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## Choosing Between Voltage Feedback (VFB) and Current Feedback (CFB) Op Amps

The application advantages of current feedback and voltage feedback differ. In many applications, the differences between CFB and VFB are not readily apparent. Many of today's high speed CFB and VFB amplifiers have comparable performance, but there are certain unique advantages and disadvantages associated with each. This tutorial examines some of the important considerations associated with the two topologies.

### DC AND OPERATIONAL CONSIDERATIONS FOR VFB AND CFB OP AMPS

#### VFB Op Amps

- For precision low frequency applications requiring high open-loop gain, low offset voltage, and low bias current, the VFB op amp is the proper choice. Input offset voltages of high speed bipolar input VFB op amps are rarely trimmed, since offset voltage matching of the input stage is excellent, typically ranging from 1 to 3 mV, with offset temperature coefficients of 5 to 15  $\mu\text{V}/^\circ\text{C}$ . With trimming, input offset voltages of less than 20  $\mu\text{V}$  are achievable. Op amps which use the auto-zero architecture offer offset voltages less than 5  $\mu\text{V}$ , but will not be considered here. The auto-zero op amp is covered in [Tutorial MT-055](#).
- Input bias currents on VFB op amps (with no input bias current compensation circuits) are approximately equal for (+) and (-) inputs, and can range from 1 to 5  $\mu\text{A}$ . FET input op amps are available with input bias currents less than 200 fA, suitable for applications such as electrometers. (e.g., [AD549](#)).
- The output offset voltage due to the input bias currents can be nulled by making the effective source resistance equal in both the inverting and non-inverting inputs. This scheme will not work with bias-current compensated VFB op amps which have additional current generators on their inputs. In this case, the net input bias currents are not necessarily equal or of the same polarity.
- The VFB op amp is very useful in applications where the feedback network controls the overall response, such as in active filter applications. Some VFB op amps, however, are de-compensated and must be used above the specified minimum closed-loop gain.
- The simplified model for the VFB op amp is well understood and is presented in all analog electronic textbooks.
- The VFB architecture lends itself to low supply voltage applications where rail-to-rail inputs and outputs are required.

## CFB Op Amps

- Current feedback (CFB) op amps, on the other hand, are less well understood and documented. Many designers choose VFB op amps simply because they understand them better.
- CFB op amps generally have lower open-loop gain and less accuracy than a precision VFB op amp.
- The input impedance of the inverting and non-inverting inputs of CFB op amps are not equal, and CFB op amps generally have unequal and uncorrelated input bias currents because the (+) and (-) inputs have completely different architectures. For this reason, external bias current cancellation schemes are also ineffective. CFB input bias currents range from 5 to 15  $\mu\text{A}$ , being generally higher at the inverting input.
- Because CFB op amps are generally optimized for a fixed feedback resistor value, there is little flexibility in the feedback network other than setting the closed-loop gain. This makes CFB op amps unsuitable for most active filters, except for the Sallen-Key filter which can be designed with the appropriate fixed feedback resistor. Figure 1 summarizes the dc and operational considerations for VFB and CFB op amps.
- The CFB architecture does lend itself to rail-to-rail inputs and outputs.
  - ◆ **VFB Op Amps**
    - High open loop gain and DC accuracy
    - Low offset voltage available (<20  $\mu\text{V}$ )
    - Low bias current (JFET, CMOS, or bias current compensation) available (<200 fA)
    - Balanced input impedance
    - Flexible feedback network
    - Rail-to-rail inputs and outputs available
  - ◆ **CFB Op Amps**
    - Lower open loop gain and DC accuracy
    - Higher offset voltage
    - Inverting input impedance is low, non-inverting input impedance is high
    - Input bias currents not as low as VFB or as well matched
    - Fixed feedback resistor needed for optimum performance

**Figure 1: DC and Operational Considerations for VFB and CFB Op Amps**

## AC CONSIDERATIONS FOR VFB AND CFB OP AMPS

### VFB Op Amps

- A distinguishing feature of VFB op amps is that they offer a constant gain-bandwidth product over a wide frequency range.
- In addition, high bandwidth, high slew rate, low distortion VFB op amps are available which use the "H-Bridge" architecture for low quiescent current ([Tutorial MT-056](#)).
- VFB op amps are good for all types of active filter architectures because of the flexibility of the feedback network.

### CFB Op Amps

- The CFB topology is primarily used where the ultimate in high bandwidth high slew rate, and low distortion are required. A more detailed discussion of CFB op amp ac characteristics can be found in [Tutorial MT-057](#).
- For a given complementary bipolar IC process, CFB generally yields higher FPBW (hence lower distortion) than VFB for the same amount of quiescent supply current. This is because there is practically no slew-rate limiting in CFB. Because of this, the full power bandwidth and the small signal bandwidth are approximately the same. However, the "H-Bridge" architecture used in high speed VFB op amps almost the same level of performance as CFB op amps ([Tutorial MT-056](#)).
- Unlike VFB op amps, the inverting input impedance of a CFB op amp is very low. This is advantageous when using the op amp in the inverting mode as an I/V converter, because there is less sensitivity to inverting input capacitance than with VFB.
- The closed-loop bandwidth of a CFB op amp is determined by the value of an internal capacitor and the external feedback resistor and is relatively independent of the gain-setting resistor (the resistor from the inverting input to ground). This makes CFB op amps ideal for programmable gain applications which require a gain-independent bandwidth.
- Because CFB op amps must operate with a fixed feedback resistor for optimum stability, they have limited applications as active filters, other than the Sallen-Key filter.
- Small values of stray capacitance across the feedback resistor in a CFB op amp are likely to cause instability.

- ◆ **VFB Op Amps**
  - **Constant gain-bandwidth product**
  - **High slew rate and high bandwidth available**
  - **Low distortion versions available**
  - **Flexible feedback network**
  - **Good for active filters**
- ◆ **CFB Op Amps**
  - **Bandwidth relatively constant for various closed-loop gains**
  - **Gain-bandwidth product is not constant**
  - **Slightly higher slew rate and bandwidth available for given process and power dissipation (compared to VFB)**
  - **Low distortion versions available**
  - **Fixed feedback resistor for optimum performance**
  - **Stray feedback capacitance causes instability**
  - **Difficult to use in active filters other than Sallen-Key**
  - **Low inverting input impedance reduces effects of input capacitance in I/V converter applications**

**Figure 2: AC Considerations for VFB and CFB Op Amps**

## NOISE CONSIDERATIONS FOR VFB AND CFB OP AMPS

### VFB Op Amps

- Precision VFB op amps are available with input voltage noise less than  $1 \text{ nV}/\sqrt{\text{Hz}}$ . Most JFET or CMOS input VFB op amps have input current noise less than  $100 \text{ fA}/\sqrt{\text{Hz}}$ , with some less than  $1 \text{ fA}/\sqrt{\text{Hz}}$ . However, the total output noise depends not only on these values but the closed-loop gain and the actual values of the feedback resistors ([Tutorial MT-049](#)).
- For a VFB op amp, the inverting and non-inverting input current noise are typically equal, and almost always uncorrelated. Typical values for wideband bipolar VFB op amps range from  $0.5 \text{ pA}/\sqrt{\text{Hz}}$  to  $5 \text{ pA}/\sqrt{\text{Hz}}$ . The input current noise of a bipolar input stage is increased when input bias-current compensation generators are added, because their current noise is not correlated, and therefore adds (in an rss manner) to the intrinsic current noise of the bipolar stage. However, bias current compensation is rarely used in high speed op amps.

### CFB Op Amps

- The input voltage noise in CFB op amps tends to be lower than for VFB op amps having the same approximate bandwidth. This is because the input stage in a CFB op amp is usually operated at a higher current, thereby reducing the emitter resistance and hence the voltage noise. Typical values for CFB op amps range from about  $1$  to  $5 \text{ nV}/\sqrt{\text{Hz}}$ .

- However, the input current noise of CFB op amps tends to be larger than for VFB op amps because of the generally higher bias current levels. The inverting and non-inverting current noise of a CFB op amp is usually different because of the unique input architecture, and are specified separately. In most cases, the inverting input current noise is the larger of the two. Typical input current noise for CFB op amps ranges from 5 to 40 pA/√Hz. This can often be dominant, except in cases of very high closed-loop gain where the voltage noise can become dominant.

The best way to make the noise calculations is to write a simple computer spreadsheet program that performs the calculations automatically, and include all the noise sources. The equation discussed in [Tutorial MT-049](#) can be used for this purpose.

◆ **VFB Op Amps**

- **Low voltage noise (< 1 nV/√Hz) available**
- **Low current noise available (JFET and CMOS inputs)**
- **Inverting and non-inverting input current noise equal and uncorrelated**
- **Feedback network and external resistor values must be considered to determine total noise**

◆ **CFB Op Amps**

- **Low voltage noise (1 to 5 nV/√Hz)**
- **Higher current noise (5 to 40 pA/√Hz) often dominates**
- **Feedback network and external resistor values must be considered to determine total noise**

***Figure 3: Noise Considerations for VFB and CFB Op Amps***

## SUMMARY

For most general purpose or high precision low frequency, low noise applications, the VFB op amp is usually the best choice. VFB op amps also work well in single-supply applications because many are available with rail-to-rail inputs and outputs.

The VFB op amp has a very flexible feedback network, and is therefore suitable for active filter designs.

The CFB op amp offers the ultimate in bandwidth, slew rate, and distortion performance at the expense of dc performance, noise, and the requirement for a fixed value feedback resistor. Applications of CFB op amps in active filters are limited to non-inverting configurations such as the Sallen-Key.

- ◆ Choose VFB Op Amps for
  - High precision, low noise, low bandwidth
  - Rail-to-rail inputs and outputs
  - Flexibility in feedback network
  - Active filters
  
- ◆ Choose CFB Op Amps for
  - Ultra high bandwidth, slew rate, and lowest distortion
  - Relatively constant bandwidth for different gains
  - Sallen-Key active filter

**Figure 4: Summary—VFB vs. CFB Op Amps**

## REFERENCES

1. Hank Zumbahlen, *Basic Linear Design*, Analog Devices, 2006, ISBN: 0-915550-28-1. Also available as [Linear Circuit Design Handbook](#), Elsevier-Newnes, 2008, ISBN-10: 0750687037, ISBN-13: 978-0750687034. Chapter 1.
2. Walter G. Jung, *Op Amp Applications*, Analog Devices, 2002, ISBN 0-916550-26-5, Also available as [Op Amp Applications Handbook](#), Elsevier/Newnes, 2005, ISBN 0-7506-7844-5. Chapter 1.

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