

Notch Filter Reduces Amplifier Peaking and Increases Gain Flatness

By Charly El-Khoury [charly.el-khoury@analog.com]

The [ADA4817](#) *FastFET*[™] op-amp achieves 1-GHz bandwidth with only 4-nV/ $\sqrt{\text{Hz}}$ input noise, making it the fastest, lowest noise amplifier in its class. Although the ADA4817 is unity-gain stable, a high-frequency pole increases its gain-bandwidth product from 410 MHz at high gains to 1 GHz at unity gain. Unfortunately, this pole decreases the phase margin, causing unwanted peaking in the frequency response and ringing in the step response. Adding a discrete RLC notch filter to the amplifier's non-inverting input maintains the high bandwidth and input impedance, while dramatically reducing peaking, increasing gain flatness, and reducing overshoot.

The RLC notch filter, shown in Figure 1, takes advantage of the amplifier's input characteristics to produce the desired outcome. The notch formed by R in parallel with the series LC can be shaped to compensate for the peaking produced by the amplifier and the parasitic capacitance. The result is 1-GHz bandwidth (-3 dB), 250-MHz gain flatness (0.1 dB) and less than 1-dB peaking for a gain equal to 1.

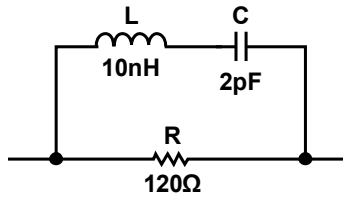


Figure 1. RLC notch filter.

The choice of resistor, capacitor, and inductor is critical. The input impedance of the ADA4817 looks like a 1.4-pF capacitor to ground. Figure 2 shows the RLC circuit with the input impedance of the amplifier. This circuit will be analyzed in depth to generate the transfer function $\frac{V_{OUT}}{V_{IN}}$.

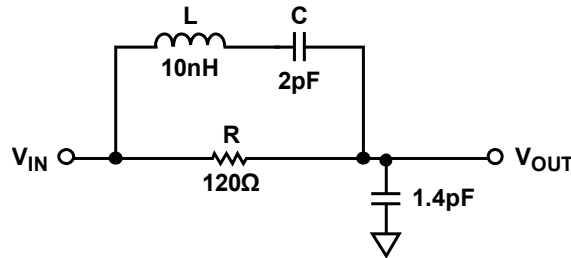


Figure 2. Notch filter and amplifier input impedance.

$$\frac{V_{OUT}}{V_{IN}} = \frac{Z_{C_1}}{Z_{C_1} + Z_R \parallel (Z_C + Z_L)} \quad \text{Equation 1}$$

Substituting $Z_C = C/j\omega$, $Z_L = j\omega L$, and $Z_R = R$, and solving for the magnitude, yields:

$$\left| \frac{V_{OUT}}{V_{IN}} \right| = \sqrt{\frac{C^2 R^2 \omega^2 + (CL\omega^2 - 1)^2}{R^2 \omega^2 (C^2 C_1^2 L^2 \omega^4 - 2(C + C_1)CC_1 L \omega^2 + C^2 + 2CC_1 + C_1^2) + (CL\omega^2 - 1)^2}} \quad \text{Equation 2}$$

Where C_1 is the amplifier's input impedance and $\omega = 2\pi f$. Figure 3 shows the magnitude response using equation 2 with $C_1=1.4$ pF. The values of L and C determine where the transfer function crosses 0 dB. The value of R determines the depth of the notch.

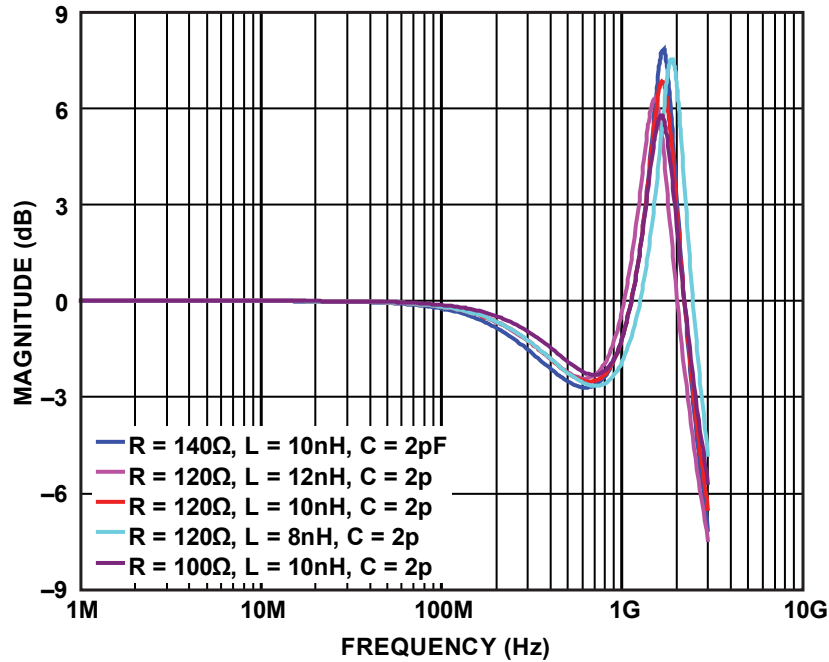


Figure 3. Various RLC notches.

To compensate for the amplifier's peaking, add the individual frequency responses of the amplifier and the filter, adjusting R , L , and C for the flattest overall response. This can be done with Excel or most circuit simulation software. The notch can be shaped to reduce peaking, increase flatness, and reduce overshoot. Figure 4 shows the overall design, where the notch is connected to the non-inverting input.

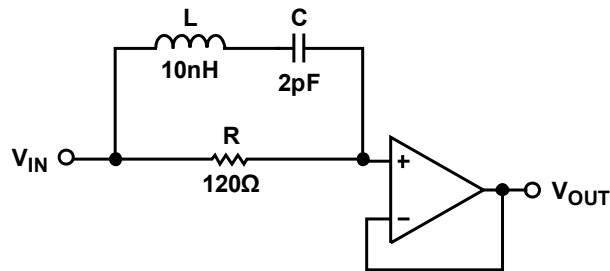


Figure 4. Overall circuit.

Perhaps the most important feature of the FET-input ADA4817 is its extraordinarily low input bias current. The notch circuit maintains this characteristic while preserving the amplifier's low distortion and noise. Figure 5 shows the frequency response of the ADA4817 with and without a notch filter. Note that bandwidth is maintained while flatness is extended and peaking is reduced.

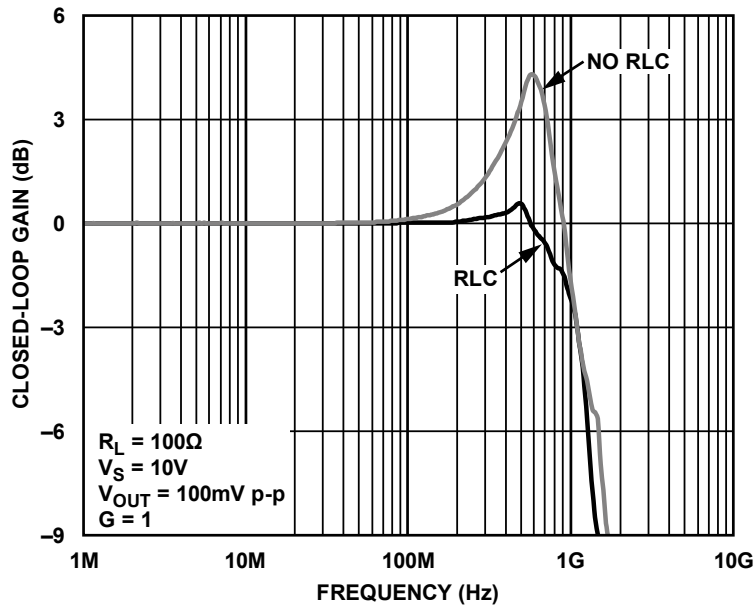


Figure 5. With and without RLC.

Figure 6 shows the step response of the ADA4817 with and without the *RLC* circuit. The same design can also be used to shape the frequency response of other FET-input amplifiers. This design maintains the high input impedance of the FET input, but an *RLC* to ground can be used with amplifiers where this is not a requirement.

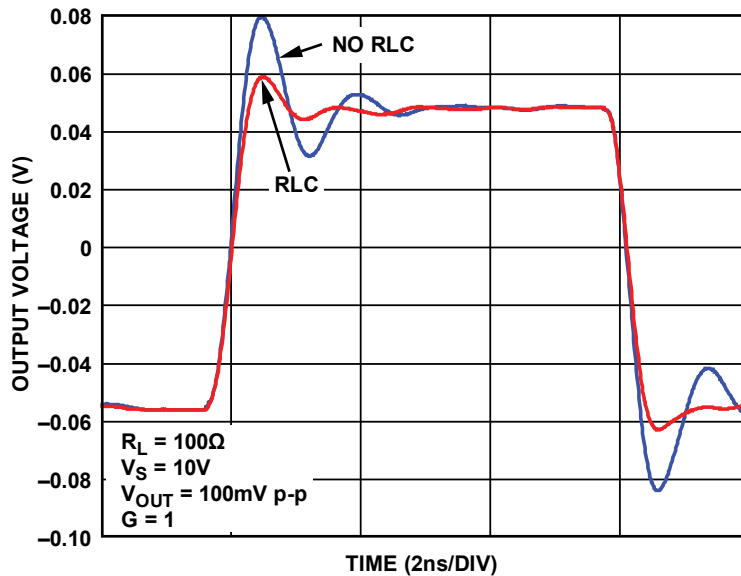


Figure 6. Pulse response with and without RLC.

Conclusion

Adding a discrete RLC notch filter in front of the ADA4817 FET-input op-amp dramatically increases its performance. This novel, yet simple, technique decreases peaking, increases gain flatness, and reduces overshoot—all while maintaining the original 1-GHz bandwidth (–3 dB). This robust, inexpensive solution adds three new components, but the additional cost may be worth it if flat frequency response, lower overshoot, and enhanced performance are important.