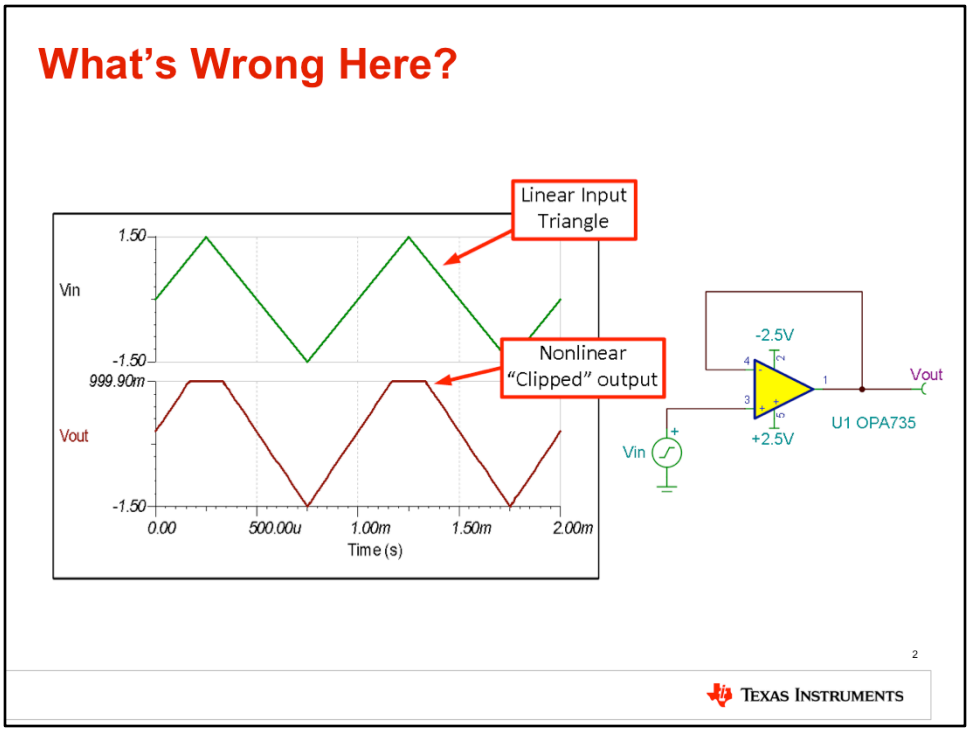
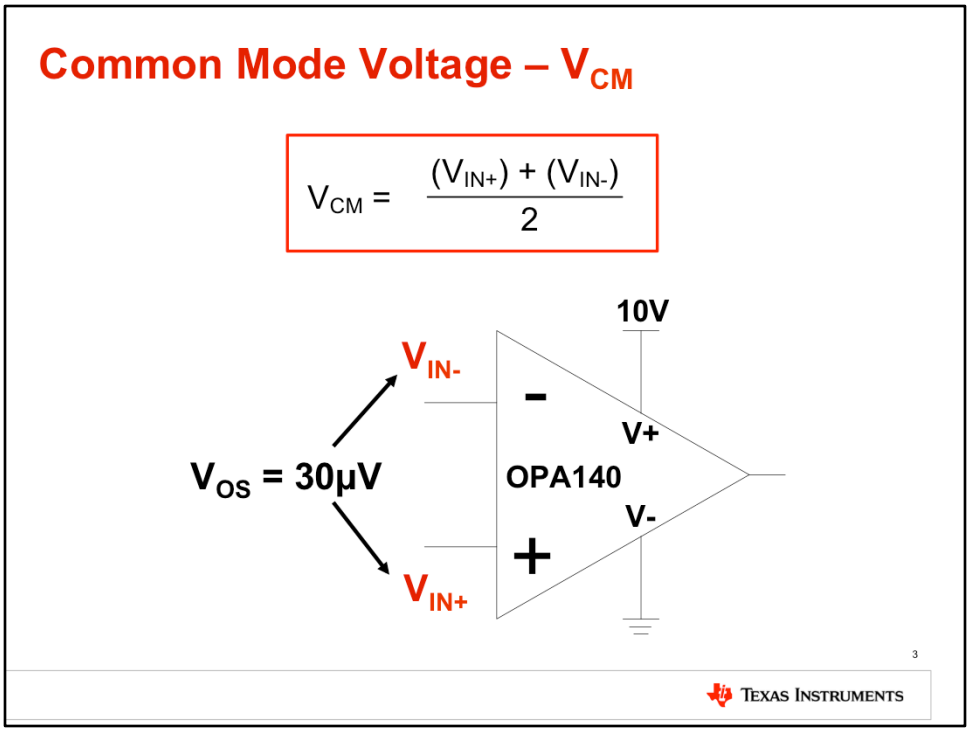
Hello, and welcome to the TI Precision Lab discussing op amp input and output limitations. In this video we'll discuss op amp common-mode input voltage, input and output voltage swing limitations, and show how to determine the source of circuit errors caused by these limitations.

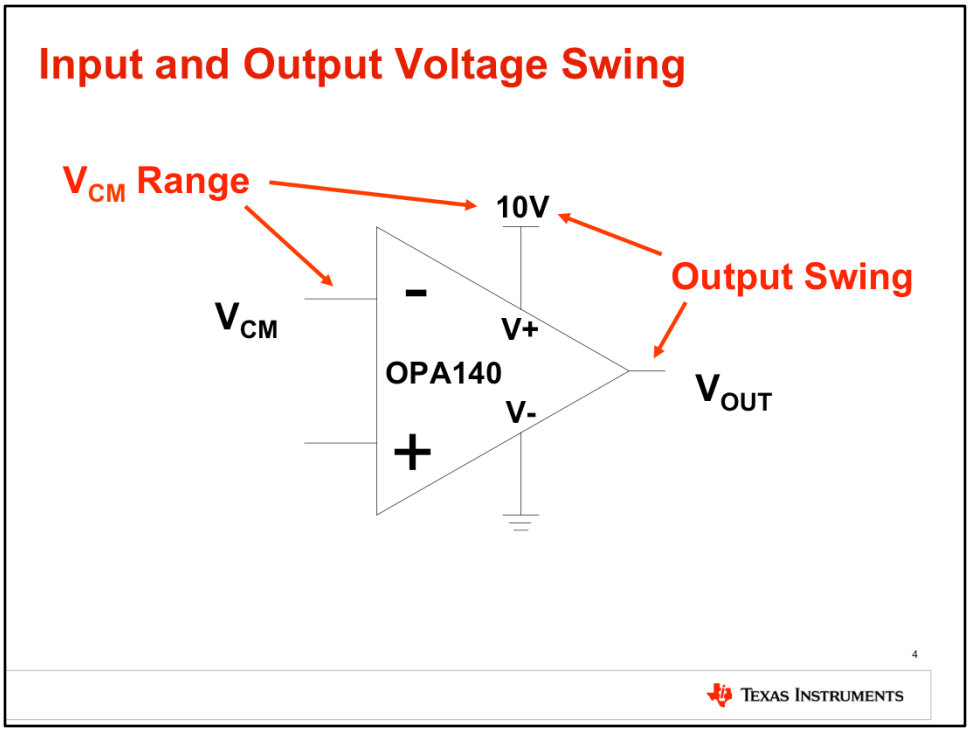


Lets start by considering this simple non-inverting buffer circuit. An triangle-wave input signal of +/- 1.5V is applied to the non-inverting input, and one might expect the output to look exactly the same. For some reason, the op amp output does not increase past +1V. This type of nonlinearity is called "clipping."

What is causing this clipping behavior? We'll answer this question later in the lecture, but first let's define some terms that are necessary to properly understand this issue.



Common mode voltage is defined as the average voltage which is applied to the two inputs of an amplifier. In the case of an op amp, the two inputs are at the practically same potential, with only a small offset between them. So, effectively you can see the common mode voltage on either input.

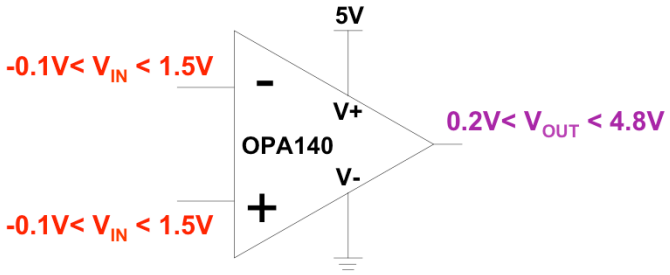


Common mode input voltage range is also known as input voltage swing. This term describes the range of input common mode voltages that can be used for normal linear operation of the amplifier. The common mode input voltage range is always defined relative to the positive supply and the negative supply. When you exceed the common mode input range, the output becomes nonlinear.

Output voltage swing is the range of output voltages that allow for linear operation of output signals. Output swing is also defined relative to the power supplies. The output signal becomes distorted and non-linear if you exceed the op amp's output swing specifications.

Translating the Data Sheet

Parameter	Conditions	Min	Typ	Max	Unit
Input Voltage Range					
Common-Mode Voltage Range V_{CM}		(V-) – 0.1V		(V+)-3.5	V
Output					
Voltage Output V_{OUT}	RL = 10kΩ, AOL ≥ 108dB	(V-) + 0.2V		(V+)-0.2V	V



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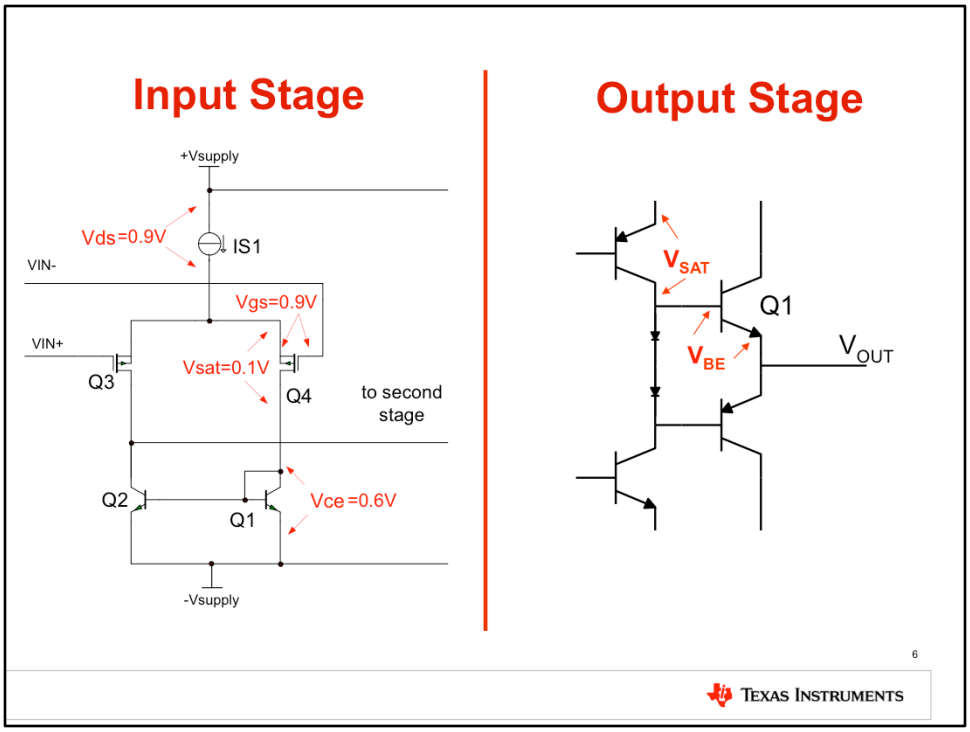
Let's look at how common mode voltage and input and output voltage swing are typically defined on a data sheet.

The common mode voltage range is defined here with the minimum and maximum limits given relative to the power supplies. The negative supply, V-, is zero volts in this case, so zero volts minus 0.1V gives us -0.1V for the minimum common mode limitation. The positive supply, V+, is 5V, so 5V minus 3.5V gives us 1.5V for the maximum common mode limitation. Therefore, applying an input common mode voltage below -0.1V or above 1.5V will result in nonlinear output.

The output swing is given here, and it's the same type of definition which is relative to the supply voltages. The minimum output voltage is V- + 0.2V, or 0.2V in this case, and the maximum output voltage is V+ - 0.2V, or 4.8V. Driving the output below 0.2V or above 4.8V will cause the output to become nonlinear.

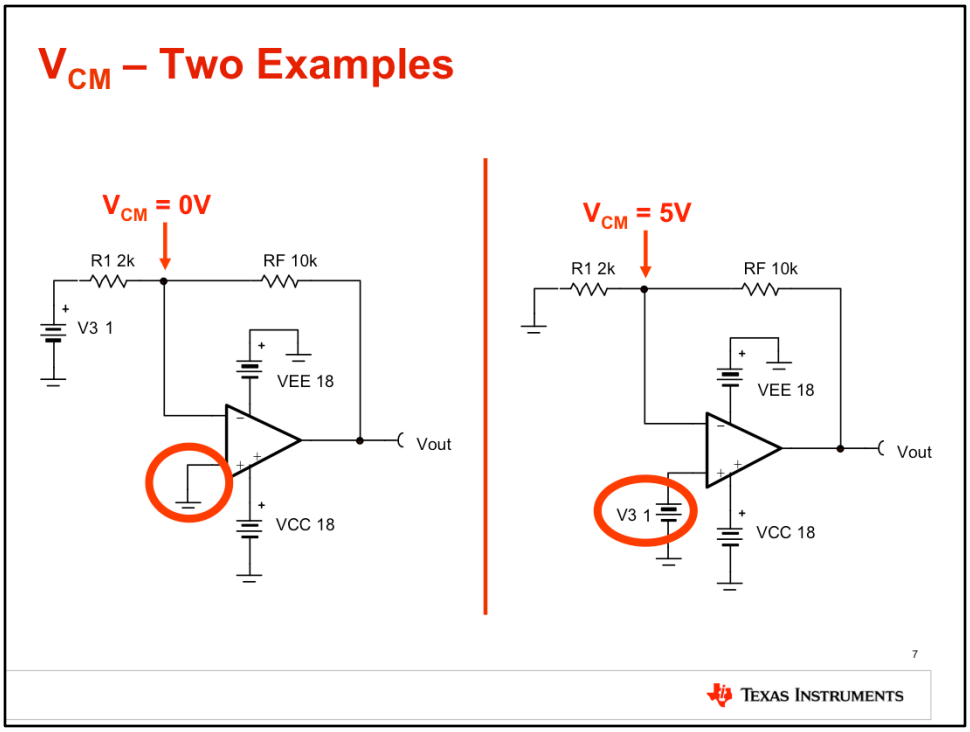


Let's discuss what elements inside the amplifier actually cause the input and output limitations.

On the left you can see a typical CMOS input stage. As the common mode input signal approaches either the positive or negative supply, the input transistors will either saturate or cutoff. Saturation and cutoff are both nonlinear modes of operation, so the amplifier cannot linearly amplify the input signal. This is what causes the common mode input voltage limitation. Please keep in mind that some CMOS amplifiers have common mode limitations which are very near or even beyond the power supply rails.

The output stage voltage swing limitation caused by the saturation and diode drops on internal transistors. CMOS amplifiers tend to have better output voltage swing limitations, because CMOS transistors can have lower saturation voltages.

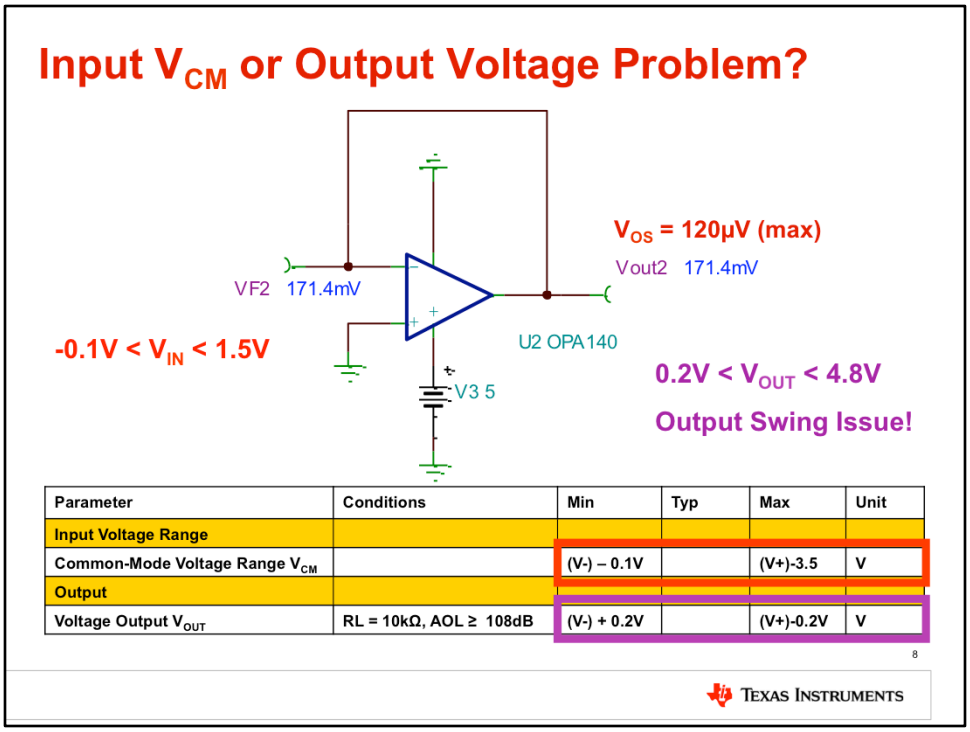
Amplifiers which can accept common mode input voltage ranges up to the power supply rails, and can swing the output voltage near the supply rails, are referred to as rail-to-rail amplifiers.



Here are two example circuits which have very different common mode considerations.

The op amp in the circuit on the left is in an inverting configuration, and notice that the non-inverting input is connected to GND, or 0V. Because of the basic properties of op amps, the inverting input will also be at approximately 0V. Therefore, the common mode input voltage of this circuit is 0V, and stays at a constant 0V regardless of the input signal. This is a good topology to use to avoid common mode limitations.

The op amp in the circuit on the right is in a non-inverting configuration, and the input signal is connected to the non-inverting input. The input signal and the common mode signal will track each other – in other words, when the input signal changes, the common mode signal will also change. Care must be taken in this configuration to avoid exceeding the common-mode voltage limitations of the amplifier.



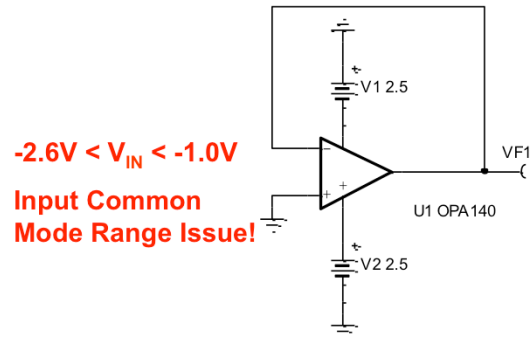
Let's now consider a real-world circuit example.

We have an op amp in a basic buffer configuration. One might expect to see 0V at the output, or a small offset depending on the V_{OS} specification of the device. However, after running a DC simulation we see that the output is almost 200mV! The maximum V_{OS} is only 120µV, so what's the problem?

First let's look at the input common mode range. Using the same technique as before, we can compute the common mode range to be from -0.1V to 1.5V. The input is connected to GND, or 0V, which is between the common mode limits of -0.1V and 1.5V, so there is no common mode input voltage violation.

Now let's look at the output voltage swing range. Again, we can compute the output range to be from 0.2V to 4.8V. Based on the input signal, the amplifier wants to drive the output to 0V, but this is below the minimum output of 0.2V! Therefore the output voltage range is being violated, which causes the actual output to clip nearly the 0.2V limit, at 171mV.

Input V_{CM} or Output Voltage Problem?



V_{OS} = 120µV (max)

-2.6V < V_{IN} < -1.0V

Input Common Mode Range Issue!

-2.3V < V_{OUT} < 2.3V

Parameter	Conditions	Min	Typ	Max	Unit
Input Voltage Range					
Common-Mode Voltage Range V_{CM}		(V-) – 0.1V		(V+)-3.5	V
Output					
Voltage Output V_{OUT}	RL = 10kΩ, AOL ≥ 108dB	(V-) + 0.2V		(V+)-0.2V	V

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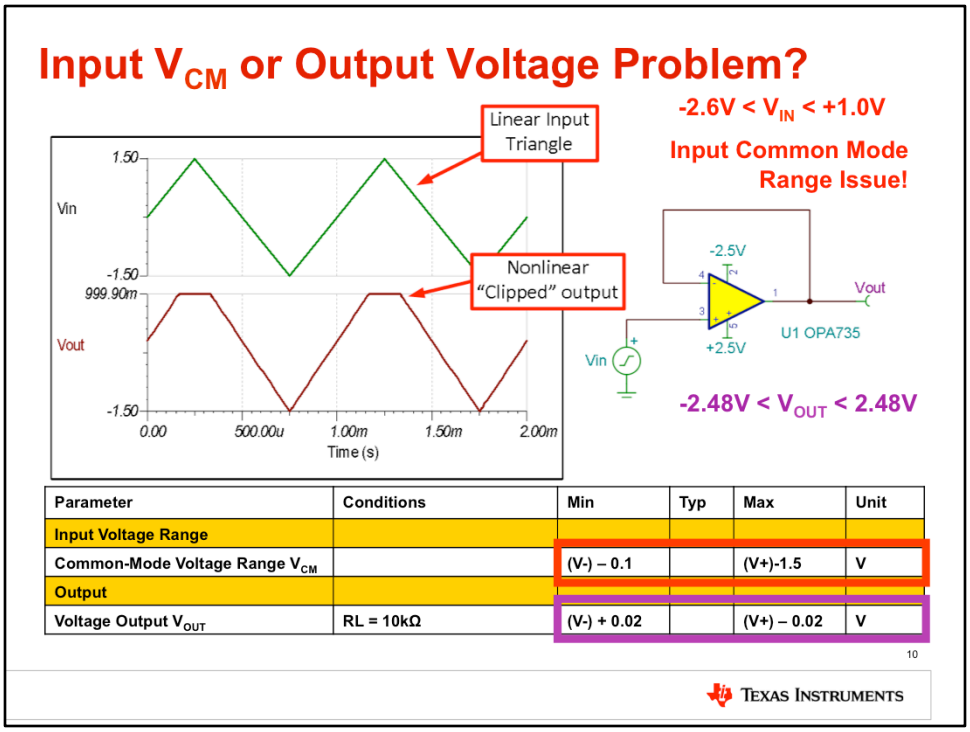
Lets look at another example. Note that this circuit has a different power supply arrangement, where the supplies are +/-2.5V.

Let's first consider the output voltage range. Using the data sheet specifications and the given power supply voltages, the output range is calculated to be from -2.3V to +2.3V. The amplifier wants to drive the output to zero 0V, and zero is inside the output range, so this circuit does not have an output voltage swing violation.

What about the input? The applied input common mode voltage is zero volts as in the previous circuit, but the input common mode voltage range is now from -2.6V to -1V. 0V is above that range, so we have a violation of the input common mode range. That is why we see hundreds of millivolts at the output, rather than microvolts.

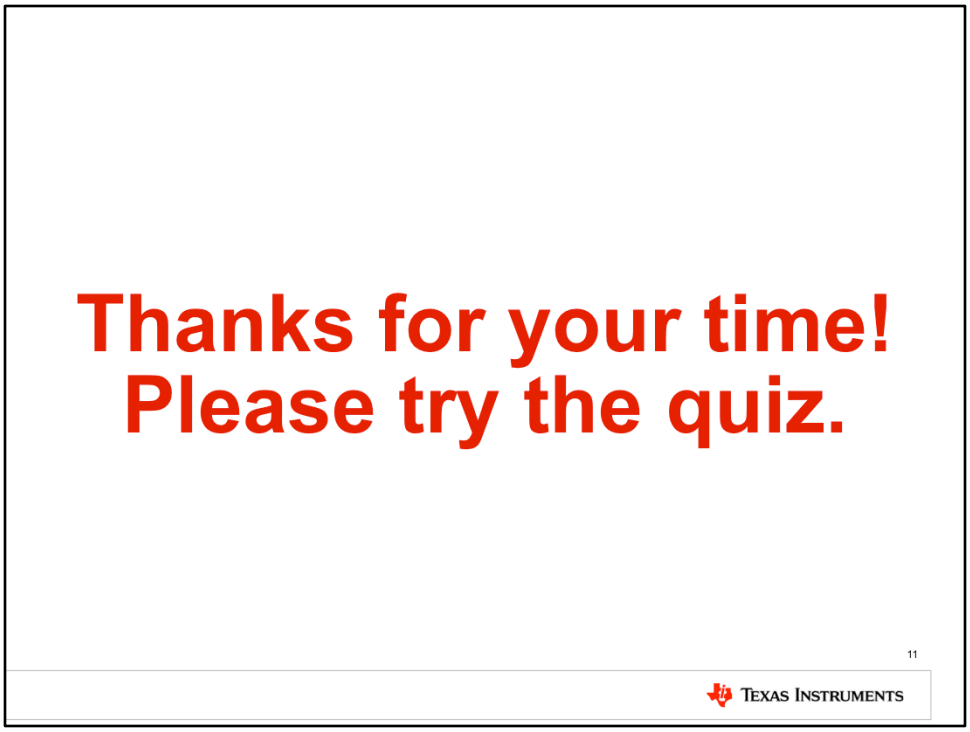


Parameter	Conditions	Min	Typ	Max	Unit
Input Voltage Range					
Common-Mode Voltage Range V_{CM}		(V-) – 0.1		(V+)-1.5	V
Output					
Voltage Output V_{OUT}	RL = 10kΩ	(V-) + 0.02		(V+) – 0.02	V

Finally, let's return to our original problem of output voltage clipping past 1V on the OPA735.

Let's first consider the output voltage range. Using the data sheet specifications and the given power supply voltages, the output range is calculated to be from -2.48V to +2.48V. The amplifier wants to drive the output from -1.5V to +1.5V, which is within the normal output range, so this circuit does not have an output voltage swing violation.

What about the input? Again, using the data sheet specifications, the allowed common-mode voltage range is calculated to be from -2.6V to +1V. Because this op amp is in a non-inverting buffer configuration, the VCM tracks the input, which is from -1.5V to +1.5V. Since the maximum VCM is +1V, we are exceeding the maximum by applying a triangle wave up to +1.5V. This violates the input common mode range and saturates the input stage transistors, so the output clips at 1V.



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

Input and Output Limitations

Multiple Choice Quiz

TI Precision Labs – Op Amps

Quiz: Input and Output Limitations

1. An amplifiers common mode voltage is ____.

a. The maximum input voltage.
b. The minimum input voltage.
c. The average of the voltage applied to the inputs.
d. The differential input voltage.

2. Exceeding the common mode input range will ____.

a. Cause a nonlinear response.
b. Cause damage to the device.
c. Draw excessive current.
d. Limit the circuits bandwidth.

3. Input and output swing limitations _____.

a. Are given relative to the power supplies.
b. Guidelines for preventing damage to the devices.
c. Calculated using ohms law.
d. Are only valid for dc signals.

Quiz: Input and Output Limitations

4. An inverting op amp configuration has a constant common mode voltage regardless of the input signal.

a. True
b. False

5. An non-inverting op amp configuration has a constant common mode voltage regardless of the input signal.

a. True
b. False

6. A rail-to-rail input amplifier allows common mode signals _____.

a. Near ground
b. Near the positive power supply
c. That cover the full range from positive to negative supply.
d. To be applied without damaging the device.

Quiz: Input and Output Limitations

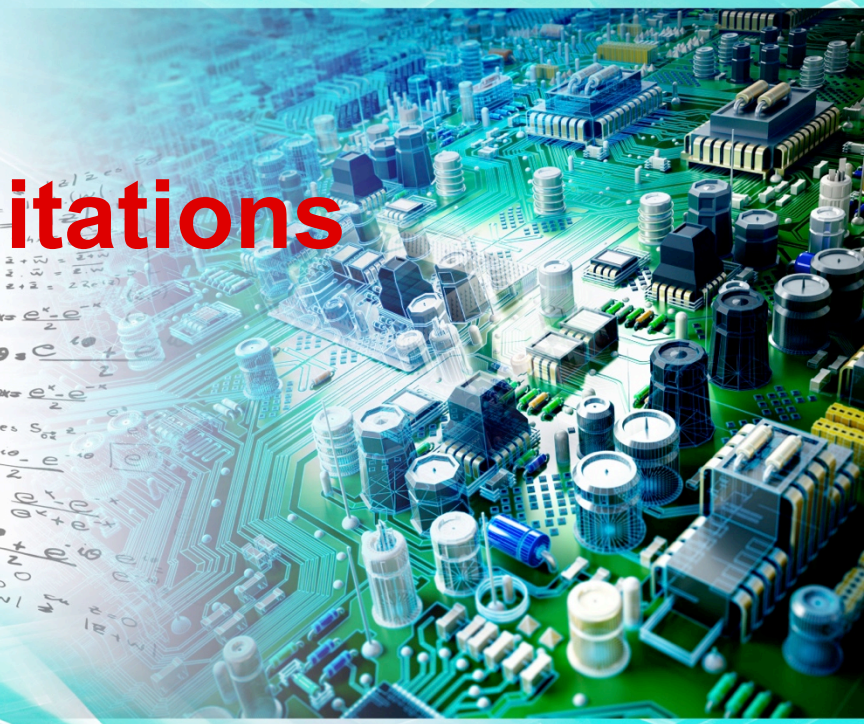
7. What causes the common mode limitations in amplifiers?

a. Overheating semiconductor junctions and ESD diodes.
b. Internal capacitance and inductance.
c. Transistor and polysilicon resistor scaling.
d. Saturation and cutoff of transistors in the input stage.

Input and Output Limitations

Multiple Choice Quiz: Solutions

TI Precision Labs – Op Amps



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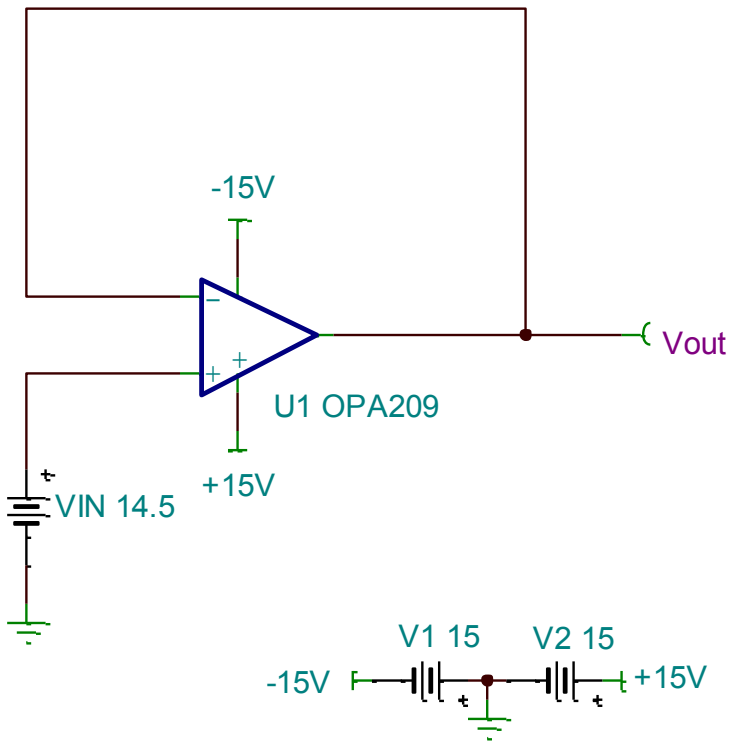
Input and Output Limitations

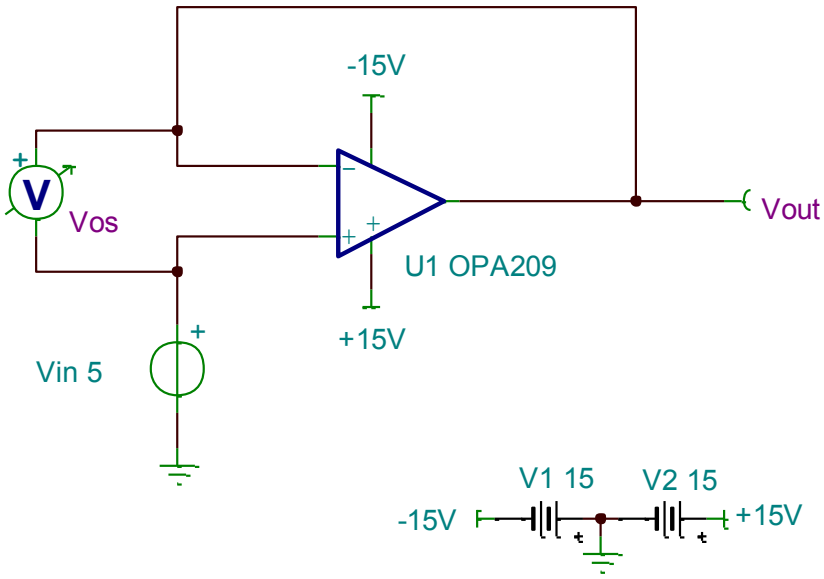
Exercises

TI Precision Labs – Op Amps

1. Does the circuit below violate the common mode range, output swing, or is it operating linearly. Test the result with Tina Spice.



2. Using Tina Spice: Do a linear voltage sweep on Vin from -15V to +15V. Looking at Vout, where do you see the output become non-linear? Looking at Vos, where do you see a significant change? How well does the model match the data sheet specifications?



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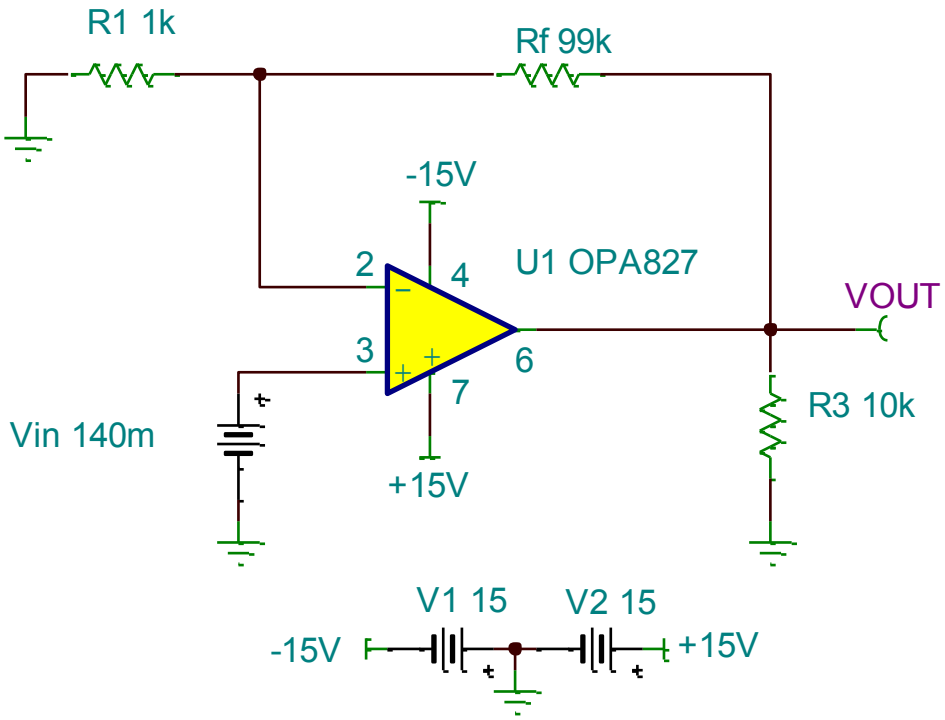
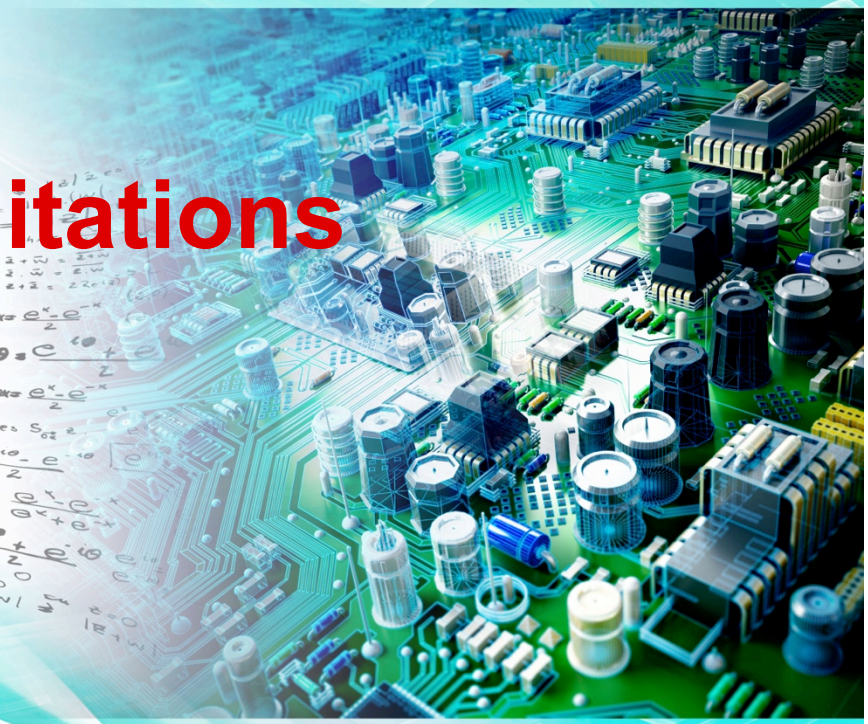


Input and Output Limitations

Solutions

TI Precision Labs – Op Amps

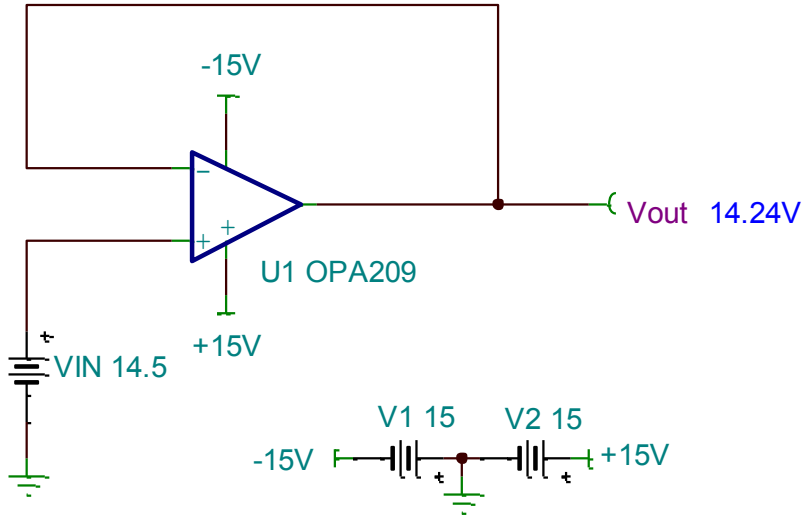


1. The input violates the input common mode range (i.e. 14.5V > 13.5V). It does not violate the output swing range (i.e. 14.5V < 14.8V). The simulation confirms that the amplifier is no longer linearly amplifying the input. If the circuit were operating properly, you would expect the output to be 14.24V (nonlinear).

Output voltage range is
-14.8V < Vout < +14.8V

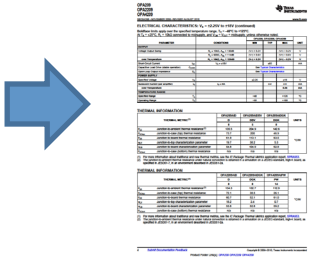
PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
Voltage Output Swing		R_L = 10kΩ, A_{OL} > 130dB	(V–) + 0.2V		(V+) – 0.2V	V
		R_L = 600Ω, A_{OL} > 114dB	(V–) + 0.6V		(V+) – 0.6V	V
INPUT VOLTAGE RANGE						
Common-Mode Voltage Range	V_{CM}		(V–) + 1.5V		(V+) – 1.5V	V

Input common mode range is
-13.5V < Vin < +13.5V

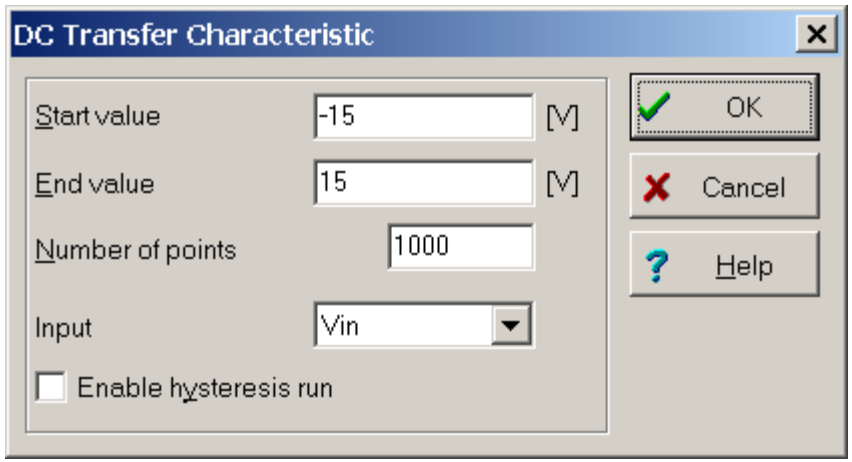


1130 - Input and Output Limitations - Problem 1.TSC

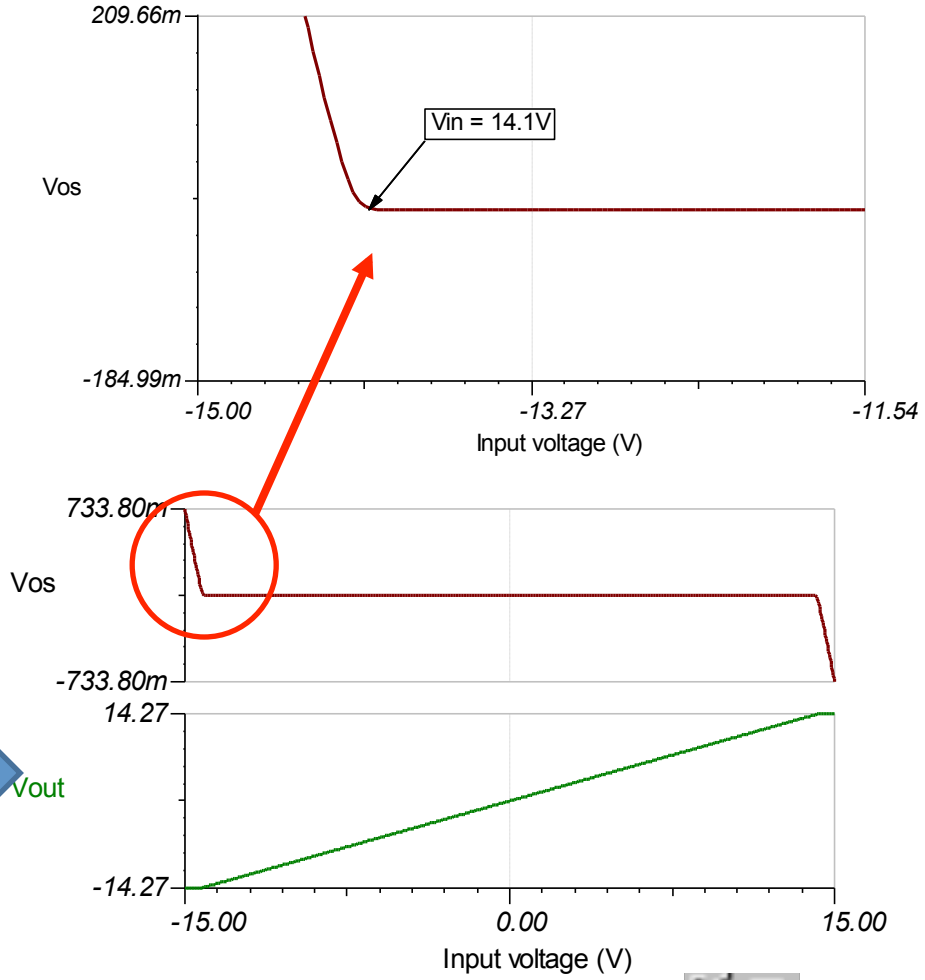
OPA209
Data Sheet



2. The simulation show nonlinearity when the common mode signal is greater then 14.1V. From the data sheet you would expect that the device would become nonlinear at 13.5V. So this model common mode range is wider then the data sheet worst case range.



Run the dc transfer characteristic and get this result. Zoom in on offset to see where the circuit becomes nonlinear.

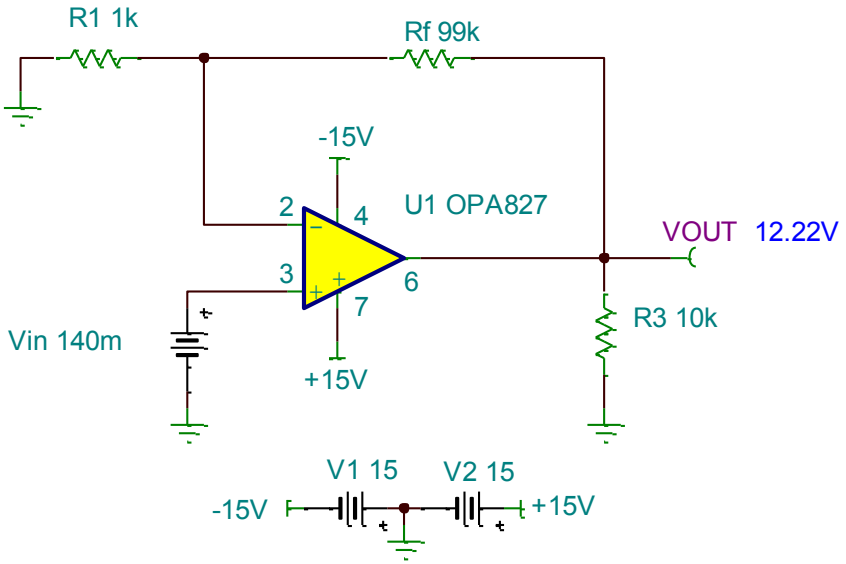


3. The expected output is 14V (i.e. 140mV x 100 = 14V). The input is inside the valid common mode range (Vin = 140mV, input range is -12V < Vin < 12V). The expected output is outside the output swing range (Vout = 14V, -12V < Vout < 12V). The simulation confirms that the output is not in the linear range.

Output voltage range is
-12V < Vout < +12V

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT					
Voltage Output Swing	R_L = 1kΩ, A_{OL} > 120dB	(V–)+3		(V+)–3	V
Over Temperature	**R_L = 1kΩ, A_{OL} > 114dB**	**(V–)+3**		**(V+)–3**	**V**
INPUT VOLTAGE RANGE					
Common-Mode Voltage Range V_{CM}		(V–)+3		(V+)–3	V

Input common mode range is
-12V < Vin < +12V



1130 - Input and Output Limitations – Problem 3.TSC

OPA209
Data Sheet