

Modeling a New Technique to Reject Parasitic Signals in Photorefectance Experiments

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Abstract

This paper describes a new method to be used in photorefectance experiments in order to reduce the influence of parasitic effects in the useful signal. Although theoretically the proposed method eliminates all the parasitic effects, the non-ideal behavior of some system components like the modulator finite switching time and the lock-in phase error, reduce the predicted performance and have been simulated using the programming language LabVIEW. Results show that the method has clear advantages over others previously described in the literature. Depending on the experimental facilities, two possible working regimes are discussed.

1. Introduction

Photorefectance measurement is a very useful experimental method for investigating physical properties of semiconductor materials. The basic principle is to measure the relative changes induced in the reflection coefficient of the material under research, depending on the wavelength of an incident beam coming from a monochromator. These changes are produced illuminating additionally the sample surface with a modulated ray coming from a laser.

It is known that photorefectance experiments suffer from a variety of parasitic phenomena. Among the most important, we can list:

- The laser light scattered by the sample surface.
- The sample photoluminescence induced by both the laser and the monochromator beam.
- The PIN photodiode dark thermal current.

Different methods have been described in the literature in order to reduce the influence of such parasitic effects. In the following paragraphs we enumerate some of them, pointing their advantages and disadvantages.

H. Shen and Dutta [1] describe a method based on a spatial deflection of the laser beam on the sample surface, with the purpose of canceling the effects of scattered and photoluminescence light. In many cases the monochromator beam area is comparable with the sample area, making this method useless.

M. Sydor and A. Badakshan [2] propose a method based on the use of a second PIN diode in order to compensate the parasitic effects. Its disadvantage lies in the difficulty of matching two PIN diodes for equal electrical and optical characteristics.

A third proposed method consists of placing a second monochromator in front of the PIN diode. Although this method eliminates all the parasitic effects, it attenuates further the signal, which is

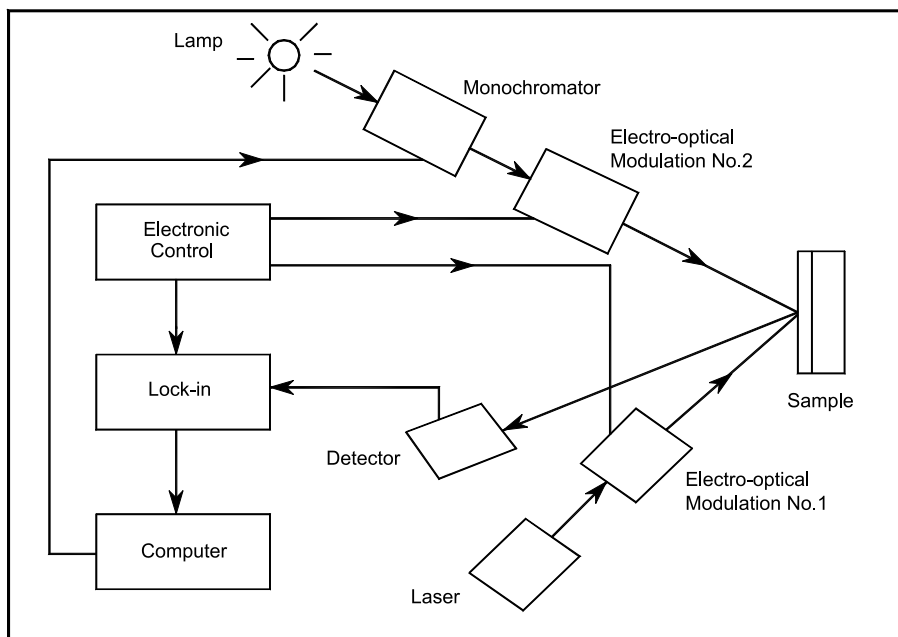


Fig. 1. Block diagram of the proposed method.

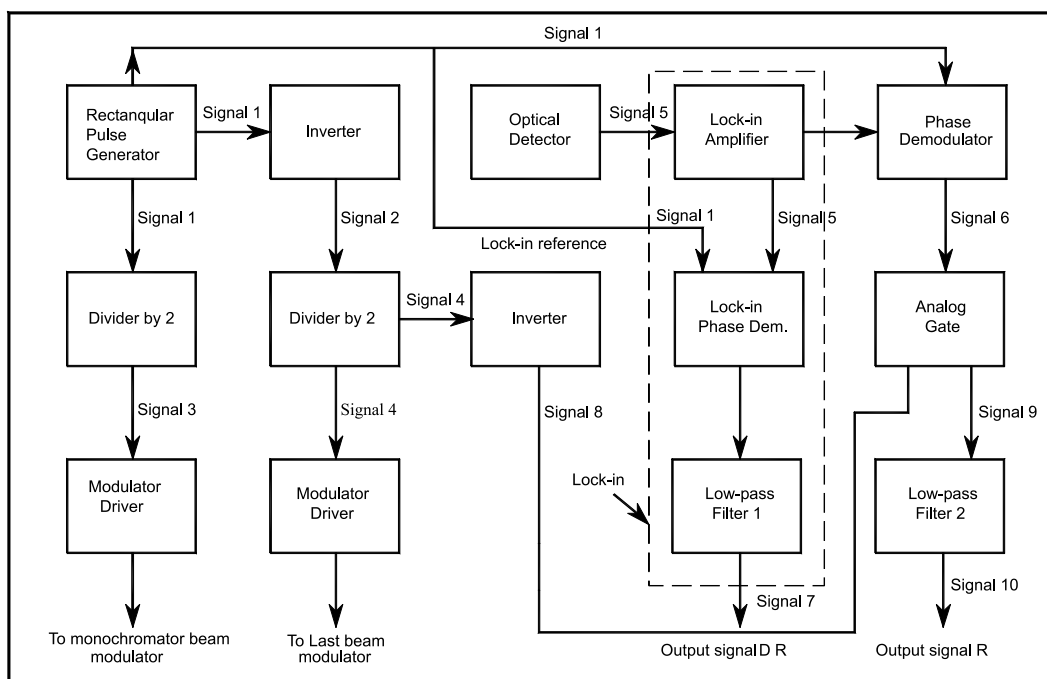


Fig. 2. Electronic control block diagram.

already small. Many authors [3,4] use an optical filter (notch filter) placed between the sample and the PIN diode, which attenuates considerably the laser scattered light. The main disadvantage in this case, is the impossibility of detecting useful signal peaks that coincide with the filter bandwidth or its harmonics. A very commonly used method consists of placing a polarizer in front of the PIN diode, with a polarization axis perpendicular to the laser polarization axis. This method can reduce strongly the laser scattered light,

but can not achieve a total cancellation, due to the fact that when reflecting, the laser light changes its polarization angle. In our opinion, the method proposed by S. Gosh, and B. M. Arora [5] is the closest to being ideal.

In this method, the laser and the monochromator beams are modulated at different frequencies and a signal with a frequency equal to the sum of both is obtained electronically. The only disadvantage of the method is the attenuation suffered by the useful signal.

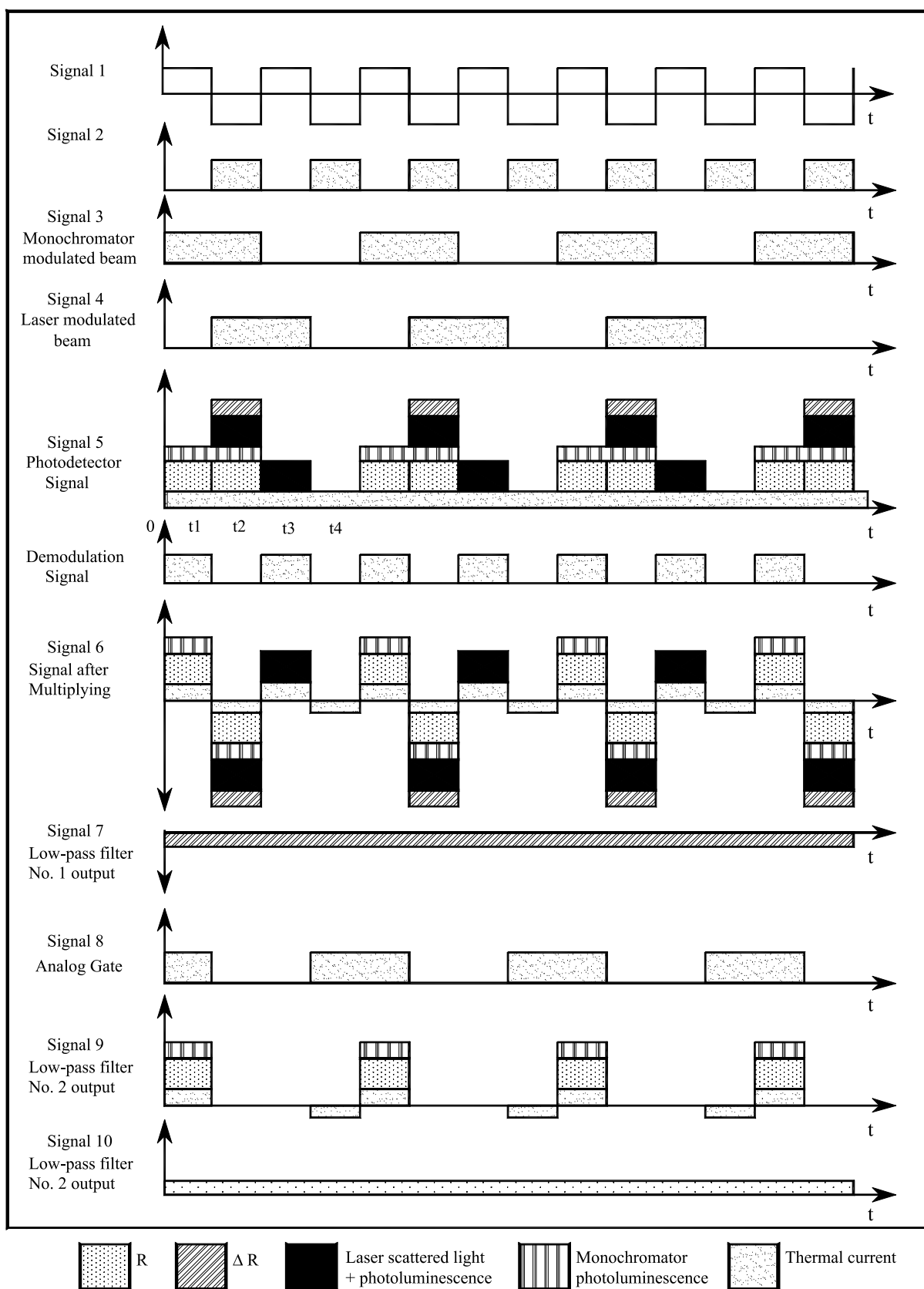


Fig. 3. Waveforms of interest at the output of various blocks.

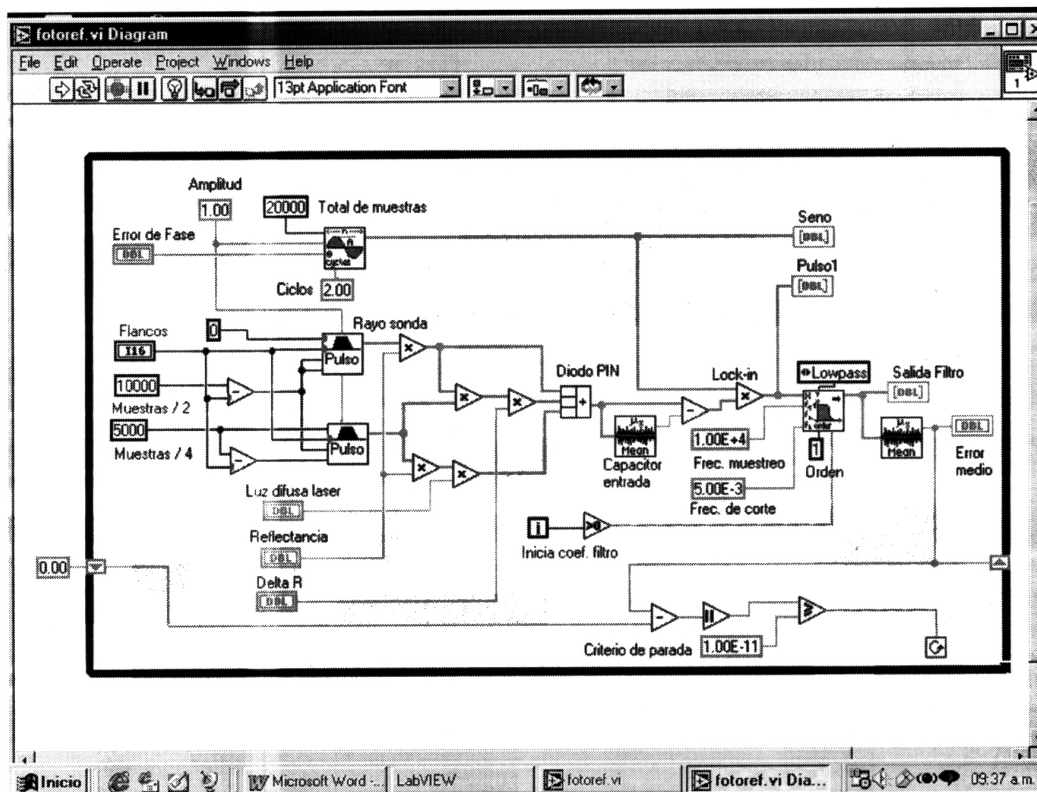


Fig. 4. LabVIEW programming window.

2. Description of the proposed new method

Fig. 1 shows a block diagram of the method proposed by the authors. The laser beam is modulated in the electro-optical modulator No. 1 and irradiates the sample modifying its optical properties.

The tungsten filament lamp produces a beam, which after exiting the monochromator is chopped in the electro-optical modulator No. 2. The beam is then reflected at the sample surface and reaches the PIN photodiode.

The two electro-optical modulators are controlled by an electronic block which supplies rectangular pulses of frequency f_0 as shown in Fig. 2. With the aid of conventional digital circuits, two trains of symmetrical pulses of frequency $f_0/2$ and out of phase 90° are generated. Each of them drives the electro-optical modulators and at the same time a synchronization signal of frequency f_0 is supplied to the lock-in detector.

Fig. 3 shows the diagram of all the important signals inside the electronic block. The legend, which identifies the various components of the induced signal in the PIN photodiode is also shown (Signal 5). These components are: the signal due to the monochromatic beam reflected during the absence of the laser beam R ; the signal due to the increase in the reflection coefficient ΔR when the laser beam is present;

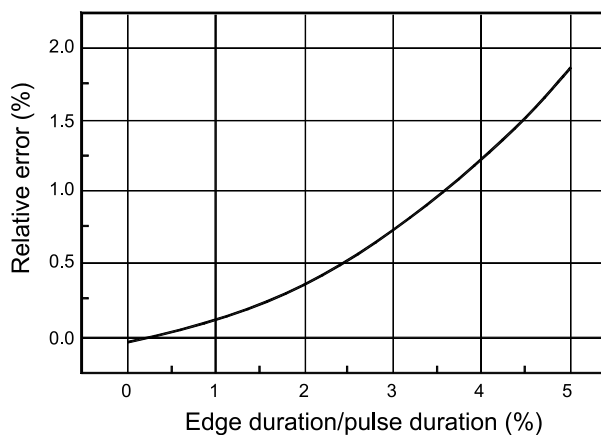


Fig. 5. Relative error dependence on modulator switching time.

the signal due to the scattered laser light and its associated photoluminescence; the photoluminescence produced by the monochromator beam and finally, the photodiode dark thermal current.

During the interval $0 - t_1$ the sample is solely illuminated by the monochromator beam. At the PIN terminal, the signal is composed of the reflected light, its induced photoluminescence and the thermal current. During the interval $t_1 - t_2$, both beams simultaneously illuminate the sample. In this case the signal induced in the PIN photodiode includes

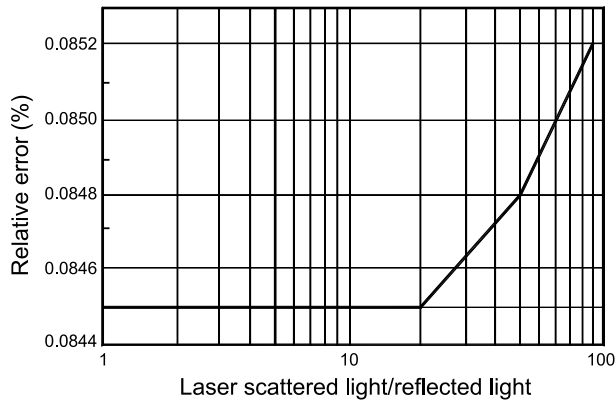


Fig. 6. Relative error dependence with the fraction **scattered light/reflected light**. The relation **edge/pulse**= 1 %.

five components due to: the photodiode thermal current; the monochromator reflected beam (the useful signal) and the induced photoluminescence and finally the laser scattered light and its associated photoluminescence.

During the interval $t_2 - t_3$, only the laser beam shines on the sample. Therefore only the laser scattered light, its associated photoluminescence and the thermal current compose the signal.

Finally, during the interval $t_3 - t_4$ the two beams are shut off and the only available signal at the PIN terminal is the dark thermal current.

Fig. 3 clearly shows that after passing the lock-in detection, a compensation of all the parasitic signals is achieved with exception of the signal due to the change in the reflection coefficient ΔR under the influence of the monochromator beam. At the Low-Pass Filter No. 2 output, the signal corresponds to the reflection coefficient R . This signal is affected by the photoluminescence of the monochromator beam which is a real disadvantage, but in many cases the error is less than 0.1 % and the results are not affected.

3. Modeling the system with labview

Although theoretically the proposed method eliminates all the parasitic effects, the non-ideal behavior of some system components reduce the predicted performance. In order to investigate the system sensibility to such departures from ideal, a numeric modeling using the programming language LabVIEW was done. The two effects evaluated were the finite modulator switching time and the lock-in phase error.

The switching time was set between 0 to 5 % of the pulse duration. On the other hand, the lock-in phase error was set to $\pm 1^\circ$. Fig. 4 shows the LabVIEW programming screen for this case. Blocks named "Pulso" are virtual instruments created

previously in order to generate pulses with variable edges and duration. The real PIN detector has been simulated as a signal-summing block. It follows a block, which suppresses the dc component as the lock-in input coupling capacitor does, the demodulator and the output filters. The program runs cyclically in order to reach a steady state value for the filter coefficients and stops when the difference between two consecutive relative error values is less than 10^{-11} . In the instrument panel there are controls to set the lock-in phase error, the duration of the pulse transitions (as a pulse duration percent) and the fractions $\Delta R/R$ and **laser scattered light/reflected light**.

4. Results presentation and discussion

Using the developed program, the influence on the measurement relative error caused by the finite choppers switching time and the fraction **laser scattered light/reflected light** was investigated

In all calculations the following sets were used: Phase error equal to 1° , $R = 0,1$, $\Delta R/R = 10^{-5}$ and $\tau = 0,1$ s (filters time constant). Fig. 5 shows the variation in the relative error with the fraction **edge duration/pulse duration**. The fraction **laser scattered light/reflected light** was set to 100, which represents a worst case. The relative error as a consequence of a phase error of $\pm 1^\circ$ is near $\pm 0,015$ % and has little influence on the results. The influence on the relative error due to the number of low-pass filters and its time constant was also investigated. Lock-in amplifiers have typically two output filters with adjustable time constants, so we examined four possible cases. The results are shown in Table 1.

The setting conditions again represent the worst case: $R = 0,1$; phase error = 1° ; $\Delta R/R = 105$; **edge/pulse** = 1 %; **laser scattered light/reflected light** = 100. In addition, Table 1 shows the maximum output ripple amplitude and the number of iterations needed to reach the steady state, because that number is proportional to the time the filters need to establish their output values. In all the cases the relative error is less than 0.4 %.

The large voltage ripple observed at the output of the lock-in amplifier is not intrinsic to this method. Using the conventional method, having a high value of the **laser scattered light/reflected light** fraction and without any other suppressing device (notch filters, color filters, polarizers, etc) the ripple will be similar. It has to be taken into account that this large ripple is only admissible in the case in which two low-pass filters with $\tau = 1$ s are used. Each additional filter with $\tau = 0,1$ s will reduce the ripple 1000 times. This ripple corresponds to a value **laser scattered light/reflected light** = 100. This is a very infrequent case. Often such fraction is less than 10.

Table 1. Results with various combination of filters and time constants

Case	Output ripple amplitude	No. Iterations	Relative error (%)
1 filter $\tau = 0.1$ s	10^{-2} V	1484	$8.5 \cdot 10^{-2}$
2 filter $\tau = 0.1$ s	$1.5 \cdot 10^{-5}$ V	1726	$8.5 \cdot 10^{-2}$
3 filter $\tau = 1$ s	10^{-3} V	13372	-0.36
4 filter $\tau = 1$ s	$3 \cdot 10^{-7}$ V	11176	-0.39

5. Conclusions

The results obtained with the LabVIEW modeling let us conclude that with our method, even in extreme experimental conditions, the relative error is very small. In real and not so severe conditions the proposed method notably rejects the parasitic signals.

In order to take full advantage of the method, we recommended the following regime, which corresponds to an electro-optical chopper built by DLK France.

$$f_0 = 10 \text{ kHz } (T_{pulse} = 100 \text{ microsecond } , \\ T_{edge} \leq 1 \text{ microsecond}).$$

Relation $T_{edge}/T_{pulse} \leq 1$ %.

Depending upon the equipment available and the researcher's needs, the lock-in output can be configured in two ways, in order to obtain the best results.

Variant 1: If the switching frequency f_0 is high (> 1 KHz), the ripple at the lock-in output does not affect the digital value of the useful signal. This is because the internal A/D converter typically used is a dual slope integration type, with a conversion time larger than the ripple period. In this case, the converter behaves like an additional low-pass filter

Variant 2: If the signal is taken from the analog output of the lock-in detector, it is then necessary to use two filters with time constant $\tau = 0.1$ s. An additional low-pass filter with $\tau = 0.1$ s must be added to the $R \cos \Theta$ output, followed by an acquisition board, which allows us to read a value every 0.5 second

If it is not desirable to add the third filter with $\tau = 0.1$ s, the two internal lock-in filters with $\tau = 1$ s can be used, but in this case the time needed to read a value is nearly 5 second.

If an additional polarizer is placed in front of the PIN diode, the laser scattered light will be strongly diminished and as a consequence, the ripple will be too. In this case, the internal lock-in low pass filters with a time constant $\tau = 0.1$ s and A/D converter could be used.

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