DESIGN NOTES

Low Power Op Amp: Low Power Filter, Headphone Driver Revisited

Design Note 1041

by Aaron Schultz

Introduction

A new family of op amps features industry leading speed versus supply current. The LTC6261/LTC6262/LTC6263 family (single, dual, quad) provides 30MHz at a low 240µA supply current, with 400µV maximum offset voltage and rail-to-rail input and output. In combination with 1.8V to 5.25V supply, these op amps enable applications requiring uncompromised performance with low power and low voltage.

Active Filters

This new set of op amps with high MHz-to-mA ratios provides an opportunity to look at filter circuits in a new light. The two filter examples discussed here display performance previously unachievable with such low power.

Second Order Bessel Filter

Ample bandwidth and low supply current enable deployment of active filters in portable and other low power applications. For instance, a second order Bessel filter, shown in Figure 1, provides a clean transient response at the expense of a less steep roll-off in the frequency domain.

Measured supply current consumption is about 230µA, although data sheet supply maximum values suggest that the consumption across production and temperature may be slightly higher. The values of resistors chosen minimize consumption at the expense of in-band noise.

If V_{REF} is derived from a high impedance resistor divider, then a large capacitor is required to ensure that the reference voltage is solid down to very low frequencies. The reference at the positive op amp input must be a good "AC ground" at all frequencies when using this inverting amplifier configuration.

The frequency response shows an expected roll-off of two poles along with a gentle droop near the 3dB point; the transient response is very clean.

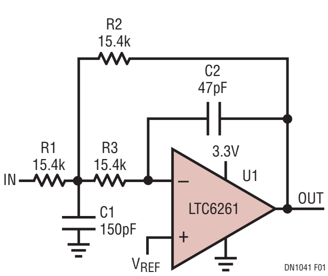

Figure 1. Second Order Bessel Filter

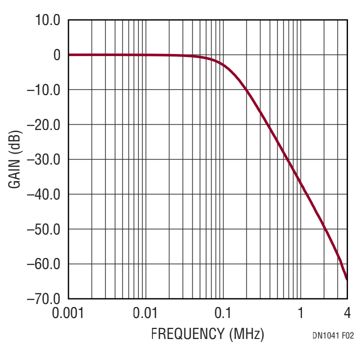

Figure 2. Second Order Bessel Frequency Response

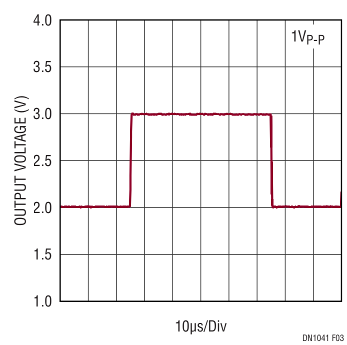

Figure 3. Bessel Filter Response

Third Order Butterworth Filter

Maximally flat magnitude response in the passband arises from use of a Butterworth filter. An extra RC stage is added in front of the filter in order to maximize the roll-off for a single amplifier circuit. Use of an extra stage complicates the math, but not intractably so.

Measured supply current consumption is about 235µA. The chosen values of resistors minimize consumption at the expense of in-band noise.

The frequency response shows an expected roll-off of three poles, an extended plateau and a sharp roll-off; the transient response includes a small amount of ringing.

Bridge-Tied Differential Output Amplifier

The low supply current at the bandwidth and noise performance allows for excellent fidelity at a fraction of the usual dissipation in portable audio equipment. As with active filters, revisiting portable audio equipment headphone drivers is a rational enterprise, given the unique capabilities of the LTC6261.

Headphone speaker impedances range from 32Ω to 300Ω; their responsivity, from 80dB to 100dBSPL per 1mW and beyond. As an example, considering a headphone speaker with 90dBSPL per 1mW, it takes 100mW delivered to reach 110dBSPL. With 32Ω, the RMS current is 56mA and voltage 1.8V; with 120Ω, 29mA and 3.5V.

Given a 3.3V supply and the output of one LTC6261 amplifier, there may not be sufficient drive capability to yield 100mW. However, the combination of two 180° phased amplifiers is enough to provide the necessary drive to reach upwards of 100mW delivered power. Duplication of this bridge drive circuit enables power to both left and right sides.

The LTC6263 provides four amplifiers in one small package. Data from a 2-amplifier LTC6262 driving what could be left or right is shown in Figures 8 and 9. Basic current consumption of the two amplifiers, with as much as $1V_{P-P}$ input but no load, is 500µA.

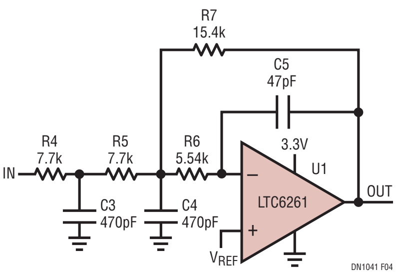

Figure 4. Third Order Butterworth Filter

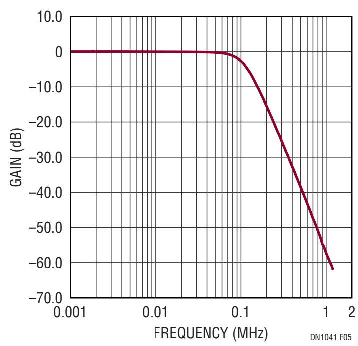

Figure 5. Third Order Butterworth Frequency Response

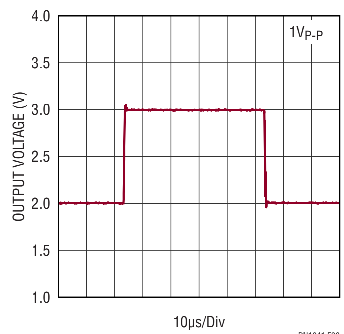

Figure 6. Butterworth Filter Response

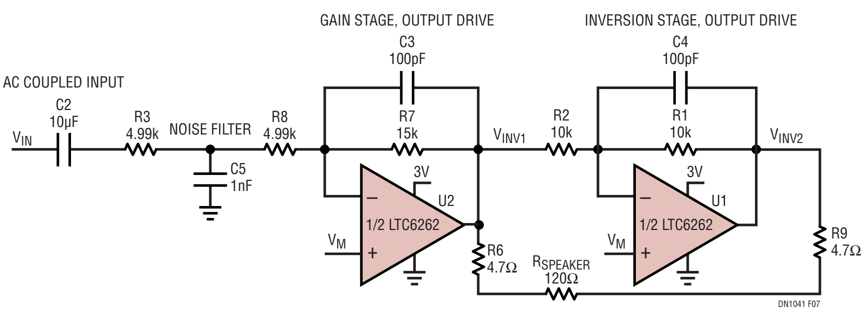

Figure 7. Audio Headphones Bridge Driver

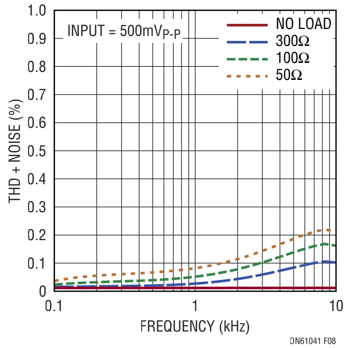

Figure 8. LTC6262 Bridge Driver THD and Noise with Different Loads vs Frequency

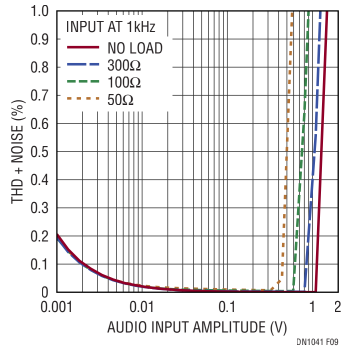

Figure 9. LTC6262 Bridge Driver THD and Noise with Different Loads vs Amplitude at 1kHz

The circuit consists of first, an inverting gain stage with closed loop gain = 1.5, and a subsequent inverting stage. The combination of inverting stages produces a single-ended input to differential output gain of 3. With 500mV$_{P-P}$ input, the output is 1.5V$_{P-P}$, or 0.75V max, or 0.53V$_{RMS}$. With 50Ω, 500mV input leads to approximately 5.6mW delivered power. At 1V$_{P-P}$ input, the circuit delivers 22.5mW. Note that it helps that the LTC6261 output can swing close to rail-to-rail with load.

The first build of this circuit in the lab produced a significant tone at a few hundred Hz. It turned out that the positive input was not well grounded as an "AC ground" over all frequencies because the voltage was not strongly pegged. The need to peg the voltage arises when using a single supply rather than a dual supply. With a single supply, V_M is not ground, but rather a mid-rail voltage created to enable inverting topologies to work properly. The resistor divider that creates V_M has large resistance values (for example, two 470k in series) to minimize additional supply current. A large capacitor ensures a strong ground at low frequencies. Indeed, the addition of a large capacitor (1µF, which forms a pole with the 470k resistors in parallel) eliminated the mysterious distortion tone.

Despite the low quiescent current, this driver delivers low distortion to a headphone load. At high enough amplitude, distortion increases dramatically as the op amp output clips. Clipping occurs sooner with more loading as the output transistors start to run out of current gain.

One significant concern in a portable device is battery drain. Music played loudly, or listeners' musical choices affect the rate of battery drain. The end-use of a device is out of the designer's control. Quiescent current, though, is not. Because much of a device's time may be spent idle, quiescent current is significant, as it drains batteries continuously. The LTC6261's low quiescent current increases battery discharge time.

Conclusion

The applications shown here take advantage of a unique combination of features available in the LTC6261 op amp family. The low quiescent current of these devices does not diminish their ability to perform at levels usually reserved for more power hungry parts. Rail-to-rail input and output, shutdown, and choice of package are features that add to their versatility.

Data Sheet Download

www.linear.com/LTC6261

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