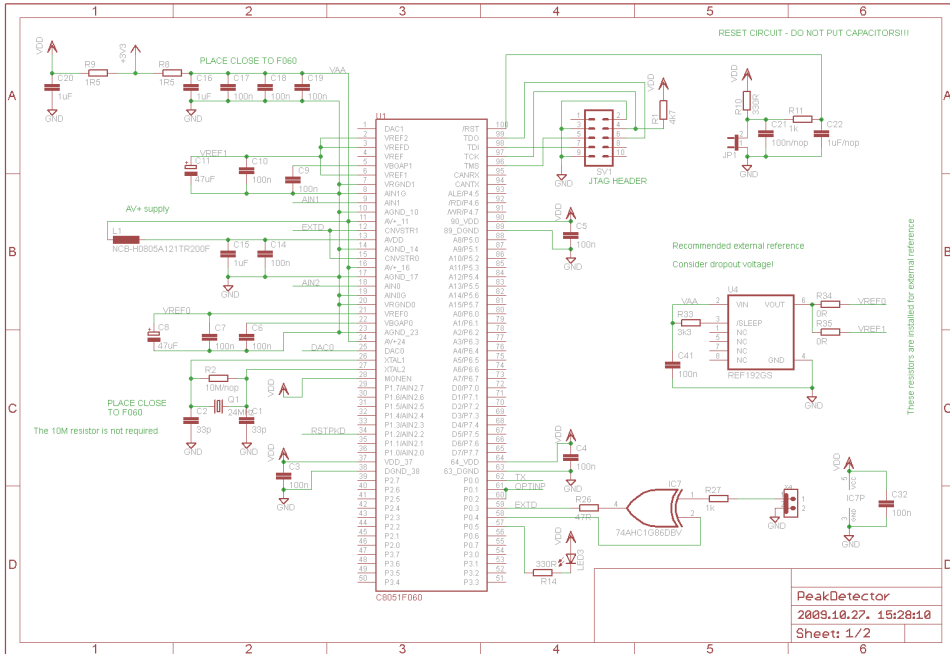
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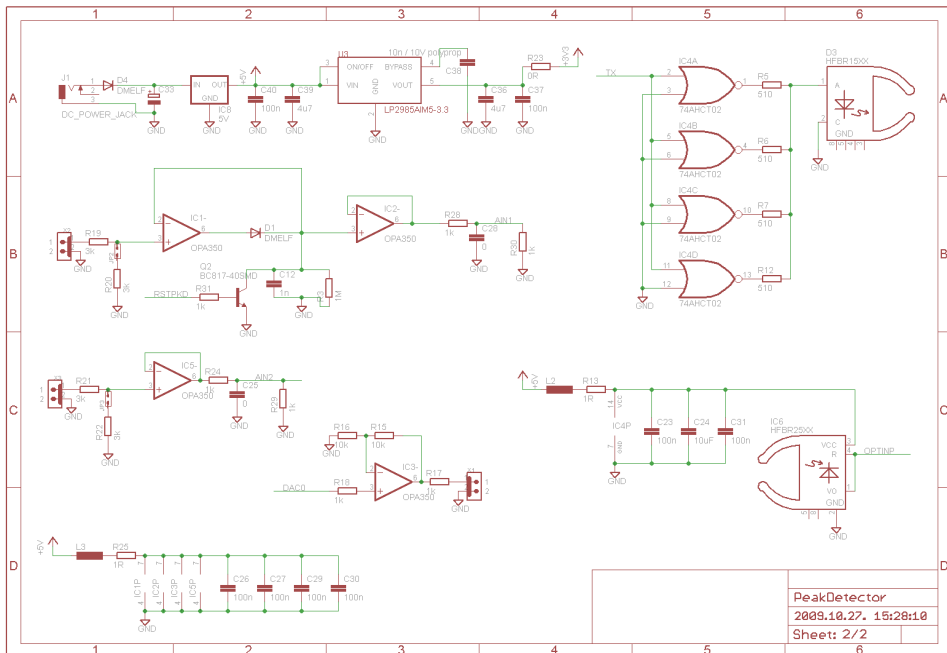
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Appendix



Schematic of the microcontroller IC



Schematic of the peak-hold and the optical-coupler circuit