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Abstract

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PHYSICS

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CONDITION FOR COMPLETE REGENERATION IN AN OPTRON WITH A PHOTORESISTOR

1. In papers (¹⁻⁵) it was shown that an optron with a photoresistor has a trigger characteristic under the condition

$$\mu = \frac{\alpha\gamma\theta k I_1 / G}{1 + r_1 G} > 1. \quad (1)$$

Here G and I_1 are the conductance and current of the photoresistor; α , γ , and θ are the differential coefficients of light output of the emitter, photoconductivity of the photoresistor, and light transmission of the optical path; and r_1 and k are the differential values of the input resistance and current gain coefficient of the electrical stage that connects the circuits of the photoresistor and the emitter (light-emitting diode).

This result was first obtained under certain special assumptions about the form of the ampere-lux characteristic of the light-emitting diode and the lux-ohmic characteristic of the photoresistor, and then without these restrictions, but, however, not in the most general form. Until now the theory has been developed only for an optron with an electrical input and, moreover, the electrical stage connecting the circuits of the photoresistor and the light-emitting diode (we shall henceforth call it a functional amplifier (⁶)) was considered only as a current converter.

In the present paper a general derivation of inequality (1) is given, its physical content is revealed, and some consequences are also discussed, opening up, in particular, the possibility of creating multistable optoelectronic elements.

2. The complete system of equations for a regenerative optron with a photoresistor as the light receiver has the form:

Fig. 1 and Fig. 2 diagrams

Figure 1: Fig. 1 and Fig. 2 diagrams

$$\begin{aligned}
 V_{10} &= V'_1 + V_1; & I_1 &= GV'_1; & G &= G(B); \\
 V_{20} &= V'_2 + V_2; & V'_2 &= V'_2(I_2); & B_1 &= B_1(I_2); \\
 B &= B(B_1, B'); & V_1 &= V_1(I_1, V_2); & I_2 &= I_2(I_1, V_2).
 \end{aligned} \tag{2}$$

Here B is the illumination of the photoresistor, B_1 is the radiation intensity of the light-emitting diode, and B' is the intensity of the external illumination. The remaining notation is clear from Fig. 1.

The optron shown in Fig. 1 is a three-terminal element with two electrical inputs and one optical input. With respect to the electrical signal applied to the photoresistor circuit, the optical signal applied to the photoresistor circuit, and the electrical signal applied to the light-emitting-diode circuit, it becomes an autonomous two-terminal network, respectively under the conditions $\partial I_1/\partial V_{10} < 0$, $\partial I_1/\partial B' < 0$, and $\partial I_2/\partial V_{20} < 0$. We shall illustrate the method for calculating these quantities using as an example an optron with an optical input.

Noting that in the case of an optical input all partial derivatives are taken at $V_{10} = \text{const}$ and $V_{20} = \text{const}$, and also taking into account the closed ring

connections implemented in the optocoupler and expressed by the system of equations (2), we obtain*

$$\begin{aligned}
 \frac{\partial I_1}{\partial B'} &= V'_1 \frac{\partial G}{\partial B'} + G \frac{\partial V'_1}{\partial B'} = \frac{I_1}{G} \left(\gamma' + \gamma \theta \alpha \frac{\partial I_2}{\partial B'} \right) - G \frac{\partial V_1}{\partial B'} = \\
 &= \frac{I_1}{G} \gamma' + \alpha \gamma \theta \frac{I_1}{G} \left(h_{21} \frac{\partial I_1}{\partial B'} + h_{22} \frac{\partial V_2}{\partial B'} \right) - G \left(h_{11} \frac{\partial I_1}{\partial B'} + h_{12} \frac{\partial V_2}{\partial B'} \right); \tag{3} \\
 \frac{\partial V_2}{\partial B'} &= -\frac{\partial V'_2}{\partial B'} = -r_g \frac{\partial I_2}{\partial B'} = -r_g \left(h_{21} \frac{\partial I_1}{\partial B'} + h_{22} \frac{\partial V_2}{\partial B'} \right).
 \end{aligned}$$

Fig. 1. Regenerative optocoupler with a photoresistor

Fig. 2. Structure of the transfer function of a regenerative optocoupler with a photoresistor.

1 –light-emitting diode; **2** –light guide; **3** –photoresistor; **4** –electrical circuit of the photoresistor; **5** –electrical coupling cascade

i.e.,

$$\left(1 + Gh_{11} - \alpha \gamma \theta \frac{I_1}{G} h_{21} \right) \frac{\partial I_1}{\partial B'} + \left(Gh_{12} - \alpha \gamma \theta \frac{I_1}{G} h_{22} \right) \frac{\partial V_2}{\partial B'} = \frac{I_1}{G} \gamma', \tag{4}$$

$$r_g h_{21} \frac{\partial I_1}{\partial B'} + (1 + r_g h_{22}) \frac{\partial V_2}{\partial B'} = 0.$$

From (4) we find

$$\frac{\partial I_1}{\partial B'} = \frac{\frac{I_1}{G} \gamma'}{(1 + r_1 G)(1 - \mu)}. \quad (5)$$

since in the h -parameters [7]

$$\frac{h_{21}}{1 + r_g h_{22}} = k; \quad \frac{h_{11} + r_g \Delta h}{1 + r_g h_{22}} = r_1. \quad (6)$$

Similarly, for an optocoupler with an electrical input in the photoresistor circuit and in the light-emitting-diode circuit, we obtain, respectively,**

$$\frac{\partial I_1}{\partial V_{10}} = \frac{G}{(1 + r_1 G)(1 - \mu)}, \quad (7)$$

$$\frac{\partial I_2}{\partial V_{20}} = \frac{y_2}{(1 + r_g y_2)(1 - \mu)}. \quad (8)$$

The cases $1 + r_1 G < 0$ or $y_2 < 0$ are of no interest, since in this case the electrical cascade in the optocoupler is already not an amplifier but a generator. Consequently, in all cases the necessary and sufficient condition for complete regeneration in an optocoupler with a photoresistor is inequality (1).

* $\partial B_1 / \partial I_2 = \alpha$; $\partial B / \partial B_1 = \theta$; $\partial G / \partial B = \gamma$; $\partial V_2' / \partial I_2 = r_g$ –differential resistance of the light guide. Note that the coefficient of photoconductivity of the photoresistor γ depends on the spectral composition of the light and therefore may be different for the radiation of the light-emitting diode and for external illumination.

** $y_2 = (h_{22} + G \Delta h) / (1 + h_{11} G)$ –differential output conductance of the functional amplifier.

3. The physical content of inequality (1) is fully revealed when the regenerative optocoupler is considered as a closed circuit in each of whose links a functional transformation of the signal is carried out (Fig. 2). Such links are: the light-emitting diode, the light guide, the photoresistor, the photoresistor circuit, and the functional amplifier. In them a successive transformation of the signals i_2 into b_1 , b_1 into b , b into g , g into i_1 , i_1 into i_2^* takes place. The transfer functions of these links are respectively α , θ , γ , and

Fig. 3

Figure 2: Fig. 3

Fig. 4

Figure 3: Fig. 4

$$m^* = \frac{I_1/G}{1 + r_1 G}$$

In the optocoupler complete regeneration is effected if, after passing through the whole ring of transformations, the signal does not decrease. The corresponding mathematical condition consists in the requirement that the product of the transfer functions of all the links be equal to or greater than unity, which is expressed by formula (1). With this approach it is immediately clear that this formula is valid regardless of which of the links in the ring receives the input signal, i.e., for any arrangement and physical nature of the input.

The quantity μ entering into (1) has the meaning of the regeneration coefficient (transfer function) of the optocoupler.

Fig. 3. 1 –amplitude characteristic of the functional amplifier $I_2 = I_2(I_1)$; 2 – I-V characteristic of a regenerative optocoupler with a shifted transistor in the shaping circuit; 3, 4 –I-V characteristics of a regenerative optocoupler with a photoelement in the shaping circuit at different levels of external illumination

4. Knowledge of the structure of the transfer function of a regenerative optocoupler opens up possibilities for flexible and varied control of its functional properties. Thus, for example, by introducing into the optocoupler at least one link with a comb-type transfer function, one can create an element with a characteristic having several falling portions. Under certain conditions such an optocoupler becomes a multistable element (8). It can serve, for example, as an optoelectronic memory element with a memory capacity exceeding 1 bit.

Fig. 4. Circuit of a regenerative optocoupler with a functional amplifier having a stepwise current characteristic

By synthesizing a functional amplifier with a stepwise current characteristic (curve 1 in Fig. 3), we succeeded in constructing an optocoupler with two unstable regions (curve 2 in Fig. 3). The amplifier (Fig. 4) is a nonlinear chain consisting of transistor T_2 , Zener diode D , and light-emitting diode CD , connected in the feedback circuit of the amplifying transistor T_1 . In another variant, instead of transistor T_2 a silicon photoelement was used. This provided an additional possibility of controlling the shape of the volt-ampere characteristic (I-V characteristic) of the optocoupler by means of external illumination, i.e., by

means of a second emitter not included in the optocoupler. Such an emitter may be, for example, an optical

* i_1 , i_2 , b , b_1 , and g are signals of the quantities I_1 , I_2 , B , B_1 , and G .

** The transfer function of the photoresistor circuit $m^* = \partial I_1 / \partial G$ is found analogously to the calculation carried out above of $\partial I_1 / \partial B'$. It can be obtained directly from (5) with $\mu = 1$, noting that $\partial G / \partial B' = \gamma'$.

the output of the preceding stage of the optoelectronic circuit. Note that an optocoupler with an additional optical input in the form of a photocell in the functional-amplifier circuit is an element with a variable number of unstable regions, depending on the intensity of the external illumination (curves 3 and 4 in Fig. 3).

The optocouplers whose characteristics are given in Fig. 3 were assembled from standard components. With special matching of the components, the minima in the optocoupler characteristic can be brought closer together and deepened, thereby making it a multistable element.

Still more interesting is the possibility of creating a multistable optocoupler not by complicating the functional-amplifier circuit, but by technologically implementing a nonmonotonic transfer function of the light-emitting diode or the photoresistor.

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