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## Design of low frequency bandwidth filter with high selectivity

*It has been shown that for efficient separation of the useful signal and interference, which in the range of low frequencies are no more than an octave, it is best to use an active filter. The parameters of the passive elements of the scheme are calculated and the active elements are selected. The coefficients of the transfer function are specified, the frequency characteristics of the filter are calculated and the possibility of suppressing the interference is more than 40 dB.*

The construction of a selective filter to suppress the low-frequency narrow-band intensive interference and to ensure the difference in transmission coefficients in the low frequency range greater (35 ... 40) dB when changing the frequency per octave is a complicated task. The use of passive filters on LC elements is complicated due to the rather low frequency of signals, and the use of RC filters is limited by the need for schemes of the sixth or seventh order (inclination of the frequency response - (120 ... 140) dB/dec).

Therefore, at low frequencies, it is advisable to use special active RC filters that are used in information processing systems, telephony, data transmission systems, television, broadcast and high-quality sound reproduction systems. On existing active elements (operational amplifiers, OA)) the frequency range can be from zero to hundreds of kHz [1]. For the realization of this task (ensuring the difference of transfer coefficients at frequencies of 50 Hz and 100 Hz by 40 dB), the active filter, implemented according to the scheme of rice, is best on fig. 1. The theoretical derivation of transfer functions for such a scheme is given in [2]. This scheme is a biquadratic circle on three operational amplifiers and provides filtering not only interference with a frequency of 50 Hz, but also components with frequencies above 100 Hz (is a bandpass filter).

Transmitting and operator functions of this filter are defined as follows [2]:

$$K_{BPF}(i\omega) = \frac{1}{R_1C_1} \times \frac{i\omega}{(i\omega)^2 + \dfrac{i\omega}{R_2C_1} + \dfrac{R_5}{R_3R_4R_6C_1C_2}}; \tag{1}$$

$$K_{BPF}(p) = \frac{\dfrac{p}{R_1C_1}}{p^2 + \dfrac{p}{R_2C_1} + \dfrac{R_5}{R_3R_4R_6C_1C_2}} = \frac{a_1p}{p^2 + b_1p + b_0}. \tag{2}$$

As a result of the solution of equation (2) we obtain:

$$R_1 = \frac{1}{a_1C_1}; \quad R_2 = \frac{1}{b_1C_1}; \quad R_4 = R_5; \quad R_6 = \frac{\sqrt{b_0C_1}}{k_1}; \quad R_3 = \frac{k_1}{b_0C_2}. \tag{3}$$

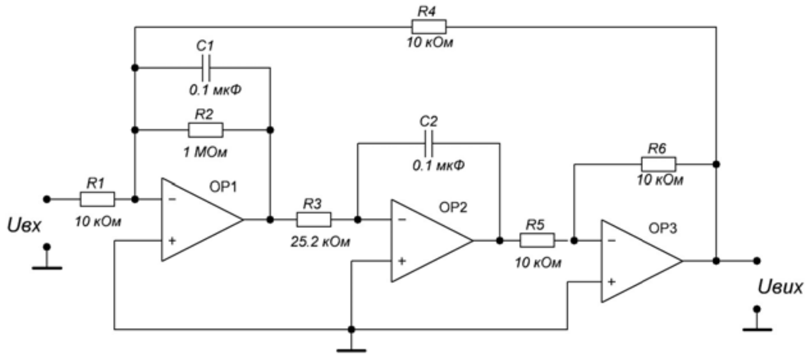

Fig. 1. Scheme of active bandpass filter

Discrete concentrated capacitors (capacitors) can not have arbitrary capacitance, so it is necessary to select their denominations for (3).

The nominal values of resistors $R_4 = R_5$ are chosen within (1 ... 20) kOhm. This means that in (3) the only free parameter is $k_1$. Therefore, the parameter $k_1$ is chosen to minimize the range of values of the resistors $R_1$ ... $R_6$.

The operator transfer function (TF), which approximates the amplitude-frequency characteristic (AFC) BPF, is required to filter the noise at a frequency of 50 Hz and frequencies above 100 Hz using a filter according to (2) the following form [1]:

$$K(p) = \frac{a_1 p}{p^2 + b_1 p + b_0} = \frac{1000p}{p^2 + 10p + 394800}. \tag{4}$$

When approximating, the main role is played by the steepness of the inclination of the frequency response in the area from the zero frequency to the frequency of the main useful signal, that is, 100 Hz. In the scheme, the values of the nominal values of capacitors $C_1$ and $C_2$ were taken at the standard range of 0.1 μF. Next, we calculate the exact values of the resistors $R_1$ and $R_2$ for (3):

$$R_1 = \frac{1}{a_1 C_1} = \frac{1}{1000 \cdot 0.1 \cdot 10^{-6}} = 10\ кОм;\quad R_2 = \frac{1}{b_1 C_1} = \frac{1}{10 \cdot 0.1 \cdot 10^{-6}} = 1\ МОм.$$

The calculated resistance values of the resistors $R_1$ and $R_2$ correspond to the existing nominal values in the standard series. From the ratio (3) we choose the resistor value $R_4 = R_5 = 10$ kOhm. If you assume the resistance of the resistor $R_6$ arbitrarily, for example, $R_6 = 10$ kOhm, then you can calculate the resistance of the resistor $R_3$:

$$R_3 = \frac{k_1}{b_0 R_6 C_1 C_2} = \frac{1}{394800 \cdot 10000 \cdot 0.1 \cdot 10^{-6} \cdot 0.1 \cdot 10^{-6}} = 25.33\ кОм. \tag{5}$$

The calculated resistance value of the resistor does not correspond to the standard values of the series. To increase the accuracy of the filter configuration, we will take the value of the resistance rating of the resistor $R_3$ near the E192 level to 25.2 kΩ.

Similarly, we calculate the values of the values of the elements of the BPF for other values of the signal frequency and noise. The scheme of the filter is realized on the following elements: capacitors $C_1$ and $C_2$ type KM-6-0.1 µF×25 V ± 10%; resistors such as C2-22-0.125 W±10%: $R_1$ and $R_4$ ... $R_6$ – 10 kΩ; $R_2$ – 1 MΩ; $R_3$ – 25.2 kΩ.

The ratio for the AFC BPF is the module of its complex TF, i.e.

$$K_{BPF}(\omega)=\frac{\omega}{R_1C_1}\times\frac{1}{\sqrt{\left(\frac{R_5}{R_3R_4R_6C_1C_2}-\omega^2\right)^2+\left(\frac{\omega}{R_2C_1}\right)^2}}. \tag{6}$$

The calculated values of the complex TF module at 50 and 100 Hz are:

$$K_{BPF}(50\ Hz)=\frac{314\cdot 10^3}{\sqrt{\left(\frac{10^4}{25200\cdot 10^4\cdot 10^4\cdot 10^{-14}}-314^2\right)^2+\left(\frac{314}{10^6\cdot 10^{-7}}\right)^2}}=1.012;$$

$$K_{BPF}(100\ Hz)=\frac{628\cdot 10^3}{\sqrt{\left(\frac{10^4}{25200\cdot 10^4\cdot 10^4\cdot 10^{-14}}-628^2\right)^2+\left(\frac{628}{10^6\cdot 10^{-7}}\right)^2}}=101.478.$$

The ratio of transmission coefficient modules at frequencies 100 and 50 Hz:

$$A=\frac{K_{BPF}(100\ Hz)}{K_{BPF}(50\ Hz)}=\frac{101.478}{1.012}=100.2747\ (40.024\ dB). \tag{7}$$

In practice, the coefficient of noise suppression is more often calculated [1]:

$$d=\frac{1}{A}=\frac{K_{BPF}(50\ Hz)}{K_{BPF}(100\ Hz)}=\frac{1}{100.2747}=0.009973\ (-40.024\ dB). \tag{8}$$

The calculated value of the coefficient of suppression of the noise meets the formulated requirements. Calculated values of the dependence of the module of the approximating transfer function on the frequency of the $K_{anp}(f)$ in step 10 Hz are given in Table 1, and graphic dependence – in Fig. 2, a [1].

*Table 1.*

Estimated values of the modulus of the approximating transfer function $K_{anp}(f)$ and of the transfer function module $K(f)$

| *f*, Hz | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $K_{anp}(f)$ | 0.000 | 0.161 | 0.332 | 0.525 | 0.785 | 1.000 | 1.492 | 2.184 | 3.535 | 7.518 | 100.000 | 8.308 | 4.337 | 2.997 | 2.320 | 1.910 | 1.632 | 1.431 | 1.279 | 1.159 | 1.061 |
| $K(f)$ | 0.000 | 0.161 | 0.332 | 0.525 | 0.758 | 1.012 | 1.493 | 2.186 | 3.540 | 7.540 | 101.478 | 8.286 | 4.331 | 2.995 | 2.319 | 1.909 | 1.632 | 1.431 | 1.278 | 1.158 | 1.061 |

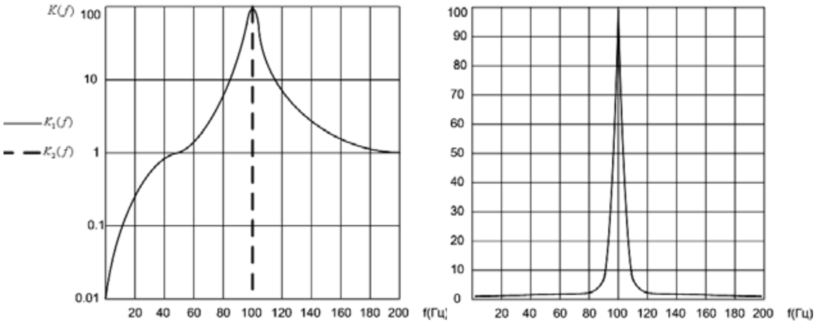


Fig. 2. AFC obtained by the approximating transmitting function ($K_1$), and the ideal characteristic of the band filter ($K_2$) (a); schedule of dependence of the transfer function module on frequency (AFC) (b)

The approximating TF (4) and the estimated values of the TF (6) module differ numerically, although the form of the approximating curve remains. Calculated values of the TF module, calculated with account of the exact parameters used in the scheme of the elements, are given in table 1.

The value of the TF module after a frequency of 200 Hz continues to decrease, which allows for efficient filtering of noise at frequencies above 100 Hz, for example, an industrial frequency of 400 Hz and alarms from radio stations operating in the long wavelength range. The graph of the dependence of the TF module on the frequency is shown in Fig. 2, b.

Input impedance of the BP is determined by the value of the resistance $R_1$, so special measures to reconcile with the previous cascade (usually reinforcing) are not necessary. Given that the OA has an output impedance (0.1 ... 1) kΩ, the load (subject to the implementation of the next cascade on a similar OA) is in order of greater impedance and will not have a significant effect on the magnitude of the signal at the output of the previous cascade, and therefore at the entrance to the BPF. The value of the output impedance is dependent on the type of active element used in the BPF circuit.

As an active element of the filter, the OA is used, the choice of which type is based on the following considerations: large input impedance, small output impedance, large gain without feedback, low current consumption, presence of microcontroller mode.

Based on these requirements in the circuit, you can use OA K555УД1A, which has the following parameters: voltage gain without feedback $K_U$ = 50000; bias voltage $U_{3M}$ = 5 mV; input current $I_{BX}$ = 7.5 nA; cut-off frequency (frequency of single-voltage amplification) $f_{3P}$ =10 kHz; coefficient of weakening of common-mode noise of $K_{ПС3}$ = 70 dB; nominal output voltage and current $U_{ВИХ.ном}$ = 2 V and $I_{ВИХ.ном}$ = 2.9 mA; current consumption $I_{СП}$ = 25 μA; rated voltage of $U_{Ж.ном}$ = ±9 V. This OA has the ability to switch microcontroller mode, low voltage supply and sufficient output current. It maintains efficiency when reducing the supply voltage to 1.2 V, which is important in the application of such an BPF in portable devices when powered from a rechargeable battery.

A typical switching circuit [3] OP K555УД1А is shown in Fig. 3

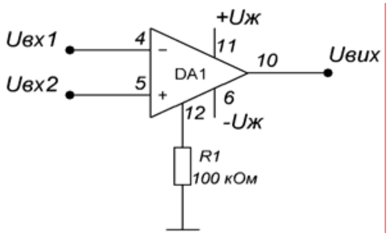


Fig. 3. Typical switching circuit OA K555УД1А

This OA can operate in the range of supply voltages ±(1.2 ... 18) V, with the maximum output voltage equal to 0.9 $U_{Ж}$, and is built in two-stage circuit and is available in the housing 201.8-6. The frequency response is corrected by one internal condenser. Provides protection of the output stage from overload and trigger mode. The main difference between such an OA is that the mode of the internal regulator, which determines the entire operation of direct current, is given from the outside. The choice of the bias current of the regulator regulates the current consumption of OA from 1 μA to the values inherent in the ordinary universal OA [4]. Resistor $R_1$ sets the microcontroller mode.

The output impedance of the OA $R_{ВИХ} = \frac{U_{ВИХ}}{I_{ВИХ}} = \frac{2}{2.9 \cdot 10^{-3}} = 690\ Ом,$

is confirmed by the preliminary considerations that, with the input resistance of the next cascade, by an order of magnitude higher output impedance of the previous cascade, the input impedance does not have a significant effect on the magnitude of the output voltage.

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