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BUILDING A COMPUTER MODEL OF AN OPTOELECTRONIC BURGLAR ALARM DETECTOR

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Abstract. *The work deals with modeling an optoelectronic burglar alarm detector at the functional diagram level by means of MATLAB tools. The developed model makes it possible to estimate the reliability of separating signals from a human intruder and interferences by means of the logic unit. It also allows determination of parameters that cause both intruder missing as false alarms.*

Keywords: modeling of systems; optoelectronics; burglar alarm detector; Matlab.

I. INTRODUCTION. SETTING THE PROBLEM

Modeling of systems at the functional diagram level is widely used in the practice of design [1]. In this work modeling of an optoelectronic burglar alarm detector has been carried out at the functional level by means of Matlab tools. Such detectors are widely used in security systems, but such fundamental features as intruder detection probability and false alarm probability are not presented in device specifications. Theoretical evaluation of interference and noise impact on the quality of the security system of the protected object is a matter of interest.

In optoelectronic passive burglar alarm detectors various methods of signal processing are used. In this paper we consider one of the most common analog methods of signal processing.

A generalized structure of the infra-red (IR) detector is shown in Fig. 1.

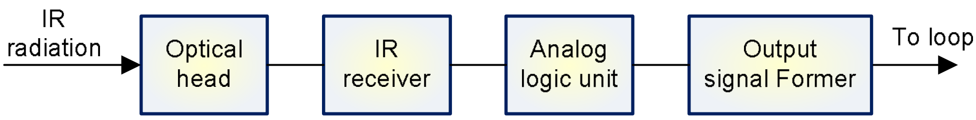

Fig. 1. A generalized structure of the IR-detector

The units of the generalized structure are as follows.

The optical head collects the heat radiation flux of from the area defined by the antenna aperture and focuses it on the pyroelectric element of the IR-receiver.

The IR receiver contains a pyroelement together with a matching element and an amplifier. The purpose of the pyroelement is converting infrared radiation into an electric signal proportional to the radiation power. This signal is then amplified and filtered by a low frequency amplifier. This separates the signal from the noise and increases the reliability of the logic unit.

The logic unit analyzes the power level and shape of the electric signal and generates the binary signal “intruder–no intruder“.

The output signal former converts the binary signal into a signal perceived by a standard burglar alarm device (usually, resistance variation of a two-terminal element included in the loop).

Reliable separation of human intruder signals from interference signals, carried out by the logic unit, determines both the undetection probability and the level of false alarms generated by the burglar alarm detector. That’s why a detailed account of logic processing of signals is of particular importance.

The analysis has been done using an analog logic unit of a typical structure.

II. THE FUNCTIONAL DIAGRAM

The functional diagram of a passive detector model is shown in Fig. 2. The characteristic features of the model, certain simplifications being made, are:

1. The optical head and the pyroelectric detector are replaced by a generator of pyroelectric detector signals consisting of three independent parts: a human intruder signal generator, a background fluctuations generator and a generator of broadband equipment and electrical noise and interference.

2. The logic unit analyzes the signal power level using amplitude selectors, and the shape of the signals – using time selectors. The integrator converts time relationships to amplitude relationships. The threshold device generates a binary signal.

3. The output signal former is simulated by displaying information messages on the screen. This model is naturally adaptable for computer simulation.

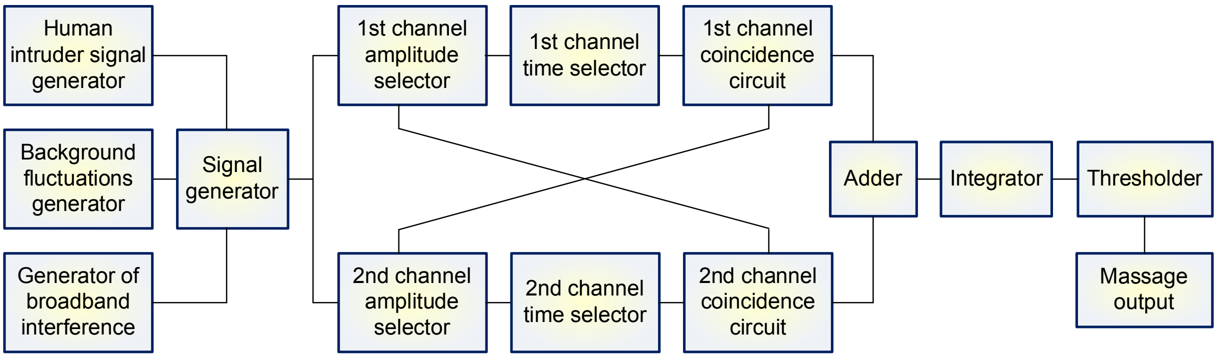

Fig. 2. The functional diagram of an IR-detector model

Computer modeling of the functional diagram by means of MATLAB tools is presented below.

III. IR-RECEIVER SIGNAL MODELING

Adequate modeling can rely only on actual measurements of the output signal of the IR-receiver of the detector when the protected area is intruded by a person or animal. These data in open scientific sources are not presented in full measure [2], which was the reason for the experiment.

The main difficulty of conducting the experiment occurs due to the frequency range of the measured signal. A man crosses the protected area of the detector within 1 ... 10 sec. In order to fix a signal of such duration, we need a storage oscilloscope with long sweep time. Earlier, only special-purpose hardware could satisfy these requirements. But with the development of computerized devices, which is a modern trend in instrument engineering now [3], as began to appear low-cost general-purpose devices having wide possibilities appear nowadays (produced mostly by little-known companies).

In the presented research we used a USB-oscilloscope OSCILL manufactured in St. Petersburg. Its stated specifications are:

– bandwidth – 15 MHz;
– input resistance/capacitance – 1 MOhm/22 pF;
– sensitivity – 22 mV/div – 10 V/div, 5 %;
– maximum sweep duration – 7.5 sec.

After the software of the oscilloscope connected to a USB port has been loaded in the computer, the front panel of the oscilloscope with its adjustment knobs appears on the monitor (Fig. 3).

The analyzed voltage is applied to a standard connector. In the example in Fig. 3a 10 Hz voltage is taken from a generator.

The stated specifications of the OSCILL USB-oscilloscope are guaranteed by the manufacturer.

The USB-oscilloscope was used to study experimentally the output signal of an IR-receiver of the “Foton” brand (Fig. 1) with a pyroelement in the focus of a reflector antenna representing an assembly of six flat mirrors. The directional pattern of this antenna has the form of a 72-degree sector and consists of six closely spaced areas.

Figure 4 shows a typical oscillogram of the output signal of an IR-receiver that occurs when an intruder crosses the reliable detection area of the detector. The oscillogram scale factors are: 5 V/div vertically and 0.5 sec/div horizontally. During the research the external conditions were held constant, namely the speed of the intruder, its trajectory and body attitude relative to the detector, room lighting and the number of working devices.

As seen in Fig. 4, the signal shape is a sequence of two bipolar pulses corresponding to the detector’s response to the intruder’s entering and leaving the protected area. The parameters of the signal fluctuate significantly, its shape remaining unchanged in general. To assess the degree of signal fluctuations, statistical processing of the information parameters of the IR-receiver signal was performed using Statistic Toolbox, a Matlab application.

The processing results are as follows:

1. Duration of the response to an intruder’s entering the protected area – 1.45 ± 0.09 sec.
2. Duration of the response to an intruder’s leaving the protected area – 1.53 ± 0.12 sec.
3. Positive pulse amplitude – 4.56 ± 0.58 V.
4. Negative pulse amplitude – 3.76 ± 0.70 V.
5. Positive pulse duration (at 0.5 amplitude level) 0.70 ± 0.15 sec.
6. Negative pulse duration (at 0.5 amplitude level) 0.78 ± 0.07 sec.
7. Duration of the interval between pulses extremes 1.94 ± 0.32 sec.

Here the first number is the arithmetic mean of the measured values, the second – the arithmetic mean of the absolute deviations of the measurements from the first number.

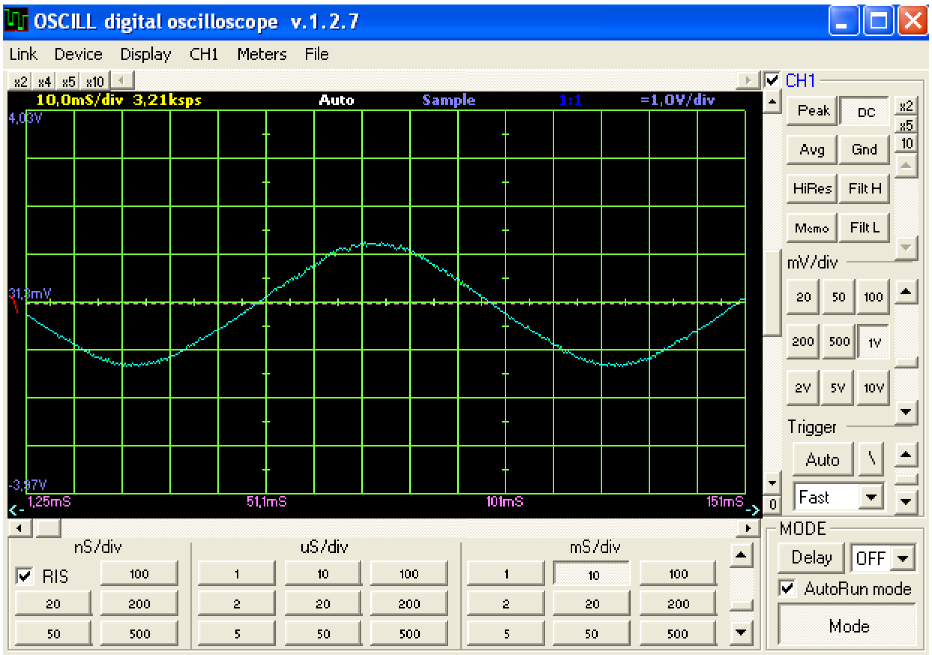

Fig. 3. The front panel of an OSCILL USB-oscilloscope

Apparently, the signal fluctuations are caused by both nonhomogeneous thermal radiation of a human body in different directions and nonhomogeneous reflection of thermal radiation from other sources by a human body. The point which is also important is the fact that it is impossible for any man to accurately control his speed. The measurement results allow us to build an adequate model of the signal and noise at the input of the logic unit of a passive infrared burglar alarm detector. For example, Fig. 5 shows a receiver output signal approximation by the following function:

$$U = \begin{cases} 18\left(1-\exp(-3t)\right)\cdot\exp(-3t), \\ \qquad\qquad 0<t<1.5; \\ -18\left(1-\exp\left(-3(t-1.5)\right)\right)\cdot\exp\left(-3(t-1.5)\right), \\ \qquad\qquad 1.5<t<3. \end{cases}$$

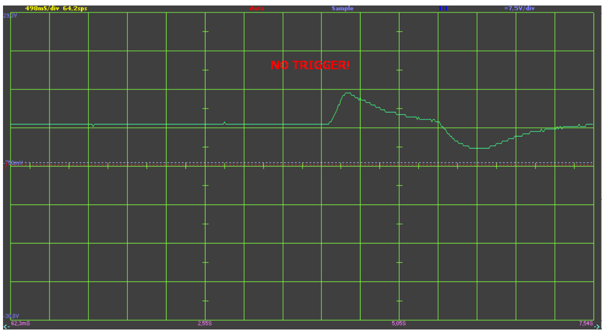

Fig. 4. Receiver output oscillogram

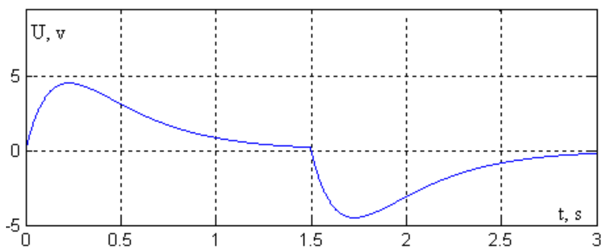

Fig. 5. Receiver output signal approximation

During modeling, the approximating parameters of the receiver's output signal are specified as input data:

T_1 – beginning of the response to an intruder's entering the protected area;

T_2 – duration of the response to an intruder's entering the protected area;

T_3 – time between the responses of receiver the to an intruder's entering and leaving the protected area;

T_4 – duration of the response to an intruder's leaving the protected area;

T_5 – time between the response of the receiver to an intruder's leaving the protected area and the end of the simulation interval;

U_2 – amplitude of the response to an intruder's entering the protected area;

U_4 – amplitude of the response to an intruder's leaving the protected area.

The output of the IR-receiver represents a mixture of a useful signal and noise. This output is supplied to the logic unit. Its amplitude should be sufficient for the unit to operate (which is provided by the receiver's amplifier).

IV. Logic processing modeling

The signal of the IR-receiver undergoes logic processing by means of two amplitude selectors, two time selectors, two coincidence circuits together comprising two channels and also an adder, an integrator and a threshold device. Consider the processing sequence.

In the beginning, the amplitudes of the half-waves of the signal (responses to an intruder's entering and leaving the protected area) are analyzed by the amplitude selectors. They are compared with thresholds P_1 and P_2, and the amplitude selectors generate pulses of a unit amplitude and duration equal to the time during which a half-wave exceeds the threshold. The amplitude selector of the first channel responds to the positive half-wave signal and the amplitude selector of the second channel responds to the negative half-wave signal.

Thus, the values of the thresholds P_1 and P_2 are the input data for modeling.

The time selectors analyze the shape of the IR-receiver signal. The extremes of the half-waves of a signal from a moving person should follow one another at regular intervals, neither too fast nor too slowly. These values are controlled by the time selectors. The trailing edge of the output pulse of each amplitude selector starts a pulse of its related time selector with a delay time T_6. Then the time selector generates a time selection pulse whose duration is T_7.

Thus, the values of selective intervals T_6 and T_7 are the input data for modeling.

The coincidence circuit of each channel repeats the pulse of the output signal of the amplitude selector of the other channel if it coincides with the pulse of the output signal of the time selector of its own channel. Then the output signals of the channels are summed up. Thus, the adder forms either only one pulse at its output or none.

The duration of this pulse is controlled by the integrator. At this stage of processing the integral of the pulse with the unit amplitude and pulse duration τ is calculated, i.e. we compute the pulse width, which is equal to the time interval in which a half-wave of the processed signal exceeds the threshold P_1 or P_2.

The time interval in which a half-wave of the processed signal exceeds the amplitude threshold should be not less than the predetermined value. This threshold value is set by the threshold device as P3. The threshold circuit compares the value of the integrator output signal (equal to the evaluated interval) with the predetermined threshold value, and if the latter is exceeded, the circuit defines two possible cases:

1. The analyzed signal of the receiver meets all the criteria required. It means that there is a human intruder in the protected area.
2. The analyzed signal of the receiver does not meet at least one of the criteria. It means that there is no human intruder in the protected area.

In the first case, the display shows the message **"Alarm"**. In the second case, the display shows the message **"Standby conditions".**

The program is performed as a Script-File.

V. Studying an IR-detector using the model

The developed model allows us to study how reliably signals from a human intruder are detected under conditions of a variety of interference and noise with the help of the logic unit described above. Interference and noise as well as their sources in a passive IR-detector are analyzed in [2]. The detector is influenced most of all by signal fluctuations, background fluctuations, and by the electric noise and interference of broadband equipment. Below we present the results of the numerical analysis of such influence made by means of Matlab tools.

VI. Signal fluctuations influence on the reliability of the detector

We have made a numerical analysis of signal processing with different time parameters within the measured variations, with signal amplitudes twice higher than the logic circuit thresholds:

$$\left|\frac{U_2}{P_1}\right| = 2; \qquad \left|\frac{U_4}{P_2}\right| = 2;$$

Figure 6 shows the results of a numerical analysis for the case of crossing the protected area by an intruder within 3 seconds. It shows the time intervals that define signal processing in the logic unit.

With this amplitude of the signal, logic processing reliably detects any movement of an intruder in the protected area for all studied variations of the signal. Thus, signal fluctuations do not affect the reliability of the logic unit.

A significant parameter is only the total duration of the signal, which is determined by the intruder's speed. For example, Fig. 7 shows the results of a numerical analysis for the case of crossing the protected zone by an intruder with a slow speed. In this case, the intruder is undetected. It is essentially an inherent disadvantage of this type of security detector.

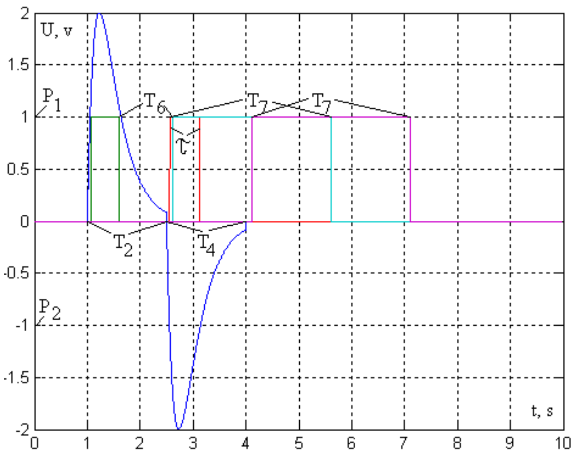

Fig. 6. An intruder's average speed:
$T_1 = 1$; $T_2 = 1.5$; $T_3 = 0$; $T_4 = 1.5$; $T_5 = 6$; $U_2 = 2$; $U_4 = 2$;
$\sigma = 0.0$; $P_1 = 1$; $P_2 = 1$; $P_3 = 0.3$;
$T_6 = 1$; $T_7 = 3$. "Alarm" (Intruder detected)

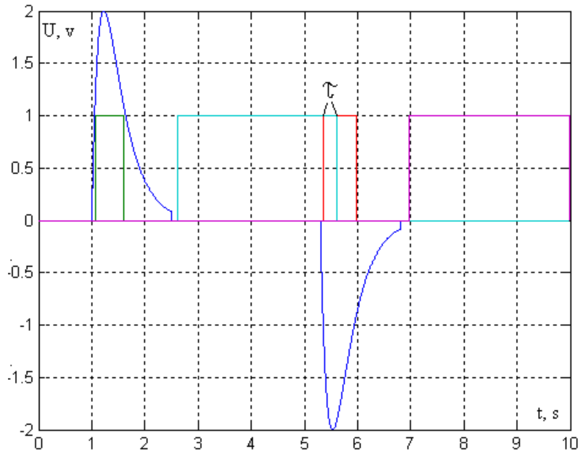

Fig. 7. An intruder's low speed:
$T_1 = 1$; $T_2 = 1.5$; $T_3 = 2.8$; $T_4 = 1.5$; $T_5 = 3.2$;
$U_2 = 2$; $U_4 = 2$; $\sigma = 0.0$; $P_1 = 1$; $P_2 = 1$; $P_3 = 0.3$;
$T_6 = 1$; $T_7 = 3$. "Standby condition" (Intruder missed)

Figures 8 and 9 show the results of a numerical analysis for the case of the most dangerous solar interference. Solar radiation causes a local temperature increase in individual parts of the walls of a room. If the light flux changes, the local temperature changes at the same rate. The logic unit of the IR-detector may mistakenly take the varying IR radiation of the wall for an intruder in the case when the output signal of the IR-receiver changes very quickly and has a significant amplitude. Such a case occurs under certain atmospheric phenomena such as sunlight, strong winds, and clouds. A small cloud "creeps" onto the sun, significantly reducing the light flux, and then is carried away by the wind (the light flux is restored). The typical time of this phenomenon – 10–20 sec [2].

A model of such a signal is shown in Figs 8 and 9. It is close to the light interference measurements given in [2].

Figure 8 presents the results of a numerical analysis for the case

$$\left|\frac{U_2}{P_1}\right| = 1.5; \qquad \left|\frac{U_4}{P_2}\right| = 1.5,$$

and Fig. 9 shows the results of a numerical analysis for the case

$$\left|\frac{U_2}{P_1}\right| = 2; \qquad \left|\frac{U_4}{P_2}\right| = 2.$$

It is evident that with a high-amplitude signal a false alarm can occur despite the fact that the time parameters of signals are qualitatively different from the parameters of the useful signal.

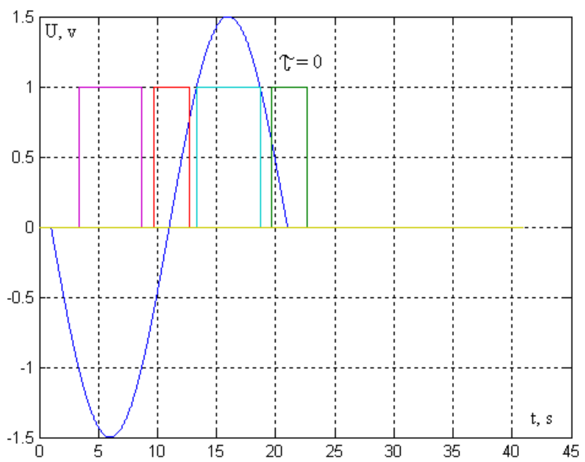

Fig. 8. Low amplitude solar interference:
$T_1 = 1$; $T_2 = 10$; $T_3 = 0$; $T_4 = 10$; $T_5 = 20$; $U_2 = 1.5$; $U_4 = 1.5$;
$\sigma = 0.0$; $P_1 = 1$; $P_2 = 1$; $P_3 = 0.3$; $T_6 = 1$; $T_7 = 3$.
"Standby condition" (No intruder)

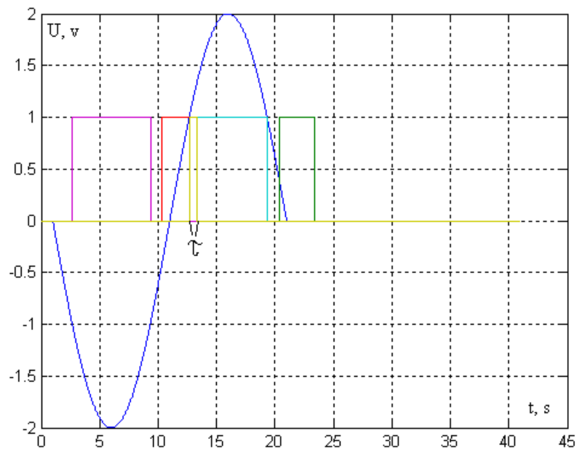

Fig. 9. High amplitude solar interference:
$T_1 = 1$; $T_2 = 10$; $T_3 = 0$; $T_4 = 10$; $T_5 = 20$; $U_2 = 2$; $U_4 = 2$;
$\sigma = 0.0$; $P_1 = 1$; $P_2 = 1$; $P_3 = 0.3$; $T_6 = 1$; $T_7 = 3$.
"Alarm" (False alarm)

VII. THE INFLUENCE OF BROADBAND NOISE ON THE RELIABILITY OF THE SENSOR

Electromagnetic interference is caused by interference from the sources of electric and radio emissions into separate elements of the electronic part of the detector. They occur when any sources of electricity and radio emission, such as measuring and consumer equipment, lighting, electric motors, radio transmitters are switched on. Strong interference can be created by lightning strikes.

The amplitude-frequency characteristics of the amplifier in the IR-receiver have a bandwidth of 3 Hz. So, the spectrum of the induced noise can be considered uniform relatively such a narrow band. Therefore, we modeled such a noise by modeling the filtering of "white" noise with a filter whose bandwidth was 0.2 ... 3 Hz.

Figures 10 and 11 show the results of numerical simulations for different "signal/noise" ratios (the values are calculated before filtering).

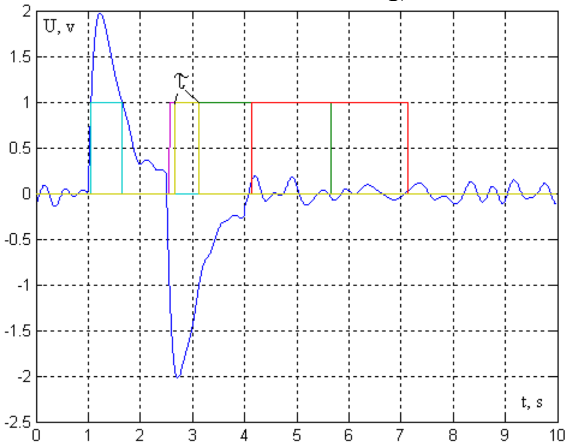

Fig. 10. Large signal, low noise:
$T_1 = 1$; $T_2 = 1.5$; $T_3 = 0$; $T_4 = 1.5$; $T_5 = 5$; $U_2 = 2$; $U_4 = 2$; $\sigma = 1$; $P_1 = 1$; $P_2 = 1$; $P_3 = 0.3$; $T_6 = 1$; $T_7 = 3$.
"Alarm" (The right intruder detection)

Figure 10 presents the results of a numerical analysis for the case

$$\left|\frac{U_2}{P_1}\right| = 2; \quad \left|\frac{U_4}{P_2}\right| = 2; \quad \left|\frac{U_2}{\sigma}\right| = 2;$$

where σ is standard deviation of the normally distributed noise.

Figure 11 presents the results of a numerical analysis for the case

$$\left|\frac{U_2}{P_1}\right| = 1.5; \quad \left|\frac{U_4}{P_2}\right| = 1.5; \quad \left|\frac{U_2}{\sigma}\right| = 0.50.$$

It can be seen that for a small value of the "signal/noise" ratio, for some unsuccessful noise implementations, the intruder may be missed. Repeated simulations (100 times) showed that the probability of such a failure is close 0.15 (15 times).

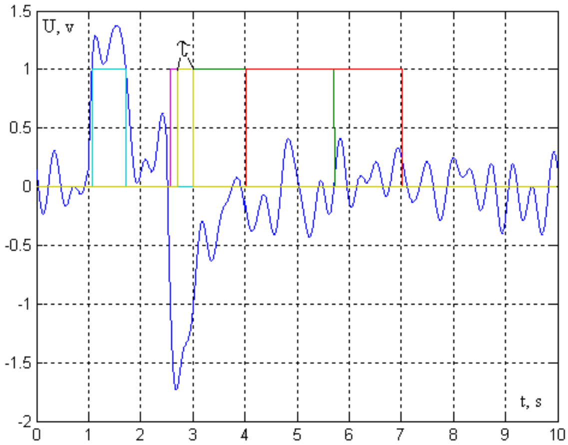

Fig. 11. Low signal, large noise:
$T_1 = 1$; $T_2 = 1.5$; $T_3 = 0$; $T_4 = 1.5$; $T_5 = 5$; $U_2 = 1.5$; $U_4 = 1.5$; $\sigma = 3$; $P_1 = 1$; $P_2 = 1$; $P_3 = 0.3$; $T_6 = 1$; $T_7 = 3$.
"Standby condition" (Skip intruder)

VIII. CONCLUSIONS

The developed model makes it possible to estimate the reliability of separating signals from a human intruder and interferences by means of the logic unit. It also allows determination of parameters that cause both *intruder missing* as *false alarms*.

The model allows evaluating the quality of the signal processing algorithm performed by this logic unit. It may be useful both for developers of burglar IR-detectors to improve data processing algorithms and for students as they study the operation principles of this type of detectors.

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Г. Є. Соколов. Побудова компьютерної моделі оптично-електронного охоронного сповіщувача

Проведено моделювання на рівні функціональної схеми оптично-електронного пасивного охоронного сповіщувача за допомогою Matlab. Розроблена модель дозволяє оцінити надійність розділення сигналів від чоловіка-порушника та від завад у логічному блоці. Вона також дозволяє знайти параметри сигналів, що створюють пропуск цілі та хибну тривогу.

Ключові слова: моделювання систем; оптоелектроніка; охоронні сповіщувачі; Matlab.

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Г. Е. Соколов. Построение компьютерной модели оптико-электронного охранного извещателя

Проведено моделирование на уровне функциональной схемы оптико-электронного пассивного охранного извещателя средствами Matlab. Разработанная модель позволяет оценить надежность разделения логическим блоком сигналов от человека-нарушителя и сигналов от помех, определить параметры сигналов, создающие случаи как пропуска цели, так и ложных тревог.

Ключевые слова: моделирование систем; оптоэлектроника; охранные извещатели; Matlab.

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