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PEAK DETECTION UNIT FOR FREE-SPACE-OPTICS RECEIVER

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Abstract

The paper presents verification of a peak detection method cooperating with infrared radiation detector module applications. The work has been divided into parts including SPICE simulations and presentation of results obtained with the constructed prototype. The design of the peak detector dedicated to applications with very short pulses requires a different approach than that for standard solutions. It is mainly caused due to the ratio of pulse width and time period. In the described application this ratio is less than 10%. The paper shows testing of an analogue circuit which is capable to be inserted in these applications.

Keywords: peak detection, infrared receiver module for optical communications, open path laser communications, free space optics, quantum cascade laser.

1. Introduction

The signal peak detection is a very attractive tool to develop a new photo-receiver construction for some optoelectronic technologies. In these technologies, the photo-receiver parameters such as detectability, bandwidth and responsivity are not so important as an operating feature. There is a need to provide some extra functional features by implementation of additional units that relate to well-defined work scenarios [1]. In these scenarios, the main issue in the design of a photo-receiver is not extra capability, *e.g.* to reduce the impact of external signal noise like in spectroscopy [2–4] or to monitor the radiation level. For *Free Space Optics* (FSO) the determination of light power recorded by the receiver and emitted by the transmitter is very important [5]. In the FSO receiver, the link range and some requirements for the signal conditioning unit, *e.g.* for an automatic gain control unit and beam pointing stabilization are defined by the radiation power [6–8]. For laser operation, optimization of the operating conditions ensuring low energy consumption and better reliability is provided by monitoring of the light signal power. Currently, there are no market suppliers of detection modules with a feature of direct monitoring of the pulse power [9]. In practice, the power analysis is performed using these modules with additional external measurement devices such as signal acquisition cards, oscilloscopes or spectrum analysers. However, this solution could be not practical when the detection module is a component of another device (*e.g.* FSO receiver) [10, 11].

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Currently, the determination of peak level of radiation pulses is provided by some advanced signal processing circuits. It is possible to directly implement these circuits in detection modules without significant changes in their complexity. During the design process, the main determinants are some features of the analysed signal. These features are described by the dynamics of amplitude changes, frequency, duration, and duty cycle. In principle, these circuits can be built basing on analogue or digital technologies. The first one uses a peak detector designed for *e.g.* automatic gain control systems. Creating ultra-fast waveform digitizers is possible due to the development of digital technology and applying fast A/D converters and FPGAs or DSPs [12].

The paper presents some works related to the construction of a pulse monitoring unit for light detection modules used in *Free Space Optical* (FSO) systems. Some selected electronic circuits that can be used for this purpose are also discussed. The developed concept of this unit and analyses of its operation are described. In the experimental part, the developed unit prototype and the results of the preliminary tests are presented. The obtained results show that operation of the designed FSO receiver with pulse power monitoring is possible.

2. Analysis of requirements for monitoring unit

In general, the analysis of requirements regarding the construction of a monitoring unit is closely related to its operation conditions. This unit works in both transmission and detection channels of the FSO system. A functional diagram of this system is shown in Fig. 1.

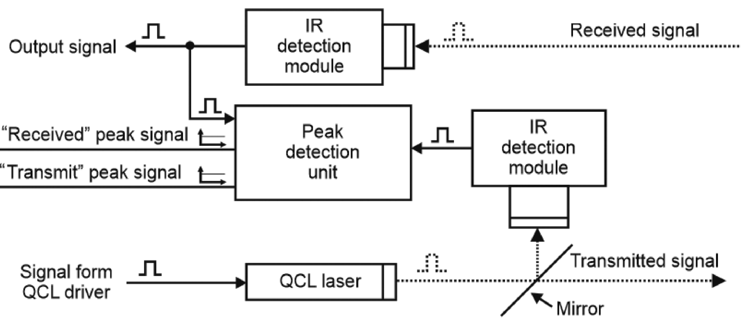

Fig. 1. A functional diagram of the FSO system.

The designed unit contains two signal paths for simultaneous monitoring the output radiation signal from the FSO transmitter and registering the signal amplitude by the FSO receiver. This configuration enables to apply the light power control depending on both safety of operation and a long data range for different atmospheric conditions [13, 14]. Additionally, information about the receiver signal amplitude can be used to diagnose the operation of the laser link or to detect potential attempts to disturb or to capture data.

An important issue affecting the construction concept of the designed unit are parameters of the output signals from detection modules. For the designed FSO link, these parameters are defined by the transmitter light modulation capabilities. The light signal is emitted by high-power pulsed quantum cascade lasers developed at the Institute of Electron Technology. These lasers enable operation with a pulse duration of about 10–20 ns and a frequency above 4 MHz. Basing on these critical parameter values, a signal modulation method of PPM-5 has been implemented.

In this way, a data rate of 10 Mb/s will be ensured taking into account possible additional functionalities of the data link transmission (correction, online BER analyses, *etc*.).

3. Monitoring unit for detection modules used in FSO system

In the described FSO system the main problem of choosing a peak detection method is due to a very short pulse width (within a 10 to 20 nanoseconds limit) and a position modulation procedure. From a viewpoint of construction of the amplitude monitoring unit they cause an important research issue.

Digital technology enables to read a pulse amplitude using an FPGA and A/D converters. However, it is a costly and complicated solution from both hardware and software points of view. The solution with FPGA described in [15] enables to detect only an excess of the adjusted threshold voltage. For precise envelop detection of nanosecond pulses a very high sample rate is required [16]. In applications with slower A/D converters an advanced additional circuit is necessary to work as a fast trigger. Such a solution makes this unit even more expensive than the detection module itself. Therefore, it was decided to try to develop an analogue circuit. In general, commonly used electronics with opamps, rectifier diodes and capacitors are not so efficient for pulses with a short duration and a variable duty factor. The simulations and lab tests of these standard circuits (with opamps' peak detector applications) showed that they significantly lower the measured peak value of a monitored signal. This is mainly due to the reverse currents of the semiconductor diodes used in popular peak detector applications. The design note [17] describes the opportunities and limitations of analogue peak detector circuits with opamps presenting the dependence of DC detector error on frequency and pulse width. The example shown in this note confirms the limitations of applicability of this circuit to cooperate with nanosecond pulses. *E.g.*, a circuit with LT1190 works with an error lower than 10% for pulses with a duty cycle width of around 55 ns. A similar standard circuit was described in [18] working with microsecond pulses and using a digital method to resolve the capacitor discharge problem associated with the diode reverse current which was mentioned above. For these reasons, it was decided to use another solution – a fast comparator with ECL outputs working as a capacitor charger.

4. Operation analysis of monitoring unit

The monitoring unit of the detection module was built based on the circuit described by Krehlik and Sliwczynski [19].

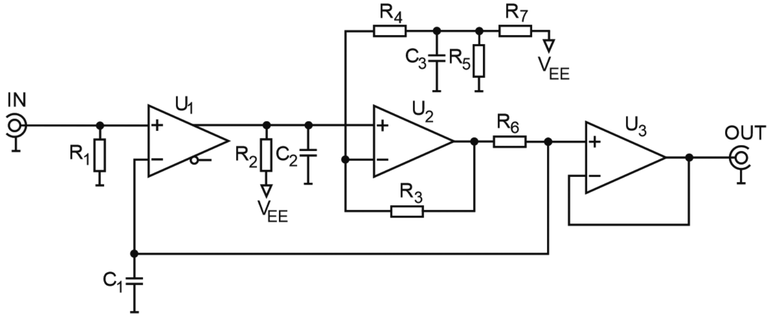

Fig. 2. A peak detector circuit for monitoring the pulse power.

To determine its initial capabilities the circuit operation was analysed by SPICE software (Multisim, National Instruments). The simulation model was built of a comparator with ECL outputs (MAX9600 model) [20]. This comparator is characterized by a very short signal propagation time of 500 ps [21]. The circuit with C_2R_2 determines the response time, while the configuration with U_2 operational amplifier provides shifting the voltage level from the comparator to one of ECL outputs. The first step of simulation cycle was testing the ability to detect *ns*-pulses with a duty cycle less than 1%. Basing on the simulations results, there had been defined a practical compromise in detection of laser pulses. It consisted in selecting a time constant of R_2C_2 (C_1 equal to C_2) circuit. The circuit performance was checked for different time constants resulting from changes in C_2 value (R_2: 1 kΩ; and C_2: 220 nF, 330 nF, 470 nF). Basing on the carried out simulation it was observed that the time constant affects not only the response time of the circuit, but also the level of signal fluctuations (Fig. 3). Moreover, a low value of R_6 can cause a significantly overloaded output signal (straight curve).

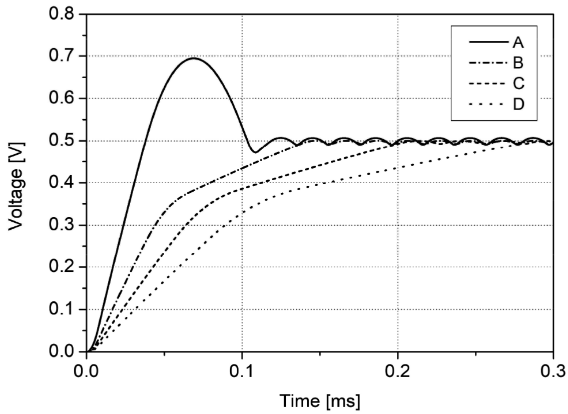

Fig. 3. Simulation responses of the peak detector for C_2 capacities of 220 nF (B), 330 nF (C), 470 nF (D). "A" curve was obtained with C_2 = 220 nF and a low value of R_6 = 1 k.

The influence of the signal to noise power ratio on the circuit operation was also determined during simulations. For a better illustration, the simulations were carried out for a 4 kHz pulse signal with a duration of 50 µs and amplitude of 500 mV. Johnson's noise with rms voltage of 46.7 mV generated in a bandwidth of 1 MHz was added to the monitored pulse signal. The accurate noise rms value was calculated based on the noise received from the amplified build-in SPICE noise source. The influence of R_2C_2 value on the circuit time constant was also determined. Fig. 4 shows some results obtained for various values of C_2 (and equally C_1) capacitors.

Based on the results, the unit noise factor was analysed. This factor is defined as – a ratio of the SNR (*signal-to-noise ratio*) value at the unit input (SNR_i) and the SNR value at the unit output (SNR_o) (1), (2):

$$F = \frac{SNR_i}{SNR_o}\,. \tag{1}$$

It can be rewritten as:

$$F = \frac{S_i/N_i}{S_o/N_o}\,. \tag{2}$$

The calculation also includes the noise resulting from the limitation of the monitoring unit. Some output signal fluctuations at the steady state are caused by this limitation which also depends

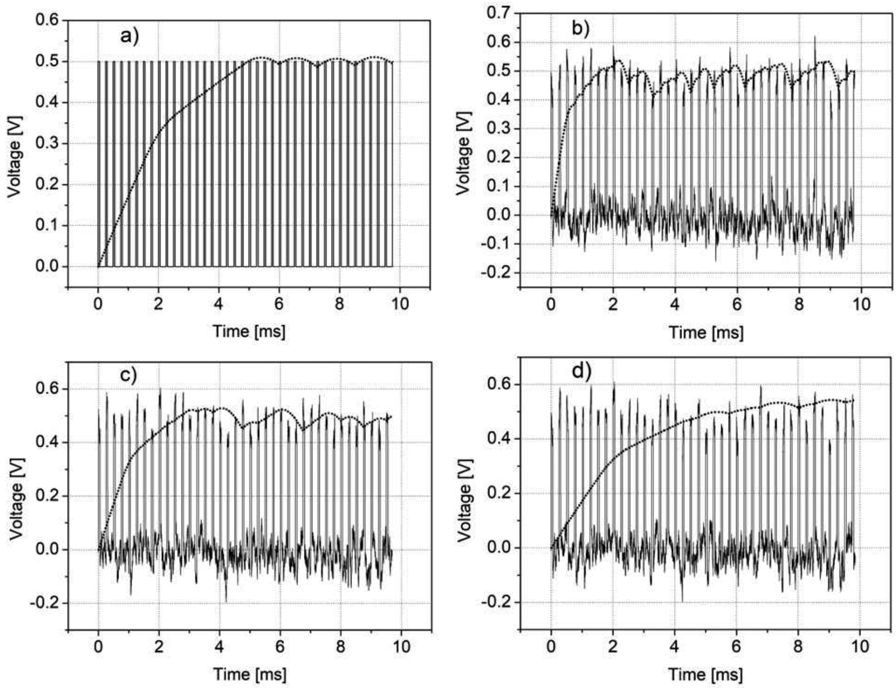

Fig. 4. Response signals of the monitoring unit for: a) a noiseless reference signal and $C_2 = 2$ μF; b) a noisy signal for $C_2 = 470$ nF; c) a noisy signal for $C_2 = 1$ μF; d) a noisy signal for $C_2 = 2$ μF.

on R_2C_2 value. The observed increase in the noise figure with the increase in C_2(C_1 equal to C_2) capacity results directly from a decrease in the noise bandwidth. Theoretically, a high value of capacity improves the SNR ratio, but in practice it also increases the response time of the monitoring unit. Fig. 5 presents some characteristics of the response time and standard deviation of output voltage (StD) versus C_1 and C_2 capacities [22].

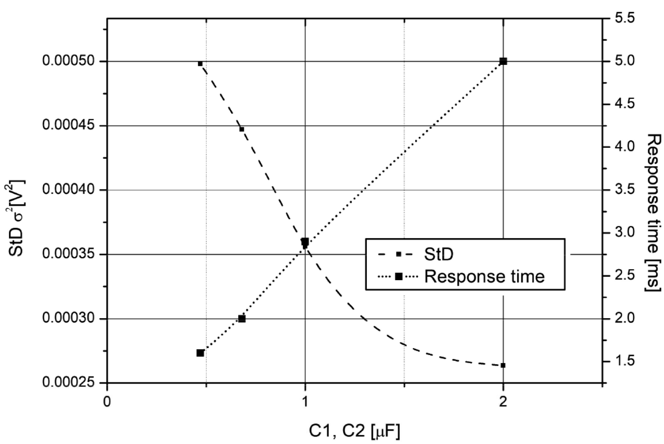

Fig. 5. The influence of the C_1, C_2 capacities on standard deviation of the output voltage and the response time of the peak monitoring unit.

5. Preliminary tests of monitoring unit with FSO detection module

The monitoring unit was made in the form of a two-sided PCB circuit with 50 Ω impedance matching to the detection module, AIP-10k-200M model produced by VIGO System S.A. (Fig. 6). During tests it was connected directly to the AC coupled output of the detection module.

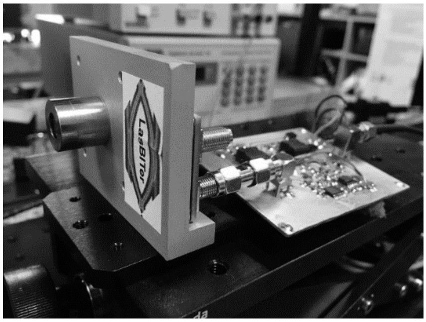

Fig. 6. A photo of the detection module with the developed monitoring unit.

Figure 7 presents the lab setup the obtained detecting device (the detection module with the peak detector unit) was tested in. The laser pulses with a wavelength of 9.3 µm, frequency of 4 MHz, duration of 16 ns and 400 mW peak power were used. The output signals from the detection module and the developed monitoring unit were recorded using a DSA 70404 analyser.

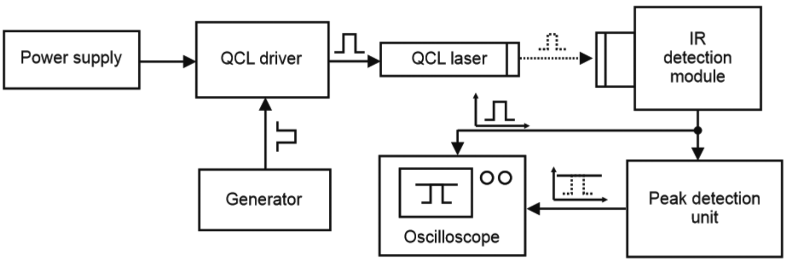

Fig. 7. A block diagram of the measurement setup.

A light pulse registered with the Vigo System detection module and an output signal of the peak detection unit are presented in Fig. 8. The levels of both signals are basically comparable, and the differences are less than 5%.

Using the same setup, the operation characteristics of the monitoring unit were determined (Fig. 9a). There is a linear dependence between the amplitude of input pulses and the output signal level with adjusted R-squared value of 0.9996. The determined linear coefficient is 1.04 and the estimated processing error of the monitoring unit is at a level of approx. 4%. The obtained results have been used to determine the control characteristics of a quantum cascade laser. Basing on AIP detection module responsivity, the configuration of the measurement setup (light path, beam divergence) and the output signal from the monitoring unit, the dependence of the optical pulse power on the laser driving voltage was established (Fig. 9b). The results were compared with the reference ones obtained using an optical power meter SOLO 2. The difference of results was below 5%.

Metrol. Meas. Syst., Vol. 26 (2019), No. 2, pp. 377–385.

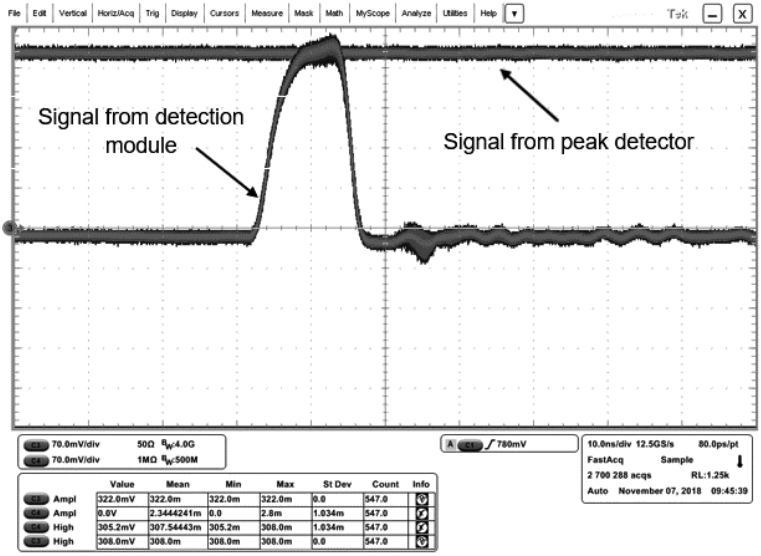

Fig. 8. A pulse shape registered with the detection module and an output signal from the monitoring unit.

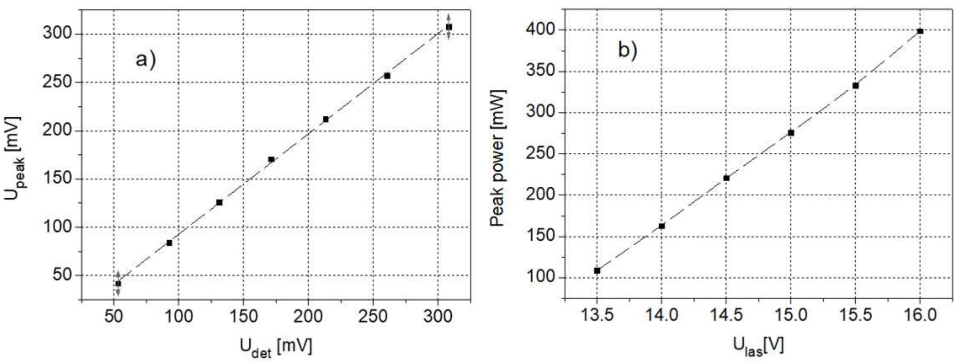

Fig. 9. Processing characteristics of the monitoring unit (a) and control characteristics of QCL laser (b).

6. Conclusions

The results of performed analyses and tests were used in constructing a pulse peak detector unit. This unit is characterized by a linear processing function and an integrated construction. In comparison with the commonly used peak detectors, the impact of low duty-cycle pulses (especially short pulses) on a decrease of its output signal is minimized. These features are very important to design optical detection modules with unique functionalities. In that way, a direct power control of optical radiation is provided. Additionally, a simple change of the unit configuration (changes of C_2 and C_1 capacitor values) can be used to increase SNR value. However, a compromise in the response time of the unit should be analysed. In the future, the monitoring unit could be directly implemented in the detection module to create a fully-integrated construction.

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References

[1] Rogalski, A., Bielecki, Z., Mikolajczyk, J. (2017). Detection of optical radiation. *Handbook of Optoelectronics, Second Edition: Concepts, Devices, and Techniques*, 1, 65–124.

[2] Mikolajczyk, J., Bielecki, Z., Stacewicz, T., Smulko, J., Wojtas, J., Szabra, D., Lentka, Ł., Prokopiuk, A., Magryta, P. (2010). Detection of gaseous compounds with different techniques. *Metrol. Meas. Syst.*, 17(4), 537–547.

[3] Wojtas, J., Bielecki, Z., Stacewicz, T., Mikolajczyk, J., Medrzycki, R., Rutecka, B. (2011). Application of quantum cascade lasers in nitric oxide and nitrous oxide detection. *Acta Phys. Pol. A*, 120, 794–797.

[4] Wojtas, J., Mikolajczyk, J., Nowakowski, M., Rutecka, B., Medrzycki, R., Bielecki, Z. (2011). Applying CEAS method to UV, VIS, and IR spectroscopy sensors. *Bull. Polish Acad. Sci. Tech. Sci.*, 59, 415–418.

[5] Mikolajczyk, J., Bielecki, Z., Bugajski, M., Piotrowski, J., Wojtas, J., Gawron, W., Szabra, D. (2010). Analysis of free-space optics development. *Metrol. Meas. Syst.*, 17(4), 537–547.

[6] Al-zubaidi, N.S., Al-dahash, J.A., Jassim, J.M., Ali, R.N. (2009). Optical Repeater for free-space laser communication System. *J. kerbala Univ.*, 7, 178–184.

[7] Juarez, J.C., Sluz, J.E., Young, D.W. (2011). Optical Automatic Gain Controller for High-Bandwidth Free-Space Optical Communication Links. *Appl. lasers Sens. Free Sp. Commun.*, 7–9.

[8] Barna, A., Bohus, J. (2015). Active stabilization of the beam pointing of a high – power KrFlaser system. *Metrol. Meas. Syst.*, 22(2), 165–172.

[9] Rogalski, A. (2011). Recent progress in infrared detector technologies. *Infrared Phys. Technol.*, 54, 136–154.

[10] Brillant, A. (2008). Laser Power and Temperature Control Loops. in *Digital and Analog Fiber Optic Communications for CATV and FTTx Applications*, 591–625.

[11] Henniger, H., Wilfert, O. (2015). *An Introduction to Free-space Optical Communications. An Introduction to Free-space Optical Communications*.

[12] Takahashi, H., Kodama, S., Kawarabayashi, J., Iguchi, T., Nakazawa, M. (1993). A new pulse height analysis system based on fast ADC digitizing technique. *IEEE Trans. Nucl. Sci.*, 40, 626–629.

[13] Andrews, L.C. (2004). *Field Guide to Atmospheric Optics*.

[14] Sousa, I., Queluz, M.P., Rodrigues, A. (2017). An Efficient Visibility Prediction Framework for Free-Space Optical Systems. *Wirel. Pers. Commun.*, 96, 3483–3498.

[15] Singh, A., Dubey, S.K. (2013). *Design and Simulation of FPGA based Digital System for Peak Detection and Counting*., 3, 804–807.

[16] Feng, L., Zhang, Q., Liu, X., Zuo, L., Yang, A. (2014). A method of peak detecting for nanosecond pulse in optical performance monitoring system. *China Commun.*, 11, 78–82.

[17] Wright, J. (1992). Peak Detectors Gain in Speed and Performance. *Appl. Note.*

[18] Barna, A., Földes, I.B., Gingl, Z., Mingesz, R. (2013). Compact energy measuring system for short pulse lasers. *Metrol. Meas. Syst.*, 20, 183–190.

[19] Krehlik, P., Śliwczyński, Ł. (2002). High-speed peak detector uses ECL comparator. *Design Ideas-September*.

[20] National Instruments. (2010). NI Multisim Fundamentals.

[21] MAX9600. *Dual ECL and Dual/Quad PECL, 500ps, Ultra-High-Speed Comparators*. Datasheet for Maxim. (2002).

[22] Dragos, D. (2011). AN1353 Op Amp Rectifiers, Peak Detectors and Clamps. *Technology*, 1–16.