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Measurement of Threshold Energy of Optical Receiving Devices

Mikhail V. Kirgetov[1], Eduard V. Kuvaldin[2], Anna A. Shulga[3]

[1]Metrology Department Chief, Metrology Department, S. I. Vavilov State Optical Institute, Saint-Petersburg, Russia

[2] Senior Researcher, Metrology Department, S. I. Vavilov State Optical Institute, Saint-Petersburg, Russia

[3] Engineer, Metrology Department, S. I. Vavilov State Optical Institute, Saint-Petersburg, Russia

Abstract: *Pulse method for measuring the threshold energy of receiving devices and photo detectors is described. The method is suitable for pulse and continuous wave mode systems. Measurements are made without disassembling the device being tested and not require a dark room. Result of radiation pulse impact on test device is observed on monitor screen or listened to by ear. Comparison of measurement results and theoretical calculations is carried out. The experiments were carried out on an optical communication system using LED emitter. The paper presents range calculation of device being tested.*

Keywords: *threshold energy, detectors, continuous mode, pulsed mode.*

1. INTRODUCTION

Performance testing and measurement of the main characteristics of receiving optoelectronic systems is usually carried out on stands [1, 2, 3]. Rapid analysis under operating conditions is possible with the use of pulse emitters. Usually test pulse is formed similar to real pulse, but this is not necessary. By analogy with pulse technique, short pulse comparable with duration of testing device pulse characteristic, which is called delta pulse (δ – pulse), is better to use. When this pulse is applied to device under test, the device itself generates a pulse on its output, called pulse characteristic of device. Delta pulse is a universal test pulse suitable for almost all types of devices. Devices that form a delta pulse of radiation are suitable for testing not only photo detector devices operating in pulse mode, such as laser rangefinders, but also devices of continuous wave mode operation. The pulsed mode operation of installation can be successfully applied to check optoelectronic systems of continuous wave operation. For them, determining factor is threshold radiation power P_p. It is related to threshold energy W_i of operating pulse by the equation

$$P_p = 0.63\ W_r / t_{0.1}, \qquad (1)$$

where $t_{0.1}$ is the duration of pulse characteristic of investigated system at level 0.1 of maximum value.

In pulse mode of measurement interference is less and moment of radiation pulse impact on matrix detectors of tested systems is better to observe.

Further method of measuring radiation threshold energy of a device operating in a continuous mode with photo detector used in optical communication system in the infrared range of spectrum as an example will be considered. The communication system uses LED emitter with a wavelength of 920 nm, operating in continuous wave mode with frequency modulation. The modulation is performed at a subcarrier frequency of 500 kHz by changing current of LED. The transmitting beam is formed by lens. The radiation divergence at half-power level is approximately 2.5 degrees. The receiver has a 100 mm diameter lens. Modulation is made by a speech signal. Check of operability and measurement of threshold energy of receiving device is made by following method.

2. MEASUREMENT METHOD

The LED emitter with a wavelength of 920 nm is installed on optical axis of test device's lens (Fig. 1) at a distance *r* from device. The distance is chosen from possibility of measuring irradiance on input pupil of receiving lens and filling entire lens with measured radiation. For a device with a narrow field of view, the distance *r* may be too large. In this case, before test device aperture diaphragm with diameter *D* is set up. Diameter of aperture depends on field of view of device and focal length of his lens.

The emitter [4] operates in pulse mode with pulse duration of 100 ns and a repetition rate of 250 Hz. In test receiver the frequency of emitted pulses repetition is listened to. Dense light filters are installed in front of emitter to determine moment of listened signal loss. Transmittances τ of light filters are measured by method of additional attenuator [5] at a wavelength of 920 nm. The same type LED as in emitter is used in measurements. LED radiation is limited by two diaphragms at angle of approximately 2–3 degrees. Transmittance is selected within range of $10^{-2} - 10^{-5}$.

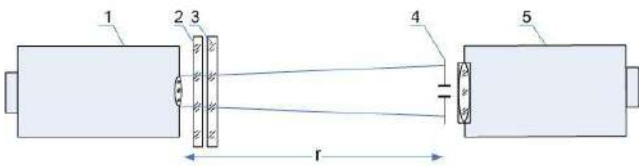

Fig. 1: Scheme of measurement: 1 – LED emitter, 2, 3 – light filters, 4 – diaphragm, 5 – tested device

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The emitter is calibrated by radiation energy *W*. Reference photodiode (PD) with calibrated energy responsibility S_e [6] is set at a certain distance r_1 from emitter behind diaphragm with area *A* and signal voltage *U* measured by an oscilloscope. The distance is selected thus energy decrease within limits of PD measurement. The radiation energy W_1 entering receiving lens of test device with an area A_1 is equal to

$$W_1 = W A_1 / r^2,$$

where $W = U A / S r_1^2$.

Responsibility of reference PD receiver is approximately 1.1×10^7 *V/j.* Radiation energy on input of tested device is 10^{-8} – 10^{-9} joules. The threshold energy of the test device is calculated according to equation

$$W_p = W_1 \tau.$$

3. MEASUREMENT EQUPMENT

The emitter is a delta pulse source for system under test. Duration of output signal is determined by inertial properties of system. This is duration of pulse response for pulse mode devices, and bandwidth of receiving device for continuous wave mode systems. LED emitter with a pulse duration of 100 ns and a maximum power of 0.5 W at a wavelength of 920 nm [4] is used in experiment. The frequency of pulses repetition for checking devices with monitors was several Hertz, for ear-receiving – several hundred Hertz. Pulses frequency of repetition was determined by a multivibrator, which started a pulse duration generator with a power amplifier. In power amplifier (Fig. 2) a powerful field-effect transistor is used, since it has a shorter rise and fall time of pulse compared to bipolar transistors. The field-effect transistor requires a large voltage on its input, so an additional amplifier is installed before it with a *p-n-p* type transistor to obtain a pulse of positive polarity and an amplitude close to voltage of power supply. Transistors were selected with a minimum initial current to save power supply power.

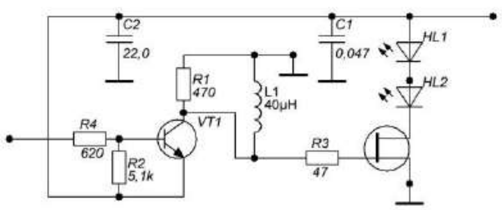

Fig. 2: Scheme of short pulse generator of LED radiation

To obtain short pulses of radiation the load of the first transistor includes inductance, which together with input capacitance of field-effect transistor forms an oscillating circuit. The circuit is shunted by a small resistance, so as to obtain a single period of oscillation. By reducing the inductance, pulse duration up to 100-150 ns could be obtain with widespread transistors and LEDs. Further duration shortening of radiation pulse could be achieved only in laser diodes with field-effect transistors with a small input capacitance. Thus, in scheme under consideration with a laser diode at a wavelength of 1.06 microns, a pulse duration of 10 ns was obtained. At the same time, peak power in radiation pulse was 10 times greater than in continuous wave passport mode of laser diode radiation.

The photodiode energy meter used a silicon photodiode with 10 mm receiving pad diameter. Load of photodiode is parallel connection of a resistor and an integrating capacitor (Fig. 3).

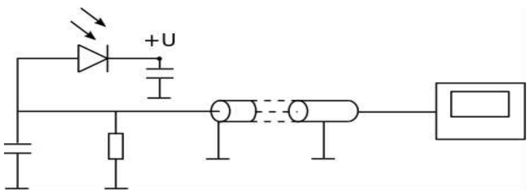

Fig. 3: Scheme of connection of measuring photodiode

The resistor is used to calibrate the spectral responsibility of S_p in A/W with conversion to energy responsibility S_e in V/j according to the formula $S_e = S_p/C$, where *C* is capacity of integrating capacitor [5]. Receiver limits of measurement with an oscilloscope with a sensitivity of 1 mV/div at a photodiode supply voltage of 6 V and for a wavelength of 920 nm are 2.5×10^{-8} – 1×10^{-5} W for power and 1.5×10^{-9} – 6×10^{-7} J for energy. The upper limits correspond to linearity limit of photodiode conversion characteristic.

4. THEORETICAL CALCULATION

4.1 The calculation of device energy threshold under test

For optimal photo detector with first-order photoelectric filters [7] with a noise coefficient N=4 and a temperature for normal operating conditions of device, the noise voltage at load of photodetector is

$$U_n = 4.5\cdot10^{-11}/C^{0,5}.$$

This equation can be used for preliminary calculations of optimized photo detector device in energy measurement mode. Resistor *R* is selected from maximum acceptable zero offset due to the dark current. In the case when load of photo detector is oscillating circuit equivalent circuit resistance R_e instead of *R* is used. For case of threshold energy, when signal voltage $U_s = U_n$

$$W_p = 4.5\cdot10^{-11}\, C^{0,5}/S_p. \qquad (2)$$

Here S_p is the spectral responsibility of photo detector. In this case, S_p is equal to 0.4 A/W for a wavelength of 920 nm. The capacity of a 3×3 mm silicon photodiode

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is 100 pF. After substituting these values in the equation (2), the value of threshold energy $W_p = 1{,}1\times10^{-15}$ j is derived.

Accuracy of measurements and calculations are verified by calculation the range of tested communication system and compartment calculated data with experiment data.

4.2 Calculation of LED optical communication network range

The maximum operating distance of device L can be calculated using formula for rangefinders [2]

$$L = D\,(W\rho_1 / W_p)^{0,5} / 2, \qquad (3)$$

where D is diameter of input pupil of receiving lens, W is the energy of emitter, ρ_1 is transmittance of receiving lens, W is the energy on receiving lens, proportional to illumination from source, which is equal to

$$W = W_1 / L^2, \qquad (4)$$

where W_1 is time integral of energy intensity of light. In an experimental optical communication device, LED with a lens was used with radiation power $P = 80$ mW. In LED emitter was installed a lens that reduces the divergence of the beam of half power $\alpha_1 = 2.5$ degrees, which corresponds to 0.0019 steradian. Then light intensity $P_1 = P/2\,\alpha_1 = 80/2\cdot0.0019 = 21050$ mW.

Energy can be defined as result of division power of LED on time interval determined by bandwidth of detector. Bandwidth of 5 kHz is corresponding to spectrum of speech signal. This interval will be $t = 2\times10^{-4}$ s. Then $W_1 = P_1 t = 4{,}1\times10^{-3}$ j. Range L and energy W_1 are included in equations (3) and (4). Substitution (4) in (3) leads to equation

$$L = D\,(W_1 P_1 / L^2 W_p)^{0.5} / 2.$$

Solving the equation, we have

$$L^4 = W_1 P_1 D\, 2 / 4\, W_p.$$

From both parts of equation can be extracted the square root and finally we have

$$L^2 = D\,(W_1 P_1 / 4\, nW_p)^{1/2}.$$

Where n is the signal-to-noise ratio equal to 6, which is necessary for speech intelligibility. Substitution of data given below gives the following results for maximum range of tested device

$$L^2 = 0{,}1\,(4{,}1\cdot10^{-3}\cdot0{,}8/4\cdot6\cdot1{,}1\cdot10^{-15})^{1/2} = 3.5\cdot10^{-4},$$

$$L = 160 \text{ m}.$$

5. EXPERIMENTAL RESULTS

The threshold energy of receiving device of considered optical communication was measured according to scheme on Fig. 1. The distance r was 2 m, the distance r_1 was 0.5 m. 3 light filters with overall transmittance 1.4×10^{-2} were used in measurements. Threshold energy was 2×10^{-13} joules. It was bad result, because gain of photo detector amplifier is small or noise factor of amplifier is large. So maximum measured distance of considered LED optical communication system was 50 m. The result 52 m was calculated by equation (5). Threshold power can be calculated from equation (1). In this case time interval t is used instead of $t_{0.1}$.

6. CONCLUSIONS

The pulse method for checking performance and measuring threshold energy is easy to operate and requires a minimum amount of simple test equipment. The method does not require the use of special equipment for alignment and dark room. The operation of receiving device can be checked using only one pulse emitter. In this case, there is no need to move and disassemble the receiver. For complex and expensive systems, it is advisable to include a pulse emitter in the equipment delivery set. The considered method of measurement and test equipment is suitable for testing photo detector devices of pulsed and continuous wave mode operation.

REFERENCES

[1] E. V. Kuvaldin, A. G. Ershov, V. F. Zakharenkov, V. M. Polyakov, L. N. Arhipova, *Testing unit for laser rangefinder,* Sixth International Symposium on Precision Engineering Measurements and Instrumentation, 754457 (31 December, 2010), doi: 10.1117/12.885857

[2] E. V. Kuvaldin, A. A. Shulga, *Light source for measurement of threshold power and energy of optical radiation,* J. Opt. Technol., vol. 84, pp. 108-112, February 2017.

[3] A. G. Ershov, E. V. Kuvaldin, *Setup for measuring the threshold energy of radiation in the infrared region of the spectrum*, J. Opt. Technol, vol. 86, pp. 367–369, June 2019.

[4] E. V. Kuvaldin, A. A. Shulga, *Pulsed light-emitting diode emitter*, J. Opt. Technol, vol. 84, pp. 85–89, September 2017.

[5] E. V. Kuvaldin, A. A. Shulga, *Calibration of Power meters of optical Radiation Over a Broad Range,* Proc. of Applied optics-2018, p. 608, December 2018.

[6] E. V. Kuvaldin, *Calibration of Radiation Sources and Detectors Over a Broad Range of Measurement of the Energy of Optical Radiation*, Measurement Techniques, vol. 61, i. 8, pp. 1-6, DOI: 10.1007/s11018-019-01567-4.

[7] E. V. Kuvaldin, *Choice and optimization of functional scheme of diffuse reflection spectrophotometer. Part 2,* Scientific device building , vol. 11, i. 2, pp.26-30, February 2001.