

## Replacing Output Clamping Op Amps with Input Clamping Amps

### INTRODUCTION

Various systems like ultrasound and imaging systems, have instances where the analog signal might suddenly spike to a voltage extreme. But many downstream circuits like A/D drivers place restrictions on the analog input signal levels in order to maintain their performance. These devices can draw excessive current in an overdrive condition or else be driven into a region of saturation which will have a long recovery time.

Various clamp amps can be used in these systems to restrict signal excursions at their outputs to protect downstream devices. So far most of the clamping amplifiers have relied upon an output clamping architecture and are called output clamp amps (OCAs). A new architecture called an input clamp amp (ICA) offers superior clamping accuracy and lower distortion.

Figure 1 illustrates the relative performance of the two devices. It can be seen that the ICA more closely tracks a straight line in the linear region up to the point that it bends over into the clamp region. On the other hand, the OCA breaks away from a straight line sooner as it approaches the clamp voltage. Of course the extent to which the response more closely tracks a straight line is indicative of the amplifier's linearity in that region.

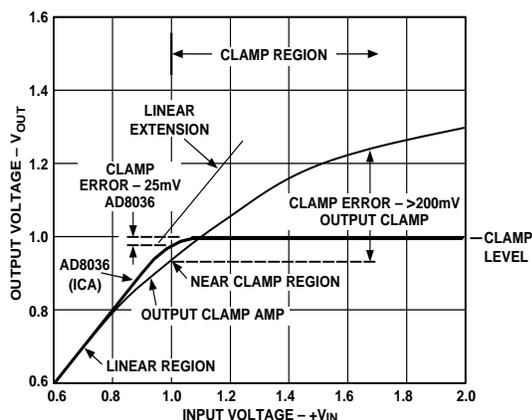


Figure 1. Output Clamp Error vs. Input Clamp Error

To compensate for this added distortion, OCAs are required to have their clamping levels set wider than the maximum excursion of interest if minimum distortion is desired. Therefore, when substituting an ICA for an OCA, the clamp region can be narrowed without adding extra distortion. This will lower the voltages experienced by downstream circuitry during overdrive. In most designs, making this adjustment requires only a minor modification to the circuit that generates the clamp voltages.

Figure 2 illustrates this concept. The amplitude of the linear signal for each type of amplifier is the same. However, the upper and lower clamp levels of the OCA must be set wider in order to preserve the signal linearity due to the larger near-clamp distortion region. Thus for overdrive conditions, the downstream circuitry will see larger signals when driven by an OCA than an ICA.

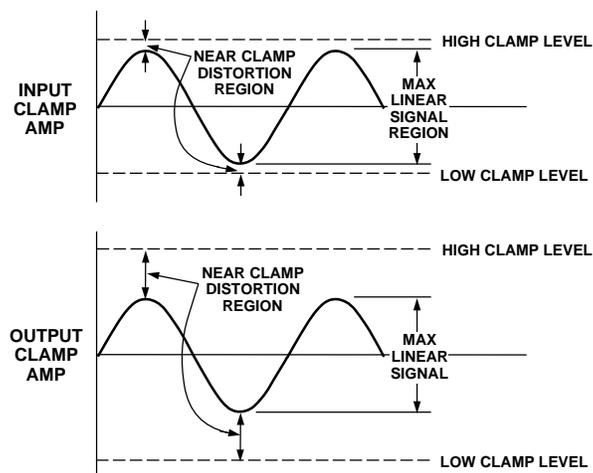


Figure 2. Comparison of Near-Clamp Distortion Regions of ICA vs. OCA

In addition the overdrive response will be further improved as a result of the superior overdrive characteristics of the ICA. The output of an ICA will not go more than 10 mV past the level set by the clamps for clamping stages with low gain. On the other hand, an OCA will

overshoot by a few hundred millivolts depending on the magnitude of the overdrive signal. Once again Figure 1 illustrates this concept. The ICA performance can be seen to be relatively flat in the clamp region independent of the magnitude of the overdrive, while the OCA output keeps on increasing along with increasing overdrive amplitude.

The first two input clamp amps, the AD8036 and AD8037, introduced by Analog Devices operate with an ICA structure. But because of differences in their operation, except for circuits that operate with a gain of +1, substituting an ICA into a design that has been implemented with an OCA is not a “drop-in” replacement, even though the pinouts of the parts are identical. However, because the pinouts are identical, the required circuit modifications will, in general, be not too extensive. Each configuration though must be handled on a case-by-case basis. The following details the considerations for making this substitution.

### Inverting Operation

The first consideration is the polarity of operation of the op amp. The input clamping op amp architecture of the AD8036 and AD8037 does not operate in the inverting mode. Therefore it is not possible to directly replace an OCA with an ICA for inverting configurations. In order to benefit from the ICA’s superior clamping characteristics in inverting applications, a separate inverting stage is required.

Figure 3 shows a circuit with an inverting stage followed by an ICA, the AD8036 in a noninverting configuration for providing the overall function of an inverting clamping amplifier. The circuit shown will have a gain of  $-R_F/R_I$  and will clamp at  $V_H$  and  $V_L$ . The operation of the clamping stage will be explained further in the next section. In all clamp circuits,  $V_H$  must be greater than  $V_L$ , but the two can be anywhere within the output range of the part.

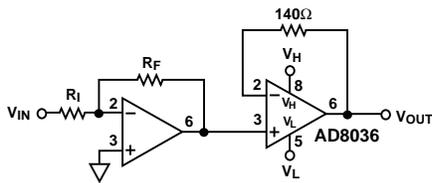


Figure 3. Inverting Clamping Circuit

For circuits that require a gain of more than (minus) 1, the designer has a choice as to how to distribute the gain between the inverting stage and the clamp stage. For greatest accuracy, the ICA should operate at lower gains because the clamp accuracy is a function of the gain as will be detailed in the next section. Additional required gain can be provided in the inverting stage.

## NONINVERTING OPERATION

### Unity Gain

For the case of substituting for a noninverting OCA, the most important consideration is the gain at which the clamp amp is operating. This is because the output clamping level for an ICA is a function of the closed loop gain of the amplifier.

The first case to consider is a noninverting unity gain. For OCAs, the clamping levels are simply equal to the voltages applied to  $V_H$  (Pin 8) and  $V_L$  (Pin 5). For an ICA, these voltages are multiplied by the closed loop gain in order to calculate the clamping levels. But since the gain is +1, the ICA and OCA will both have the same clamping levels. Thus, a direct substitution can be made. Figure 4 is an example of a unity gain clamping circuit.

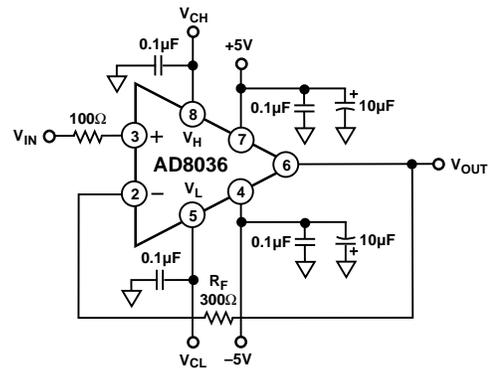


Figure 4. Unity Gain Noninverting Clamp

Since we are talking about a noninverting unity gain, the amplifier chosen must also exhibit stable operation at unity gain. Of the two ICAs, the AD8036 is compensated for operation at unity gain. Thus, the AD8036 is a “drop in” replacement for an OCA in noninverting unity gain applications. It will provide the same gain and clamp at the same levels as the OCA.

### Gains of Two or More

When the noninverting gain of the clamp amp is two or greater, the AD8037 can be used for its wider bandwidth, as it is compensated for noise gains of two or greater. However, the voltages applied to the clamp pins will have to be changed to maintain the same clamping levels, because the clamping levels are a function of the closed loop gain of the amplifier. The following equations summarize the calculations for obtaining the proper clamp voltages:

$$V_{CH} = G \times V_H$$

$$V_{CL} = G \times V_L$$

where:  $V_{CH}$  is the high output clamping level  
 $V_{CL}$  is the low output clamping level  
 $G$  is the gain of the amplifier configuration  
 $V_H$  is the voltage applied to  $V_H$  (Pin 8)  
 $V_L$  is the voltage applied to  $V_L$  (Pin 5)

In general, to maintain the same clamping levels as for an OCA, the voltage applied to either clamp pin should be set at the value desired for the clamp level divided by the closed-loop gain of the amplifier. For example, if the amplifier operates at a gain of two and it is desired to clamp on the high side at 1 V, then the voltage applied to  $V_H$  (Pin 8) should be 1 V/2 or 0.5 V. Similarly, if it is desired to set the lower clamp at -1 V, then the voltage applied to  $V_L$  (Pin 5) should be -1 V/2 or -0.5 V. Figure 5 is a schematic for a clamping stage using an AD8037 with a gain of 2.

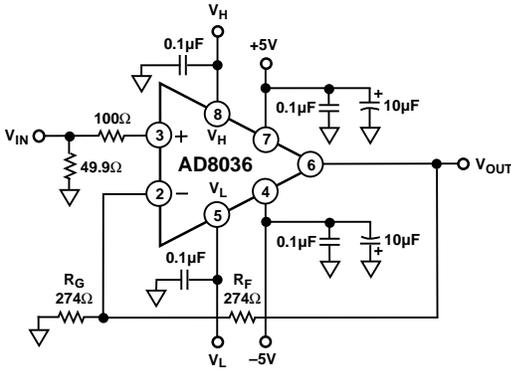


Figure 5. Gain-of-Two Noninverting Clamp

The above implies that an input offset in the clamp circuit will be multiplied by the gain of the op amp stage. To obtain the best clamping accuracy, the clamp amp should be set for a low gain and any additional necessary gain be provided by another gain stage prior to the clamping stage. The greater accuracy of an ICA over an OCA can be practically realized for clamping stages with gain of up to 10.

The discussion of distortion in the near-clamp region still applies. The clamping window must be slightly larger than the maximum signal excursion for which lowest distortion is desired. A/Ds will have a region between maximum signal level to be converted and maxi-

imum overdrive signal level that does not compromise its specifications. It is within this region that the clamping levels should be set.

### Clamping with an Offset

Some op amp applications require a dc offset voltage at their output. These are generally configured in the inverting mode where the offset can be produced by a dc voltage that is simply summed through a summing resistor as an additional input to the amplifier. Since an ICA does not support inverting mode clamping, it is not possible to clamp with this configuration.

Noninverting circuits can be created that offer both gain and offset. However, because there is an interaction among the resistors used to vary the gain and offset, the design is not as straightforward as for inverting configurations.

Figure 6 shows a noninverting configuration of an AD8037 that provides clamping and also has an offset. The circuit shows a driver for an AD9002, an 8-bit, 125 MSPS A/D converter and illustrates some of the considerations for using an AD8037 with offset and clamping. The analog input range of the AD9002 is from ground to -2 V. The input should not go far outside of this range in order to avoid drawing excessive current. The input is symmetrical about ground with an amplitude of 1 V p-p.

For the AD8037 to operate at a gain of two, a 301 Ω feedback resistor is chosen as recommended by the data sheet. For a gain of two the parallel combination of resistors R1 and R3 must be equal to the feedback resistor R2. Thus

$$R1 \times R3 / (R1 + R3) = R2 = 301 \Omega$$

The reference used to provide the offset is the AD780 whose output is 2.5 V. To find the value of R3, first assume that the input at the noninverting input is at 0 V. This will force the inverting input to also be at 0 V, which

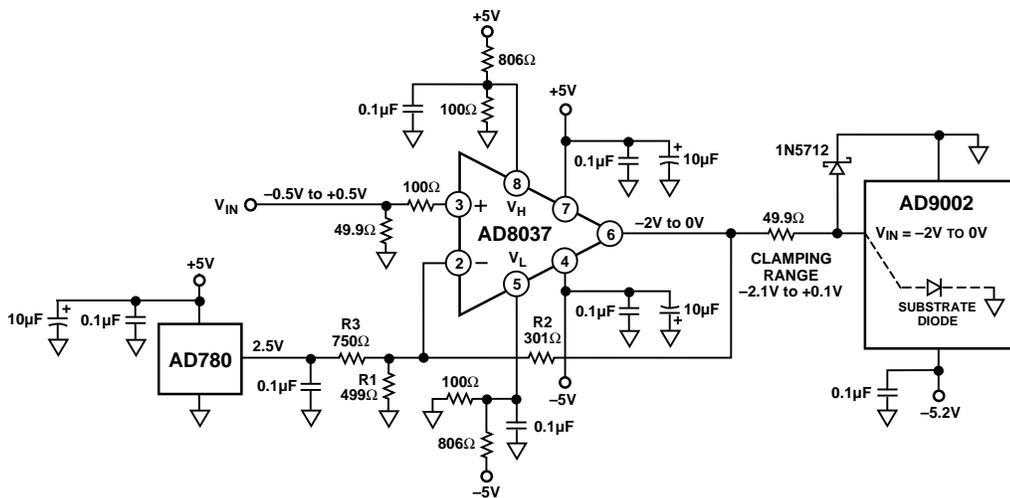


Figure 6. Gain of Two, Noninverting with Offset AD8037 Driving an AD9002—8-Bit, 125 MSPS A/D Converter

creates a condition where no current flows through R2. The output now wants to be at  $-1\text{ V}$  (midpoint of range that corresponds to input midpoint), so a current of  $1\text{ V}/301\ \Omega$  or  $3.32\text{ mA}$  will flow in R2. Since no current flows in either R1 or into the inverting input of the op amp, this same current must flow in R3. Thus

$$2.5\text{ V} = (3.32\text{ mA}) R3 \text{ or } R3 = 750\ \Omega.$$

The above equation then yields a value for R1 of  $499\ \Omega$ .

It is desirable to clamp the signal so that the output goes no more than  $100\text{ mV}$  outside of the A/D's maximum input signal range in either direction. Thus the high level clamping should occur at  $+0.1\text{ V}$  and the low level clamping should occur at  $-2.1\text{ V}$  as seen at the output.

Because the clamping is done at the input stage, a clamping level as seen at the output is affected by not only the gain of the circuit as previously described, but also by the offset. Thus, in order to obtain the clamping levels desired,  $V_H$  must be biased at  $+550\text{ mV}$ , while  $V_L$  must be biased at  $-550\text{ mV}$ . The voltage dividers created by the  $806\ \Omega$  and  $100\ \Omega$  resistors between the supplies and ground are used to create the clamp voltages.

In general the clamping levels as seen at the output can be calculated by the following:

$$V_{CH} = V_{OFF} + G \times V_H$$

$$V_{CL} = V_{OFF} + G \times V_L$$

where  $V_{OFF}$  is the offset voltage that appears at the output.

Another way to look at setting the clamp levels is by noting that the clamp signals ( $V_H$  and  $V_L$ ) are alternate non-inverting inputs that are selected when the conventional noninverting input goes outside the "window" that they establish. See Figure 7. It is desired to clamp  $100\text{ mV}$  higher and lower than the maximum excursion of the input signal with a gain of two. Therefore,  $V_H$  should be  $50\text{ mV}$  above the maximum input signal excursion of  $+0.5\text{ V}$  or  $+550\text{ mV}$ . Likewise,  $V_L$  should be  $50\text{ mV}$  below the minimum input signal excursion of  $-0.5\text{ V}$  or  $-550\text{ mV}$ . The  $50\text{ mV}$  in each case will be multiplied by two to yield  $100\text{ mV}$ , while the same offset will be applied to both the input signal and the clamps.

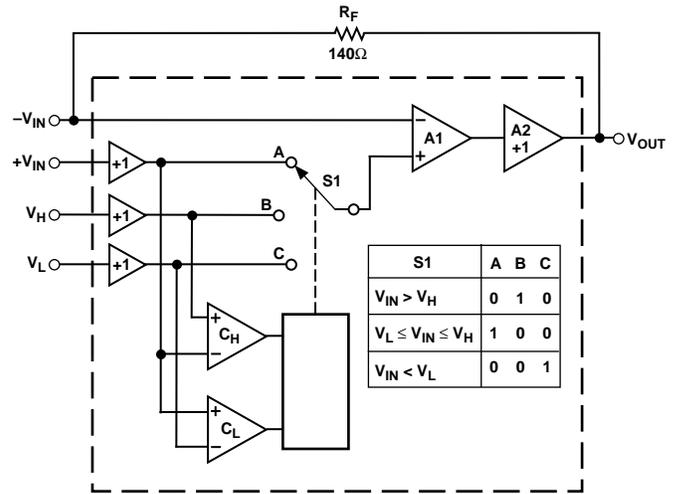


Figure 7. AD8036/AD8037 Clamp Amp System

The 1N5712 Schottky diode is used for protection from forward biasing the substrate diode in the AD9002 during power up transients.

#### OTHER CONSIDERATIONS

In general, the resistors used to generate the voltages for  $V_H$  and  $V_L$  should be kept below  $1\text{ k}$ . This will minimize errors due to bias current. It is also recommended to use a  $0.1\ \mu\text{F}$  capacitor to ground close to the op amp for bypassing  $V_H$  and  $V_L$ . If one or both of the clamp inputs is not used, the pin or pins can be left floating and the amplifier will function the same as one without clamping. If either or both clamp pins are dynamically driven and it is desired to create a nonclamping situation, then  $V_H$  can be biased at  $+V$  for no clamping for positive excursions, while  $V_L$  can be biased at  $-V$  for no clamping at negative excursions.

#### CONCLUSION

Input clamp amps (ICAs) offer superior clamping performance than output clamp amps (OCAs). For most applications an ICA can be used to replace an OCA, but depending on various circuit details, modifications will have to be made to successfully complete the change. The successful use of ICAs requires that each circuit be approached on a case-by-case basis. The techniques offered describe the circuit changes required to handle the most common situations.