Technical Article

Understanding Input Signal Swing in Op Amps

March 13, 2024 by Robert Keim

This article, the first in a two-part series on op amp signal swing, explains the characteristics and limitations of an operational amplifier's input voltages.

Operational amplifiers, commonly known as op amps, provide high performance and versatility while remaining relatively straightforward to use. Simplified behavioral models and basic circuit topologies are sufficiently accurate for many of their applications, and even complex op amp architectures can be quickly and effectively implemented with some help from simulation software or a design tool.

However, engineers also encounter scenarios in which an op amp's functional details and non-idealities play a major role in the design process. For example, signal swing—the voltage range available to input or output signals—is an aspect of op amp performance that can require careful consideration. In this article, we'll learn about input signal swing in op amps; a subsequent article will cover output signal swing.

Signal Swing Basics

Consider the simplified op amp circuit diagram in Figure 1. No power-supply pins or power-supply voltages are shown, and nothing indicates a limitation on signal swing.

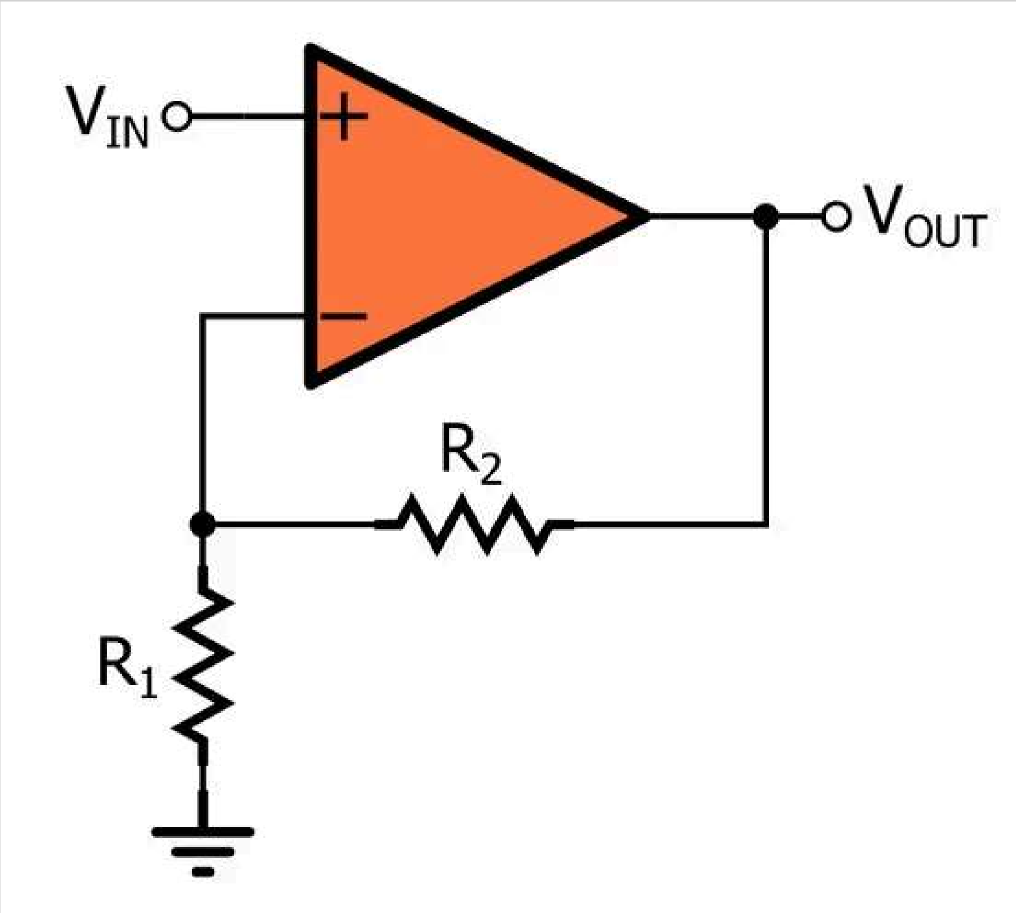

Figure 1. A simplified non-inverting op amp. Image used courtesy of All About Circuits

In this idealized environment, the input signal and the output signal can extend to any positive or negative voltage. Though completely unrealistic, this assumption works quite well in many applications for two reasons:

1. Input and output signals often stay well within the op amp's supply voltages.
2. A circuit may maintain satisfactory performance even when signals exceed a specified voltage range.

A real-life op amp always imposes restrictions on the signal swing. These restrictions are influenced by the amplifier's internal circuitry and its power supply voltages. When assessing signal swing in a particular application, you therefore need to consider both your board-level design parameters and the functional parameters outlined in the op amp's datasheet.

The available input signal swing for an op amp will be given in the datasheet, but it will often be called something like "common-mode input range" or "common-mode voltage range." To understand why, we need to explore the concept of common-mode input voltage.

Common-Mode Input Voltage

An operational amplifier is a differential amplifier with high open-loop gain. Negative feedback allows us to easily convert an op amp into a single-ended amplifier with low or moderate gain. When an op amp is configured as a negative-feedback amplifier, the voltages at the two input terminals are almost identical, even if we have the impression that one input voltage is fixed and the other input voltage is a freely varying waveform. Consider the diagram in Figure 2, for example.

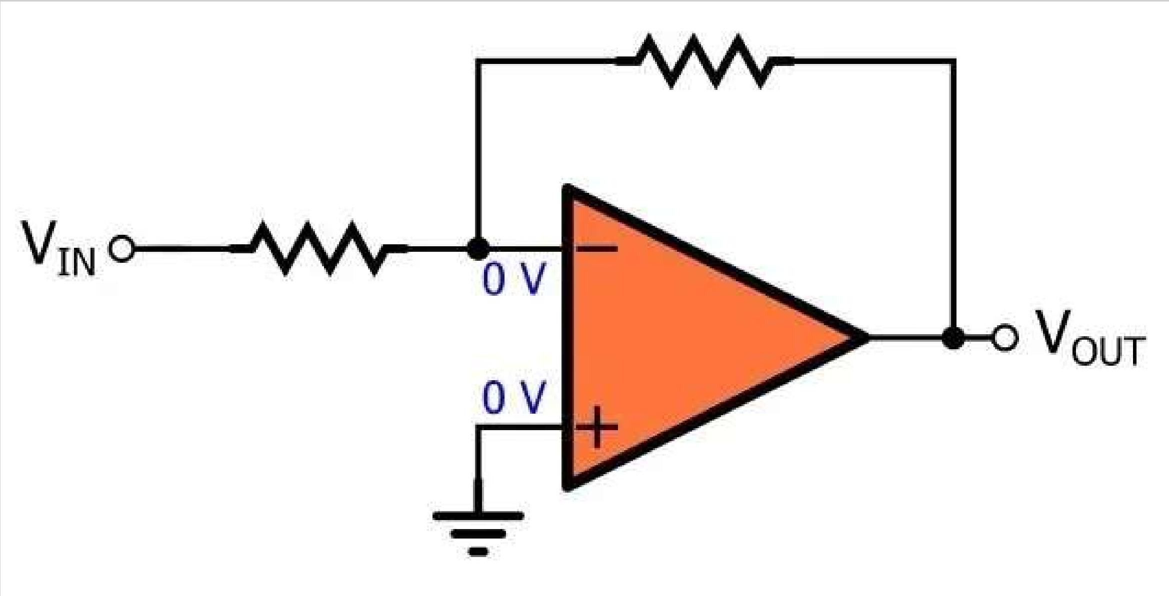

Figure 2. A no-frills inverting op amp. Image used courtesy of All About Circuits

The non-inverting input terminal is always at 0 V. As it turns out, the inverting input terminal is also held at a voltage very close to 0 V despite being connected through a resistor to a fluctuating input signal. This phenomenon is known as the virtual short.

If you apply two voltages to a differential amplifier's input terminals and then take the average value of those two voltages, you have the amplifier's common-mode input voltage. In the case of an op amp with negative feedback, the two input voltages are almost identical, and thus the common-mode voltage is the voltage measured at either input terminal.

Small deviations from the common-mode voltage are generally not relevant to discussions of signal swing. Instead, we're concerned with keeping the common-mode voltage in the acceptable range. In the next section, we'll examine what "acceptable range" means using the datasheets of some real-world op amps.

Input Signal Swing Specifications

Let's start with the OPAx277 op amp from Texas Instruments. Table 1 shows the available input signal swing recorded on its datasheet. Note that each datasheet we'll examine uses slightly different terminology for this specification—here, it's referred to as the common-mode voltage range.

Table 1. Input signal swing specs for the OPAx277. Data used courtesy of Texas Instruments

Parameter	**Min**		**Max**	**Units**
Common-mode voltage range (V_{CM})	$V_- + 2$		$V_+ - 2$	V

Scroll to continue with content

As we mentioned before, the available input signal swing depends on the supply voltage. That's why the limits are given as "$V_- + 2$" and "$V_+ - 2$." These values mean that input signals can safely go as low as:

- 2 V above the lower-voltage power rail.
- 2 V below the higher-voltage power rail.

Many newer op amps offer *rail-to-rail* input performance, meaning that input signals can extend very close to the power-supply voltages. Some rail-to-rail op amps, like the LTC6252 from Analog Devices, have an input range that fully includes the supply-voltage rails. Table 2 gives the input swing for this op amp.

Table 2. Input signal swing specs for the LTC6252. Data used courtesy of Analog Devices

Parameter	**Min**		**Max**	**Units**
Input common mode range (V_{CMR})	0		V_S	V

The LTC6252's datasheet assumes supply voltages of 5 V and 0 V. Rail-to-rail op amps can provide a workable input range even with supply voltages like 3.3 V and 0 V, making them advantageous—sometimes crucial—in low-voltage designs.

You have to be a bit careful with the term "rail-to-rail," though. The LT6023, also from Analog Devices and listed in the same *Rail-to-Rail Op Amps* product subcategory, is described as a "precision rail-to-rail output amplifier." The key here is to recognize that "rail-to-rail" modifies "output," not "amplifier." As we see in Table 3, the input stage doesn't offer rail-to-rail performance.

Table 3. Input signal swing specs for the LT6023. Data used courtesy of Analog Devices

Parameter	**Min**		**Max**	**Units**
Common mode input range (V_{ICM})	$V_- + 1.2$		$V_+ - 1.4$	V

Some op amps, such as the MAX4240 from Analog Devices, even allow input voltages to go *beyond* the rails. We can see these specs in Table 4.

Table 4. The beyond-the-rails input swing abilities of the MAX4240. Data used courtesy of Analog Devices

Parameter	**Min**		**Max**	**Units**
Input common-mode voltage range (V_{CM})	$V_{-} - 0.2$		$V_{+} + 0.2$	V

The Effects of Excessive Signal Swing

Not complying with the common-mode input range can prevent the amplifier from providing a linear input-output relationship, resulting in impaired performance. Furthermore, nonlinearity resulting from excessive signal swing isn't entirely predictable—the amount of distortion that a particular op amp creates can be dependent on the frequency of the input signal. Input range violations that appear harmless during testing may later prove to be problematic when the system is operating under different conditions.

The simulation plot in Figure 3 gives an example of distortion resulting from input range violations. The op amp used in the simulation is the LT1880, which has rail-to-rail output but an input range of $V_{IN(min)} = V_{-} + 1.0$ to $V_{IN(max)} = V_{+} - 1.2$. I used $V_{-} = -2.5$ V and $V_{+} = 2.5$ V, so my acceptable input swing should theoretically be from –1.5 V to 1.3 V.

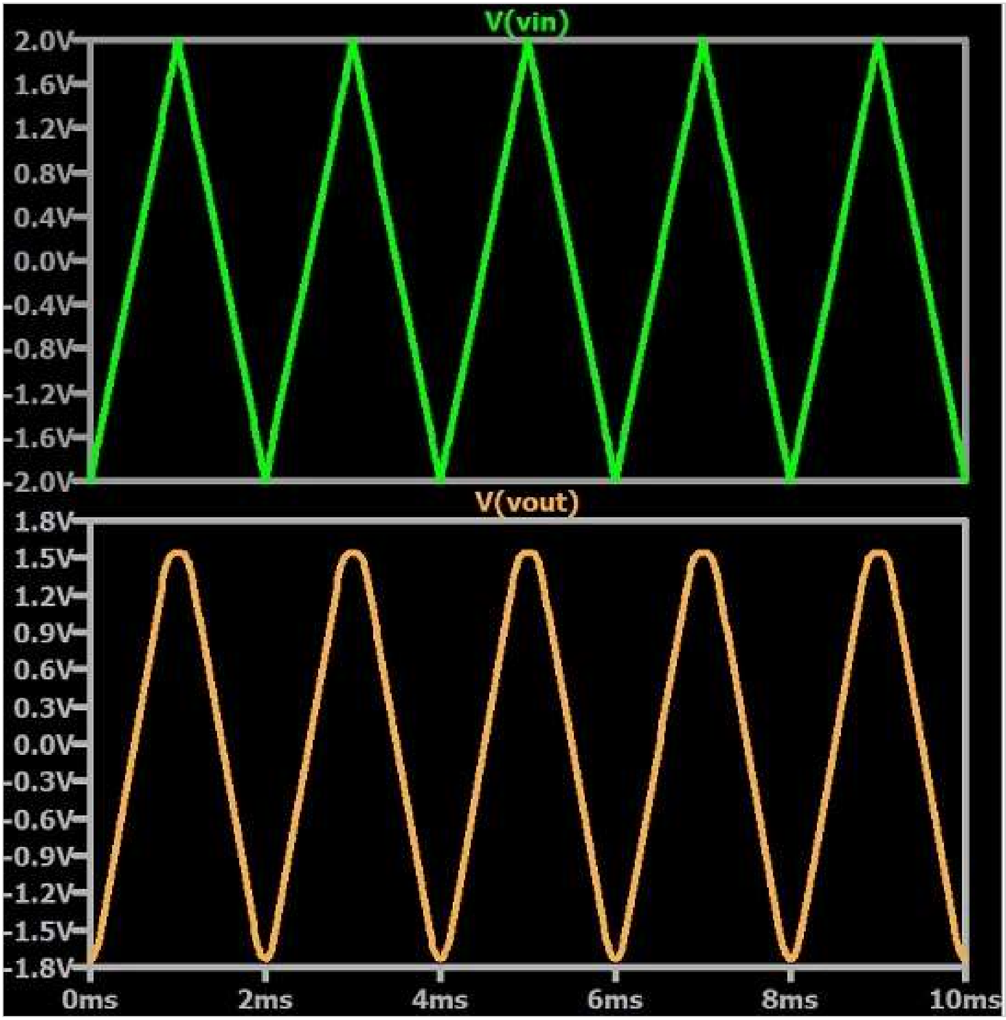

Figure 3. Simulated distortion associated with a common-mode input voltage that doesn't comply with an op amp's input signal swing specs. Image used courtesy of Robert Keim

Though the distortion resulting from nonlinearity may not be catastrophic in all applications, it's better to be on the safe side and ensure that a circuit will always comply with input swing limitations. This can usually be accomplished without too much difficulty—simply adjusting power-supply voltages or choosing a rail-to-rail op amp may suffice to prevent input range violations.

Up Next

Real-life op amp circuits always have limitations on the allowable voltage range for input and output signals, and paying careful attention to these details can be an important part of optimizing the amplifier. So far, we've only addressed input swing—we'll discuss output signal swing in the second half of this two-part series.