Development of Optocouplers with Bolometer Photodetectors

Elena Nedyalkova Koleva

Abstract - **In this paper is examined development of bolometric optocouplers with bolometer photodetectors, the bolometers are most often used for the IR range of the spectrum. Like all optocouplers, the bolometer one is used for galvanic separation; it is also used for the realization of optocouplers with open optical channels (air-gap and reflector optocouplers).**

Keywords – **Bolometric optocouplers, bolometer, optocoupler, Termistor bolometers**

I. INTRODUCTION

With bolometers the electric resistance of the sensitive film is changed when heated under the action of a radiant flood. A metal film or a semiconductor can be used as a sensitive film. The bolometers are most often used for the IR range of the spectrum.

Switch – on circuits:
- divider circuits;
- bridge circuits.

Bolometers types:
- with a thin metal film;
- semiconductor (thermistor).

The spectral sensitiveness of the bolometers is from 1 to 20 (50) μm.

Similarly to pyroelements, bolometers are quite inert devices (their time constant is a few ms).

Compared to the pyroelements, bolometers have low internal resistance (especially the thin-film metal ones).

A. Termistor bolometers

The process is based on the temperature dependence of their electrical resistance resulting from the bolometer's warming up during the absorbtion of IR rays. Their sensitive element is a thermoresistor.

Materials – oxides of Mn, Ni, Co, etc. The bolometer is painted in black.

There are also the so-called cryostat (coolable) bolometers, operating at temperatures below 20 °K. They are made of Ge, Si, C.

The bolometer optocoupler could be built in two ways:
- the bolometer can be a photodetector in the optocoupler;
- the balometer can be connected to a standard optocoupler photodetector, e.g. a phototransistor optocoupler, a Darlington phototransistor optocoupler, an optocoupler with a field, MOS or single-junction phototransistor.

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.

An IR LED for the near, mid and far range of the spectrum is proposed as a light source – a LED made of InGaAs (1 ÷ 1,3 μm) for the close IR range of the spectrum, a LED made of InGaAsP (0,9 ÷ 1,7 μm) for the medium IR range of the spectrum and a LED made of PbSe (8,5 μm) and PbTe (6,5 μm) for the remote IR range of the spectrum.

As a photodetector an industrial differential bolometer is proposed. It is a non-selective photodetector of IR radiation.

Parameters of the industrial bolometer БКМ-2 (Russia), used in the optocoupler – table 1:

TABLE 1

Resistance of the sensitive element	(0,7 ÷ 2,5) MΩ
Volt sensitiveness (a source of 373 °K temperature and 10 Hz modulation frequency)	(70 ÷ 350) V/W
Time constant	(2 ÷ 3) ms
Sensitivity threshold	$(7,5 \div 20).10^{-10}W.Hz^{-1/2}$
Specific susceptibility (ability to detect)	1.10^{8} $W^{-1}.\sqrt{Hz}$ .cm
Size of the area detected	(2,5±0,5) x (1±0,6) mm
Number of sensitive elements (one – operating and one - compensating)	2
Current across the bolometer	0,2 mA
Material of the substract	quartz

The circuit of the bolometer optocoupler is shown in fig. 1. The operation of the optocoupler is based on the change of the bolometer resistance caused by the absorbed IR radiation.

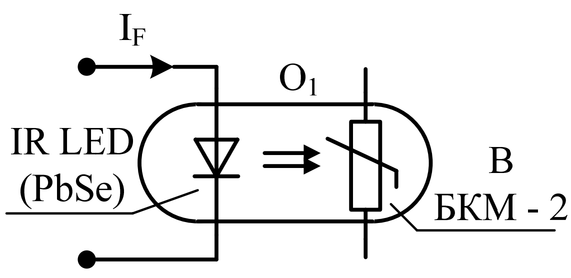

Fig. 1

The spectral sensitivity of the bolometer used is shown in fig. 2.

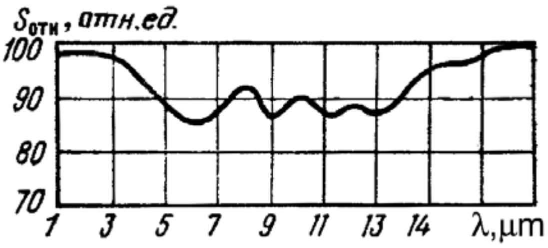

Fig. 2

Basic parameters of the bolometer optocoupler developed:

LED:

- LED current I_F = 20 mA;
- Length of the radiated wave λ = 8,5 μm (PbSe).

Bolometer:

- Resistance of the sensitive element (0,7 ÷ 2,5) MΩ;
- Voltage sensitiveness (70 ÷ 350) V/W.

Optocoupler:

- Switch-on/off times - 3 ms;
- Input-output isolation voltage - 1,5 kV.

The efficient voltage signal applied to the bolometer at a temperature difference ΔT is Eq. 1:

$$\Delta U_B = \frac{U}{4}\beta_R.\Delta T \tag{1}$$

where β_R – the resistance temperature coefficient, U – the voltage applied.

The bolometer sensitiveness is Eq. 2:

$$S_o = \frac{U}{4}.\frac{\beta_R}{Q} \tag{2}$$

where Q – the power dissipation coefficient (constant of temperature losses).

The bolometer sensitivity depends on frequency.

With sinusoidal and rectangular modulation signal is Eq. 3, Eq. 4 and Eq. 5:

$$S_f = S_o \frac{1}{\sqrt{1 + (2\pi.f.\tau)^2}} \tag{3}$$

$$\tau = \frac{C_T}{G_T} \tag{4}$$

where C_T – the thermal capacity of the sensitive element, G_T – the total thermal conductivity of the sensitive element.

$$S_f = S_o.th.\frac{1}{4.\tau.f} \tag{5}$$

Where τ – the thermal time constant of the bolometer, So – the sensitiveness, when the frequency f = 0.

The thermal noise is defined by the expression which is common for each resistor is Eq. 6:

$$\overline{U_N^{\;2}} = 4.kT.R_B.\Delta f \tag{6}$$

The temperature losses are Eq. 7:

$$Q = 2\pi.f.C_T \tag{7}$$

where Π – Peltier coefficient.

The approximate expression for the change of the bolometer resistance ΔR_B for small temperature differences ΔT, ΔT = T – T_0 – Eq. 8:

$$\Delta R_B = R_B.\beta_R.\Delta T \tag{8}$$

where R_B – the bolometer resistance at output temperature T_0.

The switch-on circuit of the bolometer optocoupler is shown in fig. 3.

A controllable voltage divider is used. It consists of a resistor R and a bolometer resistance R_B.

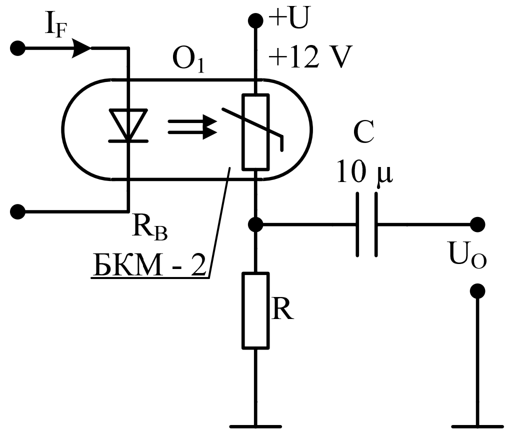

Fig. 3

The bolometer output voltage U_O can be expressed as follows is Eq. 9:

$$U_O = \frac{U}{R_B(I_F) + R}R \tag{9}$$

To compensate temperature, the bolometer optocouplers are connected to a bridge circuit – fig.4, where the optocoupler O_1 is operating and the optocoupler O_2 is non-operating (I_{F2} = 0). The voltage in the bridge diagonal is Eq. 10:

$$\Delta U = M.I.\Delta R_{B1} \tag{10}$$

where I – the current across the bolometer, M – the circuit factor depending on the relationship between the resistance in the bridge arms and the amplifier input resistance A, ΔR_{B1} – the change of the bolometer resistance B_1, R_{B1}, R_{B2} – bolometer resistance.

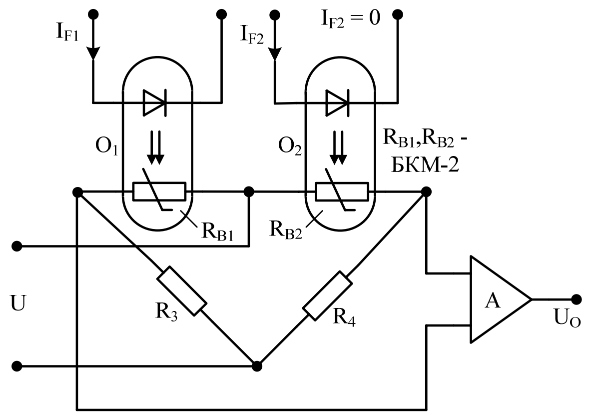

Fig. 4

For a balanced bridge when $R_{B1} = R_{B2} = R_3 = R_4 = R_B$, $M = ½$ is Eq. 11 and Eq. 12:

$$\Delta U = \frac{1}{2}.I.\Delta R_{B1} = \frac{1}{2}.I.\Delta R_B = \frac{1}{2}.\frac{U}{2R_B}.\Delta R_B = \frac{U}{4}.\frac{\Delta R_B}{R_B} \quad (11)$$

where U is the supply voltage of the bridge.

$$\frac{U}{2R_B} = I \quad (12)$$

The integral voltage sensitivity of the bolometer is determined as follows – Eq. 13:

$$S_o = \alpha.\beta_R \left[\frac{(T - T_0).R_B}{\chi.\alpha_П} \right]^{\frac{1}{2}}, V/W \quad (13)$$

where T – the absolute temperature of the bolometer; T_0 – the absolute ambient temperature; α – the coefficient of absorption of the bolometer surface; $\beta_R = \frac{dR_B}{R_B.dT}, \frac{1}{°C}$ - resistance temperature coefficient of the conducting film of the bolometer with a resistance R_B at operating temperature; χ- constant of temperature losses; $\alpha_П$ – area of the sensitive element.

For most metals is Eq. 14:

$$\beta_R \sim \frac{1}{T} \quad (14)$$

when T = 300 ºK, α_R = 0,0033.

With a limited temperature range the coefficient of the thermal conductivity of the semiconductor is Eq. 15:

$$\beta_R = -\frac{\Delta E}{2k.T^2} \approx \frac{3000}{T^2} \quad (15)$$

T = 300 ºK, β_R = -0,033; ΔE – the energy of activation of the charge carriers

The bolometer optocoupler can be switched on by means of a matching transfotmer T – fig. 5.

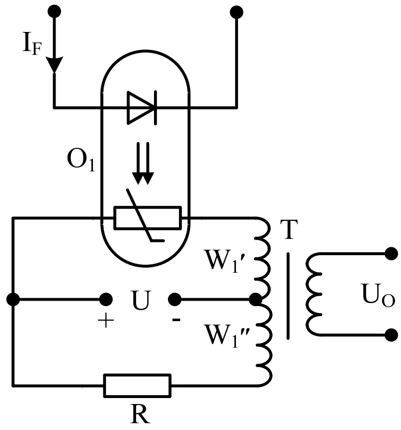

Fig. 5

It is a bridge circuit consisting of a resistor R, the bolometer resistance, and the half-two coils W_1' and W_1'' of the transformer T.

With the circuit in fig. 6 the bolometer B_1 and the resistor R_1 form a voltage divider, controlling the gate of the FET phototransistor optocoupler. The output voltage is Eq. 16:

$$U_O = (I_F, \Phi) \quad (16)$$

With the circuit in fig. 6 the output signal is controlled by two independent channels – an electric channel through the LED current I_F and an optical IR channel Φ.

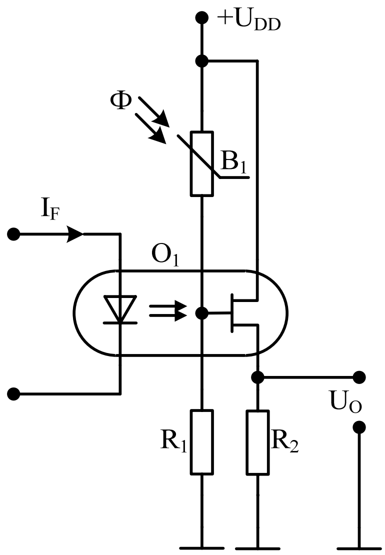

Fig. 6

II. Conclusion

The bolometer is a non-polar element and is able to operate with both dc and ac supply voltage. Like all optocouplers, the bolometer one is used for galvanic separation. It is also used for the realization of optocouplers with open optical channels (air-gap and reflector optocouplers). With the circuit in fig. 6 the output signal is controlled by two independent channels – an electric channel through the LED current I_F and an optical IR channel Φ.

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