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Synthesis of a Fourth-Order Bandpass Filter Circuit with Considering the Technological Limitations on Microelectronic Realization

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Abstract — **The new circuit of fourth-order band-pass filter (BPF) has been developed with independently adjustable parameters - non-uniformity of the amplitude-frequency characteristic (AFC), bandwidth and transmission scale factor. The basic mathematical expressions for transfer function coefficients of the BPF structure and their parameters of AFC are presented. The AFCs was show from program Micro-Cap.**

Keywords — band-pass filter, transfer function, relative frequency, center frequency of filter, amplitude-frequency characteristic.

I. INTRODUCTION

The features of the technological design of microelectronic filters are associated with ensuring the precision of their functional characteristics. The precision of circuit characteristics is determined, in general case, by the quality of the manufacture of the elements and electrophysical structures.

The precision filters are characterized by increased requirements for the accuracy of nominal values of elements or their output characteristics, their temporal stability under the influence of destabilizing factors, and also for the sign and value of the resistance temperature coefficient and the capacitance temperature coefficient or their ratio.

The analysis of traditional hybrid thin-film technology has shown that it allows the implementation of relatively stable RC-circuit. Thanks to the application of elements for surface mount technology in micro-assemblies, including elements without case, and also using of modern advances in the manufacture of stable thin-film capacitors, it is possible to obtain long time constants of RC-circuits and to manufacturing filters, which will working in high-frequency and low-frequency regions.

However, the manufacturing accuracy of resistive elements made by hybrid-film technology is ±10 % and, at best, at using of modern technologies can't be higher than (3 — 5) % [1]. In turn, active and passive elements for surface mount technology also have large errors. So, for example, the unity gain frequency of operational amplifiers can deviate for different sample up to (± 20 — 40) %, the tolerances for capacitors are (± 5 — 20) % and for the best elements without case ± 1 % (K10 — 43).

These errors do not allow us to implement a filter with precision characteristics, since the last one is possible when providing deviations of the nominal values of the elements from the calculated values at the level of ± 0.1%.

The elements rearranged using digital potentiometer chips or R-2R resistive matrices [2 — 3] to ensure the specified accuracy of reproducing the characteristics of frequency selection devices.

The circuitry of devices of frequency selection advisable using for improve manufacturability, it allows using a non-iterative tuning algorithm, in which all parameters tuned before the i-th have zero sensitivity to the i-th adjustable element [4]. The best way to meet the above criteria is the circuitry of the devices, which allows for two-way independent adjustments of the configurable parameters only by increasing the resistances of the adjusted resistors. A sufficiently large number of second – order links [5 — 12] are known to possess these properties, i.e., independent two-way adjustment of frequency and pole attenuation, and the scale factor.

In filters of a higher order (especially in multi-loop filters with low sensitivity of parameters to elements) the specified setting can't be performed to the impossibility of applying the specified algorithm. For such devices have been developed indirect setting indirect procedures, which consist in tuning of definite transmission coefficients of feedback loops [5], which ultimately leads to deviations in the characteristics because of neglect a scatter of time constant of the frequency-setting circuits and uncompensated parasitic phase errors.

The authors of publications [13 — 16] recommend using a connected-cascade structure, which is slightly inferior in

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sensitivity to the multi-loop structure, but has a simpler tuning procedure and less parasitic passage of high frequency signals to the filter output. The idea of constructing such filters is implement high-order filters with using cascaded-coupled two filters of the second order. In this case, the fourth-order filter is considered as a functionally complete product.

The purpose of this work is to development of a fourth-order band-pass filter (BPF) circuit with independently configurable parameters – non-uniformity of the amplitude-frequency characteristic (AFC), bandwidth and transmission scale factor.

II. Analysis of the Transfer Function of the Fourth Order Band-Pass Filter

In general case the transfer function of a fourth-order BPF is

$$W(p) = M\frac{p^2 b_2^*}{p^4 + p^3 a_3^* + p^2 a_2^* + p a_1^* + a_0^*}\ , \qquad (1)$$

which made on the connected-cascade implementation (Fig. 1) on identical second-order links with the transfer functions of the band-pass type

$$F_i(p) = K_i\frac{p d_p \omega_p}{p^2 + p d_p \omega_p + \omega_p^2}, \qquad (2)$$

it is convenient to present in the form of

$$W(p) = M\frac{p^2 b_2 \omega_p^2}{p^4 + p^3 a_3 \omega_p + p^2 a_2 \omega_p^2 + p a_1 \omega_p^3 + \omega_p^4}. \qquad (3)$$

The following notations is used in equations (1) - (3) :

b_k^*, a_k^* is the coefficients of the numerator and denominator of the transfer function at the appropriate degrees;

b_k, a_k is the coefficients of the transfer function normalized to the pole frequency;

K_i is the transmission coefficient of the i-th link;

M is the scale factor of the filter transfer.

It will be shown below that a change in the relative bandwidth of a fourth-order BPF without changing its other parameters (non-uniformity of the AFC and transmission coefficient) that possible when the d_p attenuation of one or two links changes, and the K_i coefficients should not change in the links. These conditions are corresponding to the links that have transfer functions with equal coefficients of the numerator and denominator polynoms at p. This circumstance was reflected in the equation (2).

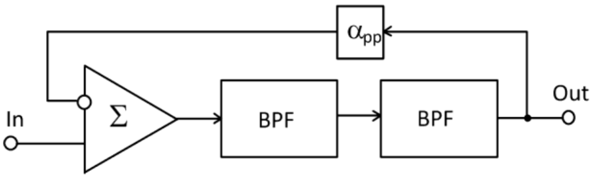

Fig. 1. The BPF structure.

In equation (3) we changing the variable p on jω and finding the complex transfer coefficient

$$W(j\omega) = M\frac{-\omega^2 b_2 \omega_p^2}{\omega^4 - j\omega^3 a_3 \omega_p - \omega^2 a_2 \omega_p^2 + j\omega a_1 \omega_p^3 + \omega_p^4}\ . \qquad (4)$$

When we dividing the numerator and denominator of the complex transmission coefficient by ω_p^4 and entering the normalized frequency $\Omega = \frac{\omega}{\omega_p}$, get

$$W(j\omega) = M\frac{-\Omega^2 b_2}{\Omega^4 - j\Omega^3 a_3 - \Omega^2 a_2 + j\Omega a_1 + 1}. \qquad (5)$$

Next is from the condition of geometric symmetry of the AFC

$$W(j\Omega) = M\left(j\frac{1}{\Omega}\right),$$

it follows that the coefficient a_1 must be equal to a_3, then

$$W(j\Omega) = M\frac{-b_2}{\Omega^2 - a_2 + \frac{1}{\Omega^2} + ja_1\left(\frac{1}{\Omega} - \Omega\right)}. \qquad (6)$$

If introduce a new variable is the relative frequency detuning $X = \frac{1}{\Omega} - \Omega$, then the last expression can be simplified:

$$W(jX) = M\frac{b_2}{X^2 + 2 - a_2 + ja_1 X}. \qquad (7)$$

The AFC of a fourth-order BPF is found as a module of the complex transmission coefficient (7):

$$A(X) = |W(jX)| = M\frac{b_2}{\sqrt{\left(X^2 + 2 - a_2\right)^2 + a_1^2 X^2}}. \qquad (8)$$

The frequencies on which the AFC reaches the maximum value are found from the condition $\frac{\partial|W(jX)|}{\partial X} = 0$:

$$X_{1,2} = \sqrt{a_2 - 2 - \frac{a_1^2}{2}},\ \ X_3 = 0. \qquad (9)$$

The relative frequency detuning $X_3=0$ corresponds to the center frequency of the filter, and $X_{1,2}$ is a bursts of the AFC.

The maximum values (rises) of the AFC find when substituting the formula (9) into equation (8)

$$A_{\text{мах}} = M\frac{b_2}{a_1\sqrt{a_2 - 2 - \frac{a_1^2}{2}}}. \qquad (10)$$

Now get the transmission of the filter at the center frequency if accepting X=0 from the formula (8)

$$A(0) = M\frac{b_2}{2-a_2}, \tag{11}$$

and, setting an arbitrary value A of the AFC, we find the frequencies:

$$X^{\pm} = \sqrt{\left|a_2 - 2 - \frac{a_1^2}{2} \pm \sqrt{2(2-a_2)\frac{a_1^2}{2} + \frac{a_1^4}{4} + \left(\frac{Mb_2}{A}\right)^2}\right|}. \tag{12}$$

After that finding the parameters of the fourth order filter without solving the task of approximation. Obtain the equations for calculating the loop gain if given the non-uniformity of the Δ AFC (see Fig. 2), which expressed in dB

$$\alpha_{pp} = 2\cdot 10^{\frac{\Delta}{10}} - 1 \pm 2\sqrt{10^{\frac{\Delta}{5}} - 10^{\frac{\Delta}{10}}}, \tag{13}$$

and attenuation of the poles of the links determinates as

$$d_p = \frac{X_{\text{cut-off}}}{\sqrt{\left|\alpha_{pp} - 1 \pm \sqrt{2}\sqrt{1+\alpha_{pp}^2}\right|}}, \tag{14}$$

for the block diagram shown on Fig. 1.

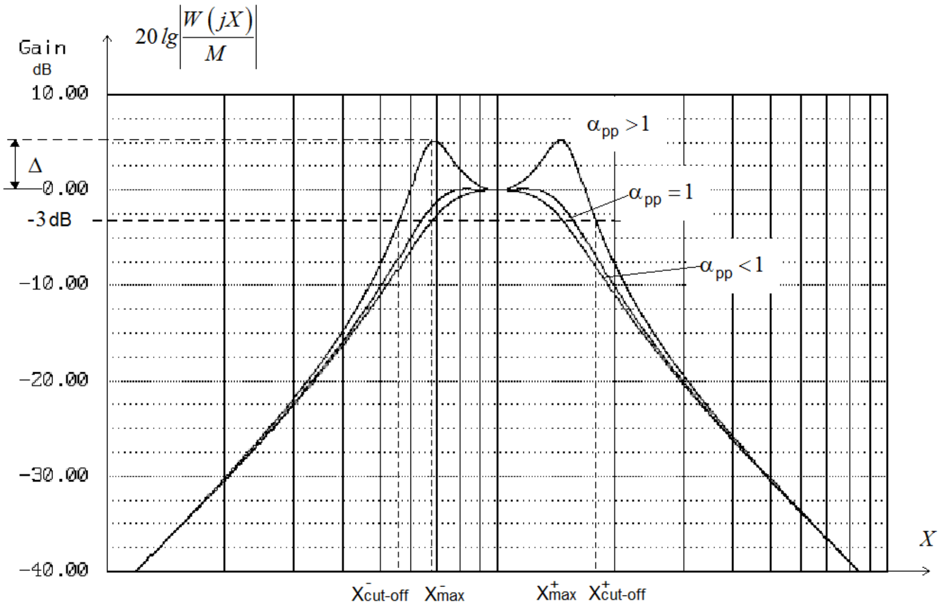

Fig. 2. Graphical definition of the AFC parameters.

III. EXAMPLE IMPLEMENTATION OF THE BAND-PASS FILTER

The analysis present that the synthesized circuits of fourth-order BPF can be realize on links, which given in works [9, 17].

The BPF circuit, which shown on Fig. 3, was designed on links from the application on patent [17] and realized on base the block diagram (Fig. 1).

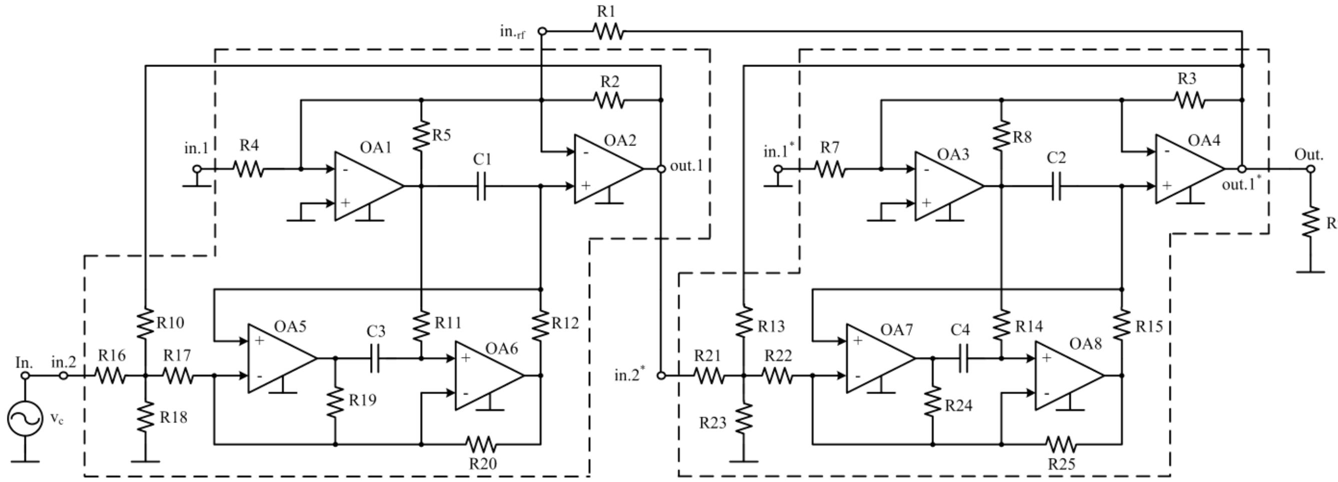

Fig. 3. The circuit of the BPF on base of structure Fig. 1.

The graph was obtained in the Micro-Cap application package and shown in Fig. 4 illustrates that the modification in the form of the AFC when the resistance of the resistor R1 changes in the BPF circuit (Fig. 3). The analysis of these graphs shows that the synthesized block diagrams have independent adjustment at non-uniformity of the AFC in bandwidth and transmission scale factor.

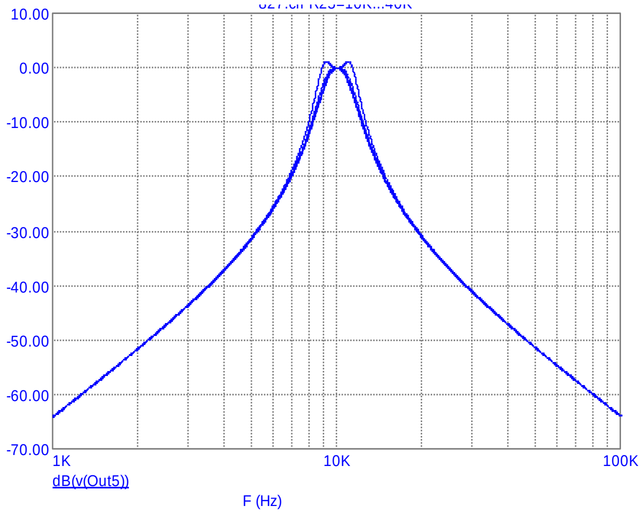

Fig. 4. The AFC family of the BPF (Fig. 3) at changes the resistance of R1.

The control of the relative bandwidth in the BPF circuit (Fig. 3) can be carried out by changing the attenuation in one or simultaneously in two links by adjusting the resistances of the resistors R18, R23. The AFC graphs for this case are shown on Fig. 5.

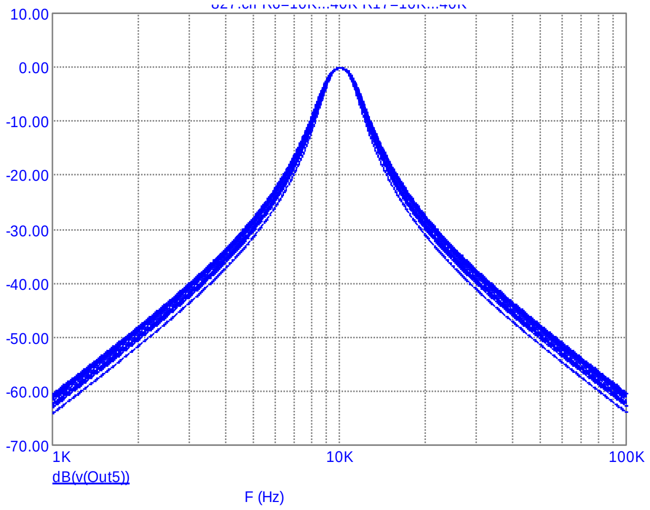

Fig. 5. The AFC family of the BPF when changing the resistances R18, R23.

CONCLUSION

A fourth-order BPF circuit has been developed that has independent adjustment at non-uniformity of the AFC in the bandwidth and transmission scale factor. It is also possible to control the bandwidth by changing the attenuation in one or simultaneously in two links.

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