DESIGN NOTES

Get 100dB Stopband Attenuation with the LTC1562 Universal Filter Family – Design Note 195

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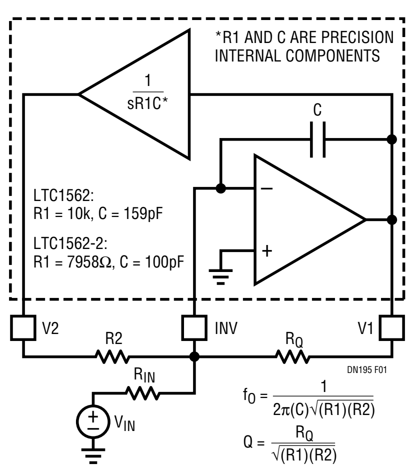
The LTC®1562 and LTC1562-2 are compact, high performance, "universal" continuous-time filter products, each containing four 2nd order Operational Filter™ blocks. These low noise, DC-accurate filters let you tailor their center frequencies (f_O) over a range of roughly 10kHz to 150kHz (LTC1562) or 20kHz to 300kHz (LTC1562-2) and replace several precision capacitors, resistors and op amps. All frequency-setting components are internal and trimmed, except for one resistor per block, which is desensitized (1% error in this external resistor's value contributes only 0.5% error to the programmed f_O). Additional components program each block's Q and gain. A complete application circuit using either the LTC1562 or LTC1562-2 on a surface mount board is about the size of a dime ($155mm^2$).

Figure 1 shows one block, or 2nd order section (each LTC1562 contains four of these), with external resistors to set the standard 2nd order filter parameters f_0, Q and gain. In this example, the section is configured so that the two outputs give lowpass and bandpass responses.



$$f_O = \frac{1}{2\pi(C)\sqrt{(R1)(R2)}}$$

$$Q = \frac{R_Q}{\sqrt{(R1)(R2)}}$$

Figure 1. An Operatonal Filter Block (Inside Dashed Line) Configured with External Resistors for Lowpass (at V2) and Bandpass (at V1) Responses. Each LTC1562 or LTC1562-2 Contains Four Such Blocks

Cascades of Figure 1 circuits, with appropriate resistor values, can realize any all-pole lowpass or bandpass filter response form such as Chebyshev, Bessel or Butterworth. Adding external capacitors permits highpass forms. These filters can suppress undesired frequencies by 100dB while maintaining low noise and distortion.

Operational Filter blocks, however, have many more creative applications. Each block has a flexible virtual-ground input (INV) and two outputs, V1 and V2. V2 is a time integrated version of V1 and therefore lags V1 by 90° over a very wide range of frequencies. Parallel paths into the virtual-ground input or from the two different outputs permit transfer-function zeroes, of which one of the most useful is the imaginary-axis zero pair, or notch.

Figure 2 shows a simple and robust notch-filtering method. A notch filter has zero gain at some frequency f_N. Notch filters are useful not only to remove frequencies *per se* but also to improve selectivity in lowpass or highpass filters by placing notches in the stopband, as illustrated below. (Such responses are broadly called "elliptics" or "Cauers.")

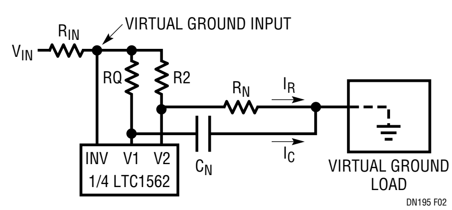


Figure 2. Robust Notch Filtering Using a 1/4 LTC1562 Operational Filter Section. R_N and C_N Control Notch Frequency

In Figure 2, a notch occurs when a 2nd order section drives a virtual-ground input through two paths: one through a capacitor and one through a resistor. The virtual ground can be an op amp input, or as in Figure 3, another Operational Filter input. Capacitor C_N adds a further 90° to the 90° phase difference between the V1 and V2 voltages.

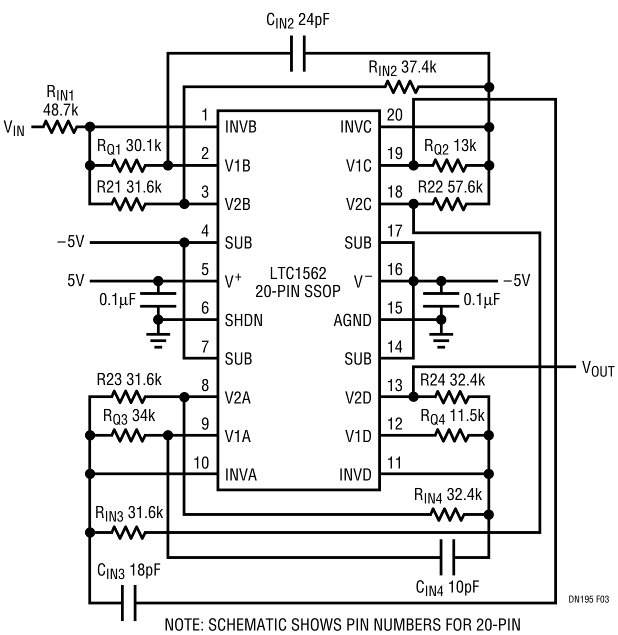
At the frequency where currents I_C and I_R have equal magnitude, the two paths cancel and a 2nd order notch occurs. This frequency is:

$$f_N = \sqrt{\frac{f1}{2\pi(R_N)(C_N)}}$$

Here, f1 is a parameter internally trimmed in each Operational Filter product (100kHz in the LTC1562, 200kHz in the LTC1562-2). The notch frequency, f_N, is independent of the center frequencies, f_0, programmed separately for each 2nd order section, as in Figure 1.

A remarkable feature of Figure 2 is its inherently deep notch response—the depth does not come from component matching as with other notch-filter circuits. Errors in R_N or C_N values change the notch frequency, f_N, but not the depth of the notch at f_N. Moreover, the square root dependence in the f_N expression desensitizes the notch frequency to errors in the R_N and C_N values.

Figure 3 shows an 8-pole modified elliptic response 50kHz lowpass filter using the notch method of Figure 2. In this filter, three operational filter blocks ("B," "C" and "A" in the pinout, in sequence) drive RC combinations as in Figure 2, giving notches at approximately 133kHz, 167kHz and 222kHz, respectively. A 2nd order lowpass section, per Figure 1 with f_0 = 55.5kHz, follows (the "D" block in the pinout). Figure 4 shows measured frequency response, which falls 100dB in a little more than one octave. The choice of notch frequencies trades off passband flatness against stopband ripple; the user can explore this trade-off via analog filter design software such as FilterCAD™ for Windows®, available free from Linear Technology (1-800-4-LINEAR). The values in Figure 3 give stopband attenuations exceeding 100dB above 140kHz. This circuit has output noise (in 500kHz bandwidth) of $60\mu V_{RMS}$ with approximately rail-to-rail input and output swings, or a peak signal-to-noise ratio of 95dB when operating from ±5V supplies. THD is –95dB with $1V_{RMS}$ ($2.8V_{P-P}$) output at 20kHz.



NOTE: SCHEMATIC SHOWS PIN NUMBERS FOR 20-PIN SSOP PACKAGE. FOR THE 16-PIN DIP VERSION, THE FOUR SUBSTRATE PINS "SUB" ARE MISSING; RELATIVE LOCATIONS OF REMAINING PINS ARE THE SAME

Figure 3. LTC1562 50kHz Elliptic Lowpass Filter with 100dB Stopband Rejection

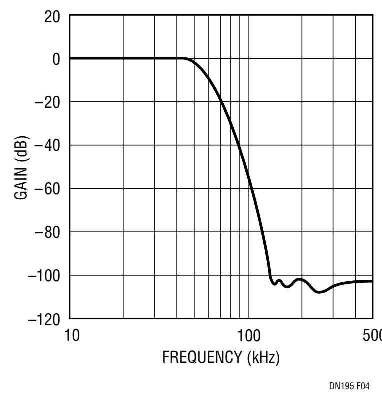


Figure 4. Measured Frequency Response for Figure 3

Note that 100dB attenuation at hundreds of kilohertz requires electrically clean, compact construction, with good grounding and supply decoupling, and minimal parasitic capacitances in critical paths (such as the INV inputs). For example, 0.1µF capacitors near the LTC1562 provide adequate decoupling from a clean, low inductance power source. But several inches of wire (i.e., a few microhenrys of inductance) from the power supplies, unless decoupled by substantial (≥10µF) capacitance near the chip, can cause a high-Q LC resonance (at hundreds of kHz) in the LTC1562's supplies or ground reference, impairing SNR and stopband rejection at those frequencies.

For literature on our Filters,
call **1-800-4-LINEAR**. For applications help,
call (408) 432-1900, Ext. 2593

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