

Input Voltage Effects on Slew Rate for Voltage and Current Feedback Amplifiers



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ABSTRACT

High slew rate is needed for many systems like waveform generation, driver circuits, and more. Insufficient slew rate may result in distortion of the output, namely long rise times or nonlinearity. It is important to know that the slew rate performance of your amplifier can be significantly reduced depending on the application circuit. This is especially true for voltage feedback amplifiers with no internal slew boosting circuitry. The slew rate of a voltage feedback op-amp is dependent on the voltage across its inputs, so a small input step could result in a fraction of the data sheet's slew rate value. The slew-rate dependency on input voltage means that high gain applications will often suffer from significantly reduced slew rate performance.

However, current feedback amplifiers do not have the same constraint. Current feedback architecture provides not only a higher slew rate, but also one that is relatively constant across different input steps. This document demonstrates the difference in performance slew-rate performance at high gain between the voltage-feedback OPA690 and current feedback OPA695.

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1 Background

1.1 Slew Rate and Slew Boost Definitions

For amplifiers, slew rate is typically defined as the rate of change of the output of the amplifier, and is measured in voltage over time. The slew rate value in the device-specific data sheet is an overall maximum measured in the specified configuration. Usually this configuration is a large input step with a low gain. Data sheets often do not provide further information for other configurations.

Slew boost is additional circuitry that allows for much higher slew rates than otherwise possible in standard amplifier architecture. It is very common for a high speed amplifier to have some sort of slew boosting circuit. However, specific slew boost architecture is not published in data sheets - in fact, it is often not disclosed if the part has slew boost or not. This adds another layer of uncertainty to the slew rate value of your specific application as slew boosting architectures may perform differently depending on how they were implemented.

1.2 Slew Rate Limits for Voltage Feedback Amplifiers

One simplified view of a voltage feedback amplifier is as a transistor differential pair, current mirror, and output buffer stage, shown in [Figure 1-1](#). The inputs of the opamp, $IN+$ and $IN-$, are inputs to the differential pair. The voltage at the inputs directly determine the current across the legs of the pair, $I1$ and $I2$. A current mirror at the bottom of the pair forces a difference current, $I2 - I1$, to flow out of the right leg. If the input voltages are perfectly matched, this current will be zero. However, if an input step is applied, it drives the inputs, and therefore the currents, apart. The difference current goes into a buffer stage and charges the compensation capacitor, CC . A capacitor's voltage change rate is known, and this gives us our overall slew rate: $v/dt = (I1 - I2)/CC$. This shows that slew rate has a direct relation to the differential input voltage (V_{ID}).

Because of the fixed tail current source, $I1$ and $I2$ can go up to the current source value, B . This sets the maximum slew rate values to $-B/CC$ to $+B/CC$. This can be a significant limitation, since the tail current source is kept small for other design reasons. From this description it is easy to see why high gain applications result in low slew rates. In high gain, the input differential voltage is very small and there is not enough difference to allow the differential pair to output the maximum current.

To improve slew rate performance, some amplifiers include slew-boost circuitry that provides another current source to add supplement current to charge the capacitor faster. Slew boost circuitry may or may not be dependent on the input differential voltage depending on the type of design. There are many good sources for further explanation of voltage feedback slew rate and slew boost, one of which is [Ramping Up on Slew Rate](#). A link to this and other resources can be found in the references section.

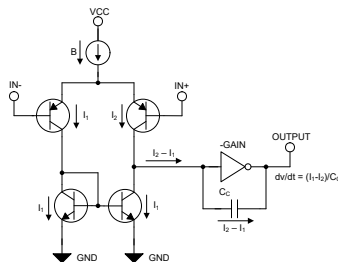


Figure 1-1. Simplified Opamp Diagram Showing Slew Rate (v/dt)

1.3 Slew Rate Internals for Current Feedback

Current feedback amplifiers can be modeled as shown in Figure 1-2 with a current mirror and a compensation capacitor. Unlike a voltage feedback amplifier, the inverting input is low impedance, which allows error current from the output to flow through the node. The current is mirrored and charges the compensation capacitor. As the output magnitude increases, more current will flow through the feedback and be available to charge the capacitor. Because the error current from a current feedback amplifier is much larger than the tail current of a voltage feedback amplifier, current feedback amplifiers can have a significantly higher slew rate than voltage feedback amplifiers. Although slew rate is still dependent on V_{ID} , the effect is small.

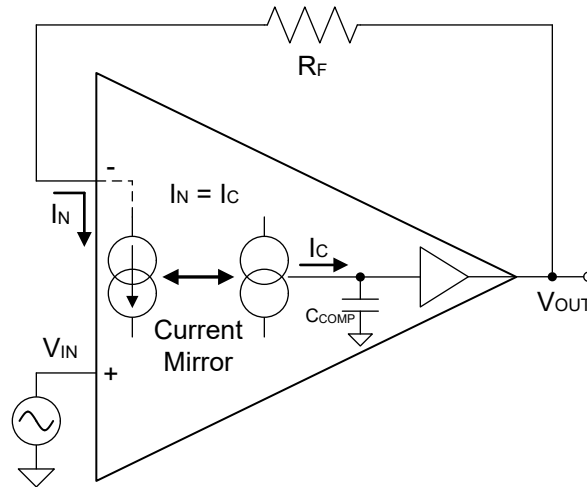


Figure 1-2. Simplified Diagram of a Current Feedback

2 Slew Rate Data Using the OPA690

The OPA690 is a voltage feedback amplifier. It has a very high slew rate for a voltage feedback amplifier due to additional circuitry supplementing the slew. The typical value in the device-specific data sheet is $1800V/\mu s$ and minimum value is $1400V/\mu s$. This is specified for a gain of $2V/V$ and an output step of $4V$, meaning that the input was a $2V$ step function. This input is called V_{ID} , as it is the differential voltage applied instantaneously across the inputs of the amplifier.

The part is set up using the DEM-OPA-SOT-1B board, in a noninverting configuration, shown in Figure 2-1.

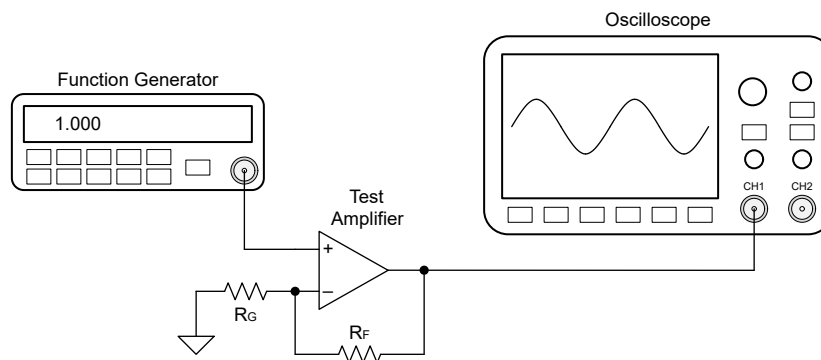


Figure 2-1. Setup for Lab Testing

The pulse response of the device-specific data sheet setup is shown in [Figure 2-2](#). The slew rate can be calculated to be 1560V/us, which is within an acceptable margin of error based on the specification.

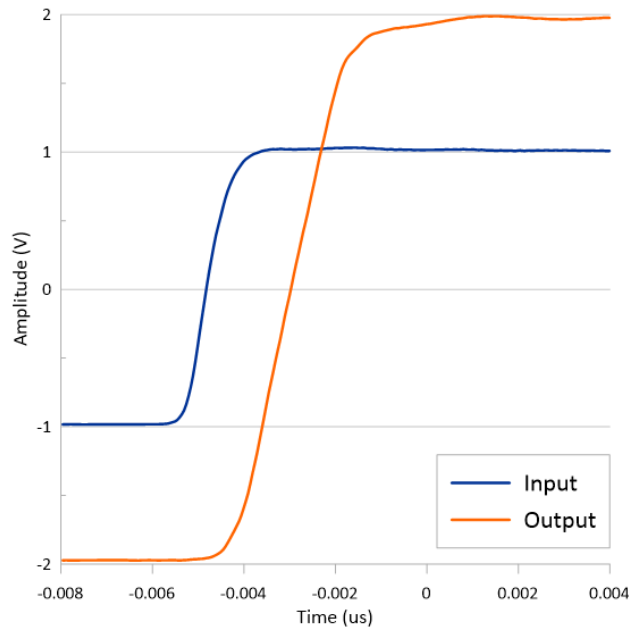


Figure 2-2. Pulse Response of the OPA690 in Data Sheet Conditions

[Figure 2-3](#) shows the pulse response with the OPA690 gain increased to 5V/V. The measured slew rate was 573V/ μ s, which is much slower than the lower gain configuration due to the limited input differential voltage.

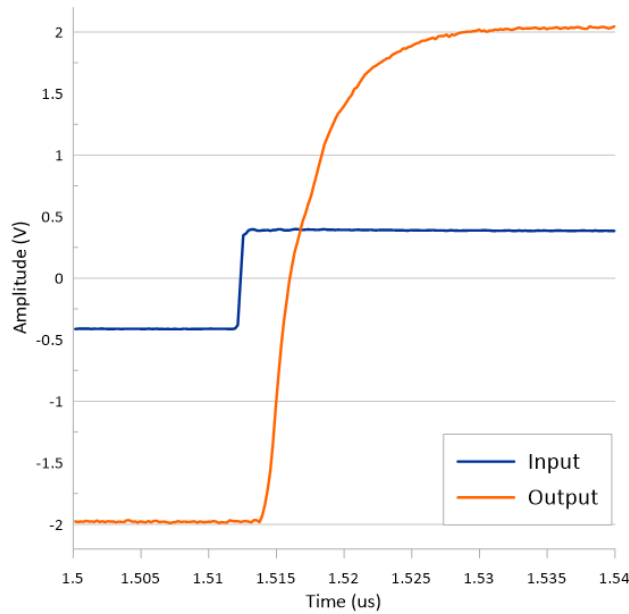


Figure 2-3. Pulse Response of the OPA690 G = 5.

Figure 2-4 shows a pulse response graph for $V_{ID} = 2, 0.8, 0.4,$ and $0.2V$, while adjusting the gain to achieve a 4V step at the output. As expected with the theory, the slew rate continuously decreases as the input differential voltage decreases.

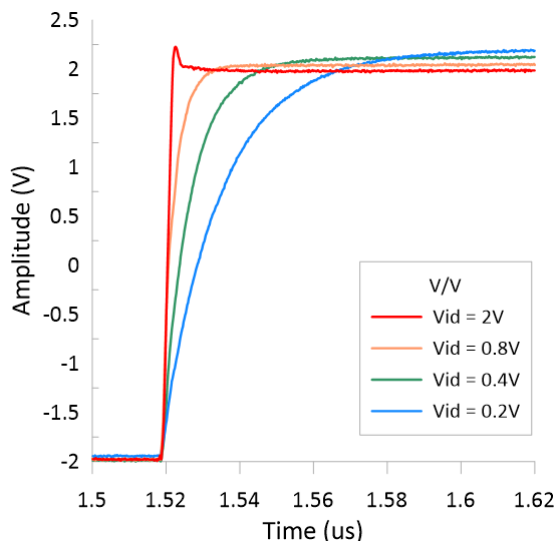


Figure 2-4. Pulse Responses of the OPA690 With Different Input Voltages and Gains

The slew rate response gets much slower for each decrease in V_{ID} . The overall relationship between slew rate and V_{ID} is shown in Figure 2-5. This direct relationship between slew rate and input differential voltage is what is expected based on the theoretical analysis.

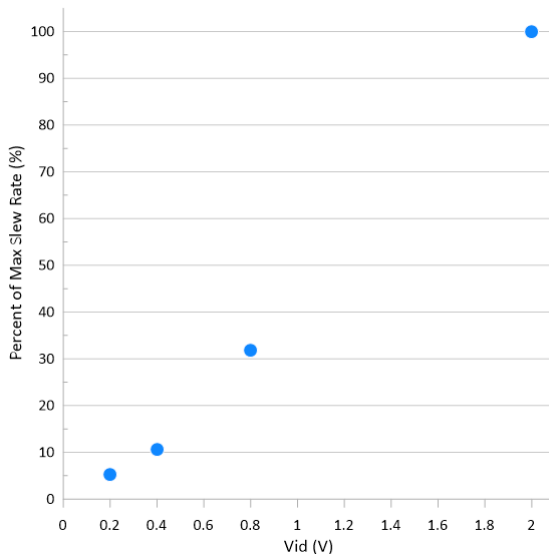


Figure 2-5. Slew Rate vs. Input Differential Voltage

Figure 2-5 highlights the dramatic drop in slew rate as V_{ID} decreases. [Ramping Up on Slew Rate](#) shows a similar graph for the relationship between slew rate and V_{ID} . However, the relationship shown is much less extreme than our findings. For example, the paper's results show that 100% of a device's maximum slew rate can be achieved with as little as 0.1V input, whereas the OPA690 needs around 2V. This is common in amplifiers with slew rate boost. Although the slew rate decreases more steeply with decreases in V_{ID} , the value is still much higher than a comparable non slew boosted amplifier.

3 Slew Rate Data Using the OPA695

The architecture of current feedback amplifiers provides not only higher slew rate, but slew rate that does not change significantly as V_{ID} changes. The following experiments were measured using the OPA695 current feedback amplifier. This part has a typical slew rate of 2900V/ μ s. The same setup shown in Figure 2-1 that was used for the OPA690 was also used for the OPA695 testing. Figure 3-1 shows the OPA695 tested in the device-specific data sheet conditions, which meets the expected performance.

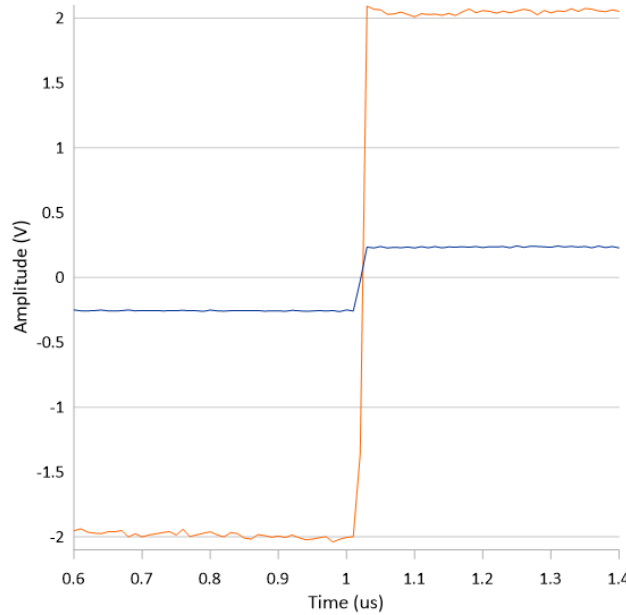


Figure 3-1. Pulse Response of OPA695 in Data Sheet Conditions

The pulse responses of the OPA695 current feedback amplifier with varying V_{ID} values are shown in Figure 3-2. Unlike the OPA690, the OPA695 shows nearly identical edge rates for each input voltage value.

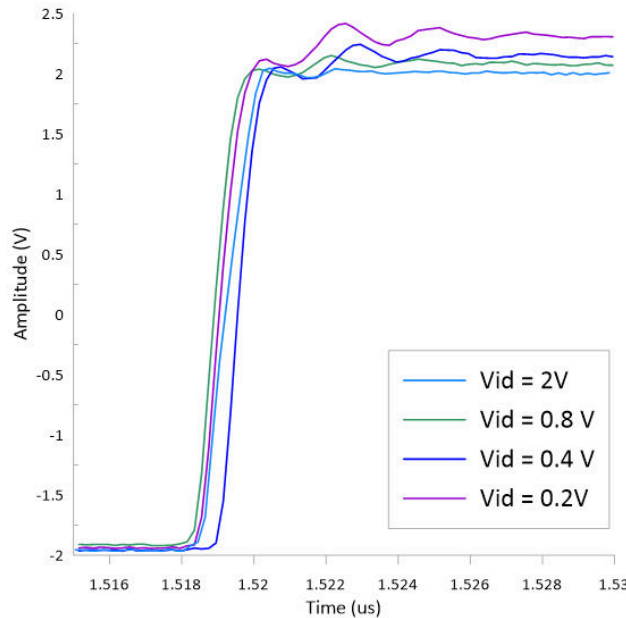


Figure 3-2. Pulse Response of OPA695 Shows Slew Rate With Varying Input Voltage and Gain

A slew rate vs V_{ID} plot for the OPA695 is shown in [Figure 3-3](#). As can be seen, the OPA695 has much less variation in slew rate than with the OPA690.

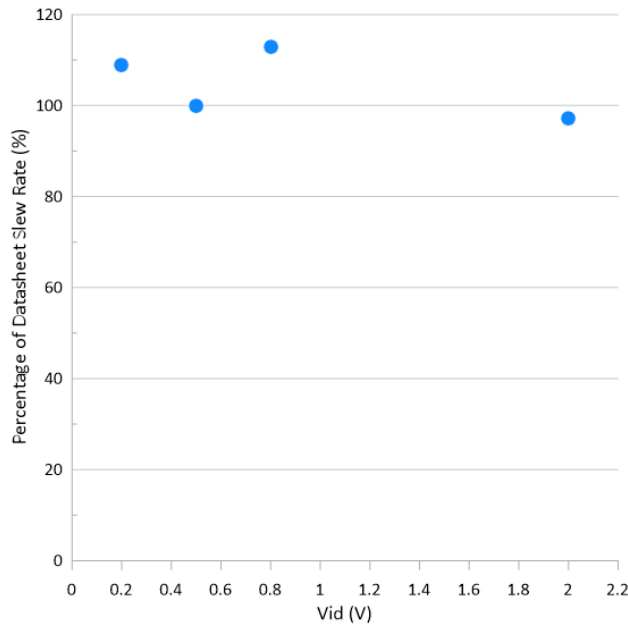


Figure 3-3. The Slew Rate of the OPA695 Does Not Seem Correlated With V_{ID}

4 Summary

For voltage feedback amplifiers it is important to be aware that slew rate is directly related to the input differential voltage. For high gain configurations, the slew rate performance of a voltage feedback amplifier can reduce dramatically compared to unity gain specifications.

For applications that need both high gain and large slew rate, a simple solution is to use a current feedback amplifier. As demonstrated by the measurements in this document, the unique architecture of current feedback amplifiers allows them to maintain their slew rate performance even with the input differential voltage is very small.

5 References

- Texas Instruments, [Ramping Up on Slew Rate](#)
- Texas Instruments, [Current feedback amplifiers - Slew rate](#), video

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