Article

Low-pass filter based on base differential and differential difference operational amplifiers

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Abstract: A new low-pass filter (LPF) circuit with independent adjustment of various, incl. digitally controlled, pole frequency resistors, pole quality factor and transmission coefficient. The proposed low-pass filter is based on the use of the properties of a multi-differential operational amplifier that performs the functions of a signal adder. The peculiarity of the filter is that it has three inputs, with respect to which different transmission coefficients are implemented, incl. inverting (-1) and non-inverting (+1). To check these properties of a low-pass filter in the Micro-Cap environment, computer simulation of a specific circuit was performed on a multi-differential operational amplifier AD 8130. Mathematical expressions are given for the main parameters of the proposed low-pass filter, which allow parametric synthesis of elements of a specific circuit under given restrictions on the used element base.

Keywords: active filters, filtering theory, low-pass filter, voltage followers, pole frequency, quality factor, frequency response

1. Introduction

To reduce the effects of aliasing [1], at the input of analog-to-digital converters (ADCs) of various modifications, the so-called antialiasing low-pass filters are switched on, which have a significant impact on the static and dynamic performance of many radio engineering and measuring systems.

The purpose and novelty of the article is to study a new low-pass filter circuit with three inputs based on a differential difference operational amplifier (DDA), which provides for sequential independent tuning by different, incl. digitally controlled resistors, transmission ratio, pole frequency and pole quality factor.

2. The main parameters of LPF on base DDA

On Figure 1 shows a diagram of the proposed low-frequency ARCF [2], in which the adder of input signals and feedback signals is made on the basis of a multi-differential operational amplifier. The low-pass filter circuit provides independent adjustment of the transmission coefficient, pole frequency and pole quality factor by different resistors. At the same time, the LPF has a low sensitivity of the transmission coefficient at low frequency to various destabilizing factors - tolerances on the parameters of the frequency-setting elements of the circuit and changes in their characteristics due to temperature or radiation.

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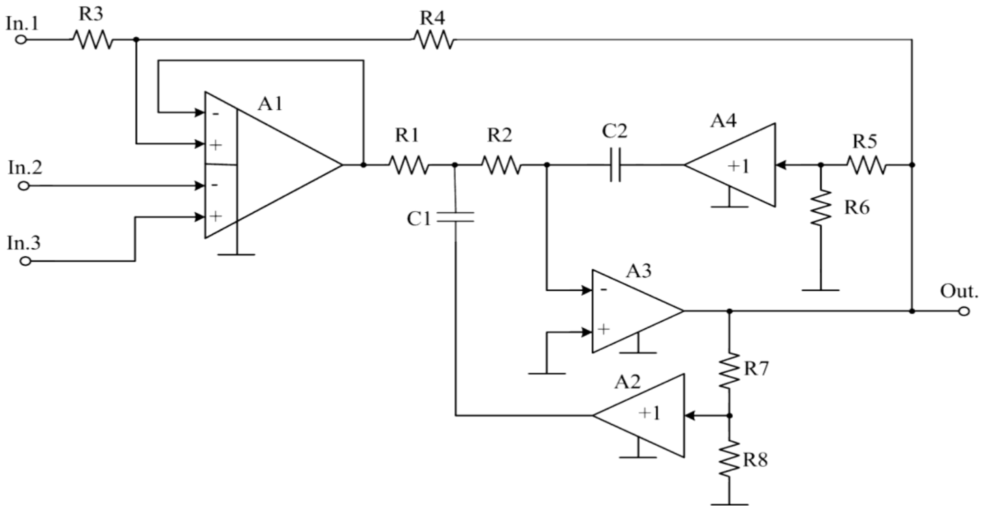

Figure 1. ARCF low frequencies based on DDA [2].

When that when introducing the notation for time constants $\tau_1 = R_1C_1$, $\tau_2 = R_2C_2$ the transmission coefficient of LPF on Figure 1 at zero frequency:

- from the main input (Input 1) to the output

$$M_{01} = -\frac{R_4}{R_3}, \quad (1)$$

- from the additional input (In2) to the output

$$M_{02} = 1 + \frac{R_4}{R_3}, \quad (2)$$

- from the additional input (In3) to the output

$$M_{03} = -\left(1 + \frac{R_4}{R_3}\right), \quad (3)$$

From equations (2) and (3) it can be established that in order to obtain M=1 (or M=-1) when using additional inputs (In.2, In.3), the resistance of the resistor R4 must be selected equal to zero (or R3=∞).

LPF transmission coefficient on Figure 1 at the pole frequency:

- from the main entrance (Input 1)

$$M_{\omega p1} = -\frac{\frac{R_4}{R_3}\sqrt{\frac{R_3}{R_3+R_4}\left(1+\frac{R_5}{R_6}\right)}}{\sqrt{\frac{\tau_2}{\tau_1}} + \sqrt{\frac{R_1C_2}{R_2C_1} + \frac{R_8}{R_7+R_8}\left(1+\frac{R_5}{R_6}\right)}\sqrt{\frac{\tau_1}{\tau_2}}},$$

(4)

- from the additional input (In2) to the output

$$M_{\omega p2} = \frac{\left(1+\frac{R_4}{R_3}\right)\sqrt{\frac{R_3}{R_3+R_4}\left(1+\frac{R_5}{R_6}\right)}}{\sqrt{\frac{\tau_2}{\tau_1}} + \sqrt{\frac{R_1C_2}{R_2C_1} + \frac{R_8}{R_7+R_8}\left(1+\frac{R_5}{R_6}\right)}\sqrt{\frac{\tau_1}{\tau_2}}}, \quad (5)$$

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- from the additional input (In3) to the output

$$M_{\omega p3} = -\frac{\left(1+\frac{R_4}{R_3}\right)\sqrt{\frac{R_3}{R_3+R_4}\left(1+\frac{R_5}{R_6}\right)}}{\sqrt{\frac{\tau_2}{\tau_1}}+\sqrt{\frac{R_1C_2}{R_2C_1}}+\frac{R_8}{R_7+R_8}\left(1+\frac{R_5}{R_6}\right)\sqrt{\frac{\tau_1}{\tau_2}}}, \quad (6)$$

Moreover, for all inputs (In.1, In.2, In.3) –
pole frequency

$$\omega_p = \frac{1}{\sqrt{\tau_1+\tau_2}}\sqrt{\frac{R_3}{R_3+R_4}\left(1+\frac{R_5}{R_6}\right)}, \quad (7)$$

- pole attenuation

$$d_p = \frac{\sqrt{\frac{\tau_2}{\tau_1}}+\sqrt{\frac{R_1C_2}{R_2C_1}}+\frac{R_8}{R_7+R_8}\left(1+\frac{R_5}{R_6}\right)\sqrt{\frac{\tau_1}{\tau_2}}}{\sqrt{\frac{R_3}{R_3+R_4}\left(1+\frac{R_5}{R_6}\right)}}, \quad (8)$$

The above mathematical expressions (1) - (8) allow us to draw the following conclusions about the advantages of the proposed LPF in comparison with the LPF prototype [3] and install the following setup sequence:

1. With the help of digitally controlled resistors R3 and / or R4, the gain at low frequency is adjusted. Further, these resistors are fixed and are not used to adjust other parameters of the circuit (formulas (1) - (3)).

2. By changing the resistance of the resistor R5 and / or R6, the frequency of the pole is adjusted (formula (7)). Further, these resistors are fixed and are not used to adjust the attenuation of the pole.

3. Pole attenuation is adjusted by resistors R7 and R8 in accordance with formula (8). Due to the fact that the low-frequency transmission coefficients (1) - (3) are determined by the ratio of the two resistors R3 and R4 and do not depend on the parameters of other elements, in the low-pass filter circuit Figure 2, their high stability is achieved under various destabilizing factors.

Due to the fact that the transmission coefficients at a low frequency are equal to M=+1, M=-1 or are determined by the ratio of two resistors R3 and R4, in the low-pass filter circuit in Fig. 2, their high stability is achieved with various destabilizing factors affecting the frequency-setting elements.

It should also be noted that by choosing the numerical value of the ratio of resistors R3 and R4 from the main input (In1), according to formula (1), in the low-pass filter circuit, the transfer coefficient can be realized either more or less than unity, and in accordance with the formulas (2) and (3) from additional inputs (In2, In3), the transmission coefficients can be set from one to the required value. Moreover, the first additional input (In.2) of the low-pass filter circuit is non-inverting, and the second additional input (In.3) is inverting. This expands the functionality of the proposed LPF.

It is important to note that when choosing the resistance of the resistor R4 equal to zero, the numerical values of the transmission coefficients (2) and (3) at low frequency from the first and second additional inputs (In.2, In.3) to the output of the circuit become equal to one M=1 (or M=-1) and do not depend on the parameters of other frequency-setting elements.

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3. Computer simulation of LPF

On Figure 2 shows a diagram of the low-pass filter Figure 1 in the Micro-Cap environment [4] using the AD 8130 DDA models [5].

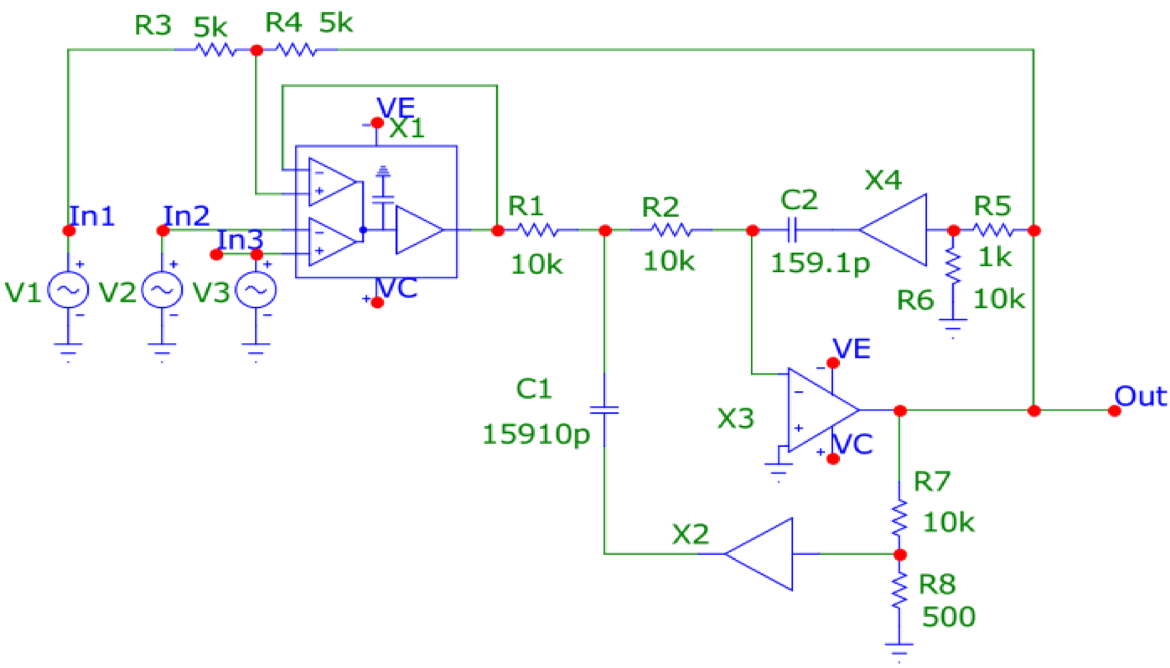
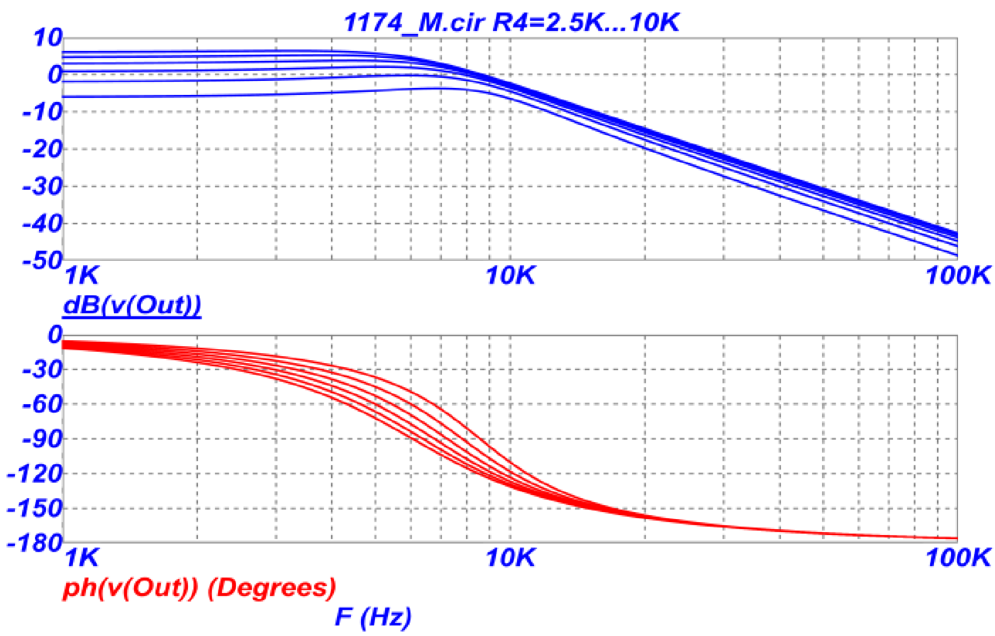


Figure 2. LPF scheme Fig. 1 in the Micro-Cap simulation environment [5].

On Figure 3 shows the amplitude-frequency (AFC) and phase-frequency (PFC) characteristics of the LPF Figure 2 in the region of the pole frequency (a) and a wider frequency range (b) when changing the resistance of the resistor R4 in the range of 2.5-10 kOhm in order to adjust the transfer coefficient for the main input In.1, and here the transfer coefficient varies in the range from -7dB to 7dB.



a)

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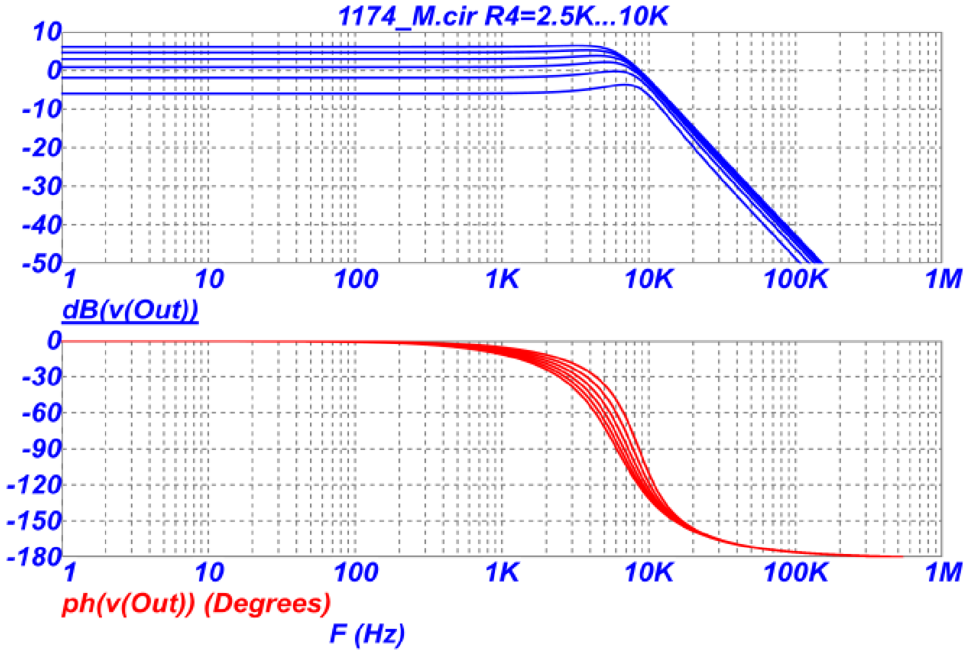
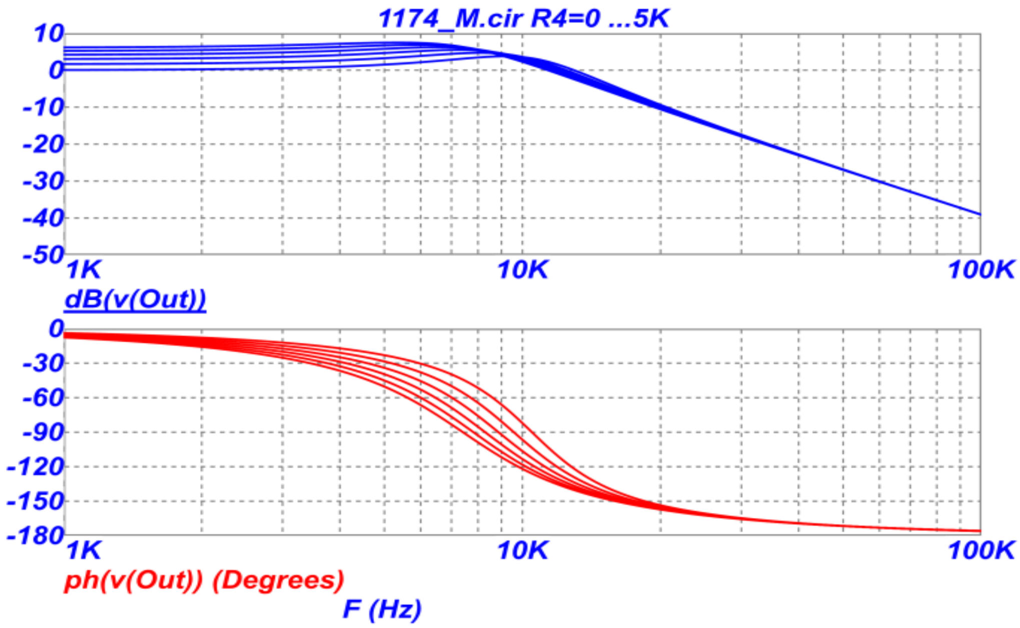


b)

Figure 3. AFC and PFC of LPF on Figure 2 around the frequency of the pole (a) and a wider frequency range (b) when the resistance of the resistor R4 changes in the range of 2.5-10 kOhm.

On Figure 4 shows the AFC and PFC of the LPF Figure 2 in the region of the pole frequency (a) and a wider frequency range (b) when changing the resistance of the resistor R4 in the range of 0-5 kOhm in order to adjust the transfer coefficient for additional inputs (In.2, In.3) in the range from 0dB to 7dB.



a)

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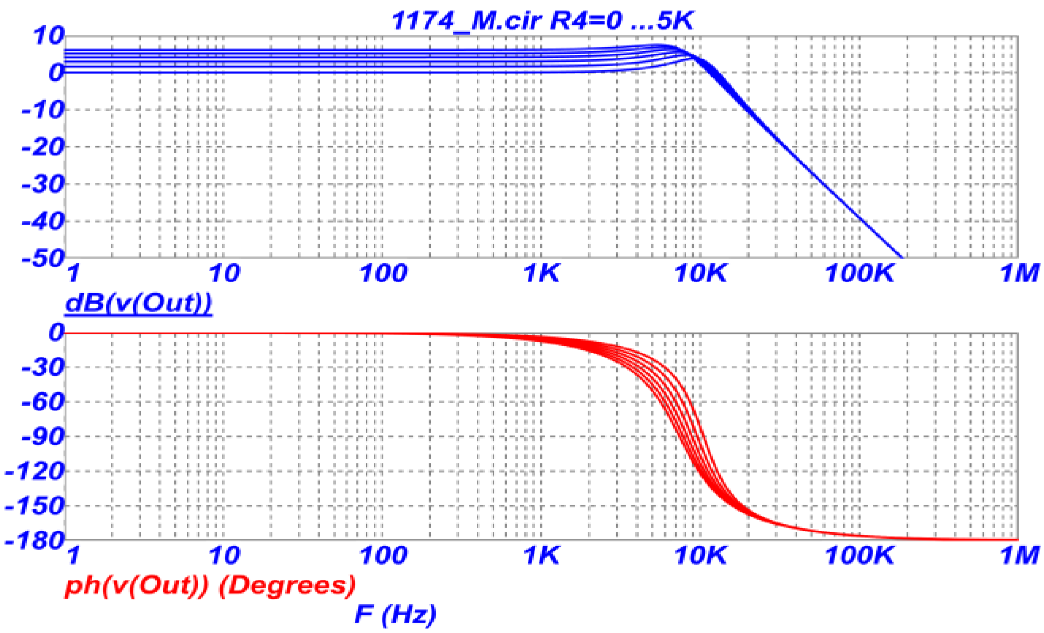
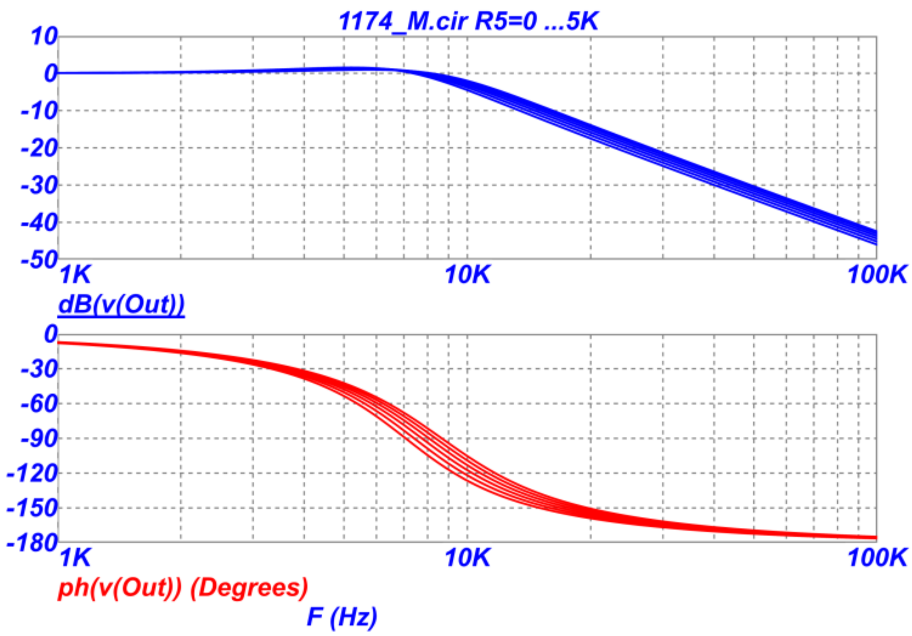


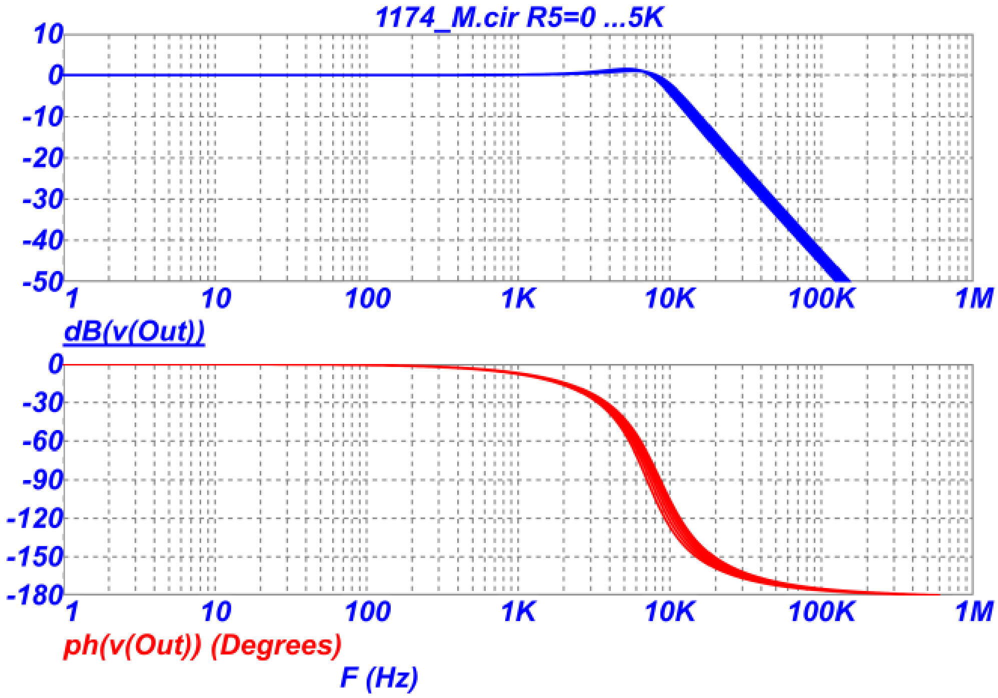
b)

Figure 4. AFC and PFC of LPF on Figure 2 in the region of the frequency of the pole (a) and a wider frequency range (b) when the resistance of the resistor R4 changes in the range of 0-5 kOhm.

On Figure 5 shows the AFC and PFC of the LPF Figure 2 in the region of the pole frequency (a) and a wider frequency range (b) when changing the resistance of the resistor R5 in the range of 0-5 kOhm in order to adjust the pole frequency.



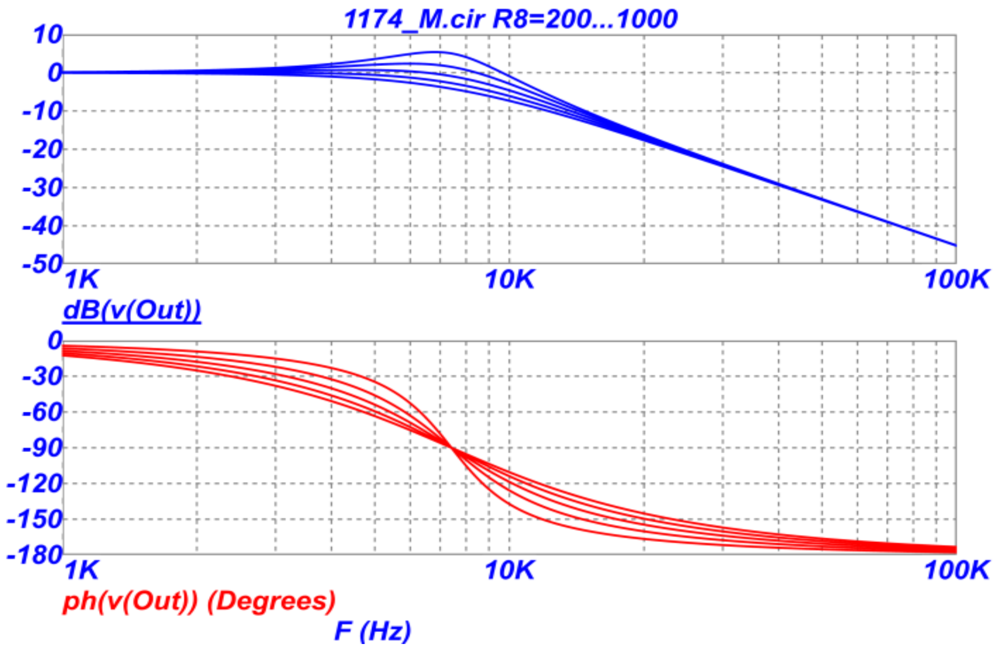
a)



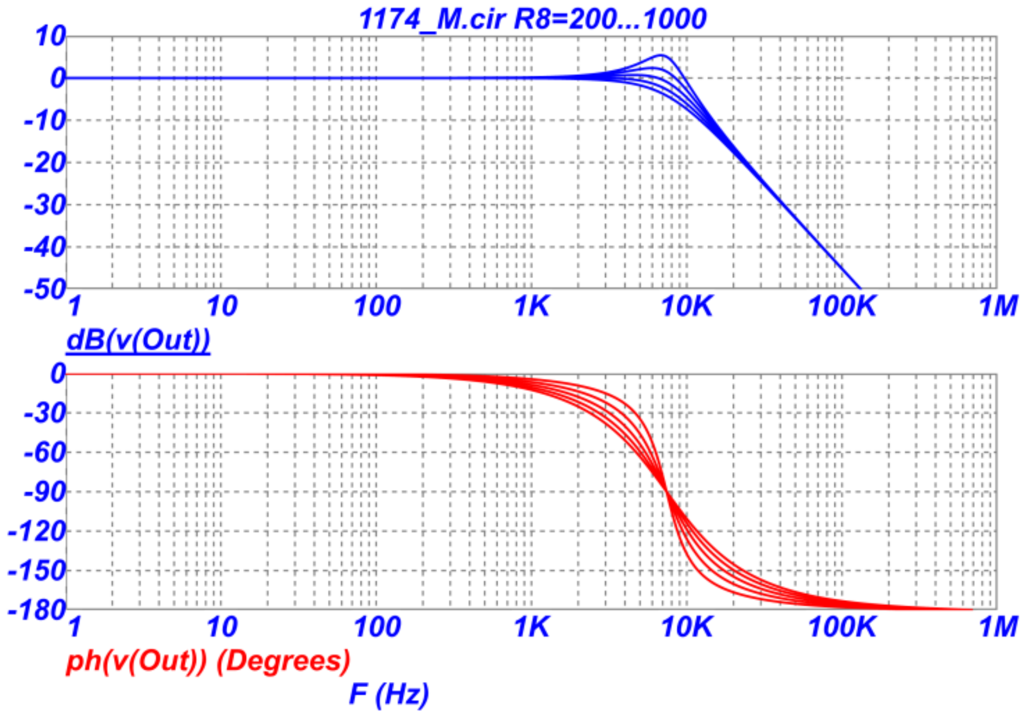
b)

Figure 5. AFC and PFC of LPF on Figure 2 in the region of the frequency of the pole (a) and a wider frequency range (b) when the resistance of the resistor R5 changes in the range of 0-5 kOhm.

On Figure 6 shows the AFC and PFC of the LPF on Figure 2 in the region of the pole frequency (a) and a wider frequency range (b) when changing the resistance of the resistor R8 in the range of 0.2-1 kOhm in order to adjust the attenuation of the pole.



a)



b)

Figure 6. AFC and PFC of LPF on Figure 2 in the region of the pole frequency (a) and a wider frequency range (b) when changing the resistance of the resistor R8 in the range of 0.2-1 kOhm in order to adjust the attenuation of the pole.

4. Conclusion

A low-pass filter circuit based on a differential difference operational amplifier has been developed and studied, in which the independent adjustment of the transmission coefficient, pole frequency and pole quality factor by different resistors is provided. At the same time, the circuit provides a low sensitivity of the transmission coefficient to various destabilizing factors - tolerances on the parameters of the frequency-setting elements of the circuit and changes in their characteristics due to temperature or radiation. As resistors in the LPF circuit, it is recommended to use digital CMOS resistance switching or digital potentiometer microcircuits.

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Conflicts of Interest: The author declares no conflict of interest.

References

1. Tchaikovsky, V.S., Eliminating the aliasing effect in analog-to-digital conversion, NiKa. 2008. [Online]. https://cyberleninka.ru/article/n/ustranenie-effekta-nalozheniya-spektrov-pri-analogo-tsifrovom-preobrazovanii (accessed on 23 Mar. 2023). (In Russian).

2. N.N. Prokopenko, P.S. Budyakov, A.V. Bugakova, D.Yu. Denisenko “Sallen-ki subclass low-pass filter with independent adjustment of the main parameters,” RU Patent 2784375, Publicated: November 24, 2022. (In Russian).

 doi:10.20944/preprints202303.0478.v1

3. D.Yu. Denisenko, N.N. Prokopenko, I.V. Pakhomov, “Low-pass filter based on a differential difference operational amplifier,” RU Patent application 2023105588, Publicated: March 10, 2023. (In Russian).

4. Amelina, M. A., Amelin, S. A. (2012). Circuit simulation program Micro-Cap. Versions 9, 10. Smolinsk: Smolenskii filial NIU MEI. .612 p. In Russian).

5. AD 8130 [Online]. https://www.analog.com/media/en/technical-documentation/data-sheets/ad8129_8130.pdf (accessed on 23 Mar. 2023).