CONTROLLABLE PHOTOPOTENTIOMETRIC OPTOCOUPLERS

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Photopotentiometric optocouplers (PPO) are electronic equivalents of mechanical resistor potentiometers. With PPOs the output quality is resistance (voltage or current) and it is converted into a function by the LED current rather than by the rotation angle of the potentiometer axle.

**Keywords:** Optocouplers, Photopotentiometer, Control, LED

1. INTRODUCTION

The law for changing the potentiometer resistance by means of the rotation angle can be linear, logarithmic and antilogarithmic.

PPOs can be designed with one or two optocouplers.

2. CIRCUITS OF PHOTOPOTENTIOMETRIC OPTOCOUPLERS

The simplest PPO circuit with a photodiode optocoupler is shown in fig. 1.

![Fig. 1](image_url)

The photodiode of the optocoupler O₁ and the resistor R form a controllable voltage divider.

The photocurrent in the output circuit is:

1. \( I_{ph} = CTR \cdot I_F \)

The output voltage is: (\( I_D << I_{ph} \))

2. \( U_R = I_{ph} \cdot R = CTR \cdot I_F \cdot R = \text{const.} \cdot I_F \)

3. \( U = U_{AK} + U_R \)

Let \( U = 12 \text{ V}, \ CTR = 10\%, \ R = 10 \text{ kΩ} \) when \( I_F = 1 \text{ mA}, \ I_{ph} = 100 \text{ µA}, \ U_R = 1 \text{ V} \)

\( I_F = 10 \text{ mA}, \ I_{ph} = 1 \text{ mA}, \ U_R = 10 \text{ V} \)

The change range of the output voltage is:

4. \( D = 10/1 = 10 \)

A greater change range of the output voltage can be obtained when an operational amplifier is used - fig. 2.

\[ U_o = -U_i \cdot \frac{R_F}{R_{ph}(I_F)} \]

For example, when \( I_F = 20 \text{ mA} \) \( R_{ph} = 100 \text{ Ω} \)

\( I_F = 0 \text{ mA} \) \( R_{ph} = 100 \text{ MΩ} \) and \( R_F = 100 \text{ MΩ} \)

The range:

\[ D = \frac{100\text{MΩ}}{100\text{Ω}} = 10^6 \]
For a linear change of the PPO output voltage by the LED current - $I_F$ a trans-impedance amplifier (DA1) current-voltage should be used – fig. 3.

(7) $U_o = -I_{ph}.R_F$

(8) $U_o = CTR_2 . I_{F2} . R_F$

Let $CTR = 10\%$, $R_F = 1\, \text{M}\Omega$, $I_{ph} = 5\, \mu\text{A}$, $U_o = -5 \times 10^{-6}$. $1.10^6 = 5\, \text{V}$

PPOs are suitable for operating with low LED currents up to 1 mA.

3. CIRCUITS OF STEREOPHOTOPOTENTIOMETRIC OPTOCOUPLERS

In order to obtain a stereopotentiometer, PPOs must have two channels – fig. 4.

(9) $U_{o1}, U_{o2} = f (I_F)$
4. PHOTOPOTENTIOMETRIC OPTOCOUPLECTERS WITH DYNAMIC LOAD

The law for changing the output voltage by the current $I_F$ is logarithmic.

PPOs are built with two basic optocoupler types:
- Photoresistor optocouplers (PRO) – fig. 5
- Photodiode optocouplers (PDO) – fig. 6
- Phototransistor optocouplers (PTO) – fig. 7
- Darlington phototransistor optocouplers (DFTO) – fig. 8
- Optocouplers with field phototransistors (OFPT) – fig. 9
- Optocouplers with an air gap (OAG) – fig. 10
- Reflective optocouplers (RO) – fig. 11

When $I_{F1} = 0$, $I_{F2} = 0$ and there is a symmetry in the circuit, the output voltage is:

\[ U_o \approx \frac{1}{2} U_{CC} \]

Let’s look at the PPO in fig. 7: $U_{CC} = 12$ V

$I_{F1} = 0$, $I_{F2} = \text{max}$  $U_o \text{ min} = U_{CEsat2} = 0.1$ V

$I_{F1} = \text{max}$, $I_{F2} = 0$  $U_o \text{ max} = U_{CC} - U_{CEsat1} = 12 - 0.1 = 11.9$ V

The change range of the output voltage is:

\[ D_U = \frac{U_o \text{ max} - U_{E_{sat1}}}{U_{E_{sat2}}} = \frac{U_{CC} - 0.1}{0.1} = \frac{12 - 0.1}{0.1} = 119 (> 10^2) \]

The change range of the current is:

$I_{F1} = 0$, $I_{F2} = 0$, $I_{D1} \approx I_{D2} = I_D$  let $I_D = 100 \times 10^{-9}$ A ($25^\circ$ C) when $R_C = 10$ kΩ

$U_{CC} = 12$ V

\[ I_C = \frac{U_{CC} - U_{CEsat1} - U_{CEsat2}}{R_C} = \frac{12 - 0.1 - 0.1}{10k\Omega} = 1.18mA \]

\[ D_I = \frac{I_C}{I_D} = \frac{1.18 \times 10^{-3}}{100.19 \times 10^{-3}} = 1.18 \times 10^3 (> 10^3) \]
The change range of the resistance collector/emitter $R_{CE}$ of the phototransistor is:

\begin{align*}
R_{CEH} & = 0.5 \frac{U_{CC}}{I_D} = \frac{6V}{100 \cdot 10^{-9}} = 600k\Omega \\
R_{CEL} & = \frac{U_{CEsat}}{I_C} = \frac{0.1V}{1mA} = 100\Omega \\
D_{rez} & = \frac{R_{CEH}}{R_{CEL}} = \frac{600 \cdot 10^3}{100} = 6 \cdot 10^3
\end{align*}

5. **Graphic Analytical Way of Calculating of PPO**

A graphic-analytical way of calculating a PPO with phototransistor optocouplers (PTOs) is proposed:
1. From the transfer characteristic of the PTO:
\[ I_{ph} (I_C) = f(I_F) \quad U_{CE} = \text{const} \quad \text{for} \quad I_{FX} \longrightarrow I_{phx} \]

2. From the input characteristic of the PDO:
\[ I_{ph} = f(U_{CE}); \quad I_F = \text{const} \quad \text{for} \quad I_F, I_{phx} \longrightarrow U_{CEX} \]

3. \[ R_{CEX} = \frac{U_{CEX}}{I_{phx}} \]

4. Building the dependence \( R_{CE} = f(I_F) \) (non-linear)

For photodiode optocouplers (PDOs):

1. From the transfer characteristic of the PDO:
\[ I_{ph} = f(I_{FX}) \quad U = \text{const} \quad I_{FX} \longrightarrow I_{phx} \]

2. From the output characteristic:
\[ I_{ph} = f(I_F) \quad \text{for} \quad I_{phx}, I_{FX} \longrightarrow U_{AKX} \]

3. \[ R_{AKX} = \frac{U_{AKX}}{I_{phx}} \]

4. Building the dependence \( R_{AKX} = f(I_F) \)

Comparison of the PPO with different types of optocouplers – table 1:

<table>
<thead>
<tr>
<th>PPO type</th>
<th>Non-linearity, %</th>
<th>Change range</th>
<th>Basic changeable parameter</th>
<th>Frequency band, kH</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRO</td>
<td>5 ÷ 10</td>
<td>&lt;10^6</td>
<td>resistance</td>
<td>10</td>
</tr>
<tr>
<td>PDO</td>
<td>1 ÷ 5</td>
<td>&lt;10^4</td>
<td>current</td>
<td>1000</td>
</tr>
<tr>
<td>PTO</td>
<td>15</td>
<td>&lt;10^6</td>
<td>current</td>
<td>100</td>
</tr>
<tr>
<td>DPTO</td>
<td>20</td>
<td>&lt;10^6</td>
<td>current</td>
<td>30</td>
</tr>
<tr>
<td>OFPT</td>
<td>1 – (low)</td>
<td>&lt;10^6</td>
<td>resistance</td>
<td>80</td>
</tr>
</tbody>
</table>

The PPOs proposed can have more than 2 channels (3-8).

6. Conclusion

Contactless circuits of controllable photopotentiometric optocouplers – mono and stereo have been proposed, as well as analytical and graphic methods for calculating the photopotentiometric optocouplers. A comparison of PPOs according to the optocoupler type has been made.

7. References