Application Report
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Using Single-Supply Fully Differential Amplifiers With Negative Input Voltages to Drive ADCs

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ABSTRACT

Parameters were established for a bipolar single-ended source that must be amplified and level-shifted to drive an ADC with a +2.5-V input common-mode voltage and a full-scale input of up to 6 V_{PP}. A good option for driving such an ADC is an FDA with a single +5-V supply, a V_{ICR} ranging from –0.1 V to +2 V, and an output voltage ranging from +1 V to +4 V. The THS4521 is an excellent choice for this application.

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1 Introduction

Fully differential amplifiers (FDAs) with a single +5-V supply can be easily used to convert single-ended signals that swing around ground to differential signals that are level-shifted to match the input common-mode requirements of differential-input ADCs. There is no real trick to it, but typically it is best to use a device such as the THS4521 with an input common-mode voltage range (V_{ICR}) that includes ground. A circuit is proposed and analyzed to show how an FDA with a single +5-V supply can implement the design.

FDAs have been compared to two standard inverting single-ended-output operational amplifiers (op amps), configured in differential architecture and tied together using a common-mode output loop. While this is valid as a concept, there are important differences. For this discussion, an important difference to remember is that when using a standard single-ended-output op amp in inverting configuration, the input common mode is controlled; but when using an FDA, the output common mode is controlled.

When using a standard single-ended-output op amp in inverting configuration, the positive input is not driven from the source, and is usually tied to ground or some other reference voltage. The input common-mode voltage at the input pins of the op amp is held at the voltage applied to the positive input by negative feedback, where the op amp drives the error voltage across its input pins to 0 V. This is usually referred to as a virtual short, an important concept in op amp theory.

When using an FDA to convert a single-ended input to a differential output, the alternate input not driven by the source is driven by the output through the feedback network. The virtual-short concept is still valid, but the inputs are no longer tied to a reference, and move around with the signal. The output common-mode voltage is controlled by the input to the V_{OCM} pin.

The following discussion assumes familiarity with FDA concepts and use. For more information on FDA fundamentals, see James Karki, “Fully-differential amplifiers,” Application Report in Section 4.

2 Circuit Analysis

2.1 Proposed Circuit

The proposed circuit for a single-ended bipolar input signal is shown in Figure 1. V_{S+} is the power supply to the amplifier; the negative supply input is grounded. V_{IN} is the input-signal source, is shown as a ground-referenced signal swinging around ground (±0 V), and is thus a bipolar signal. R_G and R_F are the main gain-setting resistors for the amplifier. V_{OUT+} and $V_{OUT–}$ are the differential output signals to the ADC. They are 180° out of phase, and level-shifted to V_{OCM}.

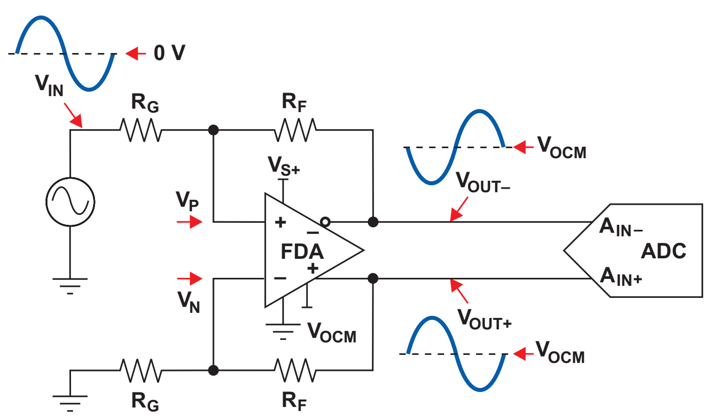

Figure 1. Single-Ended Bipolar Input Circuit

2.2 Analysis

For analysis, assume the FDA is an ideal amplifier with no offset and with infinite gain.

The gain from the single-ended input to the differential output is set by R_F and R_G:

$$\frac{V_{OUT\pm}}{V_{IN}} = \frac{R_F}{R_G} \tag{1}$$

Note that there is no multiplication by 2, as with other devices and circuit architectures used to convert single-ended inputs to differential outputs.

Each single-ended output is half the differential-output common-mode voltage (+V_{OCM}):

$$V_{OUT+} = \frac{V_{IN}}{2} \cdot \frac{R_F}{R_G} + V_{OCM}$$

and

$$V_{OUT-} = \frac{-V_{IN}}{2} \cdot \frac{R_F}{R_G} + V_{OCM} \tag{2}$$

For proper operation, the input voltages at V_P and V_N must not exceed the input common-mode voltage range (V_{ICR}) of the amplifier, and the outputs must be able to support the voltage-swing requirements of the ADC input. Violating V_{ICR} leads to nonlinear operation that increases distortion and is often mistaken for output-saturation problems.

To verify that the V_{ICR} is not violated, the virtual-short concept can be used to calculate the voltage at either FDA input pin, as $V_P \approx V_N$. Either Equation 3 or Equation 4 can be used, but Equation 4 is easier:

$$V_P = V_{OUT-} \times \frac{R_G}{R_G + R_F} + V_{IN} \times \frac{R_F}{R_G + R_F} \tag{3}$$

$$V_N = V_{OUT+} \times \frac{R_G}{R_G + R_F} \tag{4}$$

Due to the difference in output and input commonmode voltage, the feedback circuit draws a current equal to the difference in the common-mode voltages divided by $R_F + R_G$. If the gain-setting resistors on the two sides of the FDA are not matched, the difference in common-mode voltage also causes an offset in the output. Use resistors with a low tolerance of 1% or better.

2.3 Example

To see how the circuit works, assume that the input signal is 2 V_{PP} and the ADC to be driven is the ADS1278. The full-scale differential input of the ADS1278 is 5 V_{PP}, and the input common-mode voltage is +2.5 V. The THS4521 with a single +5-V supply can be used as the FDA.

First verify that the THS4521 can support the required voltages. The maximum gain to avoid saturating the ADC is 2.5 V/V. Equation 1 can be used to set R_F at 1 kΩ and R_G at 400 Ω. To set the required input common-mode voltage of the ADC at +2.5 V, the V_{OCM} of the THS4521 can simply be bypassed to ground with a 0.1-μF capacitor, because V_{OCM} defaults to midsupply (+2.5 V) if not driven. Each output will then swing 2.5 V_{PP} (±1.25 V) around +2.5 V, so the outputs must support +1.25 V to +3.75 V. The THS4521 data sheet (SBOS458) shows that the required output-voltage range is within specification. Note that other converters with different requirements for the input common-mode voltage require the V_{OCM} pin to be DC-biased to meet those requirements.

Equation 3 can be used to calculate V_P at the positive and negative peaks of the input signal. At V_{IN} = –1 V, V_{OUT-} = +3.75 V.

$$V_P = 3.75\text{ V} \times \frac{400\,\Omega}{1400\,\Omega} - 1\text{V} \times \frac{1000\Omega}{1400\Omega} = +0.357\text{ V}$$

At $V_{IN} = +1$ V, $V_{OUT-} = +1.25$ V

$$V_P = 1\text{V} \times \frac{400\,\Omega}{1400\,\Omega} + 1.25\text{ V} \times \frac{1000\,\Omega}{1400\,\Omega} = +1.071\text{ V} \tag{5}$$

Alternatively, Equation 4 can be used to calculate V_N at the positive and negative peaks of the input signal. At V_{IN} = –1 V, V_{OUT+} = +1.25 V.

$$V_N = 1.25\ V \times \frac{400\ \Omega}{1400\ \Omega} = +0.375\ V$$

At V_{IN} = +1 V, V_{OUT+} = +3.75 V

$$V_N = 3.75\ V \times \frac{400\ \Omega}{1400\ \Omega} = +1.071\ V \qquad (6)$$

The voltages calculated for V_P and V_N are the same as predicted. The THS4521 data sheet (SBOS458) shows that the required input-voltage range is within specification.

Though the input signal swings negative below ground, no negative voltages are required at the FDA pins. When used for conversion from single-ended to differential, the input common-mode voltage to the FDA is modulated with the signal. In contrast, when the input and output are both differential, variation of the input common-mode voltage is much lower and approximately equal to the weighted average (set by R_F and R_G) of the output common-mode and input common-mode voltages.

Several things happen to V_{ICR} when the gain is decreased or increased:

- When the gain decreases, the input voltages (V_P and V_N) are driven closer to the output voltage. For a gain of 1, V_{ICR} equals half the output swing on either output. Attenuation, where the gain is less than 1, is a special case; see Jim Karki, “Using fully differential op amps as attenuators, Part 2: Single-ended bipolar input signals,” Analog Applications Journal (3Q 2009) in Section 4 for more information.
- When the gain increases, the input voltages (V_P and V_N) are driven closer to the input source voltage. As the gain increases, R_F becomes larger and/or R_G becomes smaller; assuming that the output-voltage swing is the same, the input-signal swing becomes smaller. V_{ICR} equals the input common mode of the source, which in this case is 0 V, or ground. For a more practical example, given the same 5-V_{PP} differential output as before but with the input reduced so the required gain is 10, V_{ICR} = +0.114 V to +0.341 V.

2.4 Simulation

Always simulate circuit ideas to catch errors and verify that assumptions are valid. Figure 2 shows the result of a transient analysis from TINA-TI™. To see this simulation, go to http://www.ti.com/lit/zip/slyt394 and click Open to view the WinZip directory online (or click Save to download the WinZip file for offline use). If you have the TINA-TI software installed, you can open the file THS4521_SE_to_DIFF.TSC to view the example. To download and install the free TINA-TI software, visit www.ti.com/tina-ti and click the Download button.

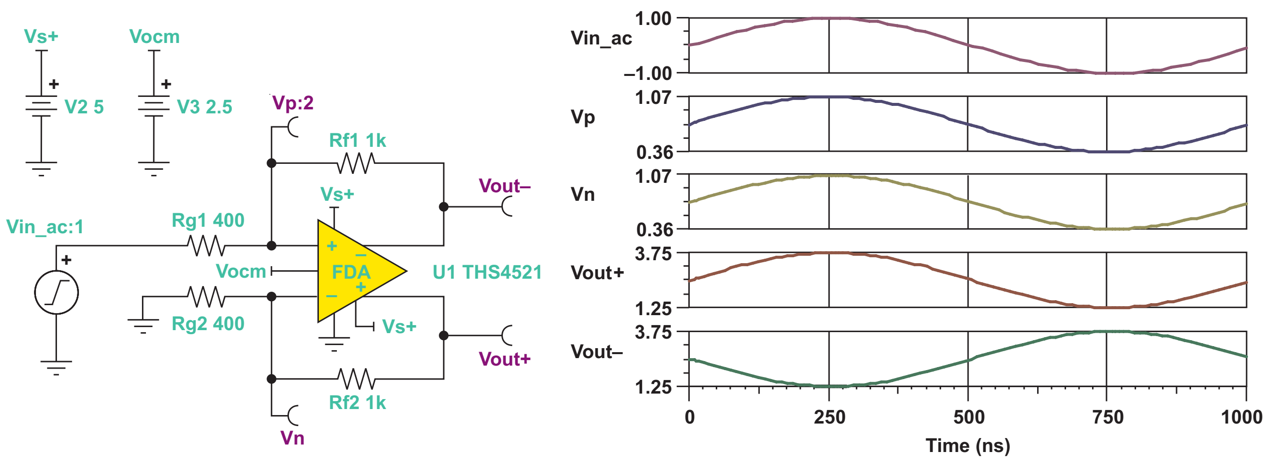

Figure 2. TINA-TI Simulation of Example Circuit

3 Conclusion

Parameters were established for a bipolar single-ended source that must be amplified and level-shifted to drive an ADC with a +2.5-V input common-mode voltage and a full-scale input of up to 6 V_{PP}. A good option for driving such an ADC is an FDA with a single +5-V supply, a V_{ICR} ranging from –0.1 V to +2 V, and an output voltage ranging from +1 V to +4 V. The THS4521 is an excellent choice for this application, with specifications for a single +5-V supply as follows:

- Input-voltage range = 0 to +3.5 V (minimum to maximum over a temperature range of –40°C to +85°C)
- Output-voltage range = +0.2 to +4.65 V (minimum to maximum over a temperature range of –40°C to +85°C)

Table 1 shows the TI ADCs compatible with the output-drive characteristics and performance of the THS4521.

When an FDA with a single +5-V supply drives an ADC with a single +5-V supply (such as the THS4521 driving the ADS1278), the potential problem of saturating the ADC inputs is avoided, because its outputs cannot exceed the power-supply voltage.

Refer to the “Application Information” section of “Very low power, negative rail input, rail-to-rail output, fully differential amplifier,” THS4521 Data Sheet in Section 4 for details on how the THS4521 performs when driving ADCs and for other application information.

Table 1. TI ADCs Compatible With THS4521

CONVERTER TYPE	DEVICES
Successive approximation register (SAR)	ADS8317/8, ADS8321, ADS8361/4/5, ADS7861/2/3/4/5/9
Delta-sigma	ADS1251/2/3/4/8, ADS1281/2, ADS1158, ADS1271/4/8, ADS1174/8
Audio	PCM1804, PCM3110, PCM3160/8, PCM4201/2/4

4 References

For more information related to this article, download an Acrobat® Reader® file at www.ti.com/lit/litnumber, and replace “litnumber” with the TI Lit. # for the materials listed below.

1. James Karki, “Fully-differential amplifiers,” Application Report (SLOA054)
2. Jim Karki, “Using fully differential op amps as attenuators, Part 2: Single-ended bipolar input signals,” Analog Applications Journal (3Q 2009) (SLYT341)
3. “Very low power, negative rail input, rail-to-rail output, fully differential amplifier,” THS4521 Data Sheet (SBOS458)

5 Related Web Sites

amplifier.ti.com

www.ti.com/sc/device/ADS1278

www.ti.com/sc/device/THS4521

TINA-TI file for example: www.ti.com/lit/zip/slyt394

To download TINA-TI software: www.ti.com/tina-ti