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Fig. 1

Figure 1: Fig. 1

Abstract

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INVESTIGATION OF A REGENERATIVE OPTRON WITH OPTICAL FEEDBACK

1. The implementation, alongside electrical connections, of optical connections between semiconductor devices and microcircuit components opens up new functional possibilities for radio electronics (1–5). In the literature, however, we have not encountered a theoretical calculation of optronic circuits or a formulation of conditions imposed on component parameters that are necessary and sufficient for realizing definite circuit functions. Below we consider the problem of the conditions under which an optoelectronic cell with direct electrical and positive optical feedback has a bistable current–voltage characteristic. Results are also presented of an experimental investigation of a regenerative optron made on the basis of a GaP light-emitting diode and a CdS photoresistor.

Fig. 1

2. The optoelectronic cell schematically shown in Fig. 1a is described by the system of equations

$$V = V' + Jr; \qquad J = V'\left(\frac{1}{R} + \gamma I\right); \qquad I = I(J). \tag{1}$$

Here V' is the voltage drop across the photoresistor; $1/R$ and γI are its dark conductivity and photoconductivity.

We approximate the dependence of the light intensity I on the current J flowing through the light-emitting diode in the form of the following piecewise function:

$$I = a(J - J_0); \qquad a = \begin{cases} 0, & \text{for } J < J_0, \\ \alpha, & \text{for } J > J_0. \end{cases} \tag{2}$$

From (1) and (2) it follows that the current-voltage characteristic of the cell has the form

$$V = \frac{JR(\alpha\gamma Jr + A)}{\alpha\gamma JR - B}. \tag{3}$$

Here

$$A = 1 + \frac{r}{R} - \alpha\gamma r J_0; \qquad -B = 1 - \alpha\gamma R J_0. \tag{4}$$

The extremal points of the current-voltage characteristic are determined from the condition $dV/dJ = 0$:

$$J' = \frac{B}{\alpha\gamma R}\left[1 \mp \sqrt{1 + \frac{AR}{Br}}\right]. \tag{5}$$

It is seen from (5) that when $B < 0$ the equation $dV/dJ = 0$ has no real positive roots. Consequently, the inequality

$$\alpha\gamma R J_0 > 1 \tag{6}$$

is a necessary condition for an optocoupler with positive optical feedback to have a bistable characteristic. In particular, it follows from (6) that, for a light emitter with a linear characteristic ($J_0 = 0$), a trigger effect cannot be obtained in the optocoupler.

Let us note that these conclusions are valid independently of the sign of the coefficient A, since for $A < 0$ it is necessarily the case that $\alpha\gamma J_0 > r/R$, whence inequality (6) again follows.

Substituting the values of A and B into (5), we obtain

$$J' = \left(J_0 - \frac{1}{\alpha\gamma R}\right)\left[1 \mp \frac{1}{\sqrt{\frac{r}{R}(\alpha\gamma R J_0 - 1)}}\right]. \tag{7}$$

If

$$\frac{r}{R} < \frac{1}{\alpha\gamma R J_0 - 1}, \tag{8}$$

then the current-voltage characteristic has only one extremum J', corresponding to a minimum (one positive real root of the equation $dV/dJ = 0$). The maximum is located at the kink point, at the threshold value of the current $J = J_0$.

If inequality (8) has the opposite sign, then the equation $dV/dJ = 0$ has two positive real roots, but the smaller of them lies to the left of J_0 and therefore must be rejected. Consequently, (6) is the sole necessary and sufficient condition for an optoelectronic cell with optical feedback to have a trigger characteristic. In this case $V_{\max}$ always corresponds to the threshold $J = J_0$.

The physical meaning of inequality (6) consists in the requirement of sufficiently large values of the dark resistance of the photodetector R, the threshold current of the light-emitting diode J_0, and also the coefficients of photoconductivity γ and light output α; moreover, the smallness of one of these parameters can be compensated by a sufficiently large value of any of the others. The real values of the parameters of optocoupler components are often such that, even when they are matched in spectrum and other indices, a mismatch remains between the operating currents of the photodetector and the light emitter. This mismatch can be eliminated by introducing a matching amplifier into the circuit. Such an amplifier may be a transistor, and thus the possibility is preserved of implementing the circuit under consideration in solid-state form, using discrete semiconductor elements, or in integrated form.

Consideration of the circuit with a matching amplifier (Fig. 1,) leads to the inequality

$$\alpha\gamma k R J_0 > 1, \tag{9}$$

which differs from (6) in that it also contains the current gain coefficient k of the matching amplifier. This shows that the introduction of a linear matching amplifier is equivalent to increasing the photosensitivity of the photoresistance or the light output of the light-emitting diode.

Noting that

$$V_{\max} = J_0(R + r) \tag{10}$$

and substituting this value into the expression for the current-voltage characteristic (3), we find the value of the current J_2 reached after the short-circuited cell breaks down:

$$J_2 = \frac{\alpha\gamma k R V_m - AB \mp \sqrt{(\alpha\gamma k R V_m - AB)^2 - 4BV_m\alpha\gamma k r R}}{2\alpha\gamma k r R}. \tag{11}$$

The difference $J_2 - J_0$ increases as the ratio r/R decreases, and as $r/R \to 0$ the minimum of the current-voltage characteristic and its right positive

···the branch shift into the region of unrealistically large currents. Assuming

$$\alpha\gamma k R J_0 \gg 1; \qquad \alpha\gamma k r J_0 \ll 1 \tag{12}$$

and noting that

$$V_{\max} = J_0(R + r) \approx J_0 R, \tag{13}$$

we find

$$J' \approx \sqrt{\frac{J_0}{\alpha\gamma k r}}; \qquad J_2 \approx 2\frac{R}{r}J_0. \tag{14}$$

Since J' increases as $r^{-1/2}$, and J_2 as r^{-1}, reducing the ratio of the resistance of the light-emitting diode and all the other circuit elements to the resistance of the photodetector has an especially strong effect on the second rising branch of the current-voltage characteristic.

Fig. 2

In real conditions, in order to avoid rapid damage to the cell during its operation, one should maintain $r/R \sim 1$, or else use a transistor amplifier stage operating in saturation at high currents. For $\alpha\gamma k R J_0 = 3$ and $r/R = 0.1$, from formulas (7) and (11) it follows that $J' \approx 2J_0$, $J_2 \approx 14J_0$, i.e., the cell has a good operating characteristic.

Fig. 3

Fig. 4

3. We assembled, according to the circuit of Fig. 1b, an optoelectronic cell based on a GaP light-emitting diode ID-K ($J \approx$ 25–30 mA; $V \approx$ 2–3 V; $I \approx 30 \div 40$ nit) and an FS-K1 CdS photoresistor ($R \approx 3 \cdot 10^6\ \Omega$; $\gamma \approx 6000\ \mu$A/ml·V). The external appearance of this regenerative optocoupler is shown in Fig. 2. Componen-

the optocoupler were well matched spectrally and operated in the region $\lambda_{\max} = 0.6\,\mu$. The lux-ampere characteristic (lx—μA) of the photoresistor and the ampere-lux characteristic (mA—rel. units) of the light-emitting diode are shown in Fig. 3. The optical coupling between the light-emitting diode and the photoresistor was achieved by directly illuminating the photoresistor without using fiber optics. The components were arranged so that the cone of light falling on the photoresistor covered its entire working area. To increase the efficiency of light transmission, a microscopic conical reflector was used.

The experimental current-voltage characteristic of this optocoupler is shown in Fig. 4. It has a clearly pronounced trigger character, in accordance with the calculation carried out above. The steep rise of the right-hand branch of the characteristic is associated with the output of the matching amplifier into saturation.

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Note: Figure translations are in progress. See original paper for figures.