

## DIGITALLY PROGRAMMABLE, TIME-CONTINUOUS ACTIVE FILTER

by Johnnie Molina, (602) 746-7592

Programmable active filters have increased in popularity over the past decade. With the advent of switched capacitor topologies, filter parameters such as the natural frequency and filter Q can be changed simply by varying the clock frequency. But switched capacitor filters are sampled data systems and are subject to anomalies such as clock feedthrough noise and aliasing errors.

The circuit in Figure 1 shows how an analog, digitally programmable filter can be built using a UAF42. This monolithic, state-variable active filter chip provides a two pole filter building block with low sensitivity to external component variations. It eliminates aliasing errors and clock feedthrough noise common to switched capacitor filters. Lowpass, highpass, bandpass and notch (band reject) outputs are available simultaneously.

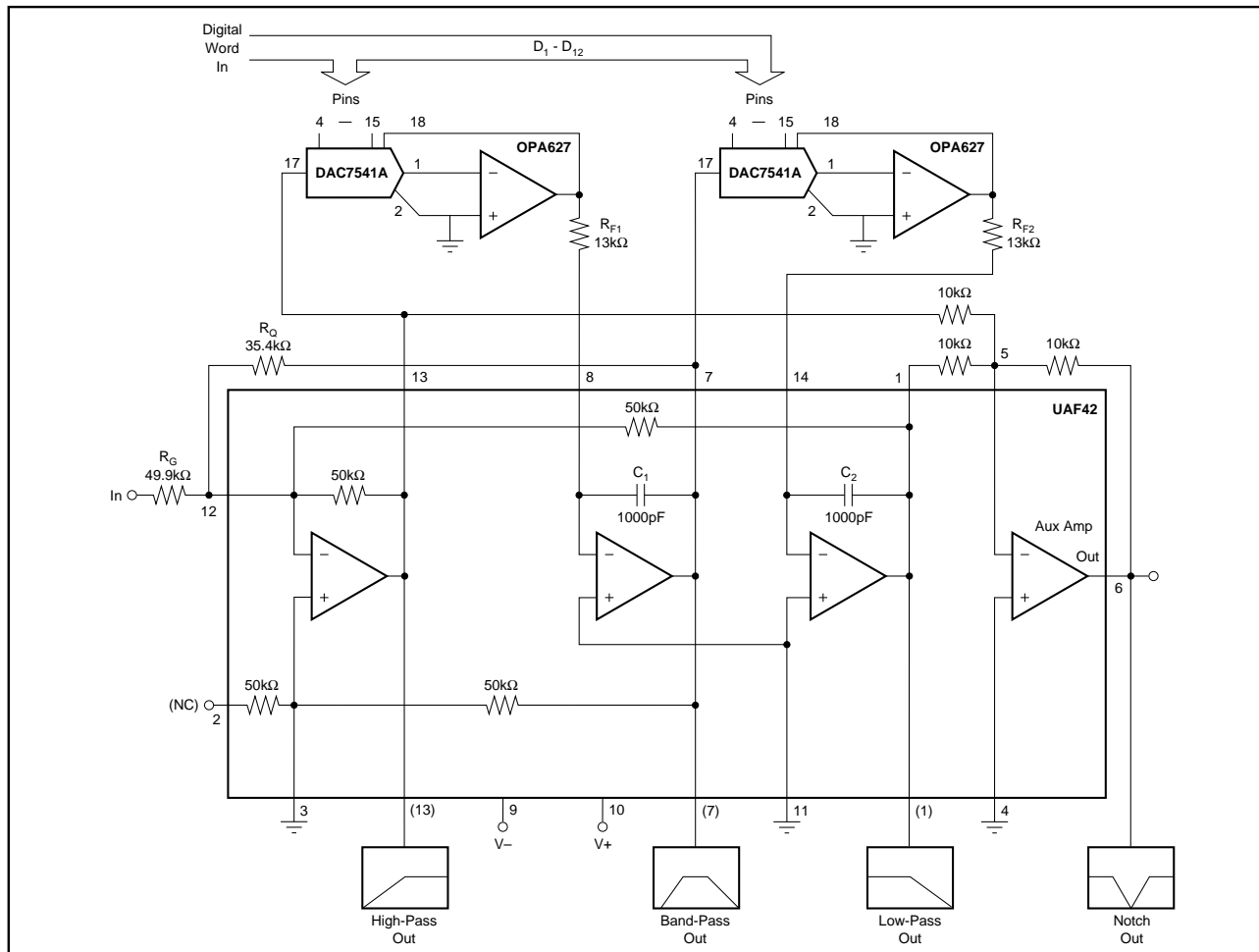


FIGURE 1. Digitally Programmable Analog Filter.

The circuit uses the UAF42 state-variable filter IC, two op amps, a few resistors and two common MDACs. Capacitors aren't required because the UAF42 has on chip 1000pF, 0.5% precision capacitors. The MDACs function as voltage attenuators which influence the unity-gain bandwidth of the integrators on board the UAF42. The filter's natural frequency,  $f_o$ , is described by the following relationships:

$$f_o = \text{DAC}_{\text{GAIN}} \cdot f_{o_{\text{MAX}}} \quad (1)$$

Where:

$$\text{DAC}_{\text{GAIN}} = \frac{X}{2^n}$$

$$f_{o_{\text{MAX}}} = \frac{1}{2 \cdot \pi \cdot 10^{-9} \cdot R_F} \quad R_F = R_{F1} = R_{F2}$$

and,

$X$  = digital word at DAC inputs  $D_1 - D_{12}$

$n$  = number DAC bits

### BUILD A NOTCH FILTER

For example, to program a 60Hz notch filter with the circuit shown in Figure 1, the digital word to the MDAC is given using Equation 1,

$$X = 6.28 \cdot 10^{-9} \cdot R_F \cdot f_o \cdot 2^n$$

Given that,

$$f_o = 60 \quad R_F = 13\text{k}\Omega \quad n = 12$$

then,

$$X = 20.1$$

The 12-bit digital word to the DAC should be 20 or 000000010100. The rounding error introduced is 0.3% ( $f_{\text{NOTCH}} = 59.8\text{Hz}$ ). Note that the natural frequency,  $f_o$ , is equal to  $f_{\text{NOTCH}}$ .

Figure 2 shows the response seen at the band reject or "Notch Out" node.

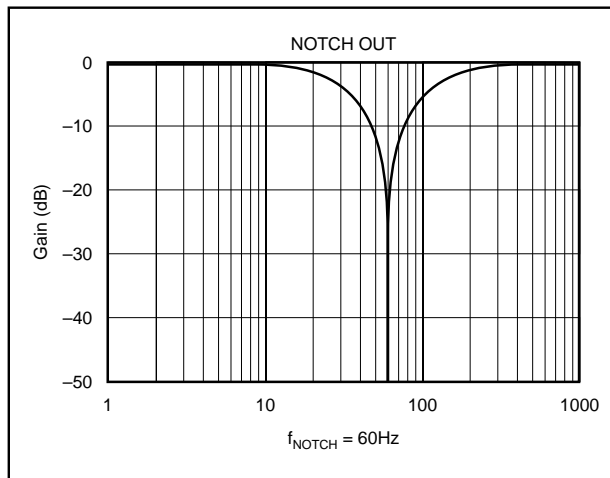


FIGURE 2. 60Hz Notch Response.

The highpass, bandpass and lowpass outputs yield the responses shown in Figure 3.

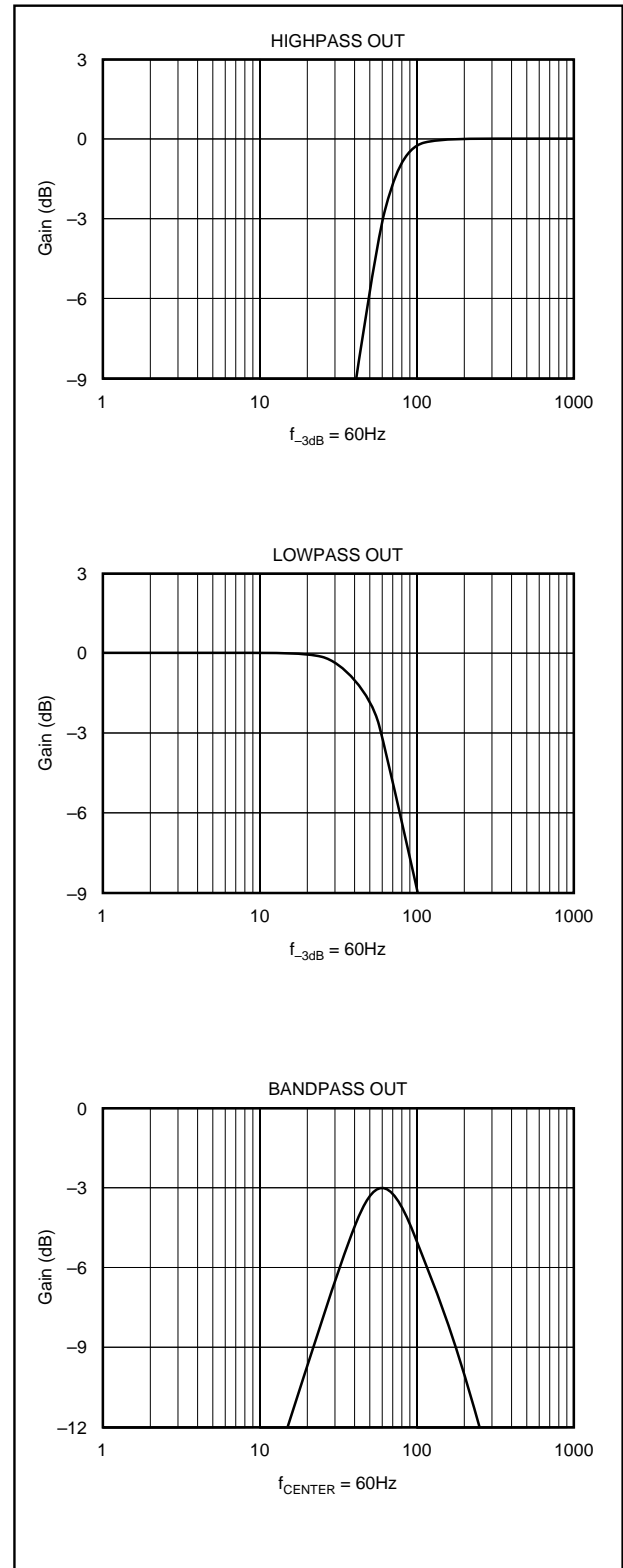


FIGURE 3. Highpass, Lowpass and Bandpass  $f_o = 60\text{Hz}$  Response.

The filter in Figure 1 is set for a Q of 0.707. This can be adjusted using Equation 2 where,

$$R_Q = 50k\Omega \cdot Q \quad (2)$$

Setting the filter to a Q of 0.707 produces second-order Butterworth responses. The Q is not affected by the natural frequency programmed by the DACs. Note that for Butterworth filters, the natural frequency is also the  $-3\text{dB}$  (half power point) for lowpass and highpass responses. It also is the center frequency for bandpass filters and the notch frequency for band reject responses. The passband gain is unity for all response types except the bandpass. For the bandpass output, the gain at  $f_{\text{CENTER}}$  is equal to the filter Q.

### LIMITATIONS

The maximum  $f_o$  in Figure 1 is set for 12.25kHz. This can be adjusted using Equation 1. Set the DAC gain term equal to  $(2^n - 1)/2^n$ ,  $f_o =$  desired maximum natural frequency and solve for RF.

For example, to extend the maximum  $f_o$  to 20kHz,

$$RF = \frac{4095}{2 \cdot \pi \cdot 10^{-9} \cdot 20\text{kHz}} = 7.96k\Omega$$

The maximum natural frequency obtainable for the UAF42 is 100kHz.

$f_o$  accuracy can decrease as the DAC gain decreases in an attempt to program low natural frequencies. For example, for a 12-bit DAC and maximum  $f_o$  set to 20kHz, the resolution giving one LSB change is,

$$\text{Resolution} = \frac{1}{2^{12}} \cdot f_{O_{\text{MAX}}} = \frac{1}{4096} \cdot 20\text{kHz} = 4.9\text{Hz}$$

When trying to program low natural frequencies like 12Hz, the digital word to the DAC would be 2.

So,

$$f_o = \frac{2}{4096} \cdot f_{O_{\text{MAX}}} = \frac{2}{4096} \cdot 20\text{kHz} = 9.8\text{Hz}$$

This is an 18% error. Resolution can be increased by reducing  $f_{O_{\text{MAX}}}$  or using a higher order DAC. RF resistor tolerance should be kept below 1% to maintain  $f_o$  error to within  $\pm 1\%$ .

The OPA627 op amps are chosen for their low offset voltage, low noise, low input bias current (FET input), and high unity gain bandwidth (GBW = 16MHz) to maintain stability.

## **IMPORTANT NOTICE**

Texas Instruments and its subsidiaries (TI) reserve the right to make changes to their products or to discontinue any product or service without notice, and advise customers to obtain the latest version of relevant information to verify, before placing orders, that information being relied on is current and complete. All products are sold subject to the terms and conditions of sale supplied at the time of order acknowledgment, including those pertaining to warranty, patent infringement, and limitation of liability.

TI warrants performance of its semiconductor products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Customers are responsible for their applications using TI components.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards must be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance or customer product design. TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used. TI's publication of information regarding any third party's products or services does not constitute TI's approval, warranty or endorsement thereof.