ANNUAL JOURNAL OF ELECTRONICS, 2009, ISSN 1313-1842

Development of Optocouplers with Pyroelement Photodetector

Elena Nedyalkova Koleva and Ivan Stanchev Kolev

Abstract - **In this paper is examined development of optocouplers with Pyroelement photodetector and Pyroelement Optocouplers. Pyroelements refer to the so called thermal optical detectors, as well as bolometers and thermoelements. Unlike photon detectors, thermal ones are quantum. The optocoupler developed is a current-voltage transformer (solid-state transfor).**

Keywords – **Piroelement photodetector, Piroelement optocouplers, Pyroelectric effect, Photo FET, piroelement**

I. INTRODUCTION

Pyroelements refer to the so called thermal optical detectors, as well as bolometers and thermoelements. Unlike photon detectors, thermal ones are quantum.

With thermal detectors the temperature of the very detector rises due to the absorption of IR rays. Therefore, the spectral sensitivity hardly depends on the wavelength. The most commonly used sensitivity is from 2 to 20 μm.

Action of pyroelements – generation of electric charges when the temperature of the pyroelectric crystal changes (pyroelectric effect). As a result of the absorption of IR rays, a spontaneous polarization of the ferroelectric crystals takes place. Materials – lithium niobate, barium-titanium zirconate, strontium-barium niobate, lead germanate, lead zitconate, etc.

The spectral sensitivity is most often within the range of (0,6 ÷ 40) μm, and with some elements – within the range of (0,2 ÷ 1000) μm. It can be seen that the spectral sensitivity is most often in the near, mid and far IR range.

A. Piroelements types

According to the number of channels, pyroelements are divided into single-channel and multi-channel pyroelements.

According to their application, pyroelements are divided into coordinate-sensitive, differential and pyroelectric transformers of images.

Pyroelements possess high internal resistance ($10^{10} \div 10^{11}$) Ω, and the output current is ($10^{-12} \div 10^{-13}$) A. The next amplifier stages are usually with field or MOS transistors, with operating amplifier or a hybrid variant of the pyroelement (along with the amplifier stage in one IC – as it is the case of the passive PID sensor.

The integral voltage sensitivity is Eq. 1:

$$S_U = \frac{\Delta U}{\Delta \Phi}, V/lm \tag{1}$$

where U – the voltage signal at the detector output, Φ – the light flux.

At relatively low modulation frequencies, the voltage sensitivity can be determined by the expression – Eq. 2:

$$S_U = \frac{I_O . R_L}{\Phi} \tag{2}$$

where I_O – the density the current across the pyroelement, R_L – the equivalent load resistor in a relevant unit.

The threshold light flux can be determined by the expression – Eq. 3:

$$\Phi_{np} = \frac{\sqrt{4k.T.R_L.\Delta f}}{S_U} \tag{3}$$

where k – Boltzmann's constant.

The cut-off frequency of the pyroelectric detector is Eq. 4:

$$f_{0,5} = \frac{C.K_T}{\pi . C_O} \tag{4}$$

where C – the relative thermal capacity per volume unit, K_T – the coefficient of heat conduction, C_O – the thermal capacity per the surface unit of the sensitive film.

The current sensitivity is Eq. 5, Eq. 6, Eq. 7:

$$S_I = \frac{\Delta I}{\Delta \Phi}, mA/lm \tag{5}$$

where ΔI – the change of the pyroelectric current;

$$S_I = \frac{\alpha_S . a(1 - R_{omp}) A_{\Pi} . \omega}{G_T \sqrt{1 + \omega^2 \tau_T^{\,2}}} \tag{6}$$

$$\tau_T = \frac{C_T}{G_T} \tag{7}$$

where α_s – the derivative with respect to the temperature of the spontaneous polarization;

a – the absorption factor of the sensitive element;

$R_{отр}$ – the reflection factor;

A_{Π} – the sub-electrode area of the pyroelement;

E. Koleva is Ph. D. in the Department of Electronics at Technical University of Gabrovo, H. Dimitar N 4, 5300 Gabrovo, Bulgaria, e-mail: elena_ndpt@yahoo.com.

I. Kolev is Prof. Dr. Science in the Department of Electronics at Technical University of Gabrovo, H. Dimitar N 4, 5300 Gabrovo, Bulgaria, e-mail: ipk_kolev@yahoo.com.

G_T – the total heat conductivity of the sensitive element;

τ_T – the thermal time constant;

C_T (J/K. m^3) – the specific thermal capacity of the pyroelectric.

A more accurate expression for determining the voltage sensitivity is as follows – Eq. 8 and Eq. 9:

$$S_U = \frac{\alpha_S.a(1-R_{omp}).A_{\Pi}\omega}{G_T.G_e\sqrt{(1+\omega^2.\tau_e^{\ 2})(1+\omega^2.\tau_T^{\ 2})}} \tag{8}$$

where τ_e – the electric time constant, G_e – the electric conductivity;

$$\tau_e = C_e / G_e \tag{9}$$

where C_e – the electric capacity, G_e – the electric conductivity.

B. Such optocouplers can be realized in two ways:

- The pyroelement can be a direct photodetector in an optocoupler which uses an IR LED radiating in the far IR range FIR (6 ÷ 40) µm as a light source – fig. 1. It is more appropriate to use LEDs made of lead selenide (PbSe) and of λ_P = 8,5 µm and ones made of lead telluride (PbTe) and of λ_P = 6,5 µm;

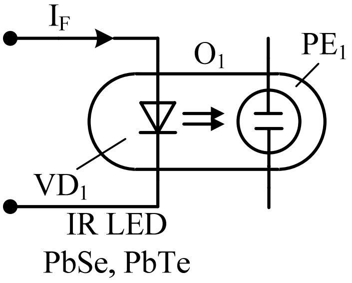

Fig. 1 Piroelement optocoupler

- The pyrolelement can control with respect to the gate the field photransistor (Photo FET), which is a photodector in the optocouplers with field phototransistors – fig. 2.

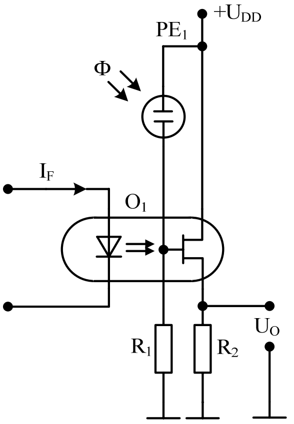

Fig. 2 Optocouplers with field phototransistors

C. The pyroelement optocoupler in fig. 1 cannot be directly applied without the next amplifier stages – fig. 3

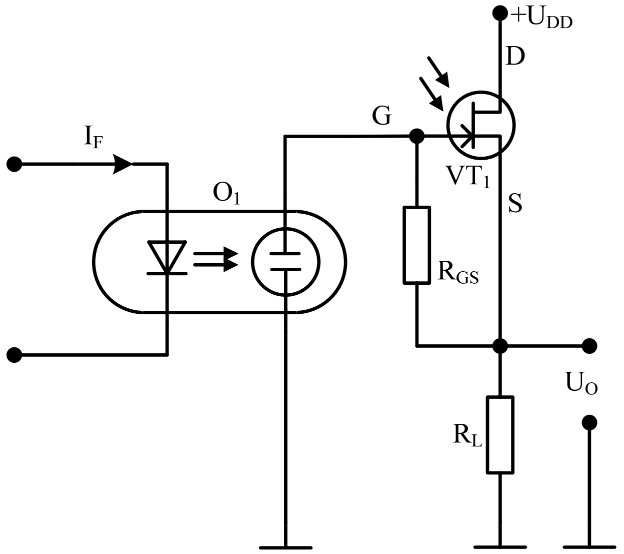

Fig. 3

In the case of the field transistor VT$_1$ a circuit of common drain (source follower) is realized. The input resistance R_I of the transistor VT$_1$ should be harmonized with that of the pyroelement – Eq. 10:

$$R_I = R_{GS}(1-K_U) = \frac{R_{GS}(S_{\max}.R_L - 1)}{2.S_{\max}.R_L - 1} \tag{10}$$

where R_{GS} – the resistance of the gate-source section; S_{max} – the maximum significance of the slope (mA/V); R_L – the load resistor; K_U – the voltage amplification factor is Eq. 11:

$$K_U = \frac{S_{\max}.R_L}{S_{\max}.R_L + 1} \tag{11}$$

The circuit input capacity at active load is Eq. 12:

$$C_I = C_{GD} + (1-K_U)C_{GS} \tag{12}$$

where C_{GD} – the capacity of the gate-drain of the field transistor, C_{GS} – the capacity of the gate-source of the field transistor.

With the optocoupler in fig. 2 the output voltage U_O is a function of one electrical quantity I_F and one optical quantity Φ – Eq. 13:

$$U_O = f(\Phi, I_F) \tag{13}$$

where Φ – the light flux in the far IR range.

The selection of the materials used for the optocoupler LEDs in fig. 1, 2 and 3 can be determined by the Eq. 14:

$$\lambda, \mu m = \frac{1{,}24}{E_g, eV} \qquad (14)$$

where E_g – the width of the forbidden band, when $\lambda_1 = 6{,}5$ µm, Eg = 0,19 eV (PbTe); when $\lambda_2 = 8{,}5$ µm, Eg = 0,146 eV (PbSe).

Selecting a pyroelement for an optocoupler of the RPY 100 Philips type.

Parameters of a single pyroelement of RPY 100 type for the IR region, produced by Philips – table 1:

TABLE 1

Spectral sensitivity	min 6,5 ± 0,5 µm > 14 µm
Noise equivalent of the power, NEP	$2{,}5.10^{-9}$ W/$\sqrt{\text{Hz}}$
Peak signal	460 µV
Noise voltage (peak to peak) (0,5 ÷ 5 Hz)	(20 ÷ 45) µV
Frequency range	(0,1 ÷ 20) Hz
Operating voltage	(3 ÷ 10) V
Field of detection with respect to the vertical and horizontal	110°
Switch-on threshold (sensitivity) (Responsivity)	(95 ÷ 150) $V.W^{-1}$
Consumed quiescent current	10 µA
Dimensions	(2 x 1) mm
Operating temperature	(–55 ÷ +85)°C

Parameters of a FET transistor:

Voltage of the gate-source segment	(–1,2 ÷ –0,5) V
Transfer coefficient of heat conductivity	1,3 mA.V–1

Figure 4 shows the spectral sensitivity of the RPY 100 pyroelement. It can be seen that it is higher than 6 µm.

Fig. 4 Spectral sensitivity of the RPY 100 pyroelement

D. The final version of the circuit of the optocoupler developed is shown in fig. 5

Parameters of the pyroelement optocoupler:

LED:

Forward current across the LED– I_F = 10 mA.

Detector:

Internal resistance 10^{10} Ω;

Peak voltage upon the pyroelement 460 µm;

Quiescent current (excluding the amplifier DA_1) 10 µA;

Spectral sensitivity of the photodetector > 6,5 µm.

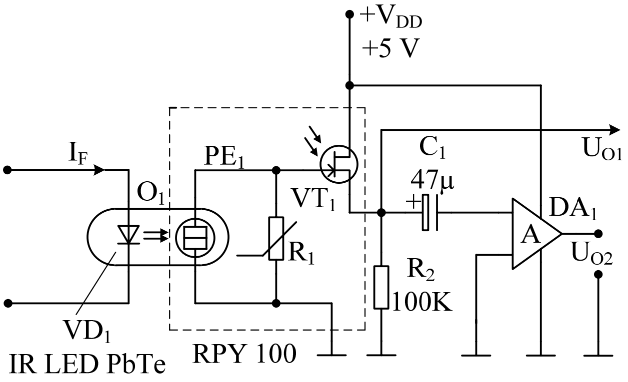

Fig. 5

Parameters of the pyroelement optocoupler:

LED:

Forward current across the LED– I_F = 10 mA.

Detector:

Internal resistance 10^{10} Ω;

Peak voltage upon the pyroelement 460 µm;

Quiescent current (excluding the amplifier DA_1) 10 µA;

Spectral sensitivity of the photodetector > 6,5 µm.

Optocoupler:

Frequency band 0 ÷ 20 Hz;

Input-output isolation voltage 1,5 kV;

Supply voltage D – S 3 ÷ 10 V.

E. Pyroelement optocouplers are most suitable for realizing air gap optocouplers – fig. 6 and reflector optocouplers – fig. 7

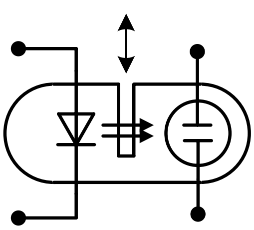

Fig. 6

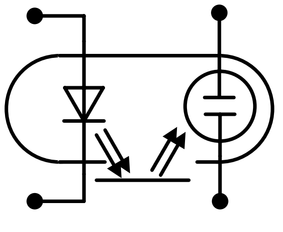

Fig. 7

Parameters of the МГ – 30Б detector (Russia) – table 2:

TABLE 2

Voltage sensitivity	1000 V/W
Threshold sensitivity	5.10^{-9} W.$Hz^{-\frac{1}{2}}$
Coefficient of non – linearity of voltage sensitivity	± 30 %
Maximum transmission frequency at 0,7 level	(50 ÷ 500) Hz
Output resistance	500 Ω
Supply voltage	± 12 V
Power consumed	0,15 W
Angle of the detection field	90°
Consumed quiescent current	(1 x 1) mm

The pyroelectric optocoupler can be realized by means of a pyroelectric detector with an integral preamplifier for registration of modulated radiation within the 2 ÷ 20 μm range. A МГ – 30Б detector (Russia) has been chosen.

The spectral characteristic of the detector is given in fig. 8.

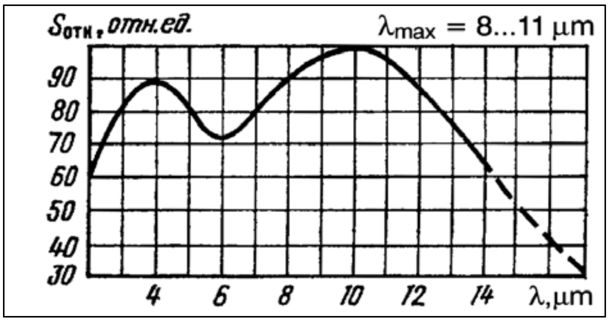

Fig. 8

F. Figure 9 presents the switch-on circuit of the optocoupler

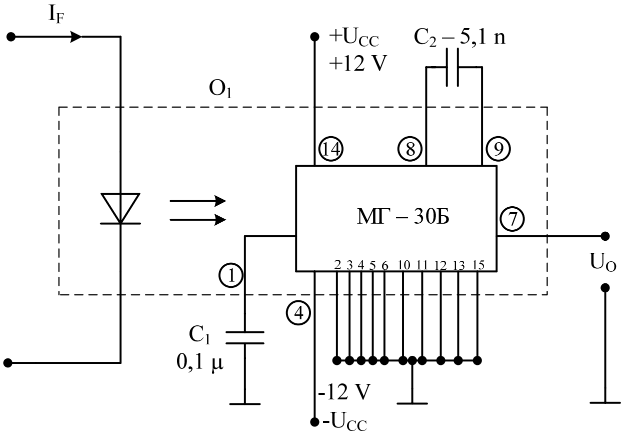

Fig. 9

Application – air-gap optocouplers and reflector optocouplers. There are not any wavelengths > 3 μm in the ambient IR background, which makes these optocouplers insensitive to the visible light.

II.CONCLUSION

The optocoupler developed is a current-voltage transformer (solid-state transfor). The low frequency band of the optocoupler determines its applications for the realization of optocouplers with open optical channels. The optocoupler in fig. 2 can be controlled by two independent channels – the electric channel (I_F) and the optical channel Φ.

REFERENCES

[1] Кременчугский,А. С. и О. В. Ройцина. *Пироэлектрические приемные устройства.* Киев, Наукова думка, 1982.

[2] Таков, Т. Б., В. С. Минчев. *Полупроводникови датчици.* С., Техника, 1986.

[3] Philips. *Optoelectronic devices*, 1986.

[4] Siemens. *Si–Photodetectors and IR Emitters.* Data Book, 1996.