Using a Differential I/O Amplifier in Single-Ended Applications

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Introduction

Recent advances in low voltage silicon germanium and BiCMOS processes have allowed the design and production of very high speed amplifiers. Because the processes are low voltage, most of the amplifier designs have incorporated differential inputs and outputs to regain and maximize total output signal swing. Since many low voltage applications are single-ended, the questions arise, "How can I use a differential I/O amplifier in a single-ended application?" and "What are the implications of such use?" This article addresses some of the practical implications and demonstrates specific single-ended applications using the 3GHz gain-bandwidth LTC6406 differential I/O amplifier.

Background

A conventional op amp has two differential inputs and an output. The gain is nominally infinite, but control is maintained by virtue of feedback from the output to the negative "inverting" input. The output does not go to infinity, but rather the differential input is kept to zero (divided by infinity, as it were). The utility, variety and beauty of conventional op amp applications are well documented, yet still appear inexhaustible. Fully differential op amps have been less well explored.

Figure 1 shows a differential op amp with four feedback resistors. In this case the differential gain is still nominally infinite, and the inputs kept together by feedback, but this is not adequate to dictate the output voltages. The reason is that the common mode output voltage can be anywhere and still result in a "zero" differential input voltage because the feedback is symmetric. Therefore, for any fully differential I/O amplifier, there is always another control voltage to dictate the output common mode voltage. This is the purpose of the V_{OCM} pin, and explains why fully differential amplifiers are at least 5-pin devices (not including supply pins) rather than 4-pin devices. The differential gain equation is $V_{OUT(DM)} = V_{IN(DM)} \bullet R2/R1$. The common mode output voltage is forced internally to the voltage applied at V_{OCM}. One final observation is that there is no longer a single inverting input: both inputs are inverting and noninverting depending on which output is considered. For the purposes of circuit analysis, the inputs are labeled with "+" and "–" in the conventional manner and one output receives a dot, denoting it as the inverted output for the "+" input.

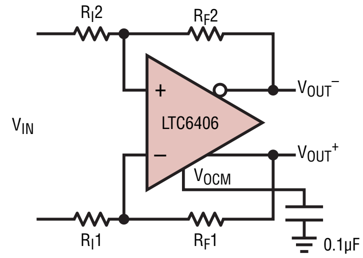

Figure 1. Fully differential I/O amplifier showing two outputs and an additional V_{OCM} pin

Anybody familiar with conventional op amps knows that noninverting applications have inherently high input impedance at the noninverting input, approaching GΩ or even TΩ. But in the case of the fully differential op amp in Figure 1, there is feedback to both inputs, so there is no high impedance node. Fortunately this difficulty can be overcome.

Simple Single-Ended Connection of a Fully Differential Op amp

Figure 2 shows the LTC6406 connected as a single-ended op amp. Only one of the outputs has been fed back and only one of the inputs receives feedback. The other input is now high impedance.

The LTC6406 works fine in this circuit and still provides a differential output. However, a simple thought experiment reveals one of the downsides of this configuration. Imagine that all of the inputs and outputs are sitting at 1.2V, including V_{OCM}. Now imagine that the V_{OCM} pin is driven an additional 0.1V higher. The only output that can move is V_{OUT}^- because V_{OUT}^+ must remain equal to V_{IN}, so in order to move the common mode output higher by 100mV the amplifier has to move the V_{OUT}^- output a total of 200mV higher. That's a 200mV differential output shift due to

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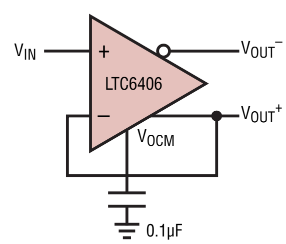

Figure 2. Feedback is single-ended only. This circuit is stable, with a Hi-Z input like the conventional op amp. the closed loop output (V_{OUT}^+ in this case) is low noise. Output is best taken single-ended from the closed loop output, Providing a 3dB bandwidth Of 1.2GHz. The Open Loop Output (V_{OUT}^-) has a noise gain of two from V_{OCM}, but is well behaved to about 300MHz, above which it has significant passband ripple.

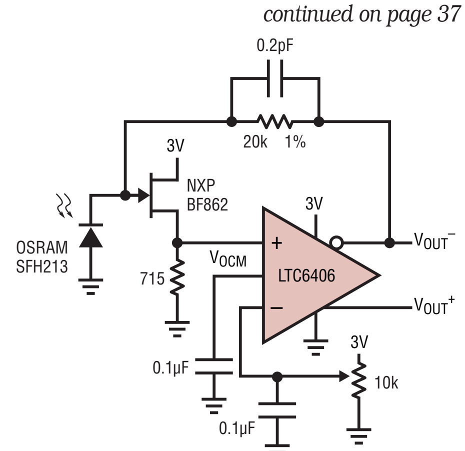

Figure 3. Transimpedance amplifier. Ultralow noise JFET buffers the current noise of the bipolar LTC6406 input trim the pot for 0V differential output under no-light conditions.

required to transmit output data. The LTC2274 has 77dB of SNR, and 100dB of spurious free dynamic range.

Signal Chain Topology

Figure 1 details a signal chain optimized for a 70MHz center frequency and a 20MHz bandwidth driving the LTC2274. The final filter and circuitry around the ADC are shown in detail. The earlier stages of the chain can be changed to suit a target application.

The first stage of amplification in the chain uses an AH31 from TriQuint Semiconductor. This GaAs FET amplifier offers a low noise figure and high IP3 point, which minimizes distortion caused by the amplifier stage. It provides 14dB of gain over a wide frequency region. The high IP3 prevents intermodulation distortion between frequencies outside the passband of the surface acoustic wave (SAW) filter.

A SAW filter follows the amplification stage for band selection. The SAW filter offers excellent selectivity and a flat passband if matched correctly. Gain before the SAW must not be higher than the maximum input power rating of the SAW; otherwise it leads to distortion. A digitally controlled step attenuator may be required in the signal path to control the power going into the SAW filter.

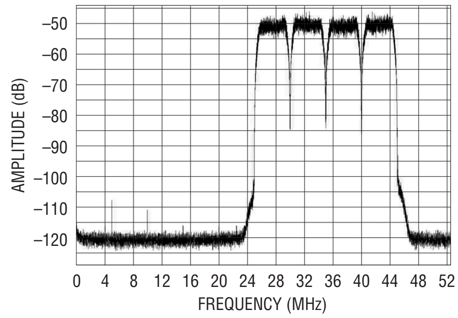

Figure 2. Typical spread spectrum performance

The second stage of amplification is used to recover the loss in the SAW filter. The insertion loss of the SAW filter is about –15dB, so the final amplifier should have at least this much gain, plus enough gain to accommodate the final filter. By splitting the gain between two amplifiers, the noise and distortion can be optimized without overdriving the SAW filter. It also allows for a final filter with better suppression of noise from the final amplifier, improving SNR and selectivity.

The output stage of the final filter needs to be absorptive to accommodate the ADC front end. This suppresses glitches reflected back from the direct sampling process.

This signal chain will not degrade the performance of the LTC2274. When receiving a 4-channel WCDMA signal with a 20MHz bandwidth, centered at 70MHz, the ACPR is 71.5dB (see Figure 2).

Conclusion

The LTC2274 can be used to receive high IF frequencies, but getting the most out of this high performance ADC requires a carefully designed analog front end. The performance of the LTC2274 is such that it is possible to dispense with the automatic gain control and build a receiver with a low fixed gain. The LTC2274 is a part of a family of 16-bit converters that range in sample rate from 65Msps to 105Msps. For complete schematics of this receiver network, visit www.linear.com.

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a 100mV V_{OCM} shift. This illustrates the fact that single-ended feedback around a fully differential amplifier introduces a noise gain of two from the V_{OCM} pin to the "open" output. In order to avoid this noise, simply do not use that output, resulting in a fully single-ended application. Or, you can take the slight noise penalty and use both outputs.

A Single-Ended Transimpedance Amplifier

Figure 3 shows the LTC6406 connected as a single-ended transimpedance amplifier with 20kΩ of transimpedance gain. The BF862 JFET buffers the LTC6406 input, drastically reducing the effects of its bipolar input transistor current noise. The V_{GS} of the JFET is now included as an offset, but this is typically 0.6V so the circuit still functions well on a 3V single supply and the offset can be dialed out with the 10k potentiometer. The time domain response is shown in Figure 4. Total output noise on 20MHz bandwidth measurements shows 0.8mV$_{RMS}$ on $V_{OUT}{+}$ and 1.1mV$_{RMS}$ on $V_{OUT}{-}$. Taken differentially, the transimpedance gain is 40kΩ.

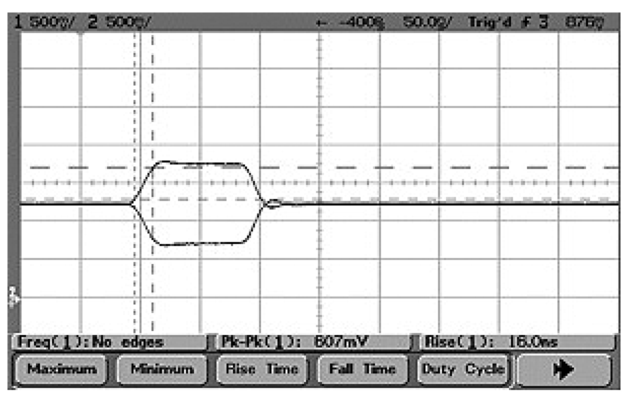

Figure 4. Time domain response of circuit of Figure 3, showing both outputs each with 20kΩ of TIA gain. Rise time is 16ns, indicating a 20MHz bandwidth.

Conclusion

New families of fully differential op amps like the LTC6406 offer unprecedented bandwidths. Fortunately, these op amps can also function well in single-ended and 100% feedback applications.