Bruce Trump Apr 16, 2013

Rail-to-Rail (R/R) op amps are extremely popular, especially useful with low supply voltage. You should know how R/R inputs are accomplished and understand some trade-offs.

Figure 1 shows a typical dual-input R/R stage comprised of both N and P-channel transistor pairs. The P-channel FETs handle the signal through the lower portion of the common-mode voltage range, to slightly below the negative rail (or single-supply ground). The N-channel FETs operate with common-mode voltage near and slightly above the positive rail. Additional circuitry (not shown) directs traffic, determining which input stage signal is processed by the next stage. Most of our dual input stage op amps are designed so that the transition occurs approximately 1.3V from the positive rail. Above this voltage, there is insufficient gate voltage for the P-channel stage so the signal path is redirected to the N-channel stage.

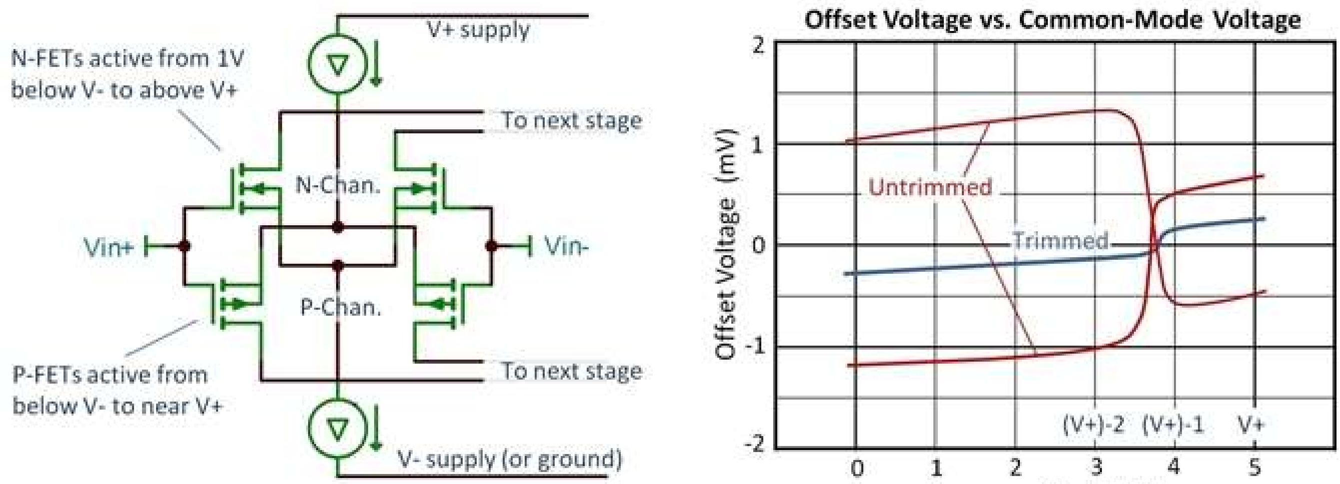


Figure 1.

The P and N input stages will have somewhat different offset voltages. If the common-mode voltage moves through this transition (as it does with R/R G=1 operation), it creates a change in the offset. Some op amps are factory trimmed by laser or electronic trimming, adjusted to reduce the offset of the input stages. This reduces the change through the transition but still leaves a residual bobble. The circuitry controlling the transition from P to N input stage is referenced to the positive supply voltage, not ground. On a 3.3V supply the transition moves to an awkward point—mid-supply.

While unnoticed in most applications, this change in offset voltage may be an issue if high accuracy is required. It can also cause distortion in AC applications. But, again, this will only be seen if the common-mode input voltage crosses the transition between stages.

Figure 2 shows a second type of R/R input stage. An internal charge pump boosts the voltage powering a single P-channel input stage to approximately 2V *above the positive supply rail*. This allows a single input stage to perform seamlessly over the full rail-to-rail input voltage range—below the bottom rail to above the top rail. No transition glitch.

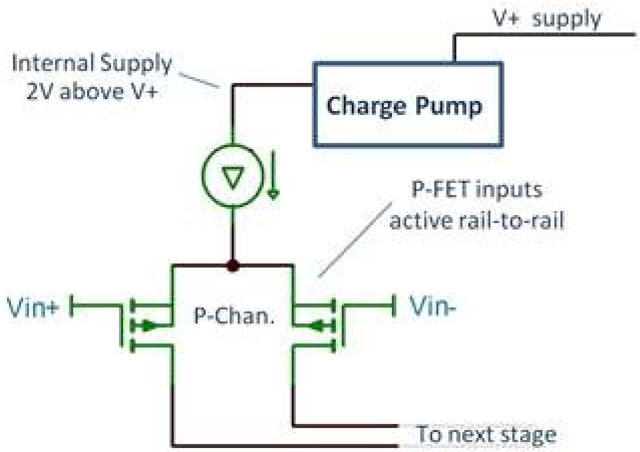
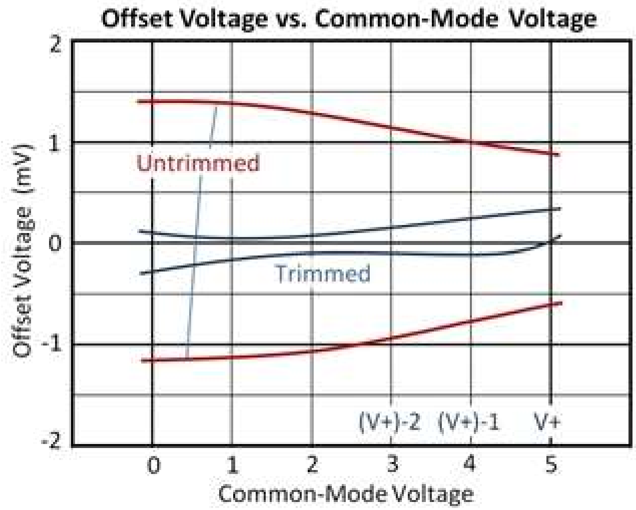


Figure 2.



Charge pump… it sounds spooky to some designers. They're noisy, right? But our most recent ones are remarkably quiet. Very little current is required because it's only powering the input stage. There are no extra pins or capacitors—it's all internal. Charge pump noise is below the broadband noise level; rarely can it be seen in the time domain. Applications that analyze the spectral response below the broadband noise level, however, may see some artifacts.

Not all applications need an op amp with R/R input. Inverting op amp circuits or amplifiers in gain greater than unity, for example, often do not require R/R input, yet still have R/R output. (Maybe this needs another blog.) Do you really need a R/R-input amplifier? Many engineers prefer to use them so they don't need to worry about exceeding the common-mode range. They use the same op amp in various points in their system—some needing R/R input, others not. Whatever your choice, with knowledge of the R/R types and tradeoffs, you can select more wisely. If in doubt, you are welcome to ask us on our E2E forum.

Here are a few example op amps:

- OPA340 Two-Input Stage, Trimmed Offset, 5.5MHz R/R CMOS
- OPA343 Two-Input Stage, Untrimmed Offset, 5.5MHz R/R CMOS
- OPA320 Charge-pumped Input Stage, Trimmed Offset, 20MHz R/R CMOS
- OPA322 Charge-pumped Input Stage, Untrimmed, 20MHz R/R CMOS

Thanks for reading and your comments are welcome.

Bruce email: thesignal@list.ti.com (Email for direct communications. Comments for all, below.)

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Jens-Michael Gross *over 12 years ago*

Thank you for this article. I never wasted a thought on how R/R is accomplished. And on large signal, it usually is a don't care anyway. But for audio use, teh dual input stage can create even audible artifacts, depending on signal composition. On my next audio project (which I have planned adn then postponed for ~15 years now) I'll definitely consider this. Especially the part with the transition point ending up mid-suipply (on an audio applciaiton this is the worst case: around zero voltage, where noise and artifacts are best audible.

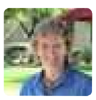
Bruce Trump *over 12 years ago*

Jens-Michael-- I realize that you are a true MSP430 guru but you should never refer to time spent thinking about analog issues as possibly “a wasted thought,” as you put it. :-) Thanks for your comments.

For those who are not familiar with Jens-Michael, I suggest that you check this link... sorry, I can't hyperlink it in these comments.

e2e.ti.com/.../jens-michael-gross-engineer-and-social-media-guru.aspx

He is, by far, the most prolific E2E community member. Come on you analog peeps... step it up! Give Jens-Michael some competition. -- Bruce



Bonnie Baker - WEBENCH Design Center *over 12 years ago*

The amplifier configuration that is geneally immune to this input stage issues is the inverting configuration. If you are willing to live with an inverted or a signal that changes from + to - or - to + this amplifier topology is good for you. Also, if you configure you non-inverting amplfier circuit in a gain of (typically) 2 or higher you will also avoid this input stage problem.

Jens-Michael Gross *over 12 years ago*

Bruce, I don't think it would have been wasted time - I just never had the idea to think about it at all. This is one of these things you just take for granted - until it turns against you. (In which case I surely had invested some time to fuigure out what's going on).

Sometimes you only know that something is worth thinking about it when you already thought about it for some reason. And it's definitely better to get alerted by this blog post then by a non-working circuit. :)