Application Report
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A Current Feedback Op-Amp Circuit Collection

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ABSTRACT

Designers often misunderstand current feedback amplifiers, although they have been available for many years. This application note will answer some questions and give a *jumpstart* to apprehensive designers.

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1 Introduction

As a young and naive designer, the author thought he knew about op-amps. Inverting op-amp gain is $–R_f/R_{in}$, noninverting gain is $1+R_f/R_{in}$, etc. Then along came the term *current feedback*. This was a rather frightening prospect—all of the things that were comfortable would be changed. Some new and exotic feedback technique would have to be learned—the gain equations would be all different, the resistors would have to be hooked up differently. The author wanted nothing to do with current feedback amplifiers!

It turned out that this was a misconception. The familiar gain topologies remain unchanged. Inverting gain is still $–R_f/R_{in}$, noninverting gain is still $1+R_f/R_{in}$. There are some peculiarities, but they are easily accommodated.

2 Current Feedback Amplifiers—Use Them Right!

The term *current feedback* refers to the internal operation of the op-amp, not some new and exotic way of connecting the output back to the input. Figure 1 shows a block diagram of how they operate.

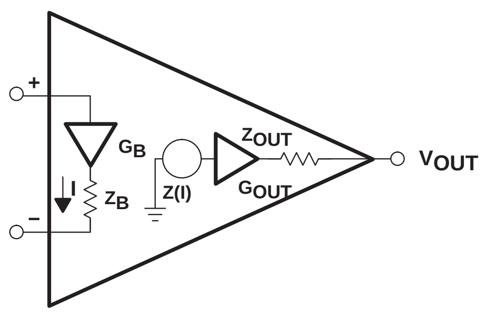

Figure 1. Current Feedback Amplifier Block Diagram

An input voltage, applied to the +input, is buffered by a unity gain voltage buffer G_B, which produces a current I through an impedance Z_B, returning through the –input. Therefore, the inverting input has very low input impedance, corresponding to Z_B. This is the first difference between voltage feedback and current feedback—the input impedance of current feedback op-amp inputs is very different. Because the inverting input has low impedance, current feedback amplifiers are not good for balanced systems such as differential amplifiers.

Continuing the discussion of the block diagram, the transimpedance gain block Z(I) is where the gain of the amplifier is accomplished. The ideal open loop transimpedance gain is infinity, the same as the ideal open loop gain of a voltage feedback amplifier is infinity. Therefore, both types of amplifier are intended for closed loop applications.

The output of the transimpedance source is connected to a unity gain output buffer G_{OUT}, which has an associated output impedance Z_{OUT}.

The designer is responsible for closing the feedback loop of the current feedback op-amp in a manner that ensures proper operation.

Current feedback op-amps, in general, are not optimized for single supply operation. Please consult the data sheet to see if single supply operation is possible, and will produce the voltage swing required by the system.

Proper decoupling techniques are crucial to correct operation. This application note does not discuss decoupling techniques, but the designer is responsible for them.

3 Gain Circuits

As is the case with voltage feedback op-amps, there are two gain configurations: noninverting and inverting.

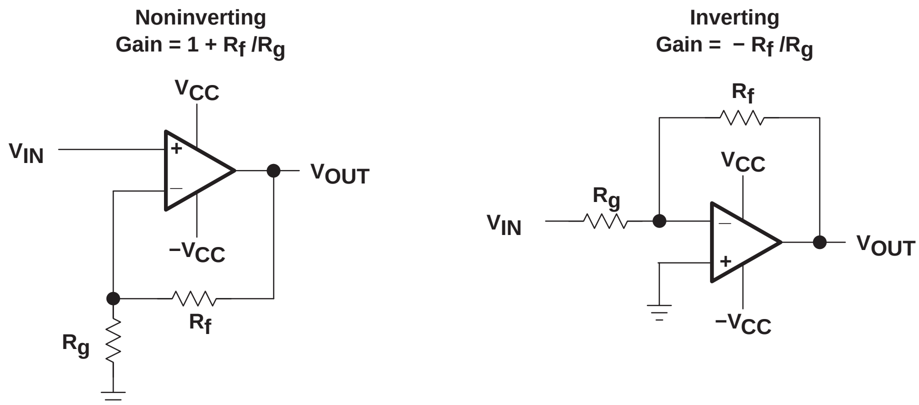

Figure 2. Current Feedback Amplifier Gain Circuits

Designers may notice that the circuit topologies are identical to those of voltage feedback amplifiers. While this is true, there are some minor peculiarities:

- It is extremely important to follow the recommendation for R_f given in the data sheet. The reason is that the value of R_f is the sole factor determining circuit stability (see Appendix A for a complete explanation).
- The inverting configuration has extremely low input impedance, and therefore is not very useful.
- If the noninverting input is capacitively coupled, it needs a small source of dc bias. That is because the input connects internally to a voltage buffer.

4 Filter Circuits

Filter circuits are used to remove unwanted harmonic components from signals, while leaving the components that are of interest.

Current feedback amplifiers have a restriction—there cannot be any capacitance connected from the output to the inverting input. This severely limits the topologies available, however it is possible to create most filter types. The designer merely has to get used to an unfamiliar topology.

4.1 Single Pole Filters

Single pole filters have a roll off of 20 dB per decade in the stopband. They come in low-pass and high-pass varieties. The varieties are all noninverting, and have the option of unity gain or gain set by the feedback resistor R_f and R2.

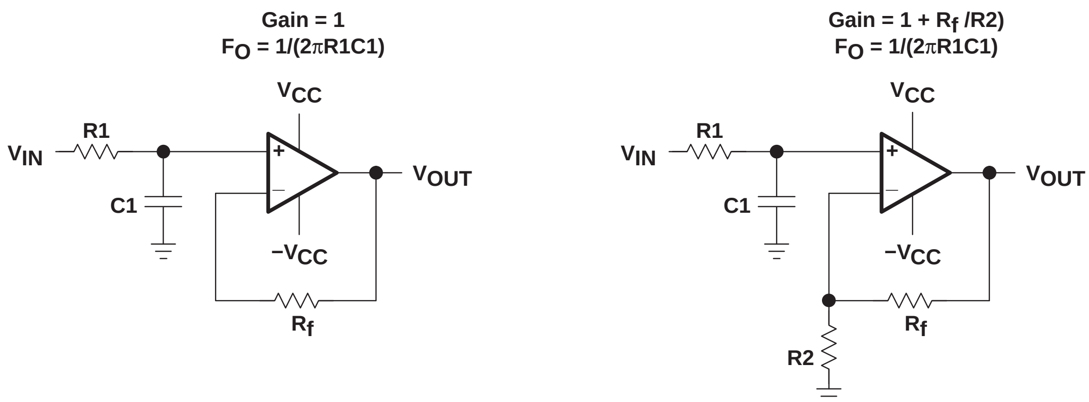

Figure 3. Current Feedback Amplifier Low-Pass Filter

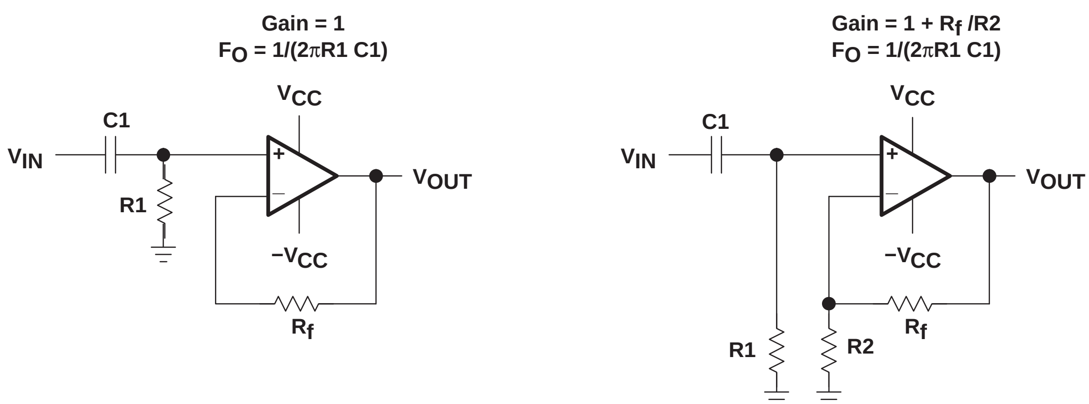

Figure 4. Current Feedback Amplifier Single Pole Filter

4.2 Double Pole Filters

Double pole filters have 40 dB per decade rejection in the stop band for Butterworth response. Although there are a number of different filter topologies, many are unsuitable for current feedback op-amps. This is due to the restriction of feedback resistor value and the restriction against using a capacitor in the feedback loop.

Designers are pretty much limited to filter topologies that traditionally used the feedback loop in a unity gain with the output shorted to the inverting input. For current feedback op-amps, the short is replaced with the recommended value of feedback resistor.

4.2.1 Sallen-Key Filters

The noninverting Sallen-Key topology is well suited to current feedback op-amps. The filter can be operated in the unity gain mode (below) or can be operated with a gain. The designer only needs to add a resistor R_g from the inverting input to ground.

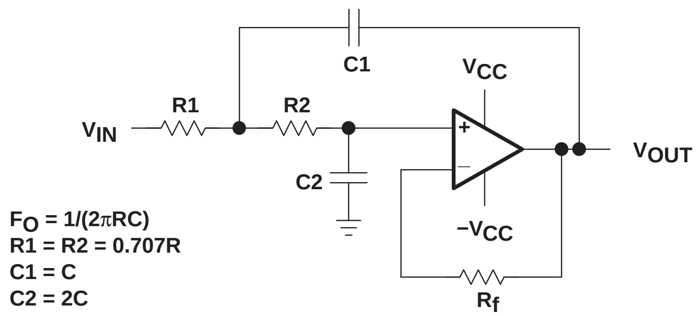

Figure 5. Current Feedback Sallen-Key Low-Pass Filter

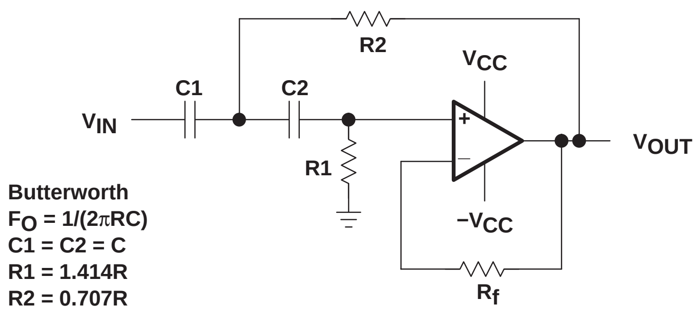

Figure 6. Current Feedback Sallen-Key High-Pass Filter

4.2.2 Twin T Filters

The Twin T filter topology is the only multiple op-amp topology suitable for current feedback op-amps. R_f must be used instead of a short from output to inverting input of both op-amps. The advantage of the Twin T topology is that it is easier to tune than the Sallen-Key. Of course the penalty is the addition of a second op-amp and some passive components.

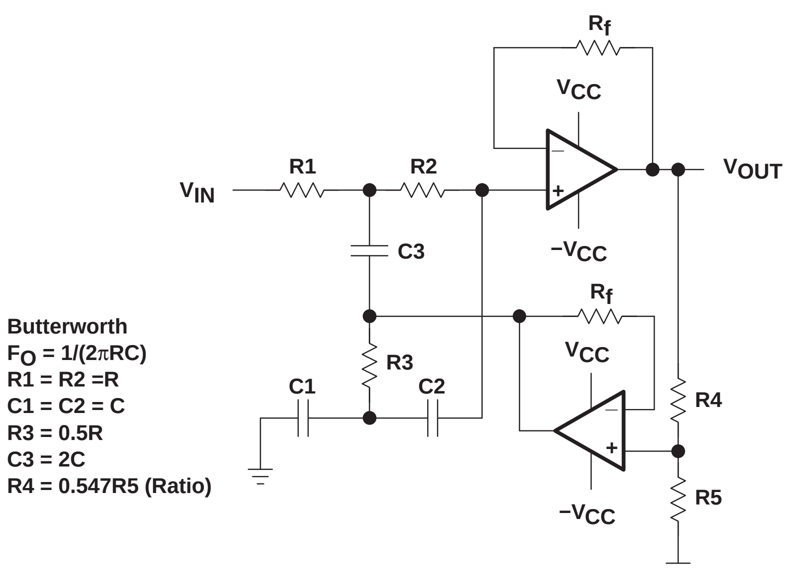

Figure 7. Current Feedback Twin T Low-Pass Filter

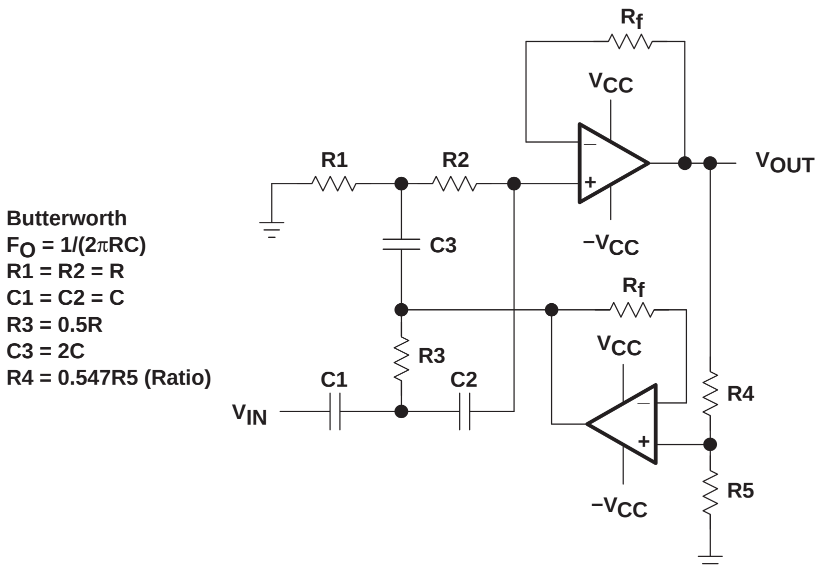

Figure 8. Current Feedback Twin T High-Pass Filter

Another key advantage of the Twin T topology is the ability to make a high Q notch filter. The reader is cautioned strongly that high Q filter design absolutely requires precision resistors and also precision capacitors (1%). These are long lead-time items; and procurement departments need to be advised early in the production cycle.

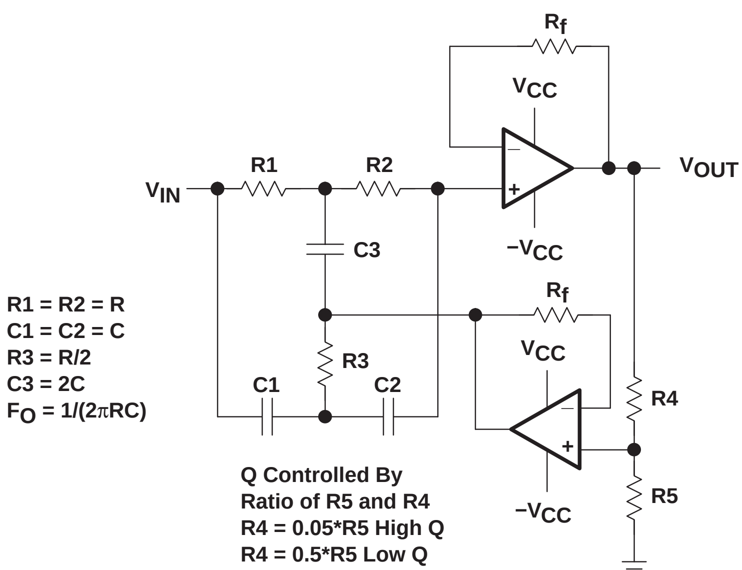

Figure 9. Current Feedback High Q Notch Filter

4.3 Bandpass Filter

There is no filter topology that can easily create a high Q bandpass filter with current feedback op-amps. There is a Sallen-Key bandpass architecture, but it tends to produce a low value resistor that is hard to obtain. The best strategy for low Q bandpass filters is to cascade a High-Pass and a Low-Pass stage.

5 Summary

Current feedback op-amps can be successfully used in a variety of applications. It is important for the designer to remember to use the recommended value of feedback resistor, and not to put a capacitor directly across the feedback path from the output to the inverting input. Virtually all filter functions, except high Q bandpass, are possible with the appropriate topology.

Appendix A Current Feedback Amplifier Stability Model

To understand why a current feedback amplifier must use a recommended value of Rf, it is necessary to delve deeper into feedback theory.

Figure A−1 shows a general feedback model, which consists of an input voltage V_{IN}, a summation block Σ, a forward gain block A, and a feedback gain block β. The input voltage is summed with a feedback voltage to produce an error voltage E.

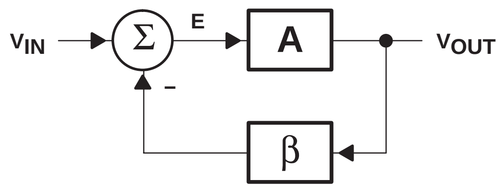

Figure A−1. Feedback Model

The output voltage V_{OUT} is then equal to the gain A times this error voltage:

$$V_{OUT} = E \times A$$

The error voltage E is equal to the difference between the input voltage V_{IN} and the output voltage V_{OUT} times the feedback factor β:

$$E = V_{IN} - \beta \times V_{OUT}$$

The error voltage is also equal to:

$$E = \frac{V_{OUT}}{A}$$

Combining these expressions and solving for V_{OUT}/V_{IN}:

$$\frac{V_{OUT}}{V_{IN}} = \frac{A}{(1 + A\beta)}$$

This expression is an important one. If a designer can derive a closed loop equation in this form, general feedback theory can be used to analyze it. The quantity Aβ is also very important. It is known as the *loop gain*, and is the quantity that determines the stability of the system. Looking at the denominator of the general feedback equation above, the condition that can produce instability is when the denominator goes to zero. This will happen when Aβ = −1 (another way of saying Aβ = |1| at a phase angle of 180° (or −180°):

$$1 + A\beta = 0$$

$$A\beta = -1 = \frac{|1|}{\angle 180^{\circ}}$$

Revisiting the noninverting topology, and applying it to the general feedback model above.

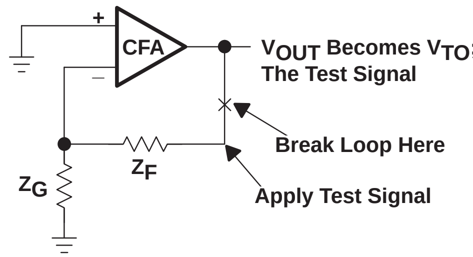

Figure A−2. Current Feedback Amplifier Noninverting Test Model

V_{IN} is, for the moment, not applied. The loop is broken in the indicated location, and a test voltage V_{TI} is applied to Z_F. V_{OUT} then becomes V_{TO}. The summation block Σ is internal to the op-amp. Combining the external components with the internal model of a current feedback amplifier, and assuming voltage buffers G_B and G_{OUT} are unity gain and Z_{OUT} is zero, the schematic reduces to:

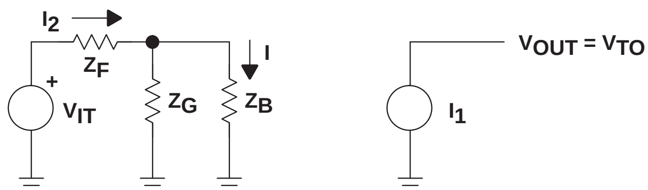

Figure A−3. Simplified Noninverting Model

V_{OUT}, of course, is the product of I_1 and the transimpedance gain Z:

$$V_{TO} = I_1 Z$$

Applying Ohm's Law to the input side:

$$V_{TI} = I_2\left(Z_F + Z_G||Z_B\right)$$

Assume G_B=1, I_2 can be expressed in terms of I_1:

$$I_2\left(Z_G||Z_B\right) = I_1 Z_B$$

V_{TI} can then be expressed in terms of I_1:

$$V_{TI} = I_1\left(Z_F + Z_G||Z_B\right)\left(1 + \frac{Z_B}{Z_G}\right) = I_1 Z_F\left(1 + \frac{Z_B}{Z_F||Z_G}\right)$$

The expression is now arranged the same way as the general feedback expression. This allows the loop gain Aβ to be calculated:

$$A\beta = \frac{V_{TO}}{V_{TI}} = \frac{Z}{\left(Z_F\left(1 + \frac{Z_B}{Z_F||Z_G}\right)\right)}$$

If $Z_B \rightarrow 0$:

$$A\beta = \frac{V_{TO}}{V_{TI}} = \frac{Z}{\left(Z_F\left(1 + \frac{0}{Z_F||Z_G}\right)\right)} = \frac{Z}{Z_F}$$

This is a very important expression. It shows that in the case of current feedback opamps, stability is almost completely determined by the value of feedback resistor.

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