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Multiple Feedback Filters

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IN THIS MINI TUTORIAL

Three sample multiple feedback filters are designed in this mini tutorial, one in a series of mini tutorials describing discrete circuits for precision op amps.

The multiple feedback filter, a popular configuration, uses an op amp as an integrator as shown in Figure 1. Therefore, the dependence of the transfer function on the op amp parameters is greater than in the Sallen-Key realization.

It is difficult to generate high Q, high frequency sections due to the limitations of the open-loop gain of the op amp. A rule of thumb is that the open-loop gain of the op amp must be at least 20 dB (×10) above the amplitude response at the resonant (or cut-off) frequency, including the peaking caused by the Q of the filter. The peaking due to Q causes an amplitude, A_0.

$$A_0 = HQ \tag{1}$$

where H is the gain of the circuit. The multiple feedback filter inverts the phase of the signal. This is equivalent to adding the resulting 180° phase shift to the phase shift of the filter itself.

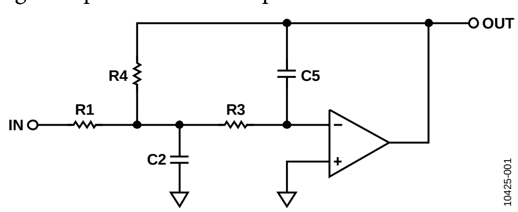

Figure 1. Multiple Feedback Low-Pass Filter

The maximum-to-minimum component value ratio is higher in the multiple feedback case than in the Sallen-Key realization. The design equations for the multiple feedback low-pass filter are given in the Multiple Feedback Low-Pass Design Equations section.

Comments regarding the multiple feedback low-pass filter can apply to the high-pass filter as well (see Figure 2). Again, resistors and capacitors are swapped to convert the low-pass case to the high-pass case. The design equations for the multiple feedback high-pass filter are given in the Multiple Feedback High-Pass Design Equations section.

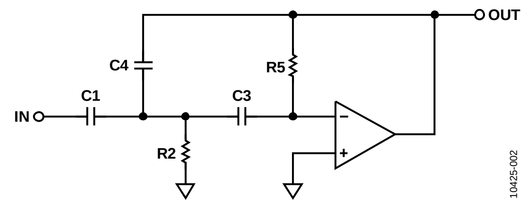

Figure 2. Multiple Feedback High-Pass Filter

The design equations for the multiple feedback band-pass filter are detailed in the Multiple Feedback Band-Pass Design Equations section.

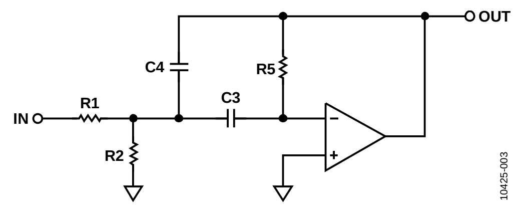

Figure 3. Multiple Feedback Band-Pass Filter

This circuit is widely used in low Q (< 20) applications. It allows some tuning of the resonant frequency, F_0, by making R2 variable. Q can be adjusted (with R5) as well, but this also changes F_0.

One way to tune the filter F_0 is by monitoring the output of the filter with the horizontal channel of an oscilloscope, with the input to the filter connected to the vertical channel. The display is a Lissajous pattern. This pattern is an ellipse that collapses to a straight line at resonance because the phase shift is 180°. In addition, adjust the output for maximum output, which occurs at resonance; however, this is usually not as precise, especially at lower values of Q, where there is a less pronounced peak.

MULTIPLE FEEDBACK LOW-PASS DESIGN EQUATIONS

$$\frac{-H\,\omega_0^{\,2}}{s^2 + \alpha\,\omega_0 s + \omega_0^{\,2}}$$

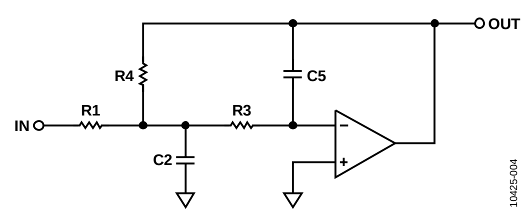

Figure 4.

$$\frac{V_O}{V_{IN}} = \frac{-H\dfrac{1}{R1\,R3\,C2\,C5}}{s^2 + s\dfrac{1}{C2}\left(\dfrac{1}{R1} + \dfrac{1}{R3} + \dfrac{1}{R4}\right) + \dfrac{1}{R3\,R4\,C2\,C5}}$$

To design the filter, choose C5. Then,

$\alpha = 1/Q$

$k = 2\,\pi\,F_0\,C5$

$$C2 = \frac{4}{\alpha^2}\left(H+1\right)C5$$

$R1 = \alpha/(2 \times H \times k)$

$$R3 = \frac{\alpha}{2\left(H+1\right)k}$$

$R4 = \alpha/(2k)$

MULTIPLE FEEDBACK HIGH-PASS DESIGN EQUATIONS

$$\frac{-H\,s^2}{s^2 + \alpha\ \omega_0\ s + \omega_0^2}$$

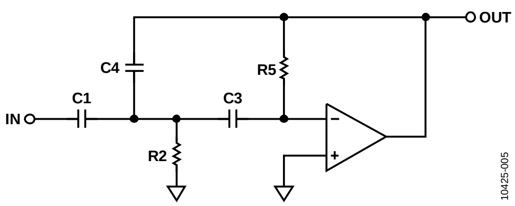

Figure 5.

$$\frac{V_O}{V_{IN}} = \frac{-s^2\,\dfrac{C1}{C4}}{s^2 + s\left(\dfrac{C1+C3+C4}{C3\,C4\,R5}\right) + \dfrac{1}{R2\,R5\,C3\,C4}}$$

To design the filter, choose C1. Then,

$\alpha = 1/Q$

$k = 2\pi\,F_0\,C1$

$C3 = C1$

$C4 = C1/H$

$$R2 = \frac{\alpha}{k\left(2+\dfrac{1}{H}\right)}$$

$$R5 = \frac{H\ (2+\dfrac{1}{H}))}{\alpha\,k}$$

MULTIPLE FEEDBACK BAND-PASS DESIGN EQUATIONS

$$\frac{-H\ \omega_0 s}{s^2 + \alpha\ \omega_0 s + \omega_0^2}$$

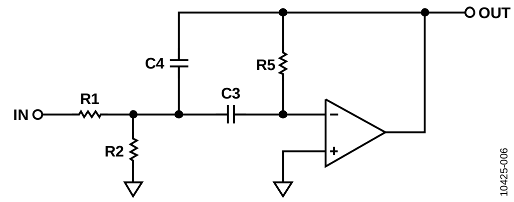

Figure 6.

$$\frac{V_O}{V_{IN}} = \frac{-s\,\dfrac{1}{R1\,C4}}{s^2 + s\,\dfrac{C3+C4}{C3\,C4\,R5} + \dfrac{1}{R5\,C3\,C4}\left(\dfrac{1}{R1}+\dfrac{1}{R2}\right)}$$

To design the filter, choose C3. Then,

$k = 2\,\pi\,F_0\,C3$

$C4 = C3$

$H = A_0/Q$, where A_0 is the gain at the center frequency

$R1 = 1/H\,k$

$$R2 = \frac{1}{k\left(2Q-H\right)}$$

$R5 = 2Q/k$

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