Method and system for elimination of background in measurements of optical energy by means of pyroelectric detector

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Abstract. A model of a processing system permitting separation of the useful signal from the background interferences of pyroelectric detector voltage response is presented. Elimination of the background is achieved by the differential method. The use of this method enables elimination of the influence of any interference to a sufficient degree.

Introduction
Pyroelectric detectors are commonly used for measurements of energy of pulse sources of radiation, especially pulse lasers. If the duration of the optical radiation pulse is short enough, then the energy measured is proportional to the peak value of the voltage response of the detector to the radiation pulse incident on its active surface:

\[ E = kV_{\text{m}}, \]  \hspace{1cm} (1)

where; \( k \) is proportional coefficient.

The voltage response signal of the pyroelectric detector and detection of its peak value can be conditioned by relatively simple configurations of electronic systems, known for many years [1]. Such known configurations of the conditioning systems are effective only for processing of the signal from a pyroelectric detector in the conditions of negligibly small interferences. It should be noted that all pyroelectric detectors show also piezoelectric properties and thus are very sensitive to acoustic interferences and vibrations. The signal generated by the pyroelectric detector is overlapped by thermal and electromagnetic interferences. In view of the above, the results of measurements can show much scatter, especially when measuring pulses of low energies. Design of a system for processing of the pyroelectric response that would permit minimisation of the interference background is a complex technical problem. Well renowned producers usually declare the use of certain technical solutions in the processing system or in the program algorithm for minimisation of the influence of interference background signals [2,3]. However, for obvious reasons the detail information on the particular solutions applied is not revealed by the producer. On the other hand, the users of the radiation energy meter claim that the work in the lowest measuring range is difficult (even in the products of renowned

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firms) because of the interfering background. These opinions imply a rather low effectiveness of the solutions applied.

In one of the earlier works [4] the author of this paper has presented the conception and a brief description of the principle of operation of an analog processing system permitting separation of the useful signal from the background. In this paper a modernised and improved version of this system is given together with a detail description of the principle of activity, analysis of selected design and construction problems and exemplary results illustrating the attractiveness of the processing system proposed.

2. Scheme and principle of work of the processing system

Thermal, acoustic and electromagnetic interferences lead to generation of undesirable component of the voltage system superimposing on the useful signal of amplitude \( V_m \). As a result the voltage pedestal level from which the useful signal grows is subjected to permanent and unpredictable changes. It should be noted that in the majority of cases the interferences are relatively slow-varying and have practically no effect on the maximum value of the useful voltage signal of the pyroelectric detector \( V_{pk} \) defined as a difference between the peak value \( V_{pk} \) and the background \( V_B \) at the moment directly preceding the initiation of the radiation signal. Thus, the subtraction of these values provides a correct information about value of the energy of the radiation pulse.

This paper presents original technical solution of the processing unit permitting effective minimisation of the background of interfering signals. The principle of work of this unit is based on the use of the differential signal. Immediately prior to the radiation pulse the background voltage \( V_B \) is stored and then the useful signal appears of the amplitude \( V_m \) including the \( V_B \) signal, and then the latter signal is subtracted from the former. The necessary demand determining the correct activity of the processing unit in elimination of the background is the information on the moment of radiation pulse release.

Fig. 1 presents a simplified block diagram of the proposed analog unit for processing of the pyroelectric detector response signal for measurement of optical radiation pulse energy.

**Figure 1.** A block scheme of the analog processing system permitting effective minimisation of the background of interfering signals.

The analog processing system is composed of three main subunits: the preamplifier M1 to enhance the initial signal \( V_s \) the pyroelectric detector, capacitor \( C \) and electronic key \( K \) and the peak detector cooperating with the analog-to-digital converter via the separating amplifier \( M2 \). The peak detector not only detects and stores the peak value of the input signal \( V_B \), but also sends the information (peak signal) on the moment the peak has appeared to the microprocessor unit that controls the work of the system, deals with data acquisition and processing. The signal \( V(t) \) at the output of preamplifier \( M1 \) is
a sum of two components: the useful signal from the pyroelectric detector of the amplitude $V_m$ and the background interference signal. It should be noted that the background interference signal includes not only acoustic and thermal disturbances but also the drift of the amplifier offset voltage and amplifier noises.

The interfering background is eliminated by subtraction operation performed with applying of the circuit of the capacitor and key inserted between the system of the preamplifier and the peak detector. The principle of operation of the system is illustrated in Fig. 2.

Prior to the radiation pulse the trigger signal appears of rectangular shape, controlling the work of the analog key $K$. The rising edge of this signal appears at time $t_1$ before a moment of the radiation pulse appearance and initiates preparatory procedures, i.e. switches on the key $K$. It means that for the time interval time $\Delta t$ in which the trigger signal has a logical value 1, the capacitor $C$ is connected to the output of the amplifier, therefore the temporary voltage value $V_C(t)$ across capacitor $C$ is equal to the temporary voltage value $V_S(t)$, which is only the background signal component. Directly prior to the optical radiation pulse (at $t_2$) the falling edge of the trigger signal appears and sets the switch of the key $K$ at off position. As a result the voltage value of the signal containing information about the background component $V_B$ is stored by the capacitor $C$ at the time just before the pulse radiation. Therefore, at $t_i$ at which the radiation pulse appears, the voltage $V_D(t_i)$ led to the input of the peak detector is described by the relation:

$$V_D(t_i) = V_S(t_i) - V_B = (V_B + V_m) - V_B = V_m$$  \(2\)
Fig. 3 presents the exemplary time courses of voltage changes at the output of the probe $V_S(t)$ and at the input of the peak detector $V_D(t)$, recorded by a digital oscilloscope.

**Figure 3.** Experimental obtained time courses of voltage changes at the output of the preamplifier $V_S(t)$ and at the input of the peak detector $V_D(t)$. Elimination of the background interference by the differential measurement ensures that the useful voltage signal of the pyroelectric detector response always grows from zero potential level.

The course labelled by $K$ is the signal controlling switching the key $K$ on and off. The time course of the voltage $V_S(t)$ reveals short pulses being the responses of the pyroelectric detector, whose peak value informs about the energy measured. The effect of interferences is significant, results in considerable changes in the pedestal level and in the maximum value of the useful signal of the pyroelectric detector response. It means that the application of simple configurations of systems processing such signal will result in significant scattering of the results of processing. The use of the method of background elimination based on the differential measurement ensures that the useful signal of the pyroelectric detector response always grows from the zero potential level. This means that the peak values of such signals are identical provided that the detector is excited by the radiation pulses of the same energy.

As mentioned earlier, correct operation of electronic system is determined by providing synchronisation of processing system with pulse source of radiation. In proposed solution of processing system both edges of rectangular triggering pulse signal from radiation source must occur before radiation pulse. The rising edge of triggering signal allows preparation of processing system to work and should occur at time $t_1$ before a moment of radiation pulse appearance to allow the capacitor $C$ to charge fully until its voltage reaches the level of background signal. The charging period of that capacitor is mainly determined by the capacity of that element, maximal current $I_{\text{max}}$ of operational amplifier and maximal value of amplifier output voltage $V_{S_{\text{max}}}$. The value of $t_1$ can be described by the inequality:

$$t_1 \geq \frac{C\cdot V_{S_{\text{max}}}}{I_{\text{max}}} + t_2$$

The falling edge of the trigger signal should occur at $t_2$ before radiation pulse, its value is sum of control and analog key circuits time delay $t_d$. 
The value of $t_1$ can be described by the inequality:

$$t_2 \geq t_d$$  \hspace{1cm} (4)$$

Exemplary calculations were done for following input data $I_{\text{max}} = 10$ mA, $V_{\text{max}} = 10$ V, $C = 10$ nF and $t_d = 2 \mu$s. Results of calculations show that values of described above times should be: $t_1 \geq 12 \mu$s, and $t_2 \geq 2 \mu$s.

Usage of too high value of time $t_2$ can have adverse effect based on difference between stored value of background signal with its current value. In consequence employed method of background cancellation will be ineffective. To long time $t_2$ can cause also noticeable relative error $\Delta V_C/V_C$ of voltage value stored on capacitor C caused by its discharge effect by analog key resistance $R_{\text{off}}$ (in off mode) and amplifier bias current $I_B$. The value of this relative error can be described by the relation:

$$\frac{\Delta V_C}{V_C} = (1-e^{-t_2/R_{\text{off}}C}) + \frac{I_Bt_2}{CV_C}$$

where $V_C$ is capacitor voltage value at the moment of triggering signal falling edge appearance.

In order to evaluate the effectiveness of the background signal elimination research was conducted based on comparing measurements from traditional and the improved system described in this paper, which provides background noise elimination. Pyroelectric detector was stimulated by series of hundred pulses of radiation with a fixed value of energy in presence of interferences. The signal from the detector output was processed simultaneously by the two systems. The effectiveness results of traditional and improved device providing background noise elimination where illustrated on histograms (Fig.4a and Fig.4b) showing the scatter of measurement results of the amplitude for both processing system.

![Histogram](image_url)

Fig. 4. Results scatter of measured voltage amplitude of pyroelectric detector for a) traditional processing system b) processing system ensuring background interference signal elimination
3. Conclusions
An original solution of the processing system ensuring background interference signal elimination, based on the principle of differential measurement has been designed, constructed and tested. A detail description of the principle of operation, analysis of selected design and construction problems, along with exemplary results illustrating the attractiveness of the processing system proposed are given. The results of the test measurements have shown high effectiveness of the system in background elimination. Experimental studies have shown that usage procedures and technical solutions allowed for very effective elimination of background interferences. Using differential measurement method not only removes pyroelectric detector background response signal but also eliminates noises cause by amplifiers path.

4. References
[1] Baker H J 1975 J. Phys. E: Sci. Instrum. 8 261J. 261-262
[2] Model 1835-C Multi-Function Optical Meter
http://www.spetroscopic.com/Newport/Newport1835C.pdf
[3] EPM1000 Joulemeter/Powermeter User’s Guide Molelectron Detector Inc.,
http://www.coherent.com/downloads/EPM1kUG.pdf, 2009.
[4] Odon A. 2001 Measurement Science Review vol. 1. 215-218.