UAF42
As a Low-pass Active Filter

Many times, instrumentation of electromechanical systems, which utilize modern switching type power electronics, produces signals with unacceptable noise levels or high frequency content obscuring the information of interest. Application of low-pass filters can often attenuate the unwanted portion of the signal. Unfortunately, with typical passive filter topologies the desirable portion of the signal is attenuated, often to an unacceptable degree. Minimizing the signal attenuation while maximizing the noise attenuation leads to complex high-order designs. Active filters are an alternative to these complex passive filter topologies.

Comprised of operational amplifiers, resistors and capacitors, active filters have gain and are easily tuned. The numerous topologies for active filters all serve as networks with a preference to pass some frequencies while penalizing other frequencies. One topology, the state-variable filter, is possibly a universal filter module. This topology provides low-pass, band-pass and high-pass outputs from one network. Some advantages of a state-variable filter include ease of tuning (electronically and voltage control included), low levels of damping achievable without stability problems, variable gain, building block for more complex topologies needing high-pass and low-pass outputs (Cauer, elliptic etc.). [1]

The Burr-Brown UAF42 Universal Active Filter can be used as a building block to construct a variety of state-variable filters. The integrated circuit includes four operational amplifiers, on-chip 1000pF capacitors and on-chip 50kΩ ± 0.5% resistors. The on-chip components are configured for use in the most common applications. [2]

Based on information presented in the manufacturer datasheet, the schematic for a second-order inverting filter was modified to allow variable gain, variable low-pass cutoff frequency and variable damping. The fourth op-amp in the package was utilized as a voltage follower to isolate a traditional first-order RC type low pass filter. The addition of the first-order stage brings the total filter order to three. The higher order provides a sharper roll-off and more attenuation at high frequencies without an unacceptable degradation in low-frequency performance. A single op-amp was added in an inverting summing configuration to provide a filter output in phase with the input. The summing amplifier was also used to adjust for any d.c. offset in the filter network. The schematic developed is presented in Figure 1. If fixed gain, damping or cut-off frequency are desired, potentiometers may be replaced with fixed resistors as appropriate.

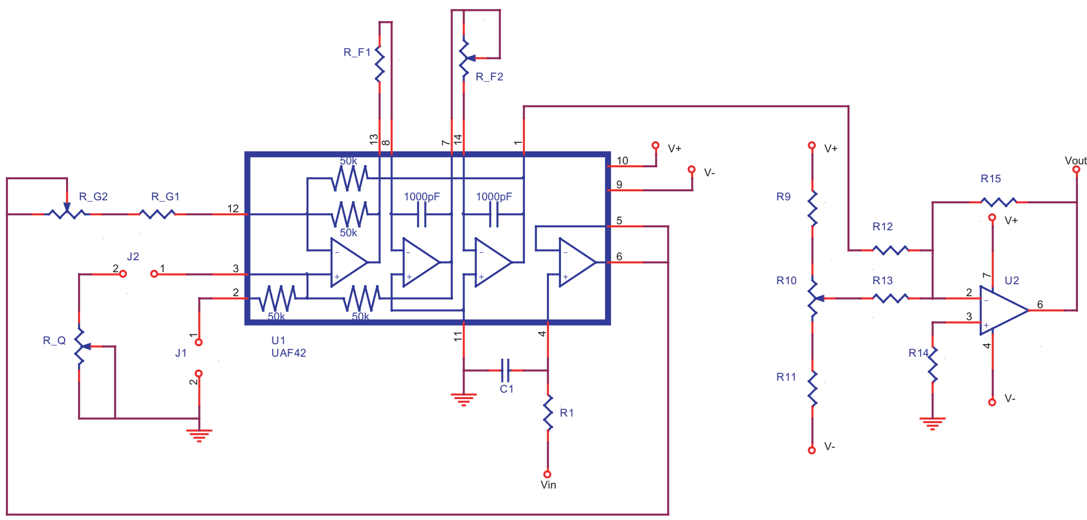

Figure 1. Active filter schematic.

For the schematic shown the filter gain is set by the value of R_G1 and R_G2 according to the following equation.

$$A_{LP} = \frac{50k\Omega}{R\_G1 + R\_G2} \tag{1}$$

The second order cut-off frequency is governed by R_F1 and R_F2 according to (2).

$$\omega_n^2 = \frac{50k\Omega}{50k\Omega(R\_F1 * R\_F2)1000\text{pF}*1000\text{pF}} \tag{2}$$

The Q value of the filter is set by resistor R_Q. (3) below gives the relationship between Q, R_Q and other circuit values.

$$Q = \left(1 + \frac{50k\Omega}{R\_Q}\right)\left(\frac{1}{\frac{1}{50k\Omega} + \frac{1}{50k\Omega} + \frac{1}{R\_F1 * R\_F2}}\right)\left(\frac{R\_F1 * 1000\text{pF}}{50k\Omega * 50k * R\_F2 * 1000\text{pF}}\right) \tag{3}$$

The values of R1 and C1 determine the first-order section's cut-off frequency. The values for these can be determined using procedures from any text on filter design. The UAF42 includes an additional on-chip $50k\Omega$ resistor that can be used to set the Q value. If this on-chip resistor is to be used, closing jumper J1 will provide the necessary connection to ground. If an external resistor will be used, jumper J2 should be connected and J1 left open. Operational amplifier U2 can be any general purpose op-amp with sufficient gain bandwidth product for the application. In this implementation, U2 is configured as a unity gain inverting summing amplifier. Resistors R12 through R15 set the gain of this stage. As the gain of this stage is included into the overall filter gain, precision resistors should be used if a fixed gain is desired. If a variable gain will be used, less accurate resistors will suffice here. Resistors R9 and R11 along with potentiometer R10 provide a variable voltage source to be summed into U2. Adjusting potentiometer R10 allows the d.c. offset to be minimized for the filter.

Tuning the filter by the following procedure:

- Apply 0V to Vin of filter circuit. Adjust potentiometer R10 to give acceptable d.c. offset.

- Apply a non-zero constant voltage to Vin. Adjust potentiometer R_G2 to set desired d.c. gain.

- Inject a random signal into the filter and measure the frequency response. The filter may be tuned to the desired cut-off frequency be adjusting potentiometer R_F2. When the cut-off frequency is changed the high-frequency roll-off portion of the response will shift left or right as the cut-off is decreased or increased. The slope of the roll-off is set at -18dB per octave. Figure 2. shows this action. When the response passes through -36dB at 4 times desired cut-off frequency, the filter cut-off frequency will be as desired. Additional checks of -54db at 8 times and -60dB at 10 times desired can be used to verify performance.

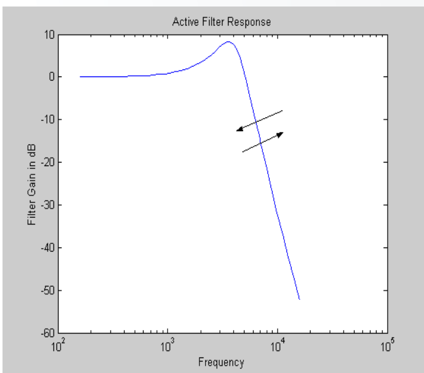

Figure 2. Cut-off frequency adjustment.

- The filter damping can be set by adjusting potentiometer R_Q to yield the desired shape of the response near the cut-off frequency. Figure 3. shows this action.

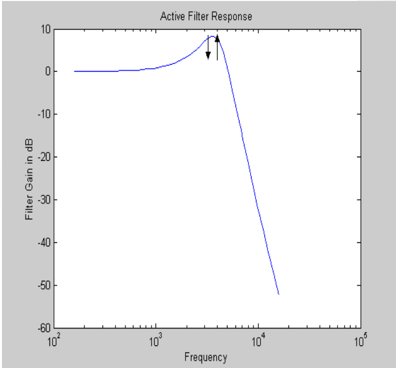

Figure 3. Q adjustment

The above mentioned design was implemented as a three-channel active filter for the purpose of conditioning induction motor phase currents. The filter was needed to remove high frequency "spikes" generated by the signal lines passing in close proximity to the power semiconductor switches. Figure 4. shows the assembled design.

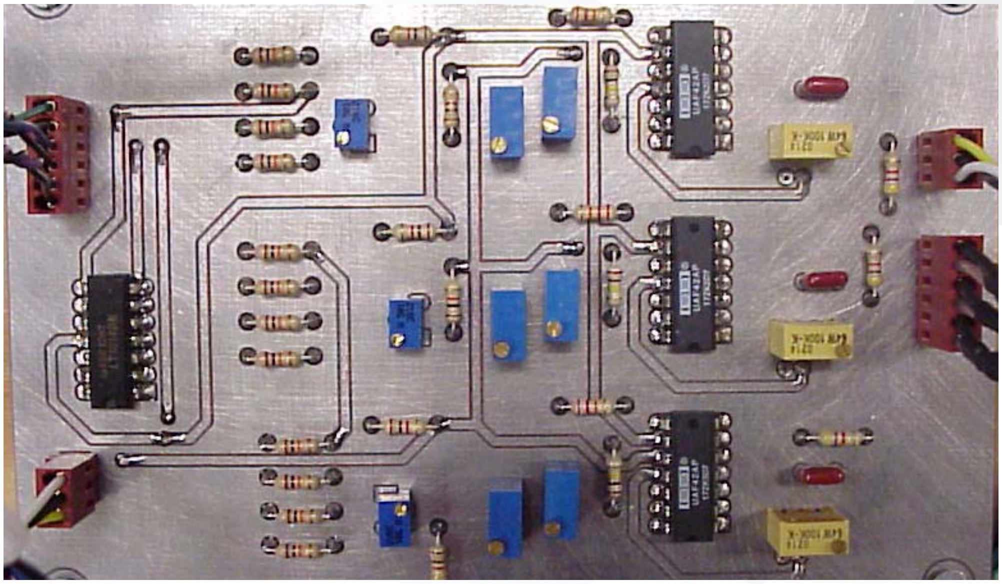

Figure 4. Three-channel implementation.

The gerber files for this design are available on the download page of this website.

For this implementation (three-channel) there are known issues. Even with use of precision components, the response of the individual channels is tedious and time consuming to match to one another. Additionally, the use of potentiometers as variable resistors provides a source of noise into the system. Use of fixed resistors is recommended is feasible.

Overall this design is versatile and useful in a variety of general purpose applications. With good engineering practices, the design can be modified to accommodate many combinations of performance criteria with minimal changes.

References

[1] Lancaster, Don. *Active-Filter Cookbook*. Howard W. Sams& Co. Indianapolis, Indiana. 1975.

[2] Texas Instruments. *UAF42 Universal Active Filter* Datasheet. Document no. SBF002. Burr-Brown. 1990.

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