Electric Optocoupler Filters

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Abstract – **When optocouplers are used in the electric filters, the frequency band of the filter can be easily tuned. This is realized by the LED current with a galvanically separated channel controlling the photodetector resistance. Both passive and active filters can be designed by means of optocouplers – for high and low frequencies, bandpass and band-stop filters.**

Keywords – **Optocouplers, Electric filters, Pasive filters, Active filters, Bandpass filters, Optocoupler – filters**

I. INTRODUCTION

The elements of optoelectronics can be used for designing optical and electric filters. With high-frequency filters photodiode and field phototransistor optocouplers are used; with middle-frequency filters – phototransistor optocouplers; with low-frequency filters – photoresistor optocouplers and optocouplers with Darlington phototransistors.

II. SINGLE-UNIT HIGH-FREQUENCY PASSIVE RC FILTER AND LOW – FREQUENCY PASSIVE RC FILTER

A. Figure 1 shows a single-unit high-frequency passive RC filter realized with a field phototransistor optocoupler O₁.

The drain-source resistance of the field phototransistor is controlled by the LED current I_F. The cut-off frequency ω of the filter is changed by the LED current I_F.

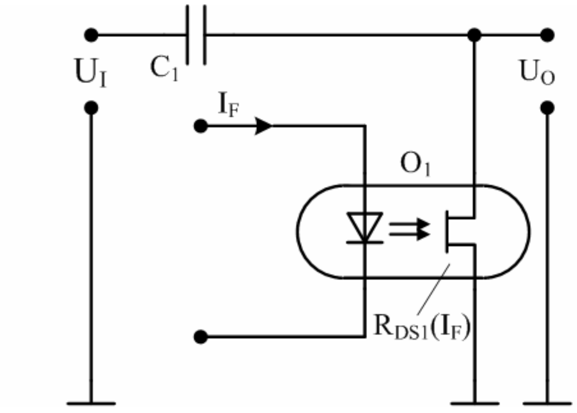

Fig. 1. Single-unit high-frequency passive RC filters

B. Figure 2 shows a circuit of a low-frequency passive RC filter with a controllable cut-off frequency determined by the Eq. 1.

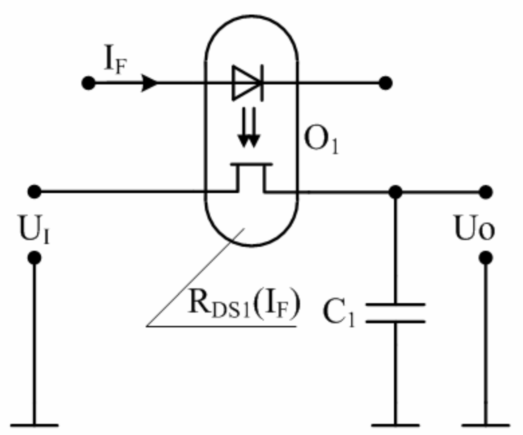

Fig. 2. Low-frequency passive RC filter

$$\omega = \frac{1}{C_1.R_{DS1}(I_F)} \qquad (1)$$

For the circuits from fig. 1 and fig. 2 at $\omega = 2nf$; $C_1 = 10.10^{-9}F$ and $R_{DS1}(I_F = 16\,mA) = 470\ \Omega$ for the optocoupler with Photo FET H11F3 of the firm FAIRCHILD. For the frequency is obtained $f \approx 34\,kHz$.

C. A bandpass filter can be obtained by connecting two single – unit passive RC filters (for low and high frequencies) in series – Fig. 3

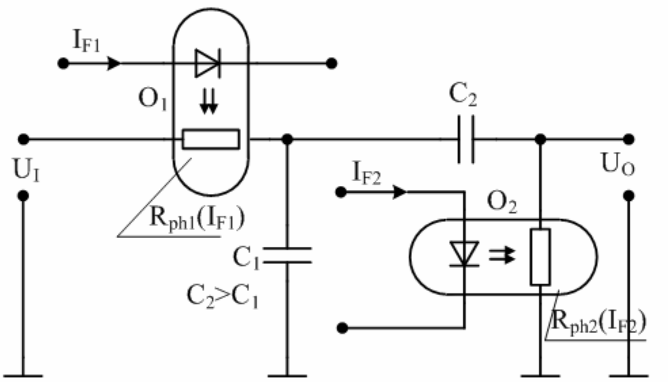

Fig.3. Bandpass filter

In this case it is realized by means of photoresistor optocouplers O_1 and O_2.

The pass band is determined by the Eq. 2 and Eq. 3:

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$$f_L = \frac{1}{2n.C_2 R_{ph2}(I_{F2})} \qquad (2)$$

$$f_H = \frac{1}{2n.C_1 R_{ph1}(I_{F1})} \qquad (3)$$

The frequency band is:

$$f = f_H - f_L \qquad (4)$$

D. When the places of the two single – unit filters are changed, the same bandpass filter is obtained – Fig. 4

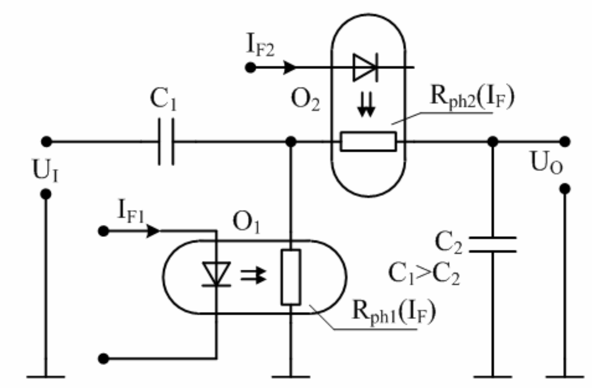


Fig. 4. Brandpass filter

The passive units of the RC filters can be connected in parallel as well. This is realized by means of adding diodes VD_1 and VD_2.

E. The development shown in fig. 5 is a band – stop filter

The cut-off frequencies are determined by the Eq. 2 and Eq. 3. The filters considered so far are passive ones.

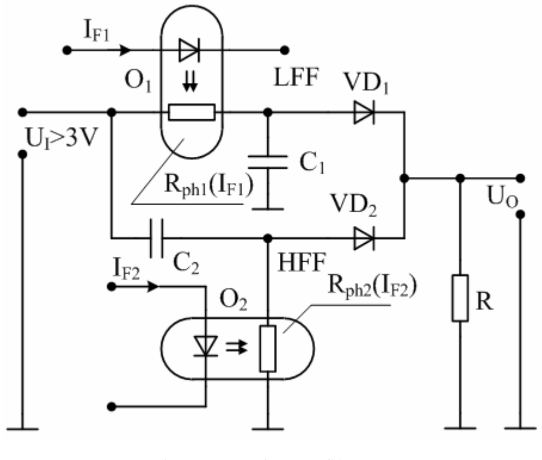


Fig. 5. Band-stop filter

III. ACTIVE RC FILTER

A. Figure 6 a shows an active RC filter with a controllable Q-factor-Eq. 5:

$$Q = \frac{\omega_O}{\Delta\omega} \qquad (5)$$

where $\Delta\omega$ is the frequency band of the filter.

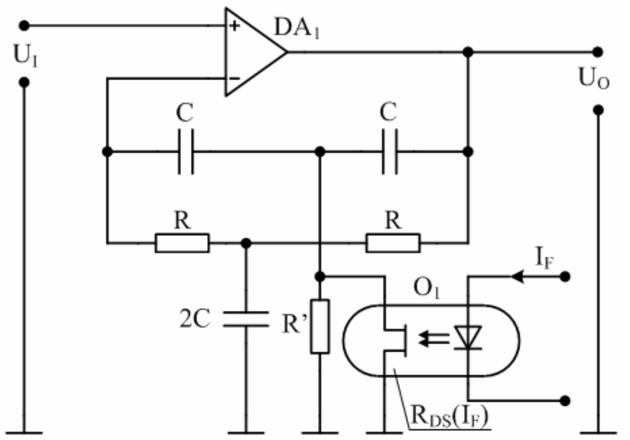


Fig. 6 a. Active RC filter

The average transmission frequency of the filter is Eq. 6:

$$f_O = \frac{1}{2n.RC} \qquad (6)$$

For the circuit from fig. 6 a. at $C = 10nF = 10.10^{-9}F$, $R = 100k\Omega$, $R' \approx 50k\Omega$, $\left(R' // R_{DS} \approx 49{,}99k\Omega\right)$, $R_{DS} = 360M\Omega$, at $I_F = 0mA$ for the optocoupler O_1 H11F3M. For frequency is obtained $f = 159kHz$.

The amplifier is with a frequency-dependent feedback with a double T-bridge which appears a passive controllable narrow-band RC filter – Eq. 7:

$$R' = \frac{R}{M}; \; \frac{R}{R'} = M = 2 \qquad (7)$$

When M = 2, the Q-factor has a nominal value is Eq. 8:

$$Q_{nominal} = \frac{K+1}{4} \qquad (8)$$

where K is the voltage amplification factor of the amplifier DA_1 (K is dimension less).

At $\omega_O(f_O)$ frequency, the feedback is missing in practice. When there is a deviation from this frequency, an optical feedback acts and the filter transmission coefficient decreases getting lower than K. By means of the LED current I_F the value R_{DS} (I_F) is changed or $R' = R / M$.

By means of the LED current I_F the coefficient M is changed and the Q-factor of the filter is controlled in a wide range on both sides of the nominal value of the frequency ω_O - fig. 6 b.

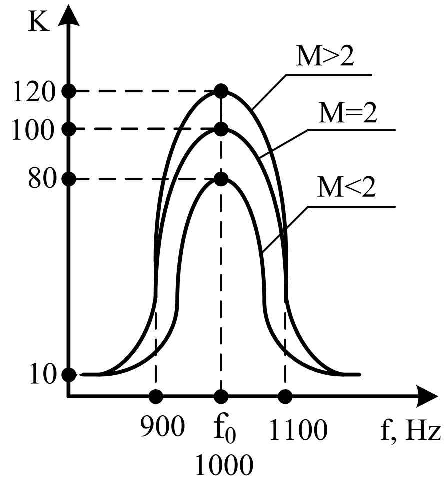


Fig. 6 b. The coefficient M is changed and the Q-factor of the filter is controlled in a wide range

IV. PASSIVE RC FILTER FOR LOW FREQUENCIES WITH HIGH ATTENUATION STEEPNESS

Figure 7 shows a passive RC filter for low frequencies with high attenuation steepness, a wide range of frequency readjustment, and a possibility for visual indication of availability or an absence of a signal.

For the circuit from fig. 7 at $C_1 = 100.10^{-9} F$, $R_1 = 10.10^3\, \Omega$, for the frequency is obtained $f = 151 Hz$.

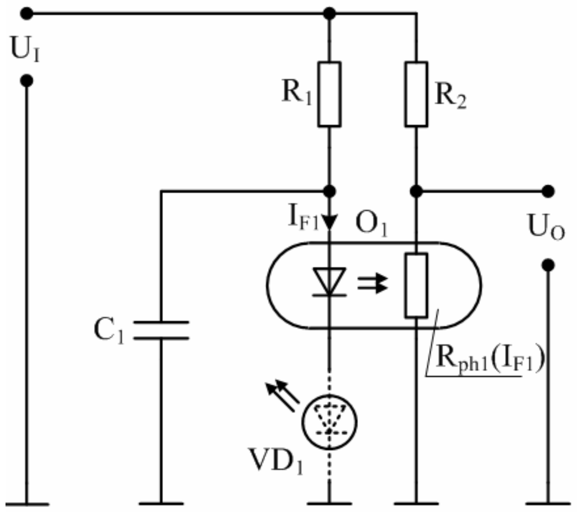


Fig. 7. Passive RC filter

Unfortunately, the controlling signal is not galvanically separated by the filter. If the input signal enters the filter pass band, a current passes through the LED of the optocoupler O_1.

The output voltage is Eq. 9:

$$U_O = \frac{U_I}{R_2 + R_{ph1}(I_{F1})} . R_{ph1} \tag{9}$$

where R_{ph1} is the resistance of the illuminated photoresistor.

When the frequency of the input signal is increased, the reactance of the capacitor X_{C1} decreases and shunts the optocoupler LED, the current across the LED falls down and the resistance of the photoresistor goes up. In this way the output voltage increases and in a given moment it is Eq. 10:

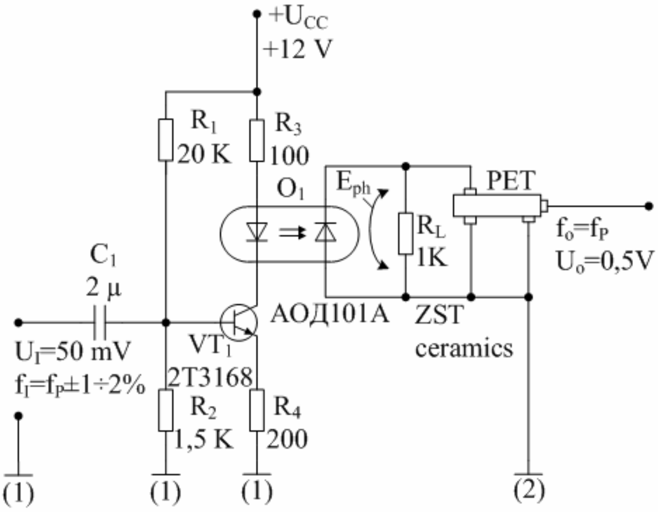
$$U_O = \frac{U_I}{R_2 + R_D} . R_D \tag{10}$$

where R_D is the dark resistance of the photoresistor.

The readjustment of the filter frequency is realized by the resistor R_1 and the capacitor C_1 or by changing the voltage U_I. If a visible LED VD_1 is used, the operation of the filter can be partially indicated. When a photothyristor is used, e.g. АОУ 103 /Russia/, or another one of the same type, a higher intrinsic transconductance is obtained.

Application of the filter in fig. 7 – digital systems for controlling the parameters of the micro-climate of production premises, information-measuring systems, temperature control, electronic speed limiters, etc.

V. PRINCIPAL CIRCUIT OF OPTOCOUPLER – FILTER IS GIVEN IN FIG. 8



Note: (1) and (2) is galvanic decoupling

Fig. 8. Principal circuit of optocoupler – filter

Known so far have optocouplers band width starting from 0 Hz by kHz and MHz range.

In this optocoupler, in the output chain of fotopriemnika include transformer piezoelectrical (PET). Thus perhaps oneself to obtain a large amplitude of the output signal to entrance and to oneself lapse through optocoupler only thus entrance conform frequency of resonance frequency of PET. Optocoupler is transformed in narrowband filter. The frequency of input signal must oneself differentiate by ± 2% from resonance frequency of PET. Usually resonance frequency of PET is in range from 10 kHz ÷ 10 MHz.

Photodiode optocoupler (O_1) is used, the photodiode works in photogalvanic mode like generator of photovoltage (E_{ph}) converter. The optocoupler (O_1) works like current (I_F) – voltage (E_{ph}) – Eq. 11.

$$E_{ph} = \varphi_T \ln \frac{K_i.I_F - I_L + I_D}{I_D} \qquad (11)$$

where φ_T – temperature potential, I_L – load current (working photocurrent of the photodiode working in photogalvanic mode, K_i (CTR) – current transfer ratio of the optocoupler, I_D – photodiode dark current of the photodiode.

At condition – Eq. 12 and Eq. 13:

$$R_L = \infty,\ I_L = 0,\ K_i.I_F >> I_D \qquad (12)$$

$$E_{ph} \approx \varphi_T.\ln \frac{K_i.I_F}{I_D} \qquad (13)$$

Differentiated resistance of the photodiode is given – Eq. 14 and Eq. 15:

$$r_{PD} = \frac{dE_{ph}}{dI_D} \qquad (14)$$

$$r_{PD} = \varphi_T \cdot \frac{1}{K_i.I_F} \qquad (15)$$

The output resistance to the photodiode (r_{PD}) oneself coordinate with input resistance of PET (z_{PT}) – Eq. 16, Eq. 17 and Eq. 18:

$$r_{pD} = Z_{PT} \text{ at } I_F = I_{Fopt} \qquad (16)$$

$$z_{PT} = \frac{\varphi_T}{K_i.I_{Fopt}} \qquad (17)$$

$$I_{Fopt} = \frac{\varphi_T}{K_i.z_{PT}} \qquad (18)$$

The optocoupler is photodiode optocoupler – GaAs Infrared LED, Si photodiode, PET from ZST ceramics* with $f_p = 49{,}5\,kHz$ (in ultrasound range), the loading resistor $R_L = 1 \div 10\,k\Omega,\ I_F = 1 \div 10\,mA$.

The PET amplifies photovoltaic input variable voltage from the photodiode.

*Optimum number electrode 4, delay signal 4,5 μs/ cm and optimum relation $\frac{\Delta f}{f_P} \leq 20$.

The parameters developed optocoupler – filter are:

LED

Forward voltage $U_F \leq 1{,}5\,V$
Forward current $I_F = 20\,mA$
Reverse voltage $U_R = 3{,}5\,V$
Pulse forward voltage trough photodiode $I_{FI} = 100\,mA$

Photodiode

Dark current $I_D \leq 2\,\mu A$

Optocoupler

Rise (fall) time $t_r(t_f) = 100\,ns$
Isolation resistance input – output $R_{IO} = 10^9\,\Omega$
Traster capacitance $C_{IO} = 2\,pF$
Current transfer factor $K_i = 1{,}0\,\%$ (I_F=10 % without PET)
Voltage transfer coefficient $K_U = 10\left(R_L = 1k\Omega, I_F = 10\,mA\right)$
Resonance frequency 49,5 kHz
Frequency band 48,5 ÷ 50,5 kHz

Application – like active narrowband filter with galvanic decoupling in the input from output signal and like raise voltage solid state transformer.

VI. CONCLUSION

Passive RC (single-unit and two-unit) low-frequency, bandpass and band-stop filters and active narrow-band filters with optocouplers have been developed. They have a number of advantages in comparison with common filters, such as easy readjustment of the frequency band with a galvanically controllable channel.

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