Technical Article

When to Use an Amplifier with Rail-to-rail Inputs – and What to Watch Out for

Xiyao Zhang

Early in my graduate school education, I was working on a project that needed a unity-gain operational-amplifier (op-amp) buffer for a monitoring circuit in our thin film deposition system. As soon as the new module was plugged in, I discovered that all of the signals close to the positive supply were clipped. My lab-mate said, "Oh, you should have used a rail-to-rail op amp instead." This was how I first learned I needed a special type of op amp to prevent over-ranging of my inputs.

In recent years, more op amps (especially those in the lower-speed precision category) feature an input common-mode range (ICMR) that includes both supply rails. This is certainly good news for designers who are just starting, like I was when I was in graduate school. In many cases, the flexibility of a rail-to-rail input/output (RRIO) amplifier enables its use in multiple places in the same system, thus simplifying the bill of materials (BOM). But even in applications where minimizing the BOM is not as critical, the flexibility of a rail-to-rail input amplifier still provides many advantages.

Unity-gain Buffer in a Low-voltage Single-supply System

One application that can realize these advantages is a unity-gain buffer in a low-voltage single-supply system. Portable and battery-powered electronic systems are ubiquitous in a number of markets, such as personal electronics, energy harvesting, and test and measurement. Most of these systems run on 3.3V or even lower, which stresses the ICMR of the signal chain.

To illustrate this input-range issue, let's use the OPAx836 family (OPA836/OPA2836) as an example. The OPAx836 is a popular op-amp family without rail-to-rail input, but is otherwise ideal for portable applications. The OPA836 and OPA2836 op amps achieve great power efficiency with 205MHz of bandwidth and 4.6nV/√Hz of input-voltage noise with a mere 1mA of quiescent current per channel. They are also available in small packages. These advantages allow these op amps to be used in portable applications, where power and footprint are important, but performance also cannot be sacrificed. The OPAx836 also features rail-to-rail output (RRO), which allows the output voltage range to be maximized for low supply-voltage operation. However, on the input side, ICMR is only V_{S-}-0.2V to V_{S+}-1.1V for the OPAx836. The 1.1V of high-side headroom is not a problem if the amplifier circuit has gain (say >1.5V/V, in which case the input does not need to fill the supply range). But taking 1.1V out of 3.3V or less total supply range in a unity-gain buffer can become quite restrictive for a portable system that needs to maximize the dynamic range.

High-side Battery Monitoring in Portable Devices

Another application for rail-to-rail input amplifiers is high-side battery monitoring in portable devices. TI's THS4281 is a high-speed op amp that can be used for these use cases. It features rail-to-rail input as well as 90MHz of bandwidth with only 0.75mA of quiescent current, which enables designers to build fast and flexible systems with low power consumption. Figure 1 shows a typical high-side current-sensing circuit using the THS4281. The rail-to-rail input is very handy here because the input common mode in Figure 1 is typically within 1V of the positive rail, which excludes most amplifiers without rail-to-rail inputs, including the OPA836.

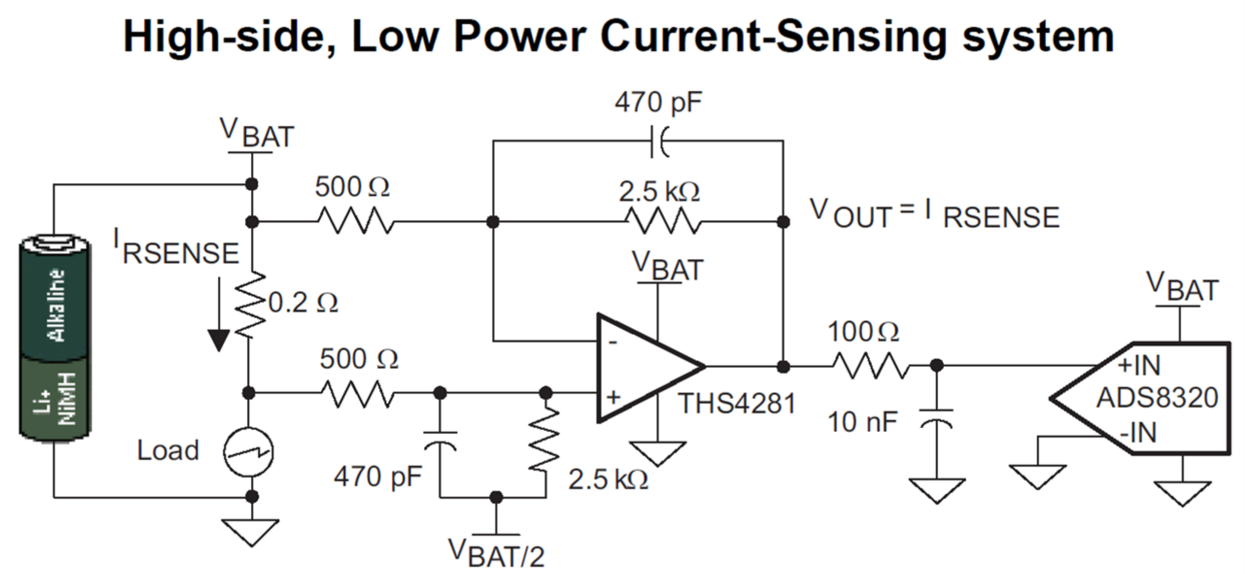


Figure 1. A Typical High-side Current-sensing Circuit for Battery Systems Using the THS4281

While rail-to-rail-input amplifiers are extremely versatile and user-friendly, there is an issue that needs careful attention. Most rail-to-rail input amplifiers use an input-stage topology similar to that shown in Figure 2. This circuit combines a main PNP/PMOS stage, which operates from below the negative rail to roughly 1.5V from the positive rail and an “auxiliary” NPN/NMOS stage, which handles the last ~1.5V of the ICMR to the positive rail. Consequently, there is usually a “switchover” or “crossover” region where the transition between the main and auxiliary stages takes place.

To identify this region, look at the offset voltage (V_{OS}) versus the input common-mode voltage (V_{ICR}) plot, such as the one shown in Figure 3 for the THS4281. In this case, the V_{OS} “jump” at V_{INCM} from V_{S+}-1.4V to V_{S+}-1V marks the region where the switchover occurs. Sometimes in a precision application where the unity-gain measurements need to be accurate within 1mV, this kind of V_{OS} jump is not desirable.

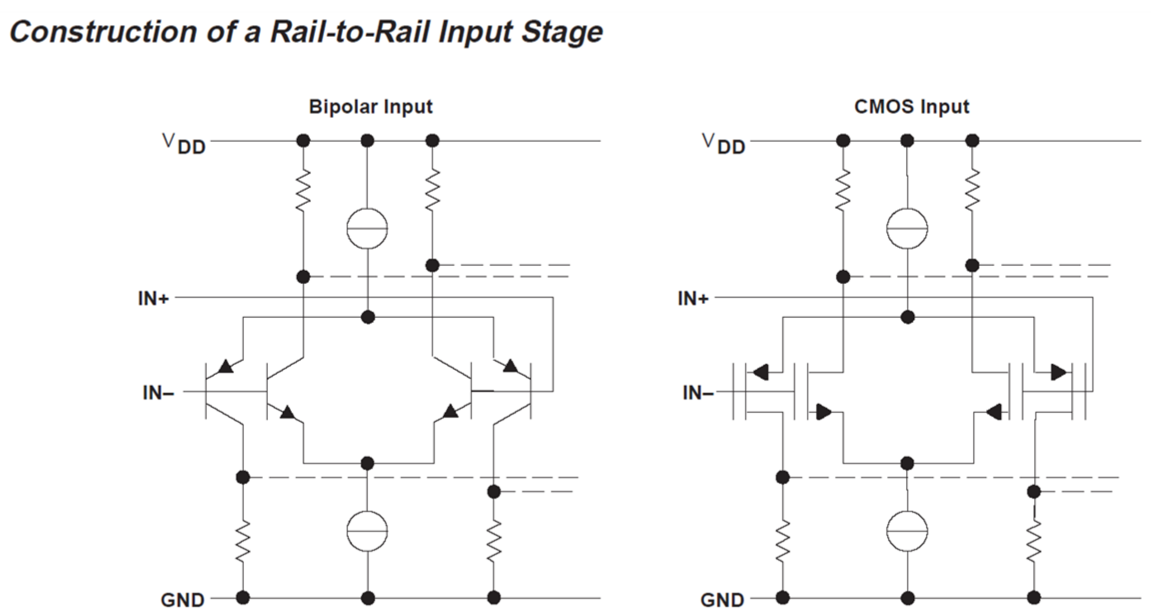
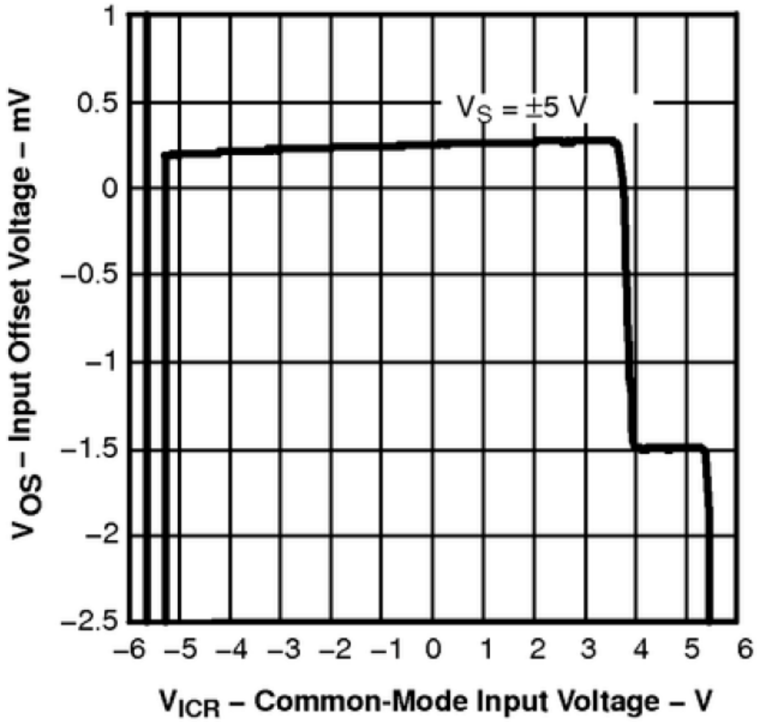


Figure 2. One Common Input-stage Topology for a Rail-to-rail Input Amplifier Using a Bipolar Junction Transistor (BJT) (Left) or MOSFET (Right)



$V_S = \pm 5$ V

Figure 3. A plot of input common-mode voltage (V_{ICR}) versus offset voltage (V_{OS}) for the THS4281

Integrated circuit designers have various techniques to reduce this crossover error, but unless you add an internal charge pump, the crossover error always exists. In most cases, this crossover region is a nuisance, rather than a showstopper. For example, in Figure 1, as long as V_{BAT} stays below 12V, the input common mode should remain above the crossover region. Similarly in an inverting or transimpedance amplifier circuit, you can still set the input common-mode voltage to any value within the supply rails, as long as you remain mindful of the switchover region. Also, since the input voltages in these op-amp circuits do not move, the switchover behavior is much less noticeable.

Conclusion

Using an amplifier with rail-to-rail inputs can offer many benefits, such as maximizing signal chain dynamic range and simplifying BOM. There are some things to be aware of, such as the V_{OS} discontinuity during cross-over. However, it is more of a nuisance, which I discussed above. What is your experience with rail-to-rail inputs? Log in and leave a comment below.

Additional Resources

- Read more about the THS4281.
- Learn more about the TI Designs Power-Optimized 16-Bit 1MSPS Data Acquisition Block for Lowest Distortion and Noise Reference Design (TIPD149), which uses the OPA836.
- Get more in-depth information about crossover behavior.
- Search TI high-speed op amps and find technical resources.

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