Choosing Op Amps For Specific Applications

Examining the important specifications for making intelligent choices of what operational amplifier to use in a given application

By C.R. Fischer

There can be little doubt that the popular operational amplifier—or op amp, for short—has become one of the most important integrated-circuit devices in analog electronics over the past 15 years or more. The incredible versatility of this device has greatly simplified the design and building tasks of analog circuits for both hobbyists/experimenters and professional manufacturer alike. Even so, confusion can reign when it comes time to make a choice of a specific device from among literally dozens of different types of op amps available to suit the needs of a specific circuit design. Faced with a confusing variety of op amp types, many experimenters simply choose traditional favorites and, in so doing, frequently lose out on what newer IC op amps have to offer.

While you don't have to fully understand the technical details of what goes on inside an op amp chip to make use of this device in your projects, it's helpful to have some idea of why such a variety of op amps exist. If you'd like to design circuits for fun or profit, this knowledge can save you a lot of time and trouble in the long run. Toward this end, let's look at some of the parameters used in specifying op amps and compare some of the strong and weak points of a dozen commonly used devices. Then we'll follow up with some tips on choosing an op amp by specific application.

A Matter of Versatility

The major reason why so many different types of op amps are available is the tremendous versatility of this device. In addition to providing amplification, the op amp can be used as a buffer, a filter, a comparator and a lot of other electronic elements. The op amp also does a lot

Typical Specifications For Popular Experimenter Op Amps

	741	1458 (dual)	LM324 (quad)	LM301	LM308	LM318	TL071	LM351	AD712 (dual)	NE5534	4136 (quad)	OP.42E
Input impedance/resistance (ohms)	2M	1M	4M	2M	40M	3M	10^{12}	10^{12}	10^{12}	100k	5M	10^{12}
Slew rate (V/μs)	0.5	0.5	0.5	0.5	0.3	50	13	13	13	13	1	50
Unity-gain bandwidth (Hz)	1.5M	1M	1M	1M	1M	15M	3M	4M	3M	10M	3M	10M
CMRR (dB)	90	90	70	90	100	100	86	100	66	100	90	98
PSR (dB)	96	96	100	96	96	80	86	100	86	10	30μV/V	9
Offset voltage (mV)	2	1	2	2	2	4	3	10	0.25	0.5	10	0.4
Noise voltage (nV/$\sqrt{Hz}$)	*	*	*	*	60	15	18	16	18	4	10	13
Average quiescent current (mA)	1.7	3.0	1.5	18	0.3	5	1.4	1.8	5	4	7	5.1

*Accurate noise data is not available for some earlier op amps, but it is safe to assume that none of these ICs should be used in applications that require low-noise devices.

with very little, namely two differential inputs, an output and very high gain. To control the amount of gain, a portion of the op amp's output can be fed back to its inverting (−) input. By shaping the frequency response of the feedback signal, you can control the frequency response of the amplifier for active filtering and other applications.

Originally, the op amp was created to process dc voltages because early amplifiers suffered from high levels of noise and a limited bandwidth that made them useless in ac circuitry. As time passed, though, customer demand and constant competition forced improvements to the point where, today, op amps can be found in top-of-the-line audio and video equipment where wide bandwidth and low noise are of paramount importance.

In spite of all of the upgrading that has occurred in op-amp technology, things are still far from perfect. Even today, we must make compromises in performance to achieve the near-ideal in specific areas. For example, you can get a higher input impedance from an op-amp circuit in exchange for increased offset voltage; or you can reduce the offset by using expensive laser-trimmed resistors inside the chip; or put up with more noise to obtain greater speed; and so on. Needless to say, even though the current state of the technology is much greater than it was back in the days when op amps first emerged, you still have to choose the op-amp type that best suits the needs of your circuit design. If you make the wrong choice, the op amp will seriously degrade circuit performance.

If you know exactly what kind of performance you want from a circuit to be built around op amps, you'll find it much easier to trade off unimportant parameters to enhance those that are important. With careful thought to judicious tradeoffs and a bit of design experience, you'll find using integrated-circuit operational amplifiers a definite plus in solving analog circuit design problems.

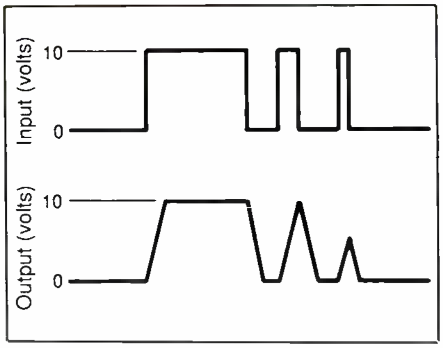

Fig. 1. These curves show how a train of varying width 10-volt pulses applied to the input of an imaginary amplifier (upper) emerge distorted at the amplifier's output (lower) as a result of slew-rate effects.

Some Important Parameters

A glance at a typical specifications sheet will give you an idea of what parameters are important in choosing an IC op amp for a given application. A typical data sheet will list more than 25 parameters. Some are closely related to each other, while others are important only to a small minority of users of the device. The table shown elsewhere in this article charts the specifications you'll find important in your design work for a dozen popular IC op amps. Let's look at the most common op-amp specifications listed in this table and discuss op amps in terms of their typical characteristics:

• *Supply Current.* This is the quiescent current required by an op amp in a no-load condition. Op amp technology has been optimized to the point that recent op amps can work on minuscule amounts of current (Precision Monolithics' new OP-90 has a typical supply current rating of only 20 microamperes). Low current drain is most advantageous in battery-powered circuitry, but it can be important in line-powered equipment as well.

Most op amps have fixed current demands. Others, like National Semiconductor's LM346, however, include a biasing input that allows the user to change the supply current from some optimum to obtain more optimal results in other parameter areas.

• *Offset Voltage.* All op amps have an offset—or error—voltage that cannot be differentiated from an input signal. An offset is usually important in dc circuitry, as capacitive coupling will remove offsets in ac circuits. What can make offset voltages especially troublesome is that they can drift with variations in temperature and supply voltage.

Offsets in op amps can vary from 10 mV or more in early versions to a more reasonable 2 mV in a garden-variety 741 to 25 μV maximum in Precision Monolithics' OP-07. A new family of op amps that use chopper-stabilization techniques reduces the offsets even more. While almost every manufacturer has premium-grade op amps that are chosen for minimal offset, these devices are difficult to find through the normal experimenter sale channels and even when they are located are usually prohibitively expensive. If minimal offset and cost are both important, remember that most single op-amp ICs have pins that allow you to trim out offsets when necessary.

Input Impedance. Many applications (like buffer, timer and sample/hold circuits) require an ultra-high impedance input to achieve optimal performance. While an ideal op amp has an infinitely high input impedance, real-life devices fall far short of the mark. The old standard 741 op amp, for example, had an impedance of roughly 10^6 ohms, which is considerably less than the input impedance of the typical FET or vacuum-tube amplifier. JFET and CMOS op amps fare much better in this department, with common IC op amps like the LM351 and TL081 weighing in in the 10^{12}-ohm range.

Using op amps with high input impedances lets you shave your parts cost and reduce real estate requirements because they allow you to use large-value resistors with small-value capacitors (larger-value capacitors cost a lot more and consume a lot more circuit space than do smaller-value ones) in time-constant networks.

• *Slew Rate.* All amplifiers, including op amps, have an upper frequency-response limit. Input signals approaching this limit will be attenuated and distorted by the op amp. The time that it takes for an amplifier's output to respond to an input signal is known as the "slew rate," which is usually specified in volts per microsecond. In Fig. 1, a 10-volt pulse is applied to the input of an imaginary op amp. When the amplifier sees this pulse, it begins creeping toward 10 volts. If the input signal lasts long enough, the output eventually reaches 10 volts—but the input and output signals hardly resemble each other! Shorter pulses can be completely swallowed up by a slow amplifier.

Slew rates of common IC op amps range from a weak 0.5 V/μs for the 741 op amp to 50 V/μs and up for the LM318. Slew rate is especially critical whenever high speed or/and low distortion are needed.

• *Unity-Gain Bandwidth.* This parameter specifies the highest frequency that an amplifier will pass at a gain of 1 (unity) without suffering attenuation in the amplification process. Unity-gain bandwidth, related to slew rate, can be confusing. For example, the unity-gain bandwidth of a common 741 is 1.5 MHz, which on the surface appears to make this op amp a great choice for audio and other low-frequency applications. But remember that most op amp applications require greater than unity

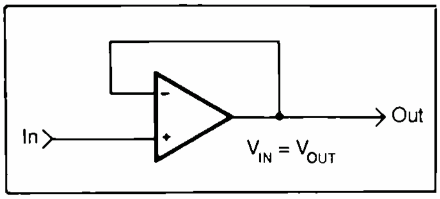

Fig. 2. An op amp used in a buffer arrangement.

gain. As the gain of an op amp is raised, bandwidth drops accordingly. A gain of 10 will reduce the 741's bandwidth to 150 kHz, a gain of 100 reduces the bandwidth to 15 kHz, and so on. All of a sudden, the 741 isn't quite as great a low-frequency amplifier as you first thought. Consequently, it's a good idea to keep the gains and frequency responses of your circuits in mind when you select op amps.

• *Common-Mode Rejection Ratio (CMRR).* In an ideal op amp, a signal applied to both the noninverting (+) and inverting (−) inputs simultaneously will be completely canceled out within the device as a result of the differential action of the inputs. The inability of a real op amp to do this is known as its "common-mode rejection ratio." CMRR spells out the amplifier's performance in canceling out a common-mode input. It is usually expressed in decibels (dB), with a higher figure considered to be better.

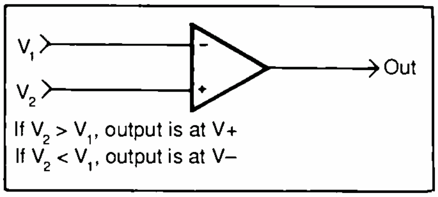

Fig. 3. An op amp used in a typical inverting amplifier arrangement is shown in A. The arrangement shown in B shows how, by adding a series of input resistors to the original single one, the same circuit can be used as a summing amplifier.

• *Supply-Voltage Rejection Ratio.* Though similar to CMRR, this parameter differs from it in that it expresses the ability of the op amp to ignore fluctuations in supply voltages (and keep them from showing up in the output signal). While often ignored in these days of regulated power supplies, there are still a few places where the supply-voltage rejection (or PSR for power-supply rejection) ratio can become a critical factor, such as in circuits where offset voltages must be kept to a minimum. In these situations, a change in supply voltage can cause a shift in the offset voltage. Another area is in battery-powered circuits. Since a battery's output voltage drops over its lifetime, changing supply voltages can often affect operation in various (and undesirable) ways. As with CMRR, PSR is often specified in decibels.

• *Noise Level.* Low noise is mandatory in professional audio and video work. Hence, the choice of amplifiers can have a large effect on the noise levels in otherwise identical circuitry. Defining the various ways of measuring noise in op amps is way beyond the scope of this article. However, a common measurement is noise voltage/$\sqrt{Hz}$. A voltage/noise figure of 10 nV/$\sqrt{Hz}$ is considered to be excellent, and with a figure of 4 nV/$\sqrt{Hz}$, the Signetics NE5334 is considered to be the best among the popularly used op amps.

Some Applications

Let us now see how the important specifications we've detailed here affect some of the most common uses of the op amp itself. We'll discuss *generic* uses here; so some of our choices may not always be appropriate for every situation. For example, the buffer to be described could be used to isolate a capacitor in a very long-period timer, where an ultra-high input impedance and low offset voltages would be needed. In another circuit, the same buffer might be used as a high-fidelity audio preamplifier in which low noise and distortion are of critical importance. In each of our examples, the basic circuits may be the same, but the parameters of interest will change with the end uses.

• *Buffer* (Fig. 2). Also known as a voltage follower, the buffer is used to isolate a high-impedance circuit and drive other electronics from a low-impedance source. In general, a very high input impedance is a must and low offsets and slew rate are desirable. A couple of good op amp choices here would be the CA3140 and LM308. The TL071 has a high input impedance and good noise and slew-rate figures that make it a good candidate for audio electronics.

• *Inverting Amplifier* (Fig. 3A). This circuit configuration has some very different characteristics from those of the common buffer. Due to feedback via R_f, input impedance, no longer very high, is the same as R_i, which means that you will usually not have to worry about the impedance of your amplifier. Keep in mind that slew rate can become important whenever high gains or/and high frequencies are involved. It's also important to keep in mind that noise and distortion are undesirable in audio and video circuitry. Some good op amp choices here include the LM318, TL070 and TL080 series, LM351 series and OP-7 series.

An inverting amplifier can be used to mix multiple inputs in a special configuration known as a "summing amplifier" (Fig. 3B). Because the output of the amplifier is the sum of the input signals, slew rate becomes more important with the op amp carrying a larger output signal.

• *Active Filters.* A very important use for op amps is in active-filter circuits, where op amps are used to selectively remove portions of an input signal. This is a very broad range of signal processing. Choice of the right op amp for a given application depends on the frequencies to be removed as much as on the type of filter (low-pass, high-pass, bandpass, etc.) being designed. As a general rule, the selected op amp should not degrade any signals you want to come through the circuit. NE5334 and LM318 op amps work very well for precision audio filtering, and the reasonably priced and readily available TL070 and LM350 series work okay for general-purpose filtering.

• *Comparators* (Fig. 5). A large family of ICs are designed to work specifically as comparators, though many so-called "general-purpose" op amps will work just as well. Sometimes a circuit will require several amplifiers and comparators, each of which can be made up of a single-amplifier IC package. Fortunately, there are a number of dual and quad op-amp ICs on the market that can be used to handle more amplifier functions in a much smaller area (and at lower cost) than do the single-amplifier devices.

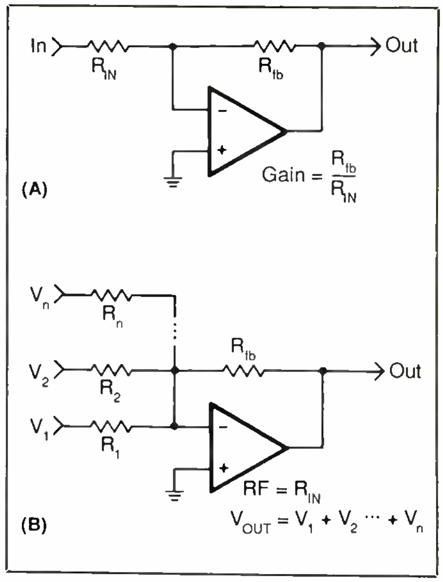

Fig. 4. The op amp is shown here used as a comparator.

In comparator applications, any op amp with a good slew rate will usually deliver good performance results. Even a slow op amp like the popular 741 will work reasonably well where speed isn't a problem. Sometimes, a high input impedance can be desirable as well. Op amps like the LM351 and TL081 seem to work fairly well as comparators.

With such a large variety of integrated-circuit operational amplifiers on the market, it's virtually impossible to subjectively grade each one. It would be hasty (and incorrect) to rate one op amp as great and another only passable or useless because there are plenty of instances where a mediocre op amp will do the job as well as a super-hot performing op amp. To use an expensive op amp in an application that can just as easily be fulfilled by a low-cost device is economically foolish.

Integrated circuit technology, including that of the operational amplifier, continues to improve by leaps and bounds. It's possible, therefore, that today's limits in op amps will be forgotten in just a year or two as new super-performing devices now on the drawing boards become available in the electronics parts marketplace. The best advice, then, is to actually use and experiment with the op amps now available to become familiar with their capabilities and deficiencies. With only a little experience in experimenting with these devices, you should have no trouble in selecting the one or more that suit any given application.

If you would like to learn more about IC op amps, read Walter G. Jung's *IC Op Amp Cookbook* (Howard W. Sams, 1974); Robert A. Witte's "Using Op Amps" (*Modern Electronics*, October 1985); and R. Fleischman's "Designing Active Filters" (*Modern Electronics*, June and July 1986). The more you know about op amps, the better prepared you'll be to match specific devices to specific applications. **ME**