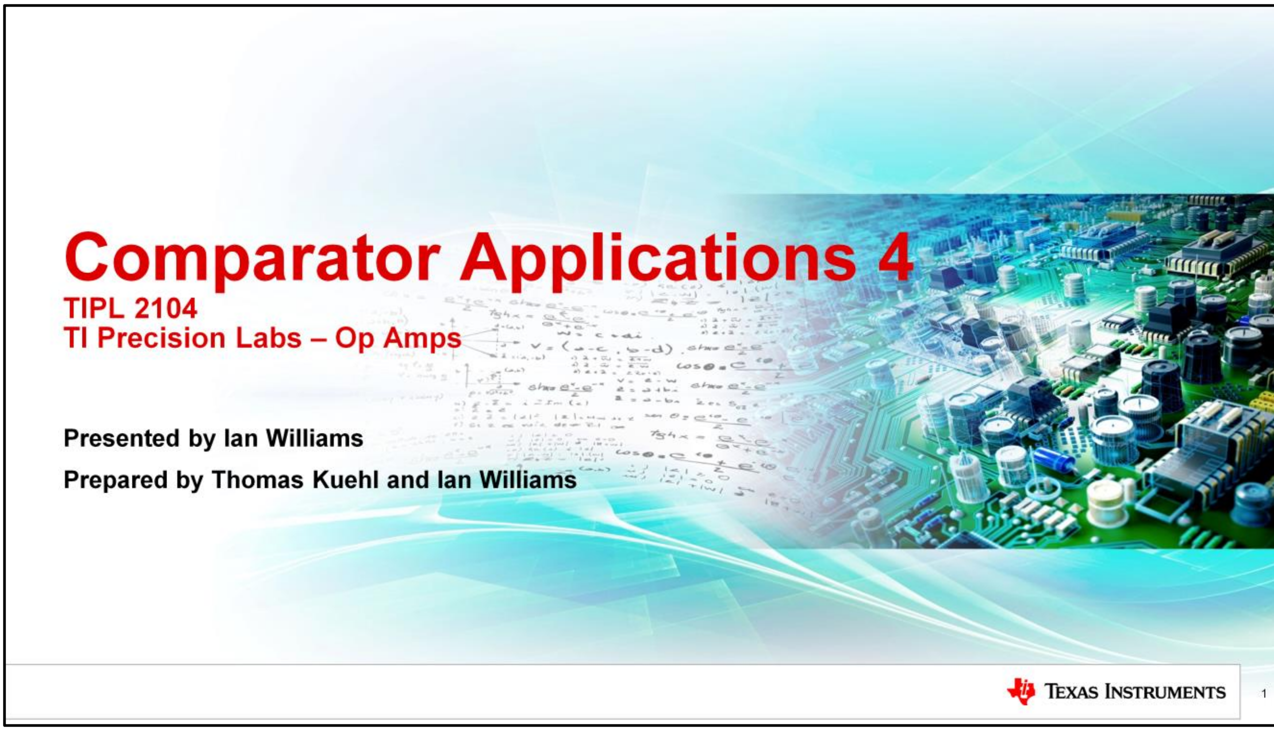
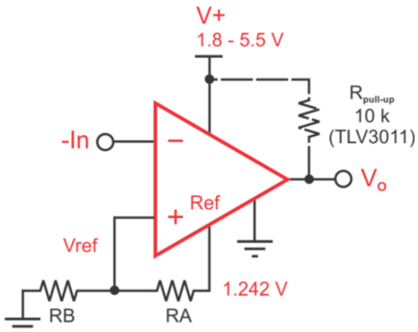


Hello, and welcome to the TI Precision Labs video discussing comparator applications, part 4. In this video we will discuss several extra features that are integrated into some comparators to help simplify your designs. We'll move on to discussing the use of op amps as comparators, and the pros and cons of doing this. We will finish this video series on comparators by pointing to some useful TI Precision Designs built with comparators.

Extra Features – Internal Voltage Reference



$$RA = RB\left(\frac{1.242\ \text{V}}{\text{Vref}} - 1\right)$$

For Vref = 1 V, let RB = 100 k and solve for RA

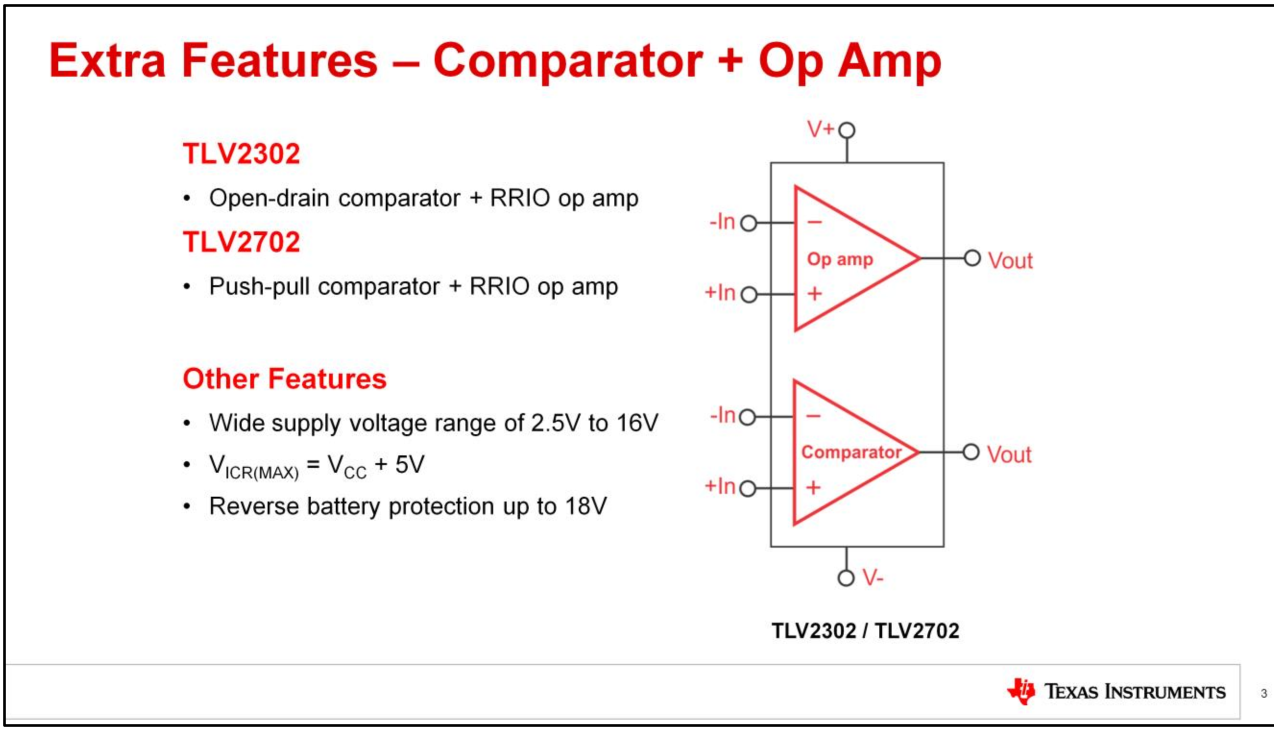
$$RA = 100\ \text{k}\left(\frac{1.242}{1.000} - 1\right) = 24.2\ \text{k}$$

VOLTAGE REFERENCE						
Initial Accuracy	V_{OUT}	V_{IN} = 5V	1.230	1.242	1.254	V
					±1	%
Temperature Drift	dV_{OUT}/dT	−40°C ≤ T_A ≤ 125°C		40	100	ppm/°C
Load Regulation						
Sourcing	dV_{OUT}/dI_{LOAD}	0mA < I_{SOURCE} ≤ 0.5mA		0.36	1	mV/mA
Sinking		0mA < I_{SINK} ≤ 0.5mA		6.6		mV/mA
Output Current	I_{LOAD}			0.5		mA
Line Regulation	dV_{OUT}/dV_{IN}	1.8V ≤ V_{IN} ≤ 5.5V		10	100	µV/V

TEXAS INSTRUMENTS 2

One example of an extra feature integrated into some comparators is an internal voltage reference, included in devices such as the TLV3011 and TLV3012. In these comparators, the internal 1.242V precision voltage reference can be very helpful when your applications requires you to compare a voltage on one input to a fixed reference voltage level. In the example shown here, a voltage divider is used to adjust the reference voltage to 1V. The equations on the right show how to calculate the values of the divider resistors in order to achieve your desired effective Vref.

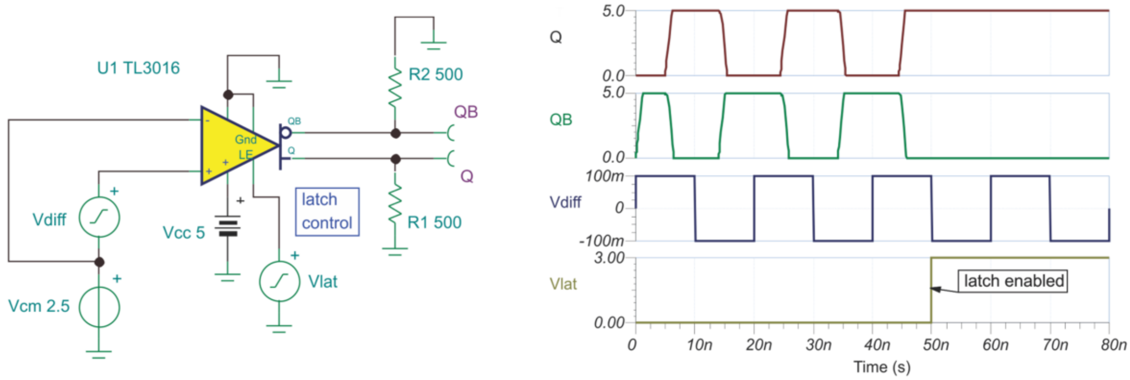
Note that using the internal reference voltage to generate Vref will generally be much more accurate than using the power supply.



The TLV2302 and TLV2702 micropower comparators contain both a comparator and a rail-to-rail input and output op amp in the same package. The TLV2302 is an open-drain comparator, while the TLV2702 is a push-pull output comparator.

For now, note that it is best to avoid trying to use an op amp as a comparator, so these devices are convenient if your application requires both a comparator and an op amp and minimizing printed circuit board space is critical. Also note that these devices have a wide power supply voltage range of 2.5V to 16V, can accept input common-mode voltages up to 5V above the positive supply, and include reverse battery protection up to 18V.

Extra Features – Complementary Outputs w/ Latch

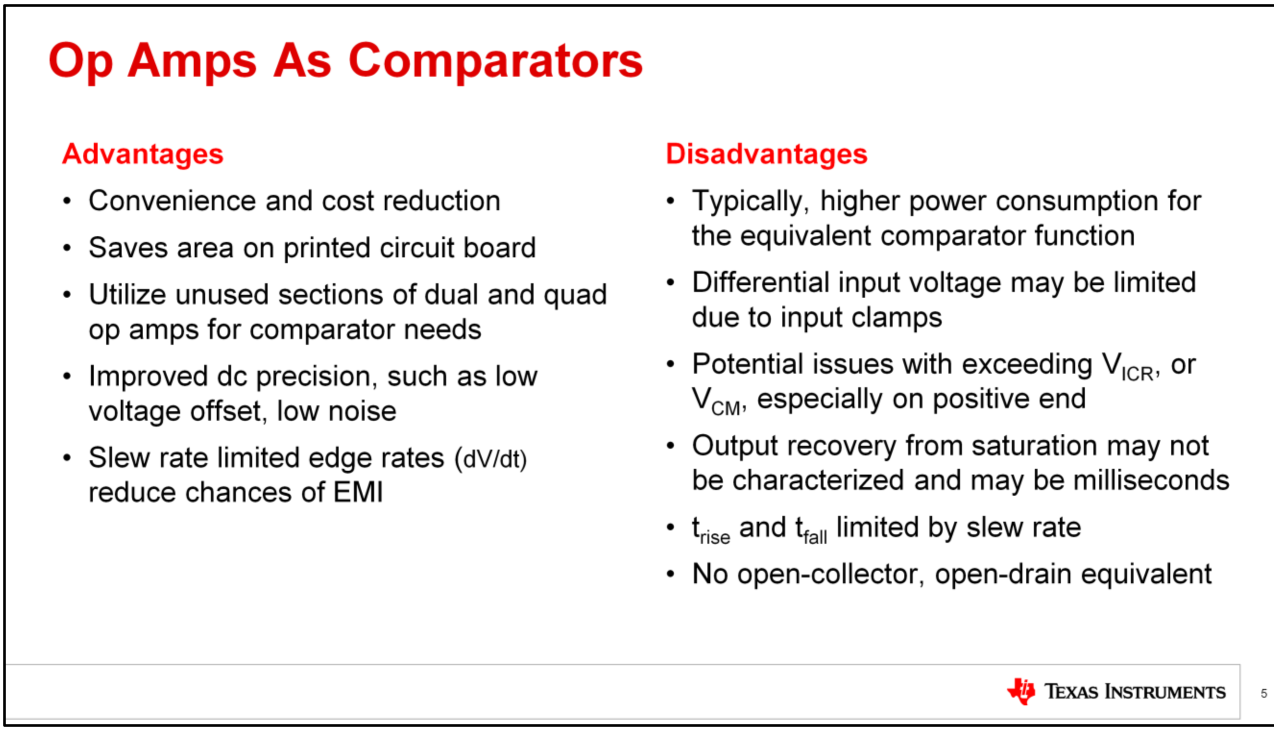


Output holds current state when latch is enabled.

Inputs can change and outputs maintain their latched-state levels!

The TL3016 ultra-fast push-pull comparator is abundant with additional features. First, it offers complementary outputs, meaning that an inverted version of the typical comparator output is also available. This can be very useful in applications where complementary signals are needed. This comparator also features a latch enable, or **LE**, function. When the LE pin is biased between 0V and 0.8 V, the TL3016 will operate as a comparator. However, when the LE pin is biased to 2V or greater, the outputs latch and hold their current states until unlatched. The outputs will not change while the latch is active, even if the inputs to the comparator change!

The simulation waveforms on the right show the operation of this device. From time zero to 50 ns, the latch function is disabled and the comparator operates normally. You can also observe the complementary outputs Q and QB in this region. At time equal to 50 ns, the latch pin is set high and the latching function is enabled. From this point on the outputs hold state, even as the input signal continues to change.



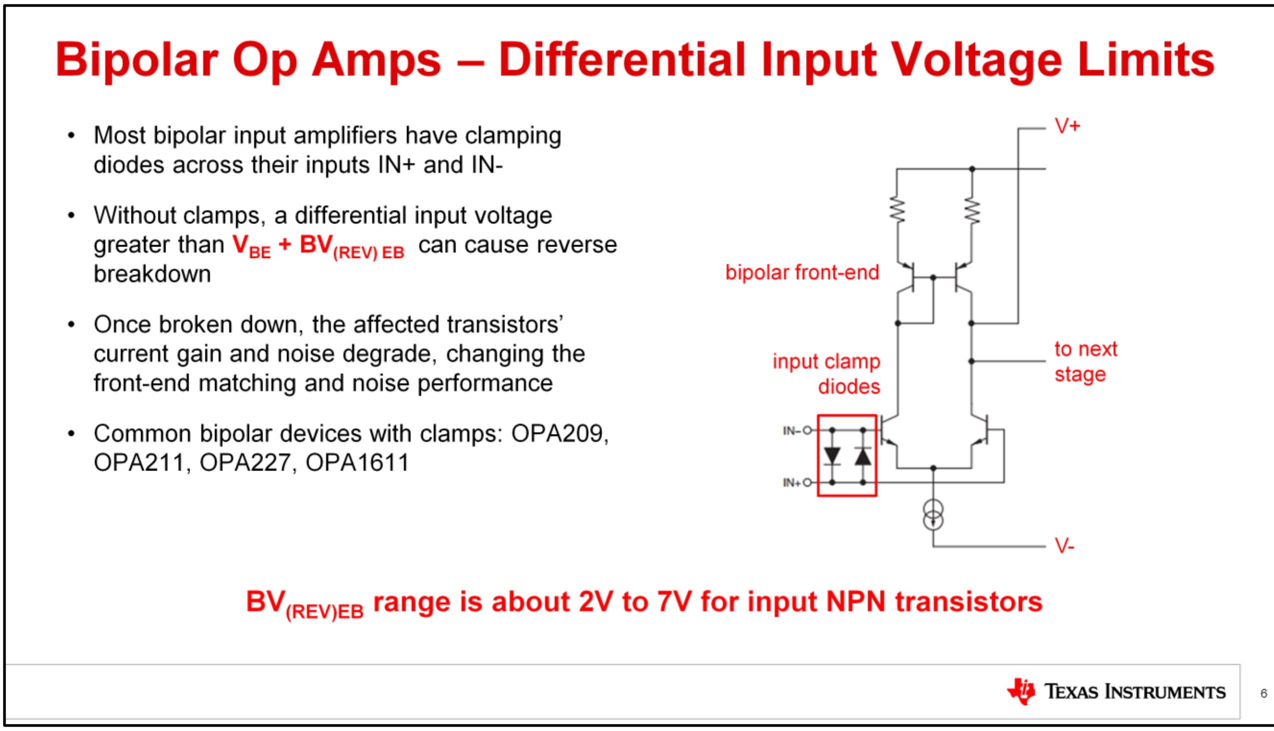
A common topic when discussing comparators is the use of op amps as comparators. There are both advantages and disadvantages to doing this which we'll now discuss.

We'll discuss the advantages first. Perhaps the most common reason engineers wish to use op amps as comparators is because of the potential savings to both component cost and printed circuit board area. If a dual- or quad-package op amp is already used elsewhere in the system and some channels are left available, it may be efficient to assign any remaining channels for comparator functions. Furthermore, most amplifiers offer better DC precision than comparators. A lower offset voltage, for example, can improve the accuracy of the comparator's trip point, as we discussed in part 1 of this video series. Finally, the rate of change of an op amp's output is limited by its slew rate, which may be advantageous if electromagnetic interference, or EMI, generated by the fast transition of comparators is a problem.

Let's now go over the disadvantages to using op amps as comparators.

First, the power consumption of most op amps will be higher than the equivalent comparators. Also, the allowable differential input voltage may be limited by the presence of input clamping diodes, depending on the op amp topology, and many non-rail-to-rail op amps will have issues when operated beyond the allowable input common mode voltage range. Perhaps most importantly, an op amp's recovery time from saturation may not be characterized and can range from hundreds of nanoseconds all the way up to milliseconds, severely impacting the circuit's timing behavior. Furthermore, the rise and fall time of an op amp is limited by the slew rate and will generally be much slower than a comparator. Finally, there is no op amp equivalent of an open drain or open collector comparator. All op amps actively source or sink current to create the required voltage at the load.

In general, op amps are not intended to be operated in saturation, which is precisely what comparators are designed to do and excel at.

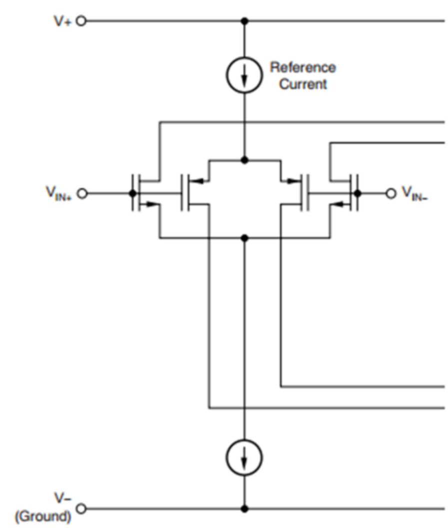


One of the biggest challenges to using an op amp as a comparator is dealing with the op amp's differential input voltage limits. Many op amps, especially bipolar-input op amps, have antiparallel input diodes, also called back-to-back input diodes, across input pins IN+ and IN-. The purpose of these diodes is to protect the base-emitter junctions of the input transistors from entering reverse breakdown when large differential input voltages are present. Once broken down, the transistors' performance severely degrades, causing permanent changes to the op amp's offset voltage, input bias current, and noise characteristics. This permanent degradation should be avoided, so the input clamps keep the differential input voltage limited to a safe level. If the limit is exceeded, one of the clamp diodes becomes forward biased and conducts current across the input pins and away from the input transistors.

Some popular TI bipolar op amps with input clamps are the OPA209, OPA211, OPA227, and OPA1611. Since comparators normally have large differential voltages applied to their inputs, bipolar op amps in general are poorly suited to be used as comparators.

Are Input Clamps Present?

- Most high-voltage CMOS op amps **do** have input clamps
  - **Examples:** OPA171, OPA172
- Most low-voltage CMOS (<18V) OPA, TLC, and TLV op amps **do not** have input clamps
  - **Examples:** OPA2325, OPA350
- JFET input op amps **do not** have input clamps
  - **Examples:** OPA140, OPA1641
- Chopper op amps **do** have parasitic input diodes associated with the switches that act as clamps
  - **Examples:** OPA333, OPA188



Low-voltage CMOS – OPA314, OPA316, TLV2374, etc.

Texas Instruments 7

Here are some **general** guidelines about the presence, or non-presence, of input clamps relative to the semiconductor process types other than bipolar.

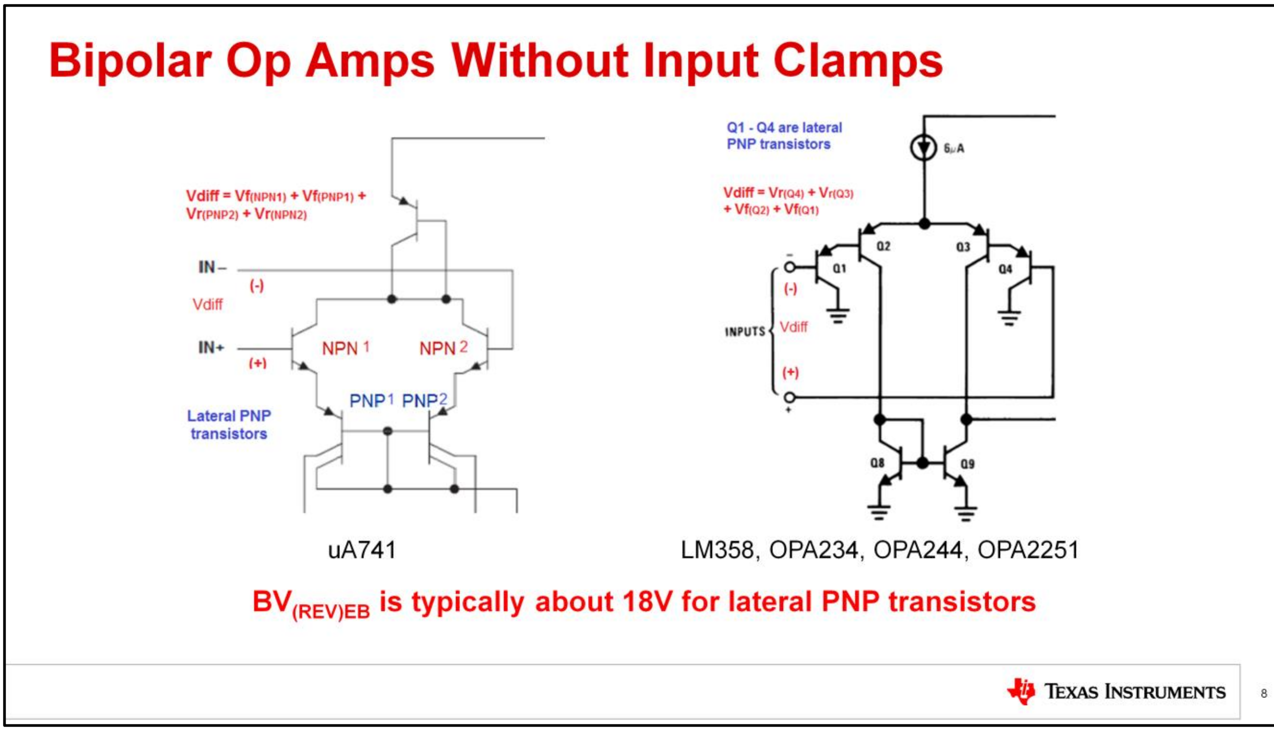
Most high voltage CMOS amplifiers, such as the OPA171 and OPA172, **do** have input clamps.

Most low voltage CMOS amplifiers, such as the OPA325 and OPA350, **do not** have input clamps.

JFET amplifiers, including the OPA140 and OPA1641, **do not** have the clamp diodes.

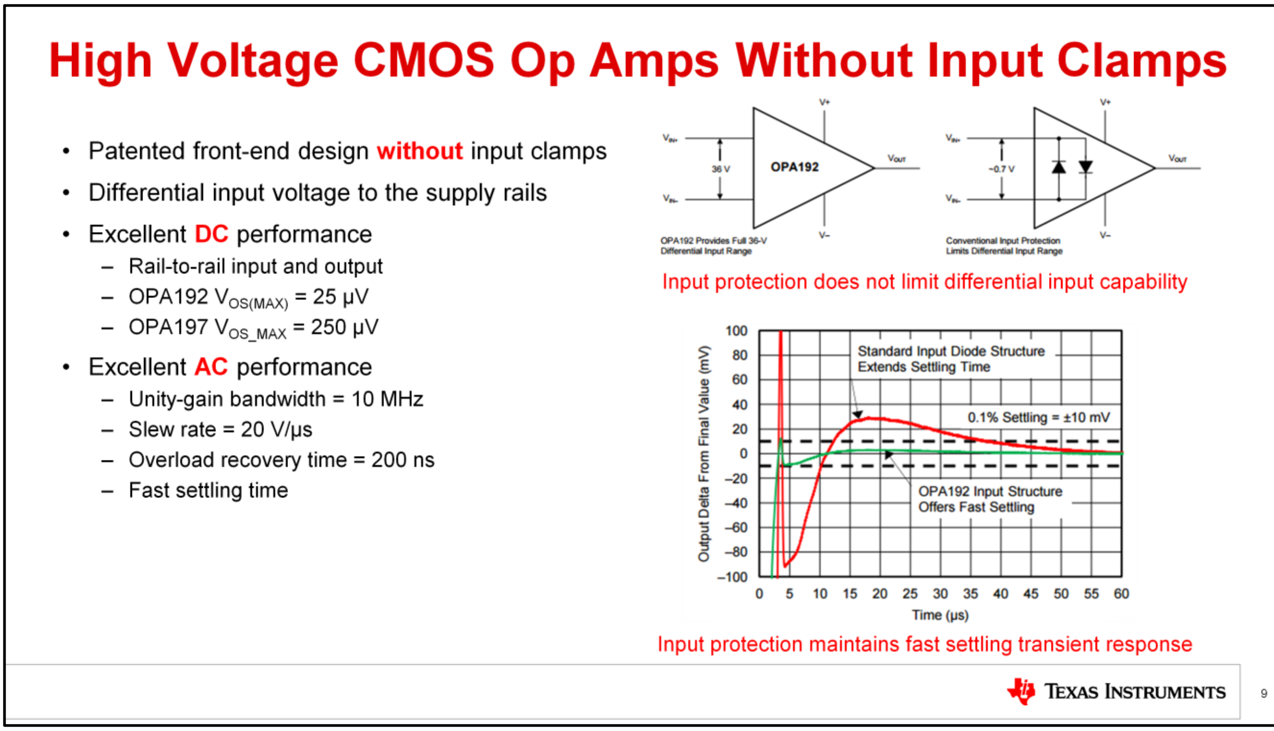
Finally, chopper amplifiers **do** have parasitic input diodes that behave the same as the typical input clamp structure. Examples of this are the OPA333 and OPA188.

Of course, there are exceptions to every rule, so use these guidelines as a starting point only!



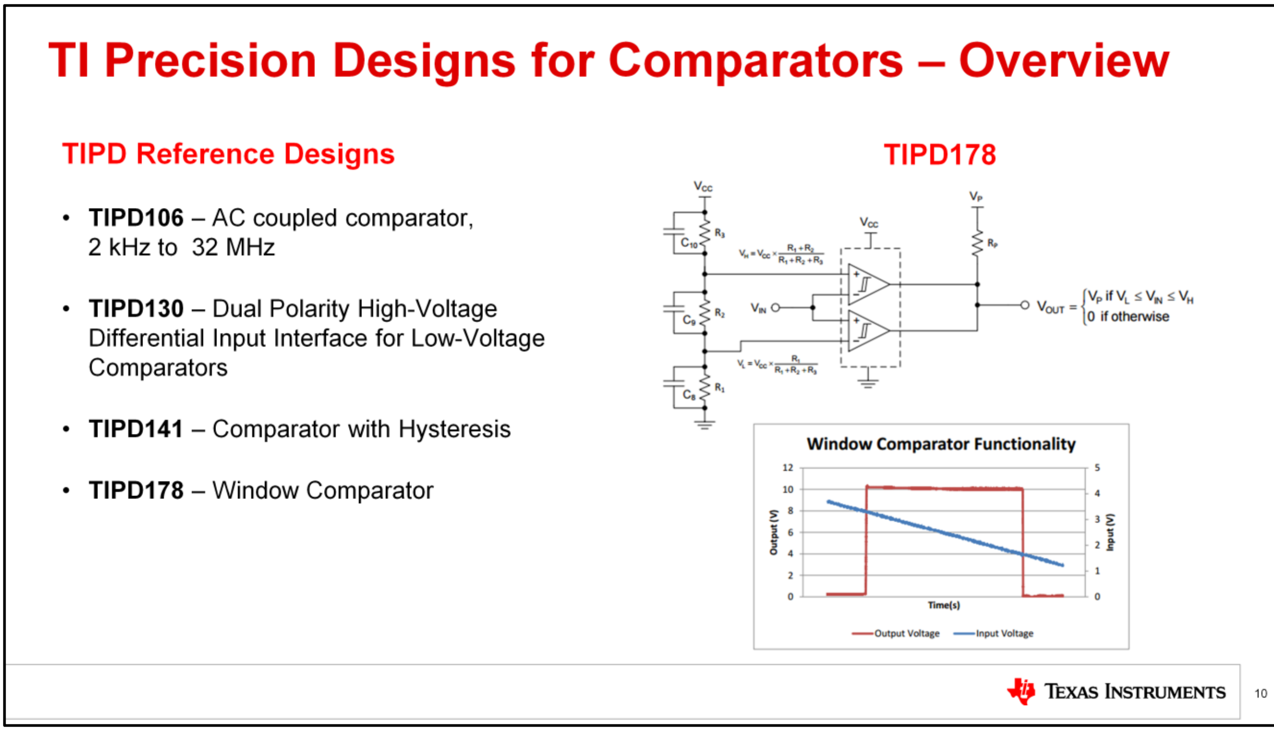
Speaking of exceptions, let me show you some examples of bipolar amplifier designs **without** antiparallel input diodes that can sustain high differential input voltages.

These bipolar amplifiers are built with lateral PNP transistors, which have a reverse breakdown voltage of about 18V, much higher than the typical NPN input transistors with reverse breakdown voltages from 2V to 7V. Some part numbers using these designs are the legendary uA741, as well as the LM358, OPA234, OPA244, and OPA2251.

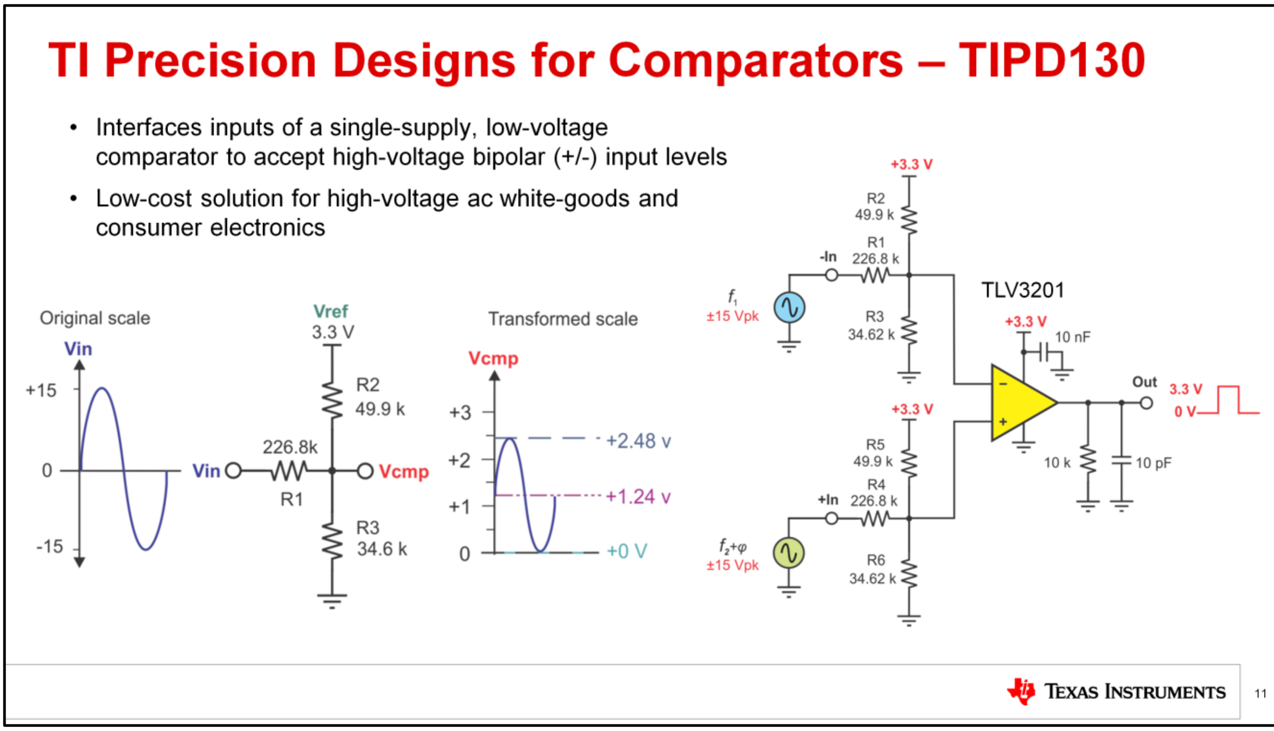


Here are some **more** exceptions to the rules. While most high voltage CMOS amplifiers do have input clamps, some of our newest amplifiers of this type, such as the OPA192 and OPA197, have a patented front-end design that does not require the clamps. Therefore, these op amps can also be configured as high-performance comparators with a differential input range as large as the power supply voltage. Both products have specs well-suited for comparator applications, with rail-to-rail input and output, very low offset, high bandwidth and slew rate, and fast overload recovery time of only 200ns.

In general, you can see whether or not an op amp can sustain large differential input voltages by reading the absolute maximum table in the amplifier data sheet. You should be cognizant of what the differential input limitations are before considering using an op amp as a comparator.

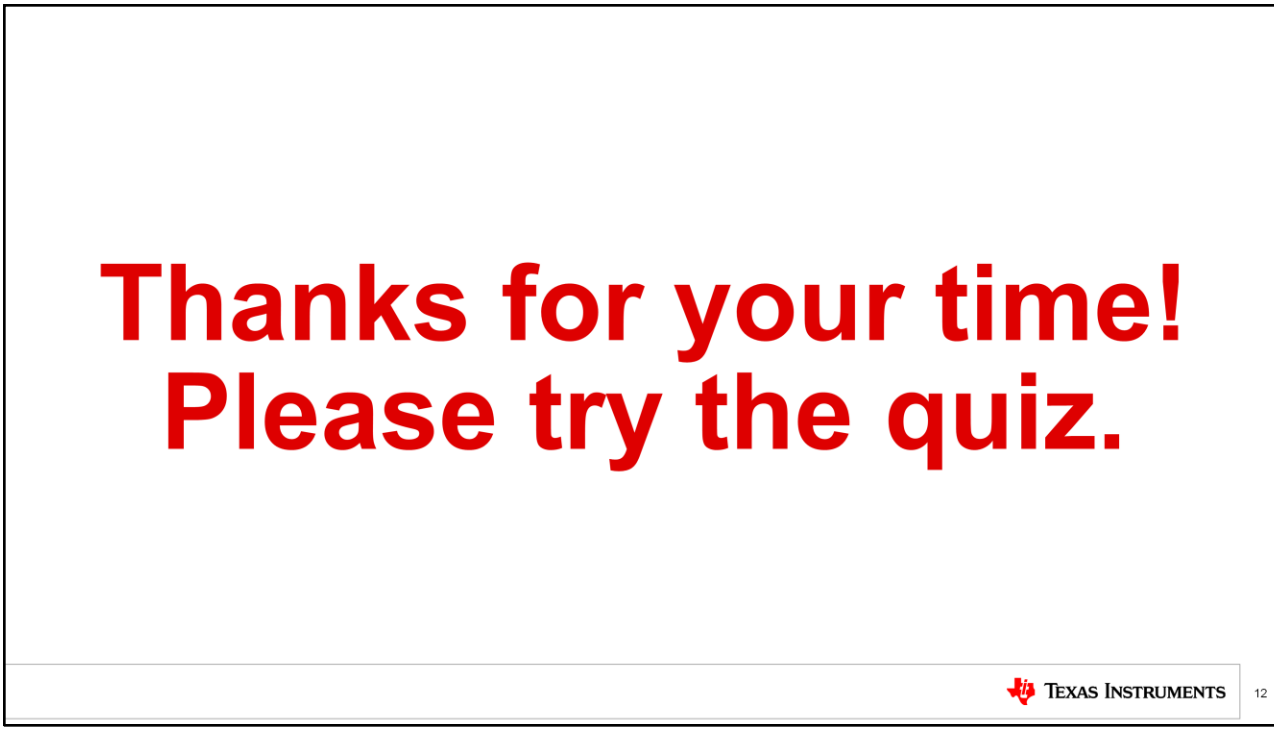


Several TI Precision Designs have been created specifically for comparator applications. TIPD106 details how to use a comparator for AC-coupled applications over a bandwidth range of 2 kHz to 32 MHz. TIPD130 shows how to connect a bipolar high voltage input to a single-supply low voltage comparator. TIPD141 describes how to configure an amplifier for hysteresis, a topic discussed in part 2 of this video series. Finally, TIPD178 details the design procedure for a window comparator, whose functionality is shown on the right hand side of this slide.



Here we show a little more detail on TIPD130, which provides a method for interfacing a low-voltage, single supply comparator with a high-voltage bipolar (+/-) input. In this case, we use the term bipolar to mean a signal which swings both positive and negative. The bipolar input signals are ±15Vpk sine waves, which if connected directly to the +3.3V single-supply comparator would greatly exceed the input common mode range and absolute maximum input range of the device.

Using a divider network made up of three resistors, the input signals are transformed to ±1.24 V_{PK} sine waves centered about a +1.24 V DC reference level. Now the two phase-differing input sine waves can be compared, with the TLV3201 setting the appropriate output level of 0V or 3.3V. Based on this schematic, can you tell if the TLV3201 is an open-drain or open-collector comparator or a push-pull comparator? Since there is no pull-up resistor on the comparator output, it must be a push-pull output device which actively drives the output pin high or low.



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

Comparator Applications 4 Quiz

TIPL 2104
TI Precision Labs – Op Amps

Multiple Choice

- Which of the following is **not** an example of an extra feature which can be found in some of TI's comparators?
  a. Internal voltage reference
  b. Offset voltage trim pins
  c. Comparator + op amp in one package
  d. Complementary outputs with latch

- On a comparator with an output latch, when the latch is enabled ____________.
  a. The output will hold its current state until unlatched
  b. The output will change to the opposite state until unlatched
  c. The output is forced high until unlatched
  d. The output is forced low until unlatched

Multiple Choice

- Which of the following is **<u>not</u>** an advantage to using an op amp as a comparator?
  a. Utilizing otherwise unused channels of a dual or quad op amp
  b. Saving component cost and printed circuit board area
  c. Improving dc precision
  d. Reducing power consumption relative to performance

- One of the biggest challenges to using an op amp as a comparator is ______________________.
  a. Designing around input offset voltage drift over temperature
  b. Routing traces with an inconvenient pinout
  c. Dealing with the differential input voltage limits caused by input clamp diodes
  d. Modifying dual/split supply designs for single supply

Multiple Choice

- Which of these semiconductor processes *usually* has input clamping diodes?
  a. JFET
  b. Bipolar
  c. Low-voltage CMOS
  d. None of the above

- All high-voltage CMOS op amps, without exception, have clamping diodes.
  a. True
  b. False

Solutions

Multiple Choice

- Which of the following is **not** an example of an extra feature which can be found in some of TI's comparators?
  a. Internal voltage reference
  b. Offset voltage trim pins
  c. Comparator + op amp in one package
  d. Complementary outputs with latch

- On a comparator with an output latch, when the latch is enabled ____________.
  a. The output will hold its current state until unlatched
  b. The output will change to the opposite state until unlatched
  c. The output is forced high until unlatched
  d. The output is forced low until unlatched

Multiple Choice

- Which of the following is **<u>not</u>** an advantage to using an op amp as a comparator?
  a. Utilizing otherwise unused channels of a dual or quad op amp
  b. Saving component cost and printed circuit board area
  c. Improving dc precision
  d. Reducing power consumption relative to performance

- One of the biggest challenges to using an op amp as a comparator is ______________________.
  a. Designing around input offset voltage drift over temperature
  b. Routing traces with an inconvenient pinout
  c. Dealing with the differential input voltage limits caused by input clamp diodes
  d. Modifying dual/split supply designs for single supply

Multiple Choice

- Which of these semiconductor processes *usually* has input clamping diodes?
  a. JFET
  b. Bipolar
  c. Low-voltage CMOS
  d. None of the above

- All high-voltage CMOS op amps, without exception, have clamping diodes.
  a. True
  b. False