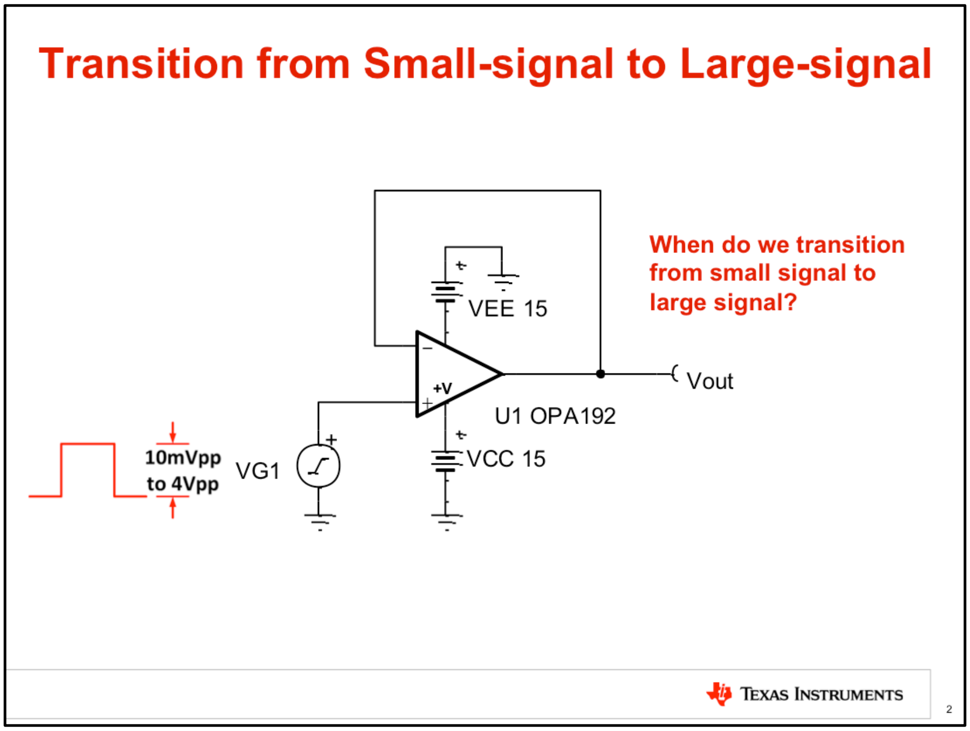
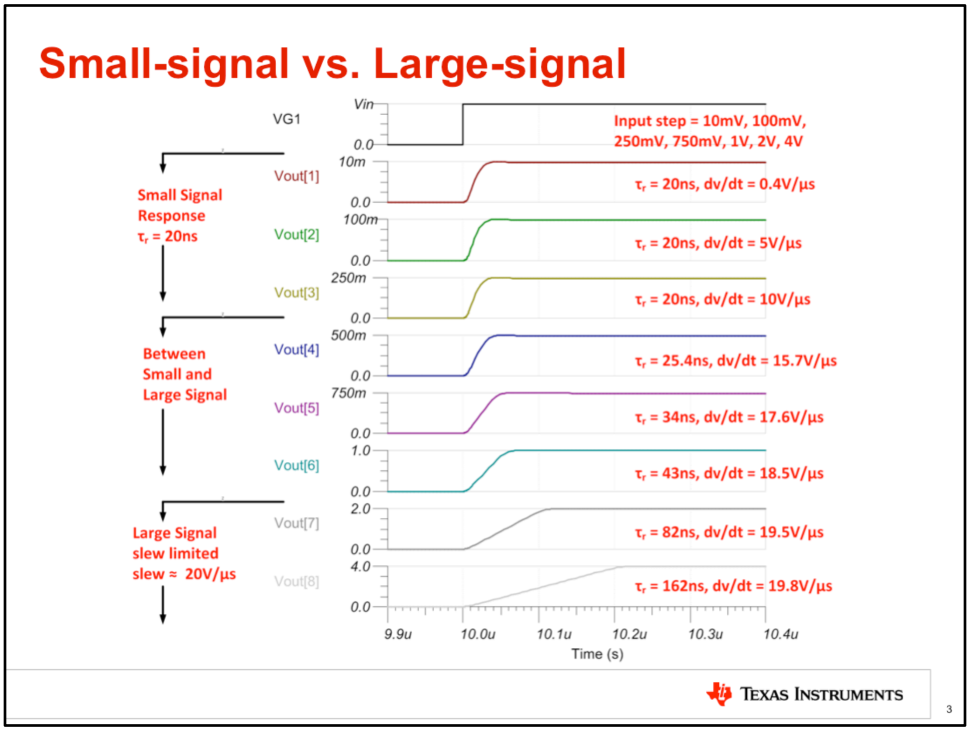
Hello, and welcome to the TI Precision Lab discussing op amp slew rate, part 3.

In this video we'll take a deeper look at the transition from small signal to large signal output response. We'll also look at how gain impacts small signal and large signal output response. Finally, we will introduce the concept of op amp overload recovery.



In the previous videos on slew rate, we discussed small-signal and large-signal output response. However, the way in which a circuit operates is not always fully large-signal or small-signal. In this section, we will discuss the transition between these two operating conditions.

Here we have a simple op amp circuit configured as a non-inverting buffer. We'll apply a range of input steps, from 10mVpp to 4Vpp, and observe the output. A transient simulation done in TINA-TI will allow us to observe whether the circuit shows small-signal or large-signal behavior.



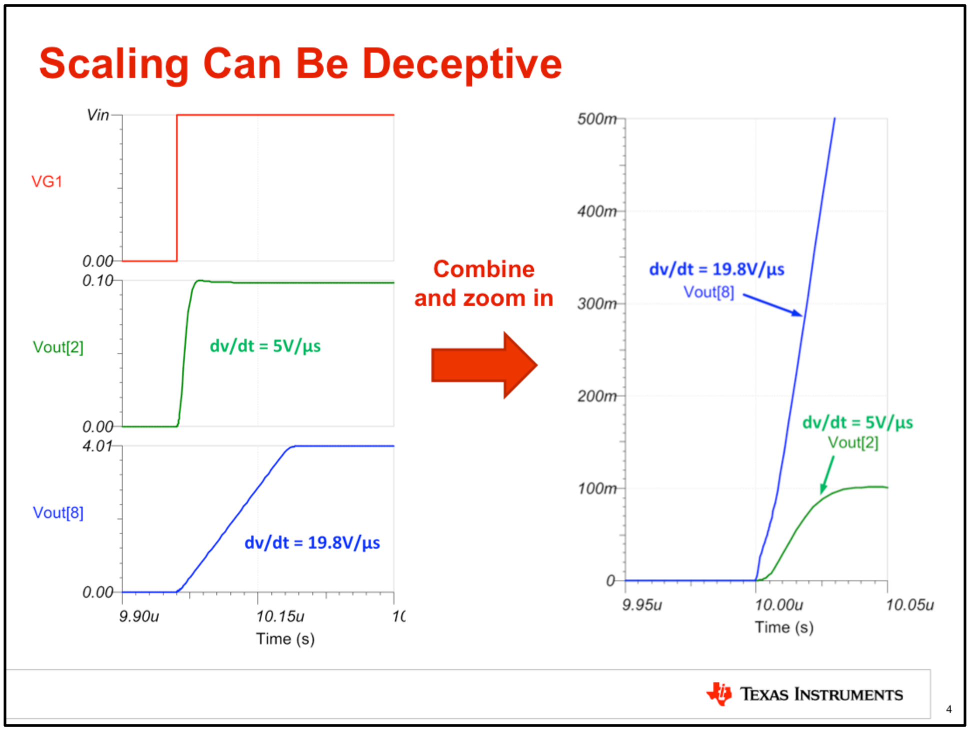
This figure illustrates the output of the non-inverting buffer circuit from the previous slide, versus different input step sizes.

Notice that the output rise time is a constant 20ns for input steps of 10mV to 250mV. Because the rise time is constant, we know that the response is small-signal. The device in this example, the OPA192, has a slew rate of 20V/us. You can see that the rate of change for the small step response is lower than the slew rate. Also, notice that the output signal increases exponentially for the small signal response, as opposed to the linear increase for amplifiers that are slew rate-limited.

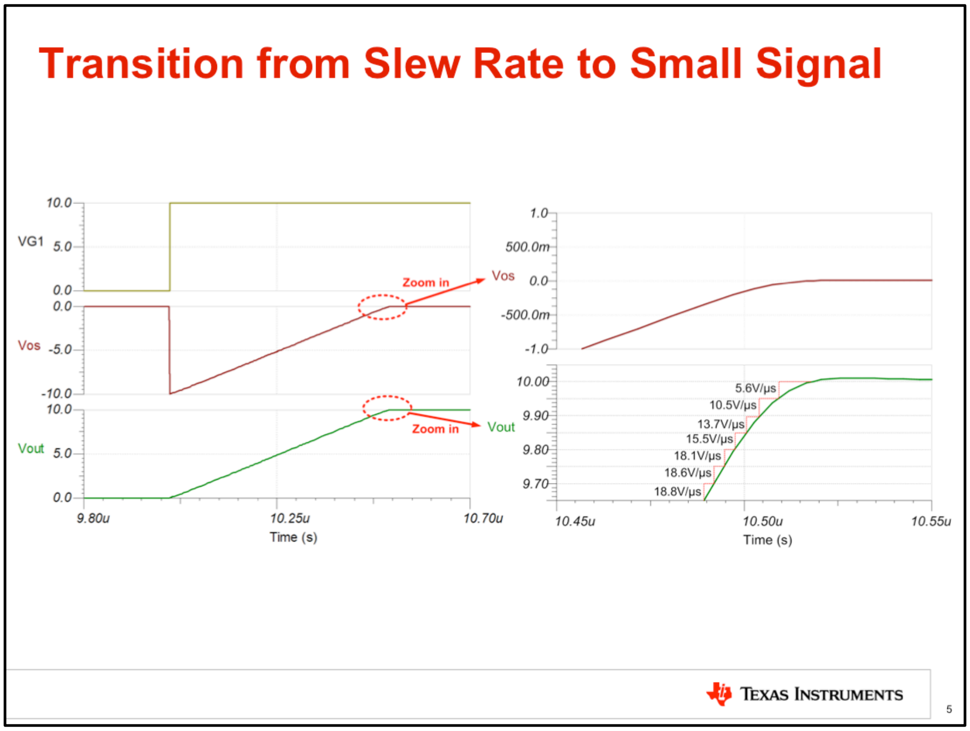
For input steps between 500mV and 1V, the amplifier is transitioning between small-signal and large-signal response. In this region the rise time is no longer constant; however, the amplifier is not yet at the full slew rate of 20V/us.

For input steps greater than 1V, the amplifier is slew rate-limited. You can see that the rate of change of the output signal is at the slew rate limit of about 20V/us. Also, notice that the output signal increases linearly in response to the input step.

In this example, input signals less than 250mV caused a small signal response and signals greater than 1V caused a large signal response. However, this transition depends on the amplifier's design and technology. CMOS amplifiers tend to reach slew limit for signals greater than 100mV, and bipolar amplifiers can slew limit at even lower input voltages. Note that the industry standard for small signal response is a 100mV step, but in practice the actual limit may be lower.

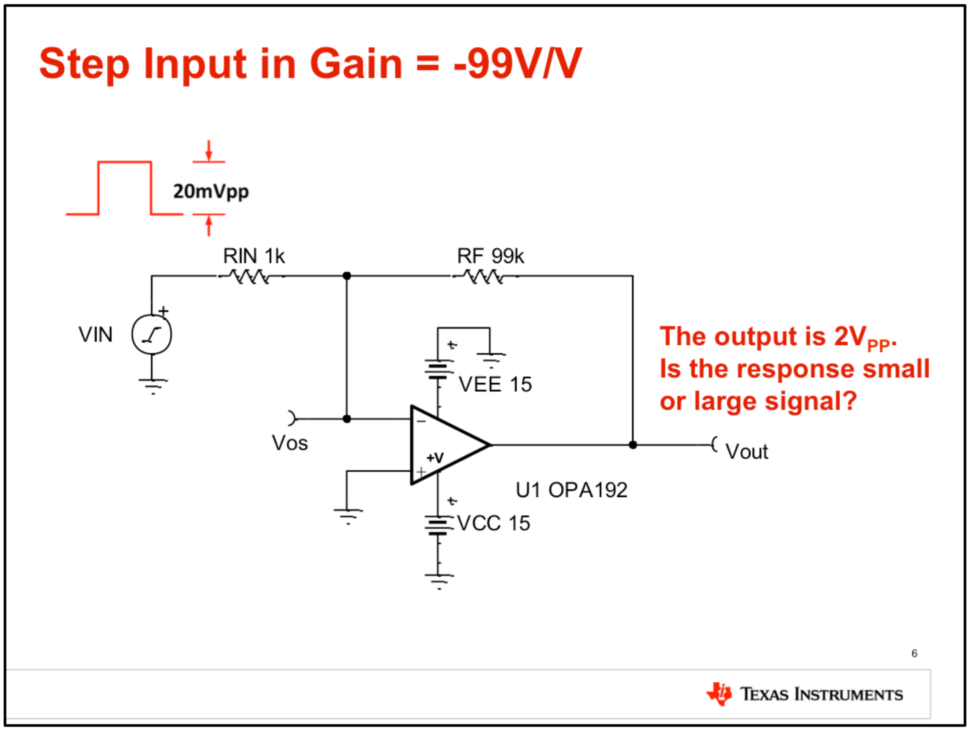


The left-hand side of this slide shows the small-signal response to a 100mV input signal in green, and the large-signal response to a 4V input signal in blue. The plots are scaled such that the two output signals have equal height. This makes the small-signal response look like it is moving faster then the large signal response. On the right, we combine the two responses to emphasize that the large signal response is slew rate-limited and is changing much faster then the small-signal response. In fact, the large signal response is changing at 19.8V/us, and the small signal response is only changing at 5V/us.



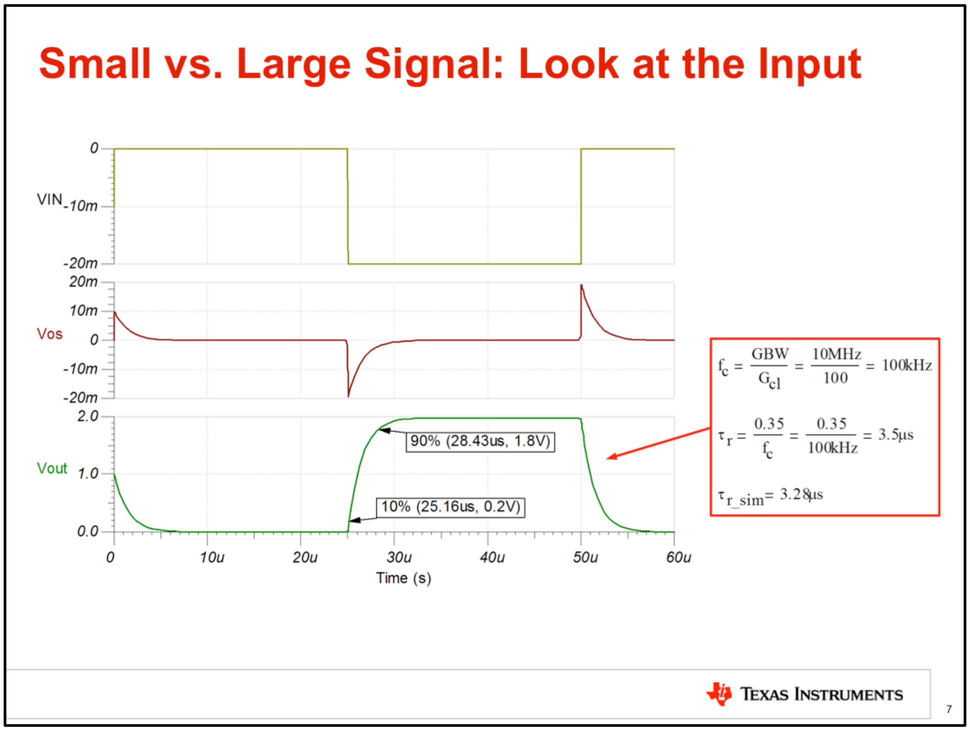
Let's take a closer look at the output of the non-inverting buffer circuit with a 10V step applied to the input.

In this case, the device is in slew-rate limit of 20V/us. However, when the signal approaches the final value of 10V, the op amp will transition to a small signal response. Zooming in on the last 300mV of the signal swing, you can see that the rate of change of the output decreases from approximately the slew rate, 20V/us, to a lower rate of change such as approximately 5V/us. Also, you can see that the shape of the output changes from the linear rise associated with slew rate limit, to the exponential behavior associated with small signal response.

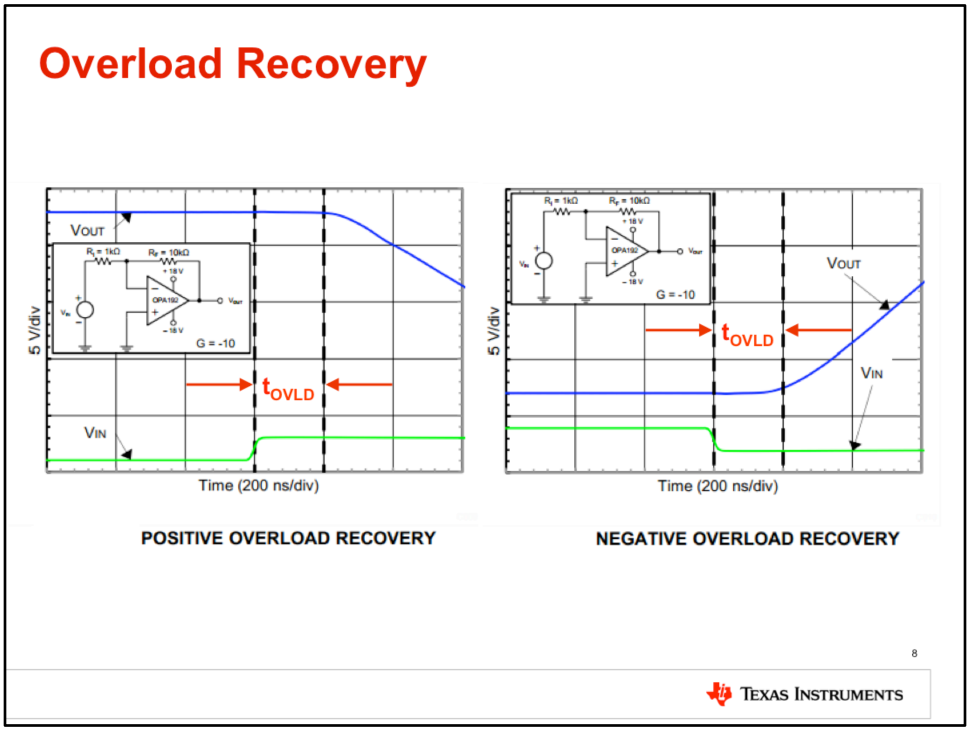


Most of the examples discussed thus far have been basic buffer circuits, also called unity-gain followers. Now let's look at amplifiers with different closed loop gains in order to see the effect that closed loop gain has on output response.

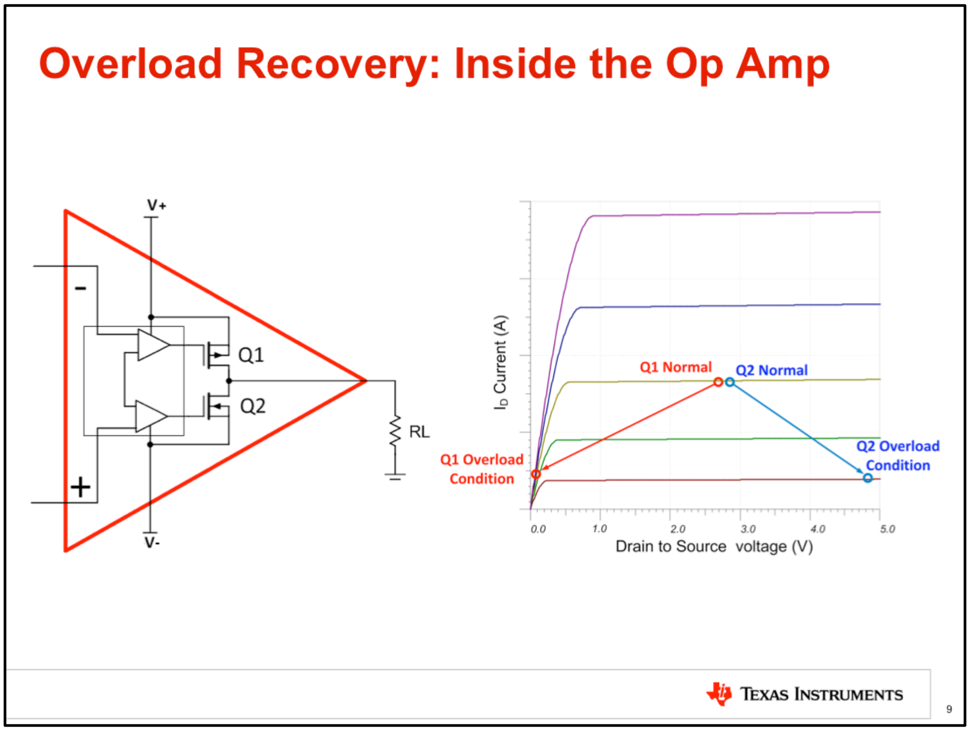
Here we show an inverting amplifier circuit in a gain of -99V/V. The input is a small signal step of 20mVpp. Based on the gain, the output should be approximately 2Vpp. Does the output respond as a small signal or as a large signal?



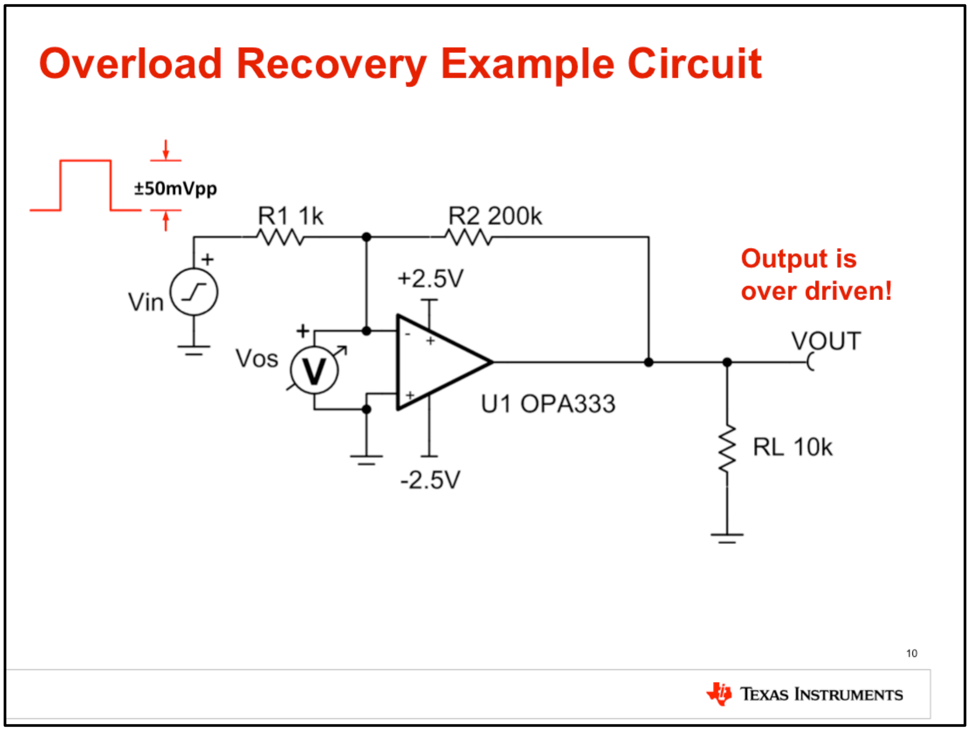
This is the simulated output response of the circuit from the previous slide. Notice that the output signals rise and fall in an exponential way, which indicates a small-signal response. Also, if we use the small signal rise time formula, we can see that the calculated rise time of 3.5us is very close to the simulated rise time of 3.28us. Thus, the amplifier responds to the 20mV input step as a small signal, and we can conclude that the amplitude of the *input* signal determines the behavior of the op amp. The output signal amplitude does not determine whether the response is small or large signal.



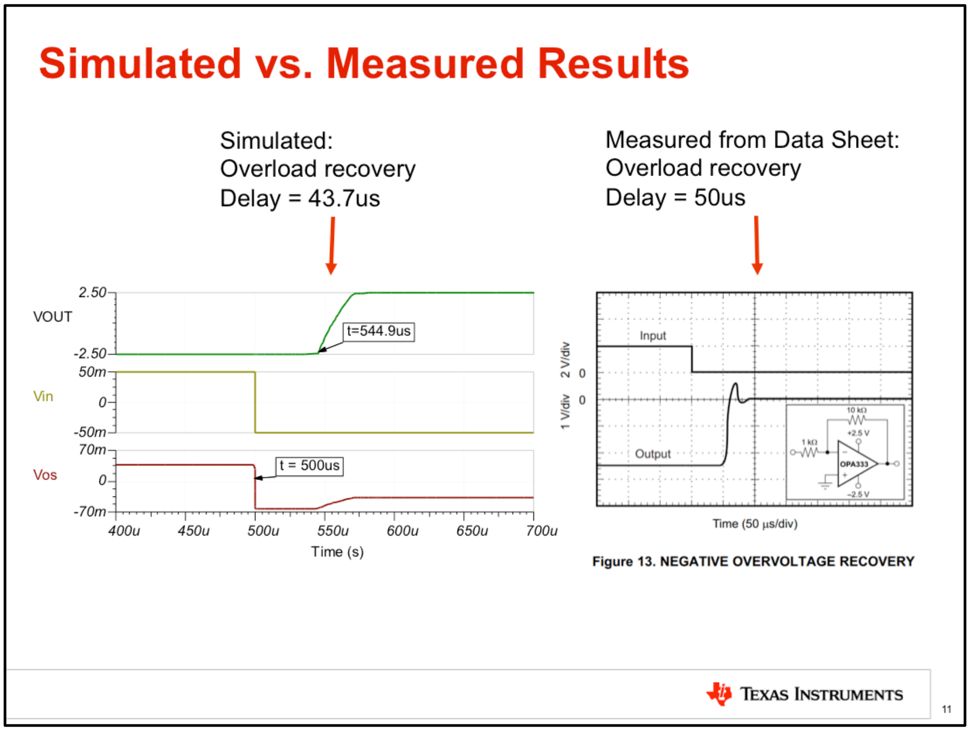
Up to this point, we have considered the small-signal and large-signal response of signals that are inside the linear range of the amplifier. In other words, we have not violated the input common mode range or the output swing limitations. Now we'll discuss what happens when we drive signals beyond the op amp's output swing limitations. Driving the output beyond its linear range is called overloading the output. Once the overload condition is corrected, there is a time delay before the overloaded output can recover, called $T_{OVERLOAD}$, and return to its normal linear behavior. In the next few slides, I'll explain overload recovery and show how it relates to small and large signal response.



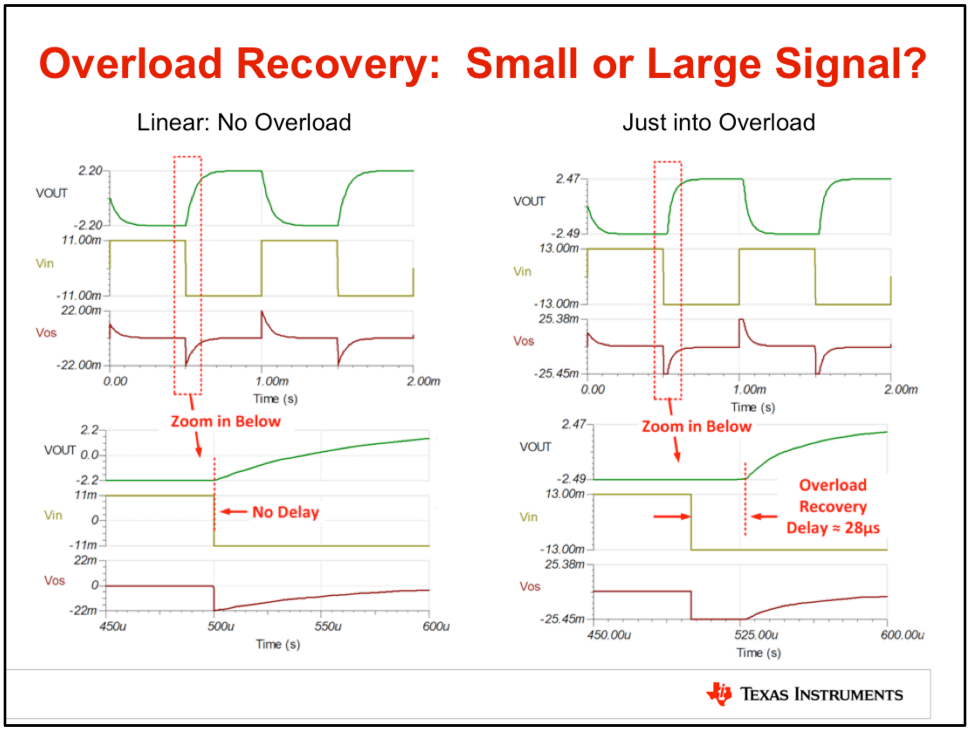
The overload condition occurs when an amplifier is driven beyond its output swing limits. In this example, if the output is driven very close to the positive supply (V+), the output transistor Q1 becomes saturated, while transistor Q2 is nearly cutoff. Also notice that the transistor Q1 is in the ohmic region of its operating curve, as opposed to the active region where it normally operates. Overload recovery is the time required for all the internal transistors in the output stage to transition from an abnormal state, whether saturated or cutoff, to a normal state.



Let's simulate the overload condition. In this example, we apply a ±50mVpp square wave to an inverting amplifier in a gain of -200V/V. The expected output in this case is ±10Vpp. Since the power supplies are only ±2.5V, it is clear that the output is driven well beyond the output swing limitations, and thus overloaded. In the following slide we'll look at the simulated transient response showing how the op amp recovers from this overload.

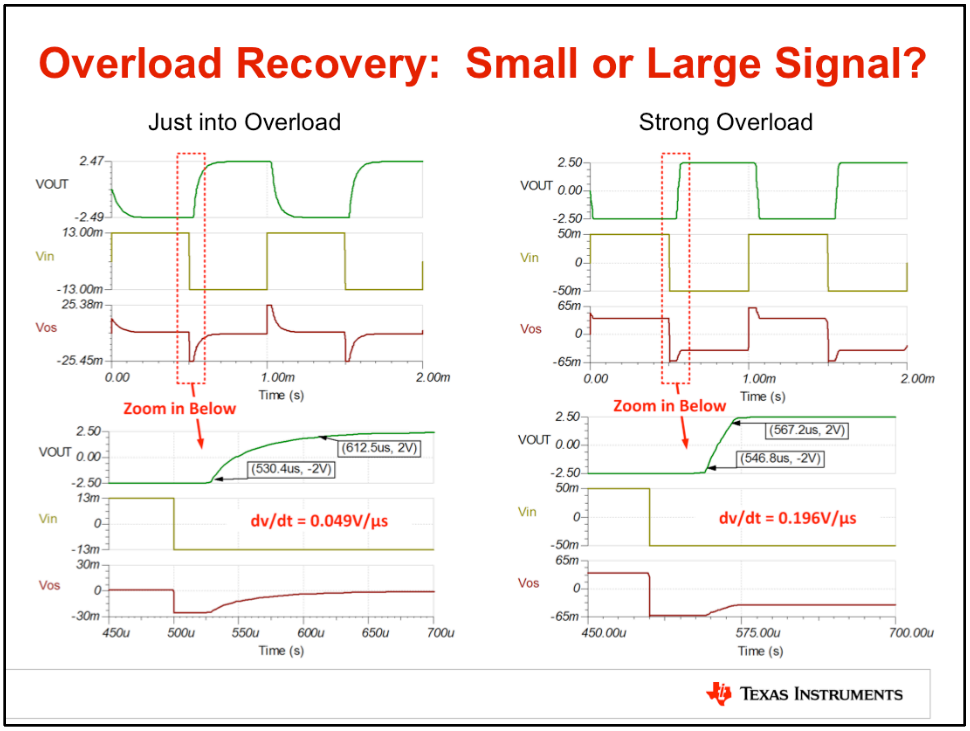


This slide compares the simulated results from the circuit on the previous page to the measured results given in the device data sheet. In both cases there is about a 50µs time delay before the output transitions out of the overload condition. In the simulation for this example, the output was heavily overdriven. Next we will examine how the output responds when we vary the amount of overdrive.

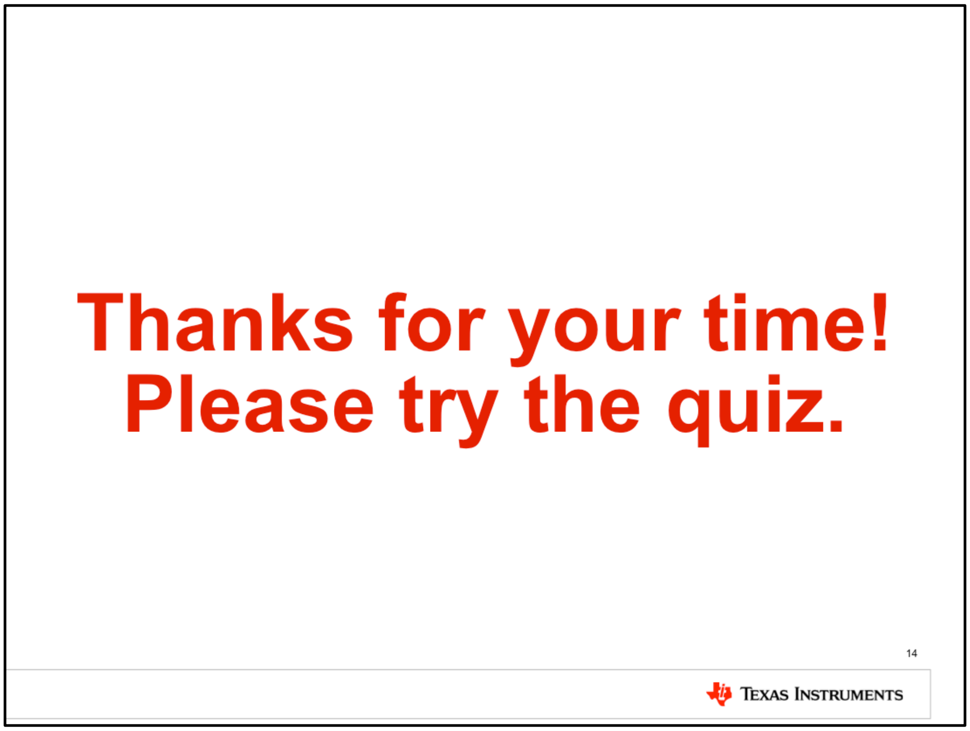


This slide shows the response of the same inverting amplifier circuit in a gain of -200V/V. The plot on the left shows the response where the output signal remains just inside of the linear response range. Since there is no overload, you can see that there is no overload time delay. Furthermore, the output has the exponential rise and fall behavior associated with a small signal response.

The plot on the right shows the response when the output signal is driven just outside the linear response range. As expected, there is a overload time delay. In this case the delay is 28µs, which is shorter than the data sheet specification, because the device is barely in overload. Also notice that the output still has the exponential rise and fall associated with a small signal response. Thus, the amplifier still responds as a small signal amplifier even though the device is in an overload condition. In the next slide we will see that significantly overdriving the output will affect the output response.



Continuing on, let's compare the response that is just barely in overload, shown on the left hand side, with one that is significantly overdriven, shown on the right hand side. Notice that the response that is just barely in overload still has a small signal response, as mentioned on the last slide. The response for this case is exponential and the rate of change of the output signal is very small compared to the slew rate (0.049V/us vs. 0.16V/us). The response on the right shows that when the output is significantly overdriven, the output will slew. Because we are significantly overdriving the output, a large input offset voltage (V_{OS}) is developed even with a relatively small input signal, which causes the output to slew.

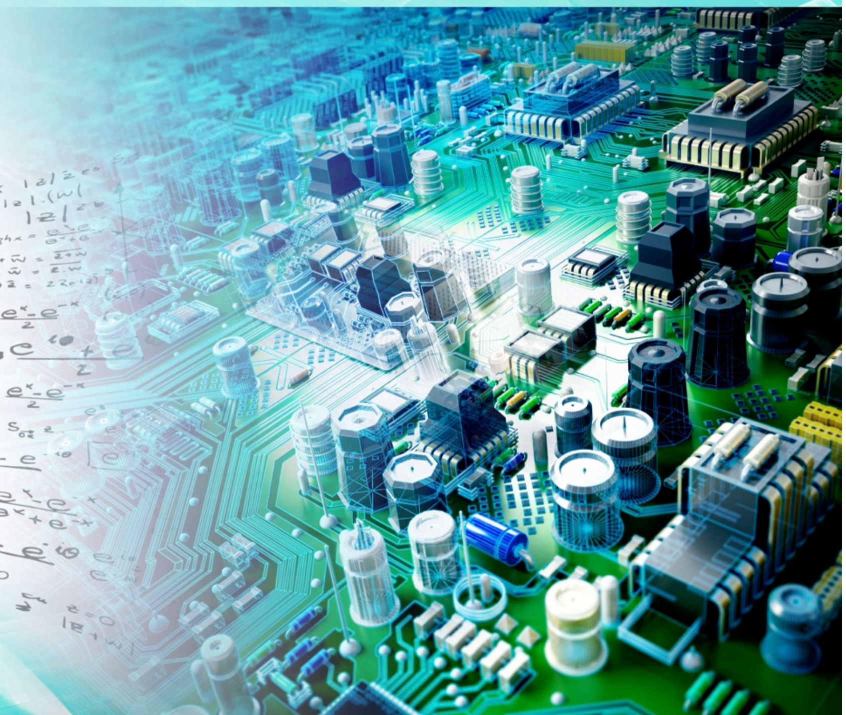


That concludes this video – thank you for watching! Please try the quiz to check your understanding of this video's content.

Slew Rate 3

Multiple Choice Quiz

TI Precision Labs – Op Amps



Quiz: Slew Rate 3

1. The industry standard definition for small signal is 100mV.

a. True
b. False

2. In practical cases, some devices begin to exhibit large signal characteristics at levels below 100mV.

a. True
b. False

3. Small signal response will have:

a. An exponential voltage increase with time.
b. The rise time is constant and depends on the bandwidth
c. A linear voltage increase with time.
d. The rise time is variable and depends on the signals amplitude
e. Answers a and b are correct
f. Answers c and d are correct

Quiz: Slew Rate 3

4. Large signal response will have.

a. An exponential voltage increase with time.
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5. Assume a 10V step is applied to the input of an amplifier. The output response will ___.

a. Be slew rate limited
b. Be slew rate limited for most of the output response, but will respond like a small signal response for the last 100mV.
c. Will exhibit a small signal response.

Quiz: Slew Rate 3

6. Depending on the amplitude of the signal applied, an amplifier will exhibit a _____.

a. Slew rate or small signal response.
b. Small signal response, large signal response, or a transition between small and large signal.
c. Phase shift.
d. Stability limitation.

7. The output of an amplifier is a 10V square wave. Is this a large or small signal response?

a. Large
b. Small
c. Transitioning between large and small response.
d. This depends on the technology of the amplifier.
e. You need to know the input signal, not the output signal to answer this.

Quiz: Slew Rate 3

8. Overload recovery is a ____.

a. Self protection of the output from a low impedance load.
b. Transition from an over temperature contrition to a normal temperature.
c. Time delay required before an amplifier begins to respond to the input signal.
d. Response to an electrical overstress event.

Slew Rate 3

Multiple Choice Quiz: Solutions

TI Precision Labs – Op Amps

Quiz: Slew Rate 3

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