Temperature Influence on the Parameters and Characteristics of the Optoelectronic Elements. Circuits for Temperature Compensation

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Abstract – **The temperature influence on the parameters and characteristics of the light sources LEDs, photodetectors, photodiodes – avalanche and PIN, phototransistors, and optocouplers – photodiode and phototransistor optocouplers are considered. Expressions for the influence of the temperature on the parameters of the optoelectronic elements are given. Temperature compensation for circuits with optoelectronic elements is proposed**

Keywords–**Optoelectronic Element, Temperature Compensation, LED, Photodetector, PIN Photodiode.**

I. LIGHT SOURCES

Forward voltage of LEDs decreases when temperature increases. It is

$$U_F(T°) = U_F(20°C) - TKU_F.\Delta T \qquad (1)$$

Temperature coefficient of U_F, $TKU_F \approx -1.5\ mV/°C$

The current-voltage characteristic of a LED is expressed as follows:

$$I_F = I_R\left(e^{\frac{U_F}{m.\varphi_T}} - 1\right) \qquad (2)$$

When taking the logarithm of expression (2)

$$U_F = \frac{m.K.T}{q}\ln\left(1 + \frac{I_F}{I_R}\right) \qquad (3)$$

where: $\frac{KT}{q}$ - temperature potential, $\frac{KT}{q}$ =25 mV by (25°C);

I_R – LED's reverse current;
T – temperature, °C;
K – Boltzmann's constant;
q – electron charge.

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The dependence of U_F on temperature is shown in fig.1. The shift of LED's volt-ampere characteristic caused by temperature is shown in fig.2.

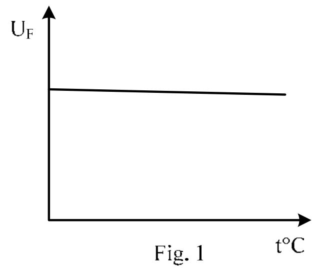

Fig. 1

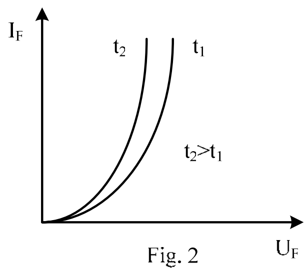

Fig. 2

The radiation of LED as a result of temperature has a negative temperature coefficient

$$I_V(\Phi_V) = (-0.55 \div -1)\% / °K$$

$$I_{V,t°} = I_{V\,20°C} - TKI_V.\Delta T$$

The example value of the decrease of radiation power caused by temperature is 100 µW/°C.

The relative change of the LED's radiation as a result of temperature is shown in fig.3.

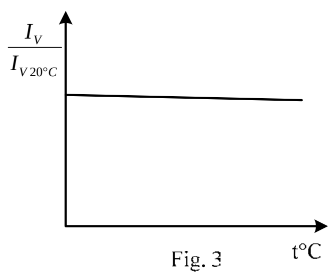

Fig. 3

The length of the LED's wave – λ and the width of the forbidden band E_g are related by the expression:

$$\lambda, \mu m = \frac{1.24}{E_g(eV)} \qquad (4)$$

The higher the temperature, the smaller the width of the forbidden band, and the longer the LED's wave. The temperature coefficient $TK\lambda_P \approx +0.3$ nm/°K.

The shift of the LED's radiation spectrum towards greater lengths of the wave when temperature increases are shown in fig.4.

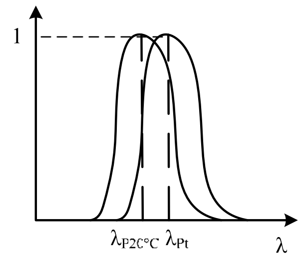

Fig. 4

II. PHOTODETECTORS

A. PIN photodiodes

With photodiodes the dark current I_D mainly depends on temperature and TKI_D is positive – fig. 5.

$$I_{D,t^\circ} = I_{D20^\circ C}.e^{\frac{kT}{q}} \tag{5}$$

This can be explained with the concentration of the non-basic current carriers P_0

$$P_0 \sim e^{\frac{-Eg}{KT}} \tag{6}$$

Figure 5 is described by expression (5)

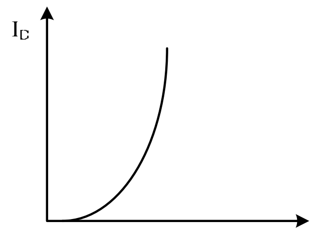

Fig. 5

The photodiode's photocurrent has a positive temperature coefficient and it slightly increases when temperature increases – fig. 6.

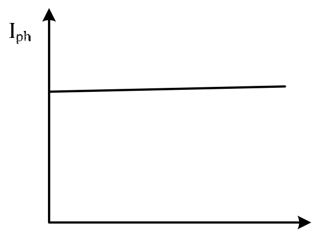

Fig. 6

The current through the photodiode is determined by the expression:

$$I = I_S\left(e^{\frac{U}{m\varphi_T}} - 1\right) - I_{Ph} \tag{7}$$

To reduce the influence of the temperature on the photodiode, the photodiode has to be cooled or photodiodes with a wide forbidden band (photodetectors for ultraviolet or violet ranges) have to be used. With them the dark current has a value of pA.

A. Photogalvanic Mode of Photodiodes

The Ph.E.M.F. generated from the photoelement is:

$$E_{ph} = \frac{KT}{q}\ln\frac{I_{phsh} - I_{RL}}{I_D} \tag{8}$$

where: I_{RL} – load current;
I_{phsh}

if $I_{RL} \approx 0$

$$E_{ph} \approx \frac{KT}{q}.\frac{I_{ph}}{I_D} \tag{9}$$

The photocurrent of a short circuit has a positive temperature coefficient, for example 0.2 %/K.

The Ph.E.M.F. of the photoelement has a negative temperature coefficient.

B. Avalanche Photodiodes

The reverse voltage of an avalanche photodiode has a positive temperature coefficient $TKU_R \sim +0.3$ V/°K

The coefficient of the avalanche multiplication M has a negative temperature coefficient – fig.7.

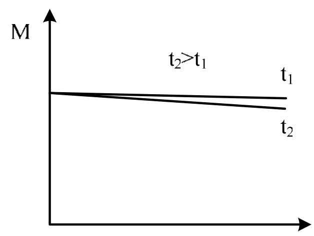

Fig. 7

C. Phototransistors

The photocurrent of the phototransistor is:

$$I_{ph} = h_{21E}.I_{phPD} + I_D \tag{10}$$

The dependences of I_D and I_{ph} on the temperature are shown respectively in fig.5 and fig.6.

Expression (10) shows that the photocurrent of the phototransistor increases when temperature increases.

III. Optocouplers

A. Photodiode Optocouplers

The current transmission ratio CTR of the photodiode optocouplers has a negative temperature coefficient

$$CTR_{t^\circ C} = CTR_{20^\circ C} - TKCTR.\Delta T \tag{11}$$

B. Phototransistor Optocouplers

With phototransistor optocouplers there is a particular temperature interval where a temperature compensation of the CTR coefficient takes place in the optocoupler. The radiation power of an IRED has a negative temperature coefficient whereas the photocurrent and the dark current have a positive one – fig.8.

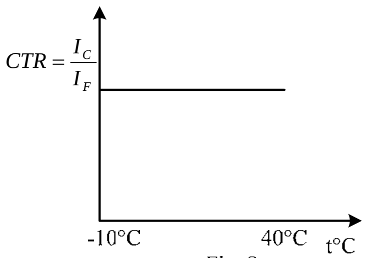

Fig. 8

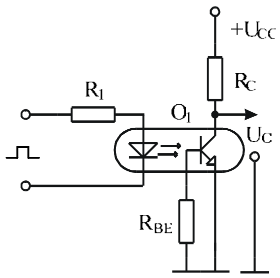

Fig. 9

To obtain good temperature stability of the phototransistor and a maximal signal/noise ratio, a resistor R_{BE} is connected between the base and the emitter of the phototransistor – fig.9.

$$R_{BE} = \frac{KT/q}{4I_D}\left(\frac{h_{21E}-1}{h_{21E}+1} + \sqrt{h_{21E}}\right) \tag{12}$$

For example, when φ_T=KT/q=25.10^{-3}V, h_{21E}=100, I_D=100.10^{-9}A, R_{BE}~686kΩ, R_{BE}=680kΩ is chosen. At 25°C, the voltage of the collector when the phototransistor is turned off is:

$$U_{CEH} = U_{CC} - I_D R_C = U_{CC} - \Delta U_{RC} \tag{13}$$

When U_{CC}=5V, R_C=1kΩ, I_D=100.10^{-9}A, ΔU_{RC}=0.1mV, $U_{CEH} \approx U_{CC}$

The temperature resistances of the LED and the phototransistor of the CNY17 optocoupler are:

LED – R_{th}=750 K/W, Phototransistor – R_{th}=500 K/W

The change of the preliminary characteristic of the phototransistor optocoupler caused by temperature is shown in fig.10.

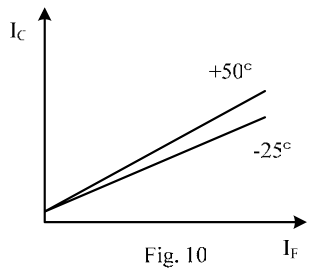

Fig. 10

The voltage between the phototransistor collector and emitter in a saturation mode is:

$$U_{CEsat} = R_{CEsat}\left(I_{ph} + I_D\right) \tag{14}$$

R_{CEsat} – resistance between the phototransistor collector and emitter in an ON state (100÷200) Ω.

I_{ph} and I_D increase when temperature increases. Therefore, U_{CEsat} also increases when temperature increases – fig.11.

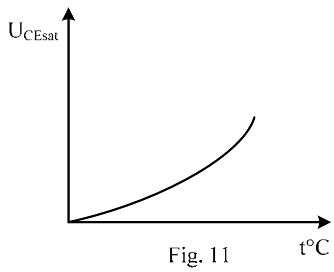

Fig. 11

$$U_{CEsat} \equiv \varphi_T = \frac{KT}{q} \equiv T \tag{15}$$

To obtain a good temperature stability of the optocoupler phototransistor, the base is fixed by a negative potential – fig.12.

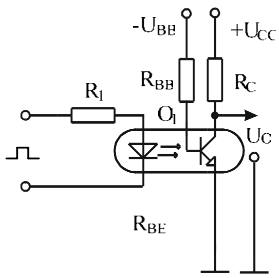

Fig. 12

The following can be written for the collector current:

$$I_C = h_{21E}.I_B^+ \tag{16}$$

$$I_C = CTR.I_F \tag{17}$$

The following is obtained from (16) and (17):

$$I_B^+ = \frac{CTR.I_F}{h_{21E}} \tag{18}$$

$$I_F = \frac{U_I - U_F}{R} \tag{19}$$

$$I_B^+ = CTR\frac{U_I - U_F}{R.h_{21E}} \tag{20}$$

When the phototransistor is set ON by the source current, U_{BB} is:

$$I_B^- = \frac{U_{BB} - U_{BE}}{R_{BB}} \quad (21)$$

IV. Circuits for Temperature Compensation

A. Photogalvanic Mode of Photodiodes

In order for the voltage across the load R_L to be constant when temperature changes and the photodiode operates in a photogalvanic mode, the circuit in fig.13 is used. Within it the thermistor R_T has a negative temperature coefficient.

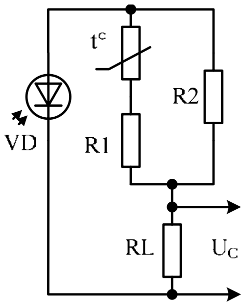

Fig. 13

B. Photodiode Operation Mode of Photodiodes. Differential Circuit

VD2 is non-operating. It is used for temperature compensation – fig.14.

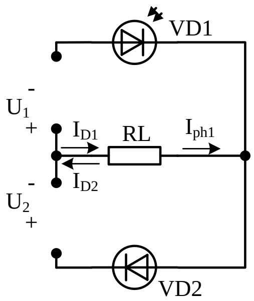

Fig. 14

The current across the load R_L is:

$$I = I_{ph1} + I_{D1} - I_{D2} \approx I_{ph1} \quad (22)$$

$$I_{D1} = I_{D2}$$

C. Bridge Circuit

R_L>>R. The current I is determined by the expression (22) $I \approx I_{ph1}$

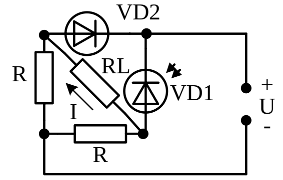

Fig. 15

D. Circuit for Temperature Compensation of Phototransistor Optocouplers

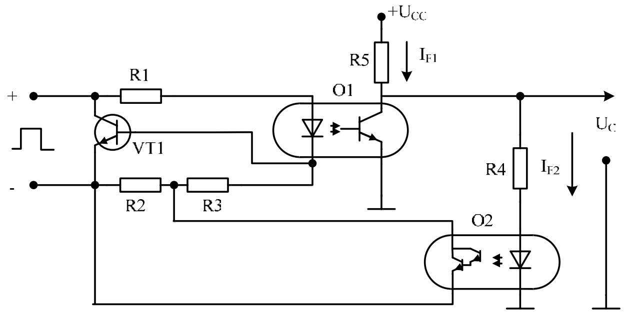

Fig. 16

R_4>R_C

The transistor VT1 is a current regulator. The 02 optocoupler is in a circuit of an optic negative feedback. The current across the optocoupler LED is:

$$I_F \approx \frac{U_{BE}}{R_3 + R_2 \parallel R_{CEO2}\left(I_{F2}\right)} \quad (23)$$

V. Conclusion

The aim of study of temperature influence at parameters and characteristics of optoelectronic elements is to develop new circuits. Using these circuits will improve functional capabilities of optoelectronic devices.

References

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