Very Low Voltage, Micropower Amplifiers (V_S < 3 V, I_{SY} < 500 µA)

Choosing and using them

by Steve Sockolov

Portable medical monitoring instruments, hearing aids, and safety monitoring equipment are all examples of products that must operate from batteries and continue operating for very long periods of time. Because of size limitations, available power is severely constrained in terms of both supply voltage and current.

Amplifiers for these applications must operate from these low voltages and draw very little current. In addition, their input and output signal ranges should be as wide as possible to obtain sufficient dynamic range (full-scale signal-to-noise). The best devices will have an output voltage that can swing from the positive supply to ground and input ranges that can even exceed the power-supply range. Amplifiers capable of reaching both supply "rails" are called rail-to-rail amplifiers.

To select amplifiers for these applications consider first the required performance rather than the manufacturing process. Low-power products are available in CMOS, bipolar and JFET processes, but you should not go by preconceptions about the range of performance each is capable of.

Until recently, CMOS low voltage designs were not practical for precision low-voltage operation. CMOS processes had relatively high threshold voltages, in the range of 1.8 to 2.1 volts. Since most amplifier designs required at least two V_{TH}s to operate, the minimum supply voltage was > 3 V, even at room temperature.

Bipolar designs, like CMOS, require at least two transistor drops; but these drops are V_{BE}s, so operation on 1.8 volts is quite practical. Amplifiers such as the OP293* dual op amp are guaranteed to operate at 2 volts, and they work well down to 1.7 volts. However, care must be taken to assure that functionality will be maintained at cold temperatures, because V_{BE} increases (at about –2 mV/°C) as temperature decreases. Thus, operation at –25°C will require an extra 100 mV, or more, of headroom beyond the minimum room-temperature operating voltage.

Currently, there are no JFET op amps with both rail-to-rail inputs and outputs; the AD820 family comes closest with its rail-to-rail outputs. JFET op amps can be very advantageous in applications calling for low noise, low bias current or wide bandwidth.

Limitations of micropower designs: Compared to standard op amps, low current amplifiers are relatively limited with regard to bandwidth, output drive, and noise level. Values for each parameter depend on the technology available during the design. Today, micro-power amplifiers can achieve speed/power ratios of 10 kHz/µA; and this will more than double within the next year. Therefore it is possible to build amplifiers with more than a megahertz of gain-bandwidth product, operating on less than 100 µA of supply current. The OP496 (see page 16) is an example of what is possible today; it has a GBP greater than 300 kHz while using only 45 µA of supply current.

Amplifier broadband noise depends on front-end current, transistor size, and processing. Because of their low power and generally smaller geometry, low-power designs generally are relatively high in input-referred noise. Again, the OP496 family, with its 26 nV/$\sqrt{\text{Hz}}$, demonstrates the capability of today's technology.

Output drive is largely dependent upon the current available to drive the amplifier's output stage. Unlike standard amplifiers, rail-to-rail designs cannot use Darlington or similar configurations to boost current. The increased voltage drops associated with high current flow are unacceptable in these designs, so output drive is often limited to microamperes; but some product designs (such as the OP293*) can output ±8 mA, even though it requires only 25 µA of quiescent supply current.

An additional output requirement is the ability to *sink*, as well as source, current. This will enable the output to slew at the same speed in both directions. If the output cannot sink current, pull-down resistors would need to be added. This would, of course, use unnecessary current and defeat the purpose of using such amplifiers to conserve power.

Determining the limits of proper operation at low voltages: Here are three convenient ways to determine if an amplifier is truly working when the voltage is reduced: the *sine-wave test*, the *offset-voltage test*, and the *supply-current test*. The first two tests are useful for checking ac and dc performance, respectively; the third is a general-purpose test.

The sine wave test is the easiest of these tests. Connect the amplifier for a gain between one and two and supply an input sine wave that is within the common mode range of the amplifier. Either look at the output waveform on an oscilloscope or measure it for distortion. As the supply voltage is decreased, there is a point at which the waveform will become obviously distorted. Just before this point is reached is the minimum operating voltage.

To perform the offset-vs.-supply-voltage test, connect the amplifier in a high gain configuration and ground the inputs. Gain should be set so that the amplified offset at the output is about one volt. Start with a supply voltage for which the amplifier is known to operate properly, then measure and record the output (offset). Decrease the supply and continue to record supply voltage and offset. When these values are plotted, and as the supply is decreased further, you will usually see a knee in the plot where the offset deteriorates rapidly, just below the minimum supply voltage for proper operation.

As operating voltage is reduced, internal biasing circuits begin to shut down. At first glance, the amplifier will still appear to work, but performance can degenerate substantially. Furthermore, additional structures may shut down as voltage is further decreased. Since the amplifier's supply current is affected by these changes, it can act as a proxy for progressive changes that may be harder to observe in a particular aspect of performance. To determine these points, plot supply current against supply voltage. There are likely to be several bends in the curve, each indicating further degradations.

APPLICATIONS

Micropower telephone headset: Headsets can be operated from battery power using the OP296* with two 2.5 volt supplies. Select a headphone that has 600-Ω impedance to keep the current drain low. This circuit will work well down to 2 volts. As the figure shows, distortion is below 1% to 5 kHz.

*The OP493 and OP496 quads (p. 16) are representative of the OP193/293/493 and OP196/296/496 families of singles/duals/quads.

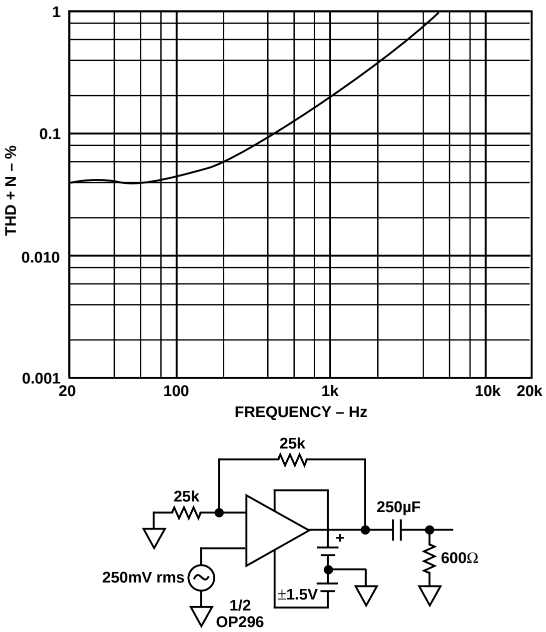

Figure 1. Headphone amplifier, with plot of total harmonic distortion.

Pulse monitor: ECG monitors require isolation to protect patients from any possible failure that could allow dangerous currents to flow through the body. Using a very low power amplifier, an electrocardiograph amplifier—used as a pulse monitor—could be powered from a source so weak that it could not supply dangerous current levels. As an example, here is a circuit that could be used for sports or other monitoring (but is not intended to be used in life-support systems).

There are three inputs to this circuit—from a set of measuring electrodes—a pair of sense inputs and a reference return input.

The front end is a standard three-amplifier differential circuit. Gain for the first stage is set by RG. Gains of 50 to 150 work well. Resistance values are chosen somewhat higher than usual to reduce current consumption. The output stage has a gain of 10 V/V and should be set to roll off at 400 to 1000 Hz, fast enough to pass an ECG waveshape, but with high-frequency noise filtered out.

The circuit requires careful layout because of the high gain and low signal levels. All leads should be kept short to reduce induced noise. The two sense inputs should be a twisted pair, shielded by the reference lead.

This pulse monitor circuit is designed to operate from two small lithium batteries, so that it may be used in portable applications, such as sports monitoring, for an extended period of time. The OP493* is guaranteed to operate with supplies as low as 2 V, and total supply current is only 100 µA, insuring long battery life. (For example, lithium cells are rated at 3.6 to 4.2 volts, but they are still supplying current when discharged to one-half their nominal voltage.)

Comparator: Amplifiers are often used as comparators, because of the convenience and availability of amplifiers with a wide variety of specifications. It's often easier to find an amplifier to meet a given set of criteria in a precision comparator application, especially where low power is essential. The newer amplifiers, with rail-to-rail inputs and outputs make excellent comparators, requiring no more components than a simple gain block.

With the OP196* in the non-inverting configuration shown, a precision comparator, with a rail-to-rail input range can be designed, using a supply current of only 50 µA. Typical falling- and rising-edge propagation delays are 12 µs and 20 µs, and a clock rate of 25 kHz is attainable. With R_1 = 10 kΩ and R_2 = 1 MΩ, the hysteresis measures about 70 mV. With R_1 near 0 Ω, the hysteresis is only about 100 µV.

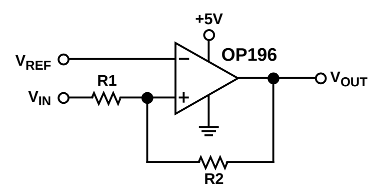

Figure 3. Non-inverting comparator.

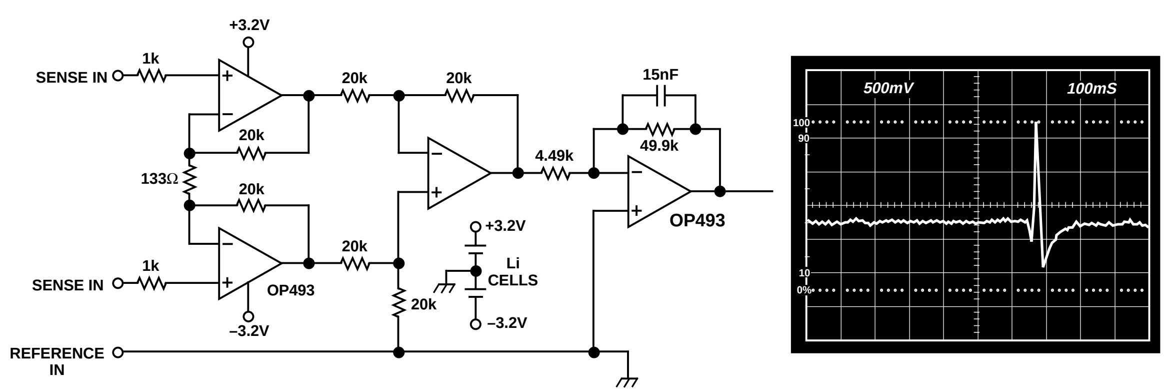

Figure 2. Pulse amplifier, with typical waveform.