

## Precision Op Amps

### PRECISION OP AMP CHARACTERISTICS

This tutorial examines in more detail some of the issues relating to amplifiers for use in precision signal conditioning applications. Although the [OP177](#) op amp is used as the "gold standard" for precision bipolar amplifiers in these discussions, more recent product introductions such as the rail-to-rail output [OP777](#), [OP727](#), and [OP747](#), along with the [OP1177](#), [OP2177](#), and [OP4177](#) offer nearly as good performance in smaller packages.

Precision op amp open-loop gains greater than 1 million are available, along with common-mode and power supply rejection ratios of the same magnitude. Offset voltages of less than 25  $\mu\text{V}$  and offset drift less than 0.1  $\mu\text{V}/^\circ\text{C}$  are available in dual supply op amps such as the [OP177](#), however, the performance in single-supply precision bipolar op amps may sometimes fall short of this performance. This is the tradeoff that must sometimes be made in low power, low voltage applications. On the other hand, however, modern chopper stabilized (auto-zero) op amps provide offsets and offset voltage drifts which cannot be distinguished from noise, and these devices operate on single supplies and provide rail-to-rail inputs and outputs. They too come with their own set of problems that are discussed later within this section.

It is important to understand that dc open-loop gain, offset voltage, power supply rejection (PSR), and common-mode rejection (CMR) alone shouldn't be the only considerations in selecting precision amplifiers. The ac performance of the amplifier is also important, even at "low" frequencies. Open-loop gain, PSR, and CMR all have relatively low corner frequencies, and therefore what may be considered "low" frequency may actually fall above these corner frequencies, increasing errors above the value predicted solely by the dc parameters. For example, an amplifier having a dc open-loop gain of 10 million and a unity-gain crossover frequency of 1 MHz has a corresponding corner frequency of 0.1 Hz! One must therefore consider the open-loop gain at the actual *signal* frequency. The relationship between the single-pole unity-gain crossover frequency,  $f_u$ , the signal frequency,  $f_{\text{sig}}$ , and the open-loop gain  $A_{\text{VOL}(f_{\text{sig}})}$  (measured at the signal frequency) is given by:

$$A_{\text{VOL}(f_{\text{sig}})} = \frac{f_u}{f_{\text{sig}}} . \quad \text{Eq. 1}$$

In the example above, the open-loop gain is 10 at 100 kHz, and 100,000 at 10 Hz. Note that the constant gain-bandwidth product concept only holds true for VFB op amps. It doesn't apply to CFB op amps, but then they are rarely used in precision applications. Loss of open-loop gain at the frequency of interest can introduce distortion, especially at audio frequencies. Loss of CMR or PSR at the line frequency or harmonics thereof can also introduce errors.

The challenge of selecting the right amplifier for a particular signal conditioning application has been complicated by the sheer proliferation of various types of amplifiers in various processes (Bipolar, Complementary Bipolar, BiFET, CMOS, BiCMOS, etc.) and architectures (traditional op amps, instrumentation amplifiers, chopper amplifiers, isolation amplifiers, etc.)

In addition, a wide selection of precision amplifiers are now available which operate on single-supply voltages which complicates the design process even further because of the reduced signal swings and voltage input and output restrictions. Offset voltage and noise are now a more significant portion of the input signal. Some general attributes of precision op amps are summarized in Figure 1.

|  |               |
|--|---------------|
| ◆ Input Offset Voltage                             | <100μV        |
| ◆ Input Offset Voltage Drift                       | <1μV/°C       |
| ◆ Input Bias Current                               | <2nA          |
| ◆ Input Offset Current                             | <2nA          |
| ◆ DC Open Loop Gain                                | >1,000,000    |
| ◆ Unity Gain Bandwidth Product, $f_u$              | 500kHz - 5MHz |
| ◆ Always Check Open Loop Gain at Signal Frequency! |               |
| ◆ 1/f (0.1Hz to 10Hz) Noise                        | <1μV p-p      |
| ◆ Wideband Noise                                   | <10nV/√Hz     |
| ◆ CMR, PSR   | >100dB        |
| ◆ Tradeoffs:                                       |               |
| ● Single supply operation                          |               |
| ● Low supply currents                              |               |

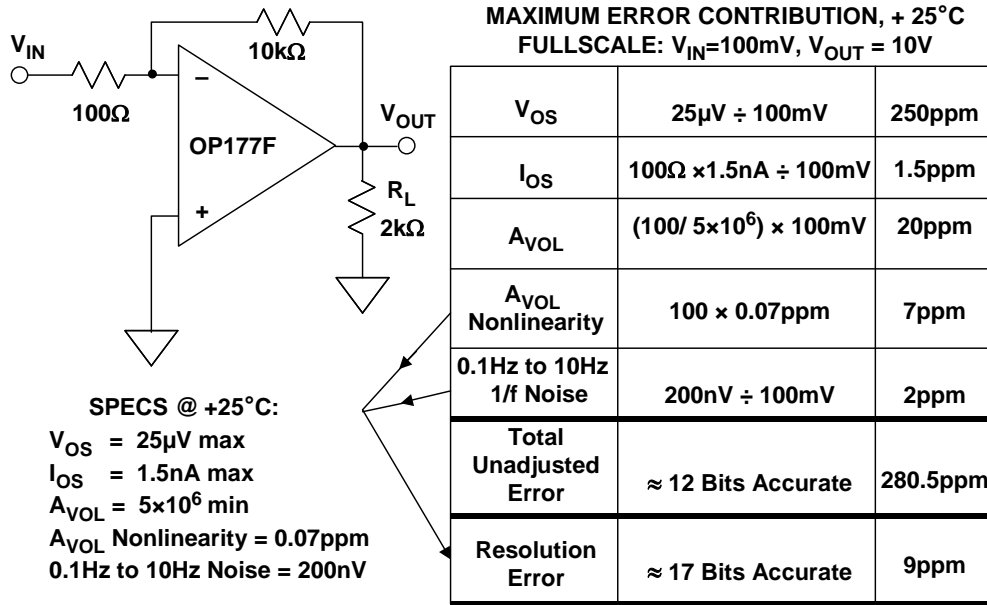
**Figure 1: Precision Op Amp Characteristics**

## PRECISION OP AMP AMPLIFIER DC ERROR BUDGET ANALYSIS

In order to develop a concept for the magnitudes of the various errors in a high precision op amp circuit, a simple room temperature analysis for the [OP177F](#) is shown in Figure 2. The amplifier is connected in the inverting mode with a signal gain of 100. The key data sheet specifications are also shown in the diagram. We assume an input signal of 100 mV fullscale which corresponds to an output signal of 10V. The various error sources are normalized to fullscale and expressed in parts per million (ppm). Note: parts per million (ppm) error = fractional error  $\times 10^6$  = % error  $\times 10^4$ .

Note that the offset errors due to  $V_{OS}$  and  $I_{OS}$  and the gain error due to finite  $A_{VOL}$  can be removed with a system calibration. However, the error due to open-loop gain nonlinearity cannot be removed with calibration and produces a relative accuracy error, often called *resolution error*. A second contributor to resolution error is the 1/f noise. This noise is always present and adds to

the uncertainty of the measurement. The overall relative accuracy of the circuit at room temperature is 9 ppm, equivalent to ~17 bits of resolution.



**Figure 2: Precision Op Amp (OP177F) DC Error Budget Analysis**

It is also useful to compare the performance of a number of single-supply op amps to that of the "gold standard" [OP177](#), and this is done in Figure 3 below for some representative devices.

LISTED IN ORDER OF INCREASING SUPPLY CURRENT

| PART NO.       | $V_{OS} \text{ max}$ | $V_{OS} \text{ TC}$ | $A_{VOL} \text{ min}$ | NOISE (1kHz) | INPUT | OUTPUT  | $I_{SY}/\text{AMP MAX}$ |
|----------------|----------------------|---------------------|-----------------------|--------------|-------|---------|-------------------------|
| OP293          | 250μV                | 2μV/°C              | 200k                  | 5nV/√Hz      | 0, 4V | 5mV, 4V | 20μA                    |
| OP196/296/496  | 300μV                | 2μV/°C              | 150k                  | 26nV/√Hz     | R/R   | "R/R"   | 60μA                    |
| OP777          | 100μV                | 1.3μV/°C            | 300k                  | 15nV/√Hz     | 0, 4V | "R/R"   | 270μA                   |
| OP191/291/491  | 700μV                | 5μV/°C              | 25k                   | 35nV/√Hz     | R/R   | "R/R"   | 350μA                   |
| *AD820/822/824 | 1000μV               | 20μV/°C             | 500k                  | 16nV/√Hz     | 0, 4V | "R/R"   | 800μA                   |
| **AD8601/2/4   | 600μV                | 2μV/°C              | 20k                   | 33nV/√Hz     | R/R   | "R/R"   | 1000μA                  |
| OP184/284/484  | 150μV                | 2μV/°C              | 50k                   | 3.9nV/√Hz    | R/R   | "R/R"   | 1350μA                  |
| OP113/213/413  | 175μV                | 4μV/°C              | 2M                    | 4.7nV/√Hz    | 0, 4V | 5mV, 4V | 3000μA                  |
| OP177F (±15V)  | 25μV                 | 0.1μV/°C            | 5M                    | 10nV/√Hz     | N/A   | N/A     | 2000μA                  |

\*JFET INPUT    \*\*CMOS    NOTE: Unless Otherwise Stated  
Specifications are Typical @ +25°C  
 $V_S = +5\text{V}$

**Figure 3: Precision Single-Supply Op Amp Performance Characteristics**

Note that the Fig. 3 amplifier list does *not* include the category of chopper op amps, which excel in many of the categories. These are covered separately, in [Tutorial MT-055](#).

## 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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