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Ask The Applications Engineer23

by Erik Barnes

CURRENT FEEDBACK AMPLIFIERSII

Part I (*Analog Dialogue* 30-3) covers basic operation of the current-feedback (CF) op-amp. This second part addresses frequently asked questions about common applications.

Q. I now have better understanding of how a current feedback op-amp works, but I'm still confused when it comes to applying one in a circuit. Does the low inverting input impedance mean I can't use the inverting gain configuration?

A. Remember that the inverting mode of operation works because of the low-impedance node created at the inverting input. The summing junction of a voltage-feedback (VF) amplifier is characterized by a low input impedance after the feedback loop has settled. A current feedback op amp will, in fact, operate very well in the inverting configuration because of its inherently low inverting-input impedance, holding the summing node at " ground," even before the feedback loop has settled. CF types don't have the voltage spikes that occur at the summing node of voltage feedback op amps in high-speed applications. You may also recall that advantages of the inverting configuration include maximizing input slew rate and reducing thermal settling errors.

Q. So this means I can use a current feedback op amp as a current-to-voltage converter, right?

A. Yes, they can be configured as I-to-V converters. But there are limitations: the amplifier's bandwidth varies directly with the value of feedback resistance, and the inverting input current noise tends to be quite high. When amplifying low level currents, higher feedback resistance means higher signal-to-(resistor-) noise ratio, because signal gain will increase proportionally, while resistor noise goes as $\sqrt{R}$. Doubling the feedback resistance doubles the signal gain and increases resistor noise by a only factor of 1.4; unfortunately the contribution from current noise is doubled, and, with a current feedback op amp, the signal bandwidth is halved. Thus the higher current noise of CF op amps may preclude their use in many photodiode-type applications. When noise is less critical, select the feedback resistor based on bandwidth requirements; use a second stage to add gain.

Q. I did notice the current noise is rather high in current feedback amplifiers. So will this limit the applications in which I can use them?

A. Yes, the inverting input current noise tends to be higher in CF op amps, around 20 to 30 pA/$\sqrt{\text{Hz}}$. However, the input voltage noise tends to be quite low when compared with similar voltage feedback parts, typically less than 2 nV/$\sqrt{\text{Hz}}$, and the feedback resistance will also be low, usually under 1 kohms. At a gain of 1, the dominant source of noise will be the inverting-input noise current flowing through the feedback resistor. An input noise current of 20 pA/$\sqrt{\text{Hz}}$ and an R_F of 750 ohms yields 15 nV/$\sqrt{\text{Hz}}$ as the dominant noise source at the output. But as the gain of the circuit is increased (by reducing input resistance), the output noise due to input current noise will not increase, and the amplifier's input *voltage* noise will become the dominant factor. At a gain, of say, 10, the contribution from the input noise current is only 1.5 nV/$\sqrt{\text{Hz}}$ when referred to the input; added to the input voltage noise of the amplifier in RSS fashion, this gives an input-referred noise voltage of only 2.5 nV/$\sqrt{\text{Hz}}$ (neglecting resistor noise). Used thus, the CF op amp becomes attractive for a low noise application.

Q. What about using the classic four-resistor differential configuration? Aren't the two inputs unbalanced and therefore not suitable for this type of circuit?

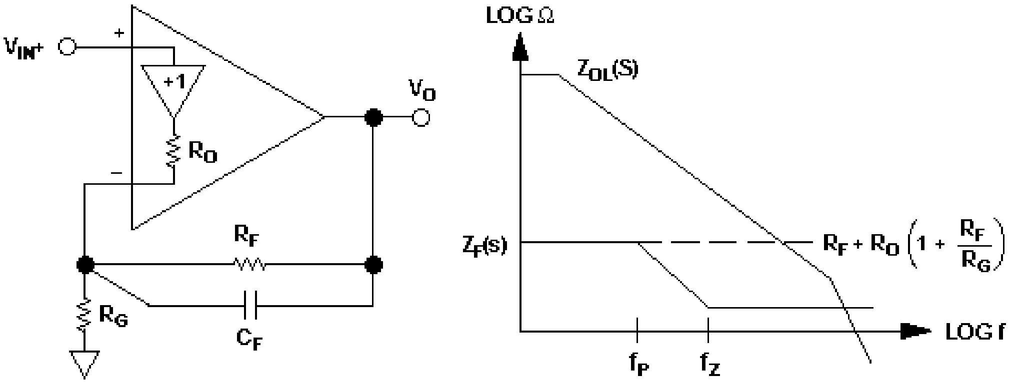
A. I'm glad you asked; this is a common misconception of CF op amps. True, the inputs are not matched, but the transfer function for the ideal difference amplifier will still work out the same. What about the unbalanced inputs? At lower frequencies, the four-resistor differential amplifier's CMR is limited by the matching of the external resistor ratios, with 0.1% matching yielding about 66 dB. At higher frequencies, what matters is the matching of time constants formed by the input impedances. High-speed voltage-feedback op amps usually have pretty well matched input capacitances, achieving CMR of about 60 dB at 1 MHz. Because the CF amplifier's input stage is unbalanced, the capacitances may not be well matched. This means that small external resistors (100 to 200 ohms) must be used on the noninverting input of some amplifiers to minimize the mismatch in time constants. If careful attention is given to resistor selection, a CF op amp can yield high frequency CMR comparable to a VF op amp. Both VF and CF amplifiers can further benefit from additional hand-trimmed capacitors at the expense of signal bandwidth. If higher performance is needed, the best choice would be a monolithic high speed *difference amplifier*, such as the AD830. Requiring no resistor matching, it has a CMR > 75 dB at 1 MHz and about 53 dB at 10 MHz.

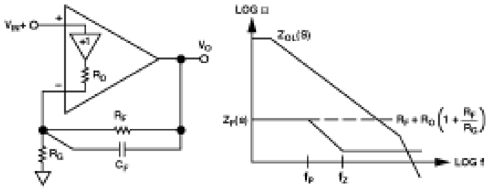
Q. What about trimming the amplifier's bandwidth with a feedback capacitor? Will the low impedance at the inverting input make the current feedback op amp less sensitive to shunt capacitance at this node? How about capacitive loads?

A. First consider a capacitor in the feedback path. With a voltage feedback op amp, a pole is created in the noise gain, but a pole and a zero occur in the feedback transresistance of a current feedback op amp, as shown in the figure below. Remember that the phase margin at the intersection of the feedback transresistance and the open loop transimpedance will determine closed-loop stability. Feedback transresistance for a capacitance, C_F, in parallel with R_F, is given by

$$Z_F(s)=\left[R_F+R_O\left(1+\frac{R_F}{R_G}\right)\right]\frac{1+\frac{sC_F R_F R_G R_O}{R_F R_G+R_F R_O+R_G R_O}}{1+sC_F R_F}$$

The pole occurs at $1/2^1R_FC_F$, and the zero occurs higher in frequency at $1/[2^1(R_F||R_G||R_O)C_F]$. If the intersection of Z_F and Z_{OL} occurs too high in frequency, instability may result from excessive open loop phase shift. If R_F goes to infinity, as with an integrator circuit, the pole occurs at a low frequency and very little resistance exists at higher frequencies to limit the loop gain. A CF integrator can be stabilized by a resistor in series with the integrating capacitor to limit loop gain at higher frequencies. Filter topologies that use reactive feedback, such as multiple feedback types, are not suitable for CF op amps; but Sallen-Key filters, where the op amp is used as a fixed-gain block, are feasible. In general, it is not desirable to add capacitance across R_F of a CF op amp.

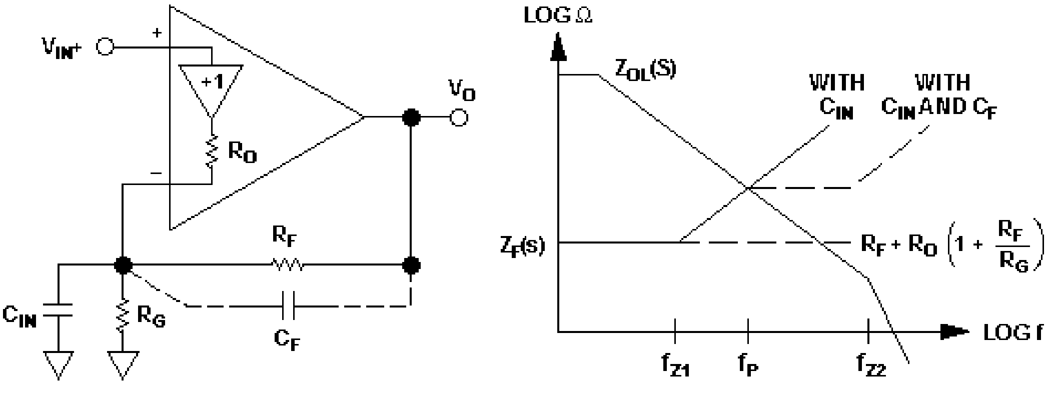


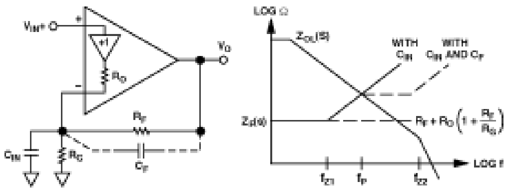


Another issue to consider is the effect of shunt capacitance at the inverting input. Recall that with a voltage feedback amplifier, such capacitance creates a zero in the noise gain, increasing the rate of closure between the noise gain and open loop gain, generating excessive phase shift that can lead to instability if not compensated for. The same effect occurs with a current feedback op amp, but the problem may be less pronounced. Writing the expression for the feedback transresistance with the addition of C_{IN}:

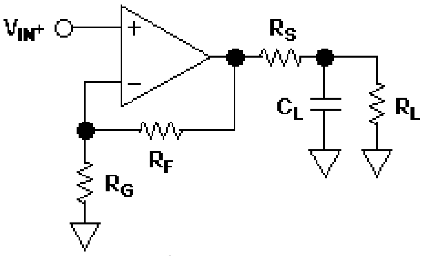
$$Z_F(s)=\left[R_F+R_O\left(1+\frac{R_F}{R_G}\right)\right]\left[1+\frac{sC_{IN}R_F R_G R_O}{R_F R_G+R_F R_O+R_G R_O}\right]$$

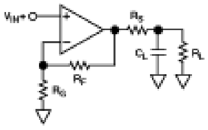
A zero occurs at $1/[2^1(R_F||R_G||R_O)C_{IN}]$, shown in the next figure (f_{Z1}). This zero will cause the same trouble as with a VF amplifier, but the corner frequency of the zero tends to be higher in frequency because of the inherently low input impedance at the inverting input. Consider a wideband voltage feedback op amp with R_F = 750 ohms, R_G = 750 ohms, and C_{IN} = 10 pF. The zero occurs at $1/[2^1(R_FiR_G)C_{IN}]$, roughly 40 MHz, while a current feedback op-amp in the same configuration with an R_O of 40 ohms will push the zero out to about 400 MHz. Assuming a unity gain bandwidth of 500 MHz for both amplifiers, the VF amplifier will require a feedback capacitor for compensation, reducing the effect of C_{IN}, but also reducing the signal bandwidth. The CF device will certainly see some additional phase shift from the zero, but not as much because the break point is a decade higher in frequency. Signal bandwidth will be greater, and compensation may only be necessary if in-band flatness , but also reducing the signal bandwidth. The CF device will certainly see some additional phase shift from the zero, but not as much because the break point is a decade higher in frequency. Signal bandwidth will be greater, and compensation may only be necessary if in-band flatness or optimum pulse response is required. The response can be tweaked by adding a small capacitor in parallel with R_F to reduce the rate of closure between Z_F and Z_{OL}. To ensure at least 45° of phase margin, the feedback capacitor should be chosen to place a pole in the feedback transresistance where the intersection of Z_F and Z_{OL} occurs, shown here (f_P). Don't forget the effects of the higher frequency zero due to the feedback capacitor (f_{Z2}).





Load capacitance presents the same problem with a current feedback amplifier as it does with a voltage feedback amplifier: increased phase shift of the error signal, resulting in degradation of phase margin and possible instability. There are several well-documented circuit techniques for dealing with capacitive loads, but the most popular for high speed amplifiers is a resistor in series with the output of the amplifier (as shown below). With the resistor outside the feedback loop, but in series with the load capacitance, the amplifier doesn't directly drive a purely capacitive load. A CF op amp also gives the option of increasing R_F to reduce the loop gain. Regardless of the approach taken, there will always be a penalty in bandwidth, slew rate, and settling time. It's best to experimentally optimize a particular amplifier circuit, depending on the desired characteristics, e.g., fastest rise time, fastest settling to a specified accuracy, minimum overshoot, or passband flatness.





Q. Why don't any of your current feedback amplifiers offer true single-supply operation, allowing signal swings to one or both rails?

A. This is one area where the VF topology is still favored for several reasons. Amplifiers designed to deliver good current drive and to swing close to the rails usually use common-emitter output stages, rather than the usual emitter followers. Common emitters allow the output to swing to the supply rail minus the output transistors' V_{CE} saturation voltage. With a given fabrication process, this type of output stage does not offer as much speed as emitter followers, due in part to the increased circuit complexity and inherently higher output impedance. Because CF op amps are specifically developed for the highest speed and output current, they feature emitter follower output stages.

With higher speed processes, such as ADI's XFCB (extra-fast complementary bipolar), it has been possible to design a common-emitter output stage with 160-MHz bandwidth and 160-V/µs slew rate, powered from a single 5-volt supply (AD8041). The amplifier uses voltage feedback, but even if, somehow, current feedback had been used, speed would still be limited by the output stage. Other XFCB amplifiers, with emitter-follower output stages (VF or CF), are much faster than the AD8041. In addition, single-supply input stages use PNP differential pairs to allow the common-mode input range to extend down to the lower supply rail (usually ground). To design such an input stage for CF is a major challenge, not yet met at this writing.

Nevertheless, CF op amps can be used in single-supply applications. Analog Devices offers many amplifiers that are specified for +5- or even +3-volt operation. What must be kept in mind is that the parts operate well off a single supply *if the application remains within the allowable input and output voltage ranges*. This calls for level shifting or ac coupling and biasing to the proper range, but this is already a requirement in most single-supply systems. If the system must operate to one or both rails, or if the maximum amount of headroom is demanded in ac-coupled applications, a current feedback op amp may simply not be the best choice. Another factor is the rail-to-rail output swing specifications when driving heavy loads. Many so-called rail-to-rail parts don't even come close to the rails when driving back-terminated 50- or 75-ohms cables, because of the increase in V_{CESAT} as output current increases. If you really need true rail-to-rail performance, you don't want or need a current feedback op amp; if you need highest speed and output current, this is where CF op amps excel.

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