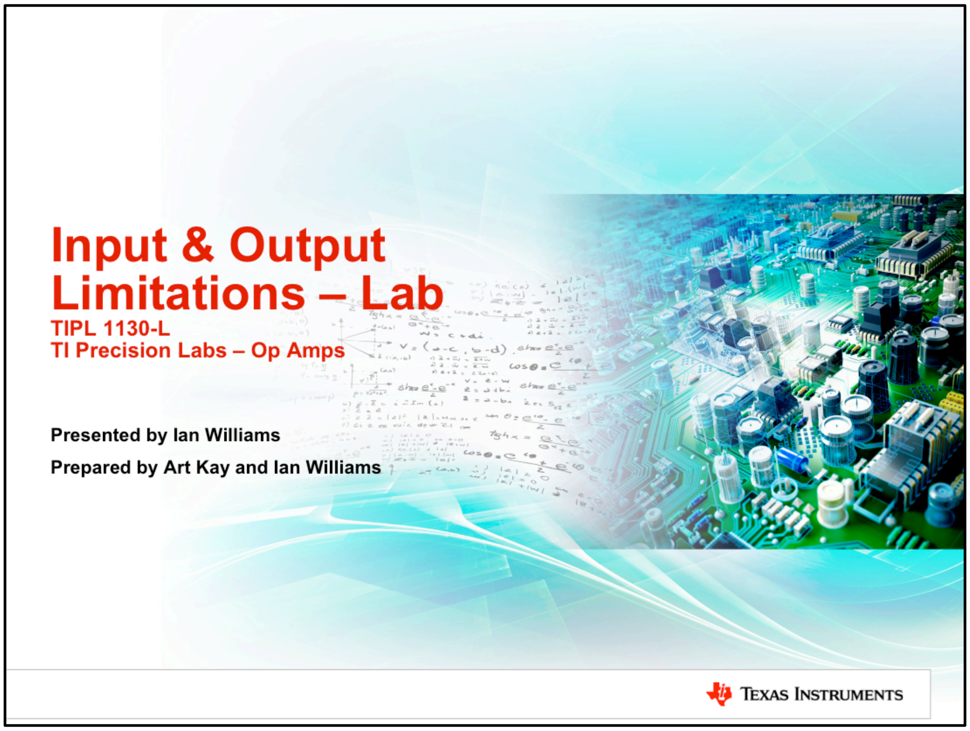


Hello, and welcome to the TI Precision Lab supplement for op amp input and output limitations. This lab will walk through detailed calculations, SPICE simulations, and real-world measurements that greatly help to reinforce the concepts established in the op amp input and output limitations lecture.

Required/Recommended Equipment

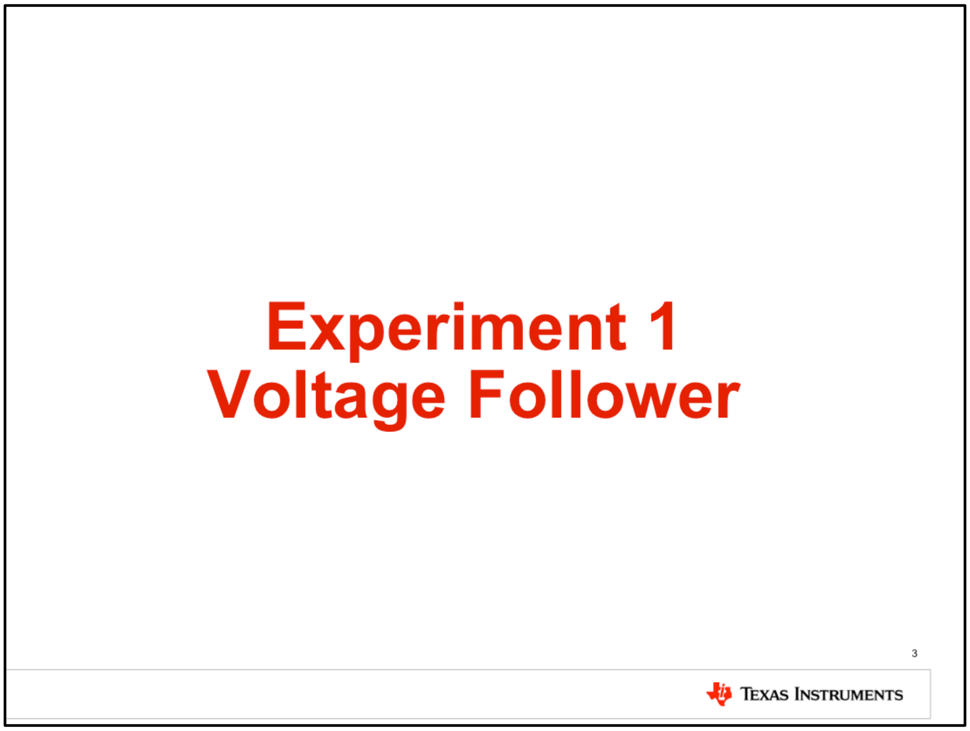
- Calculation
  - Pencil and paper
  - **Recommended:** MathCAD, Excel, or similar
- Simulation
  - SPICE simulation software
  - **Recommended:** TINA-TI™
- Measurement
  - TI Precision Labs PCB from Texas Instruments
  - Oscilloscope
  - Function generator
  - ±5V power supply
  - **Recommended:** National Instruments VirtualBench™

Texas Instruments 2

The detailed calculation portion of this lab can be done by hand, but calculation tools such as MathCAD or Excel can help greatly.

The simulation exercises can be performed in any SPICE simulator, since Texas Instruments provides generic SPICE models of the op amps used in this lab. However, the simulations are most conveniently done in TINA-TI, which is a free SPICE simulator available from the Texas Instruments website. TINA simulation schematics are embedded in the presentation.

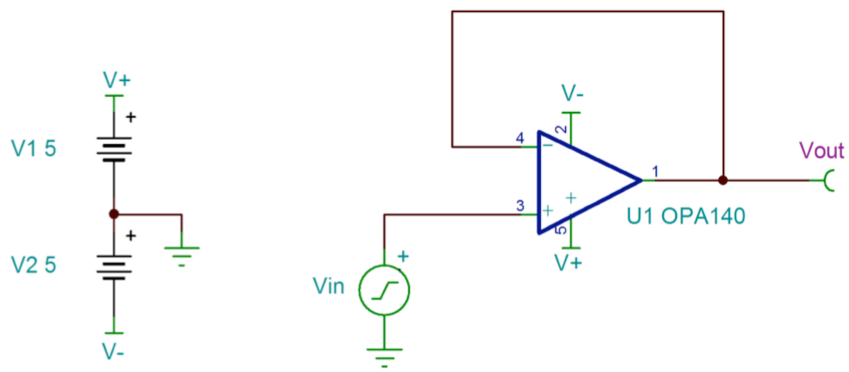
Finally, the real-world measurements are made using a printed circuit board, or PCB, provided by Texas Instruments. If you have access to standard lab equipment, you can make the necessary measurements with any oscilloscope, function generator, and ±5V power supply. However, we highly recommend the VirtualBench from National Instruments. The VirtualBench is an all-in-one test equipment solution which connects to a computer over USB or Wi-Fi and provides power supply rails, analog signal generator and oscilloscope channels, and a 5 ½ digit multimeter for convenient and accurate measurements. This lab is optimized for use with the VirtualBench.



In experiment 1, we'll determine the effects of input and output limitations in a basic voltage follower, or unity-gain buffer, circuit.

Calculation – Voltage Follower

Calculate the input common mode voltage range and output voltage swing for the circuit shown below. Use the data sheet parameters given on the next slide.



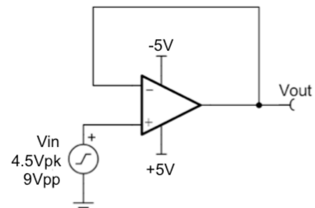
TEXAS INSTRUMENTS

First, calculate the input common mode voltage range and output voltage swing for the circuit shown here, using the techniques and equations given in the input/output limitations lecture. Use the data sheet parameters given on the next slide.

Calculation – Voltage Follower

PARAMETER		OPA140			
		MIN	TYP	MAX	UNIT
Input Voltage Range	V_{CM}	(V-) – 0.1		(V+) – 3.5	V
Voltage Output Swing from Rail	V_O	(V-) + 0.2		(V+) – 0.2	V

Calculated Answers	Min	Max
Common Mode Input Range	-5.1	+1.5V
Output Swing Range	-4.8	4.8V



With a 9Vpp (4.5Vpk) input signal, is the circuit limitation caused by input common mode range or output voltage swing?

Answer:	The maximum input common mode voltage of +1.5V is the limit, since the peak input signal is +4.5V.

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Texas Instruments

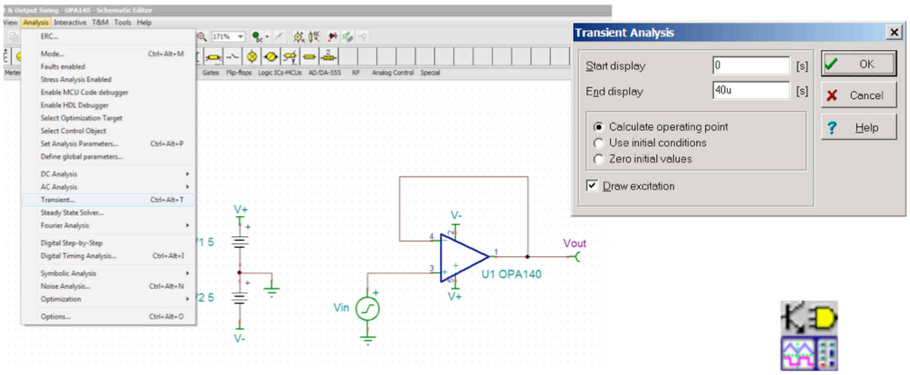
This circuit uses the OPA140. In order to perform the calculations, you need to know the input voltage range and voltage output swing values for that device. Those values are given here.

Enter your answers in the table in the middle of the slide. The solutions are already provided to allow you to check your work.

Also answer the question at the bottom of the slide. Again, the solution is already provided.

Simulation Setup – Voltage Follower

Click **Analysis → Transient** to show the common mode limitations for the OPA140. Run the analysis from 0µs to 40µs. The input is a 4.5Vpk, 50kHz triangle wave.



1130-L – Input and Output Limitations - OPA140.TSC

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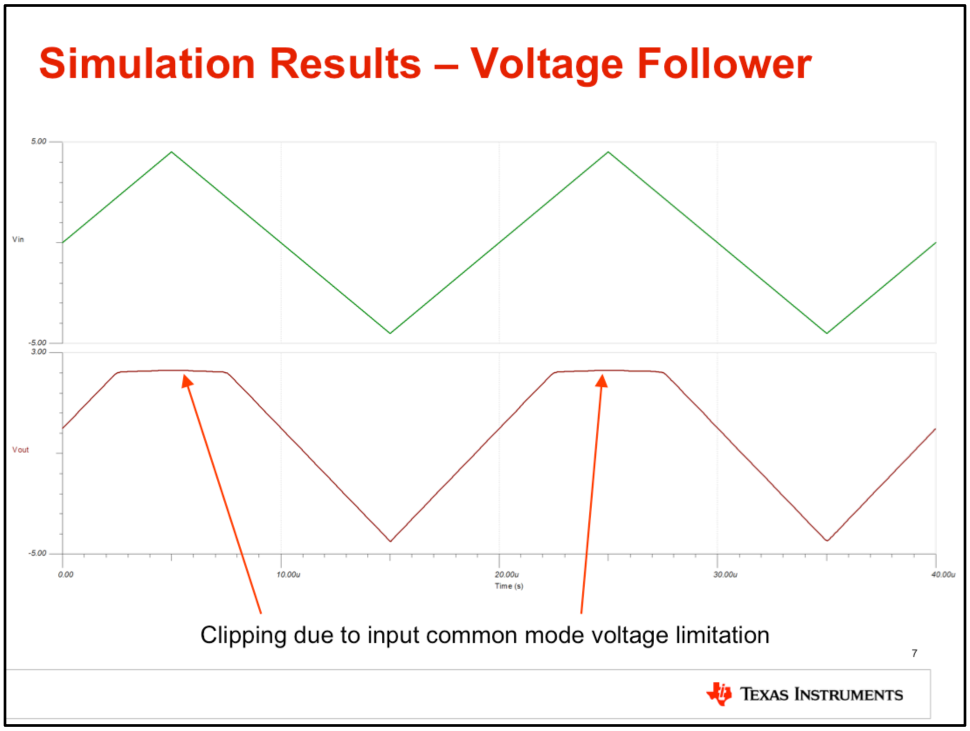
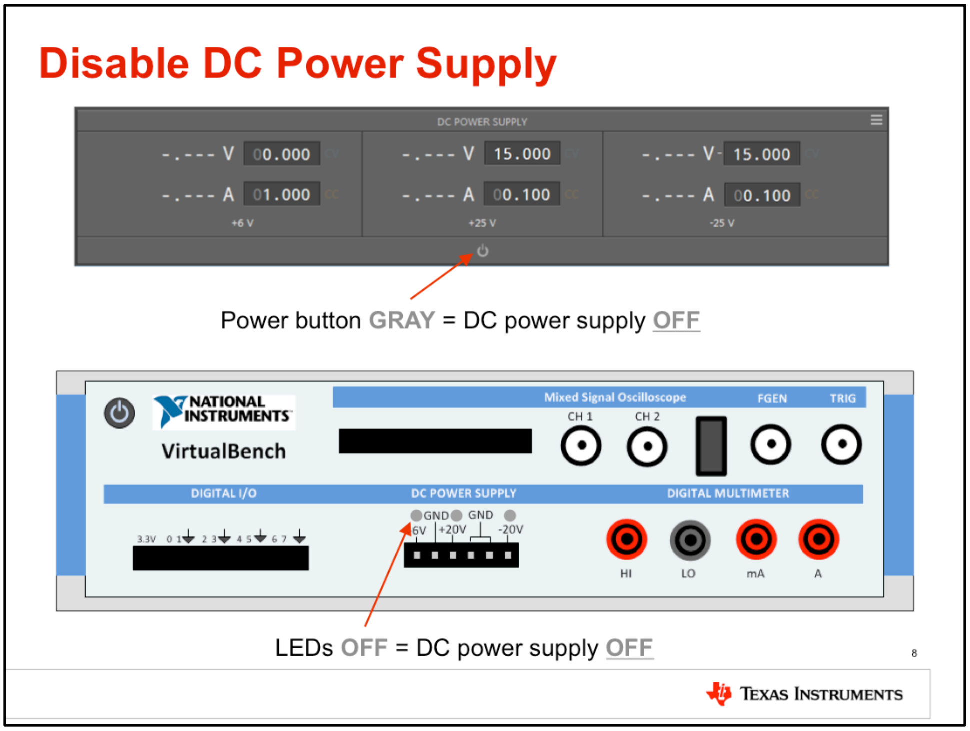
Texas Instruments

The next step is to run a SPICE simulation analysis for the transient output voltage behavior. This will allow us to see the op amp's output voltage response for a specified input signal, which in this case is a 4.5Vp, 50kHz triangle wave.

The necessary TINA-TI simulation schematic is embedded in this slide set – simply double-click the icon to open it. To simulate the transient output behavior, click Analysis → Transient. Run the analysis from 0 to 40us.

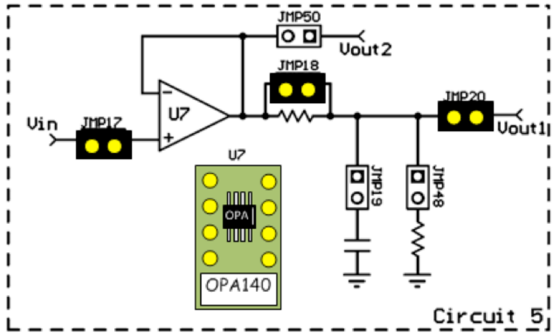


You should see a result similar to this. Vin is a triangle wave, as expected, but Vout cannot exceed +1.5V. This is due to the input common mode voltage limitation of the OPA140.



Make sure to disable the DC power supply before setting up the test PCB! In the VirtualBench software, click the power button in the DC Power Supply area to turn off the power. Check the front panel of the VirtualBench unit to make sure the LEDs are OFF! Also make sure the Function Generator is OFF!

Test Board Setup – Jumpers



Jumper, Device	Description
JMP17	Connect input to signal source.
JMP18	Short output resistance
JMP20	Connect Circuit 5 output to Vout1
U7	Install OPA140

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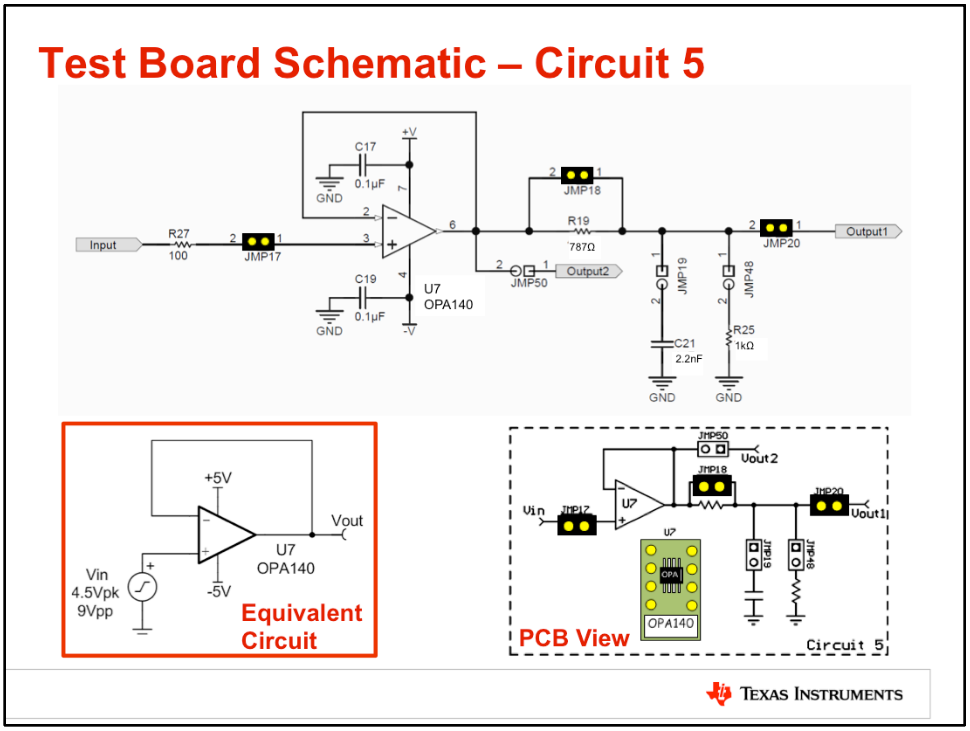
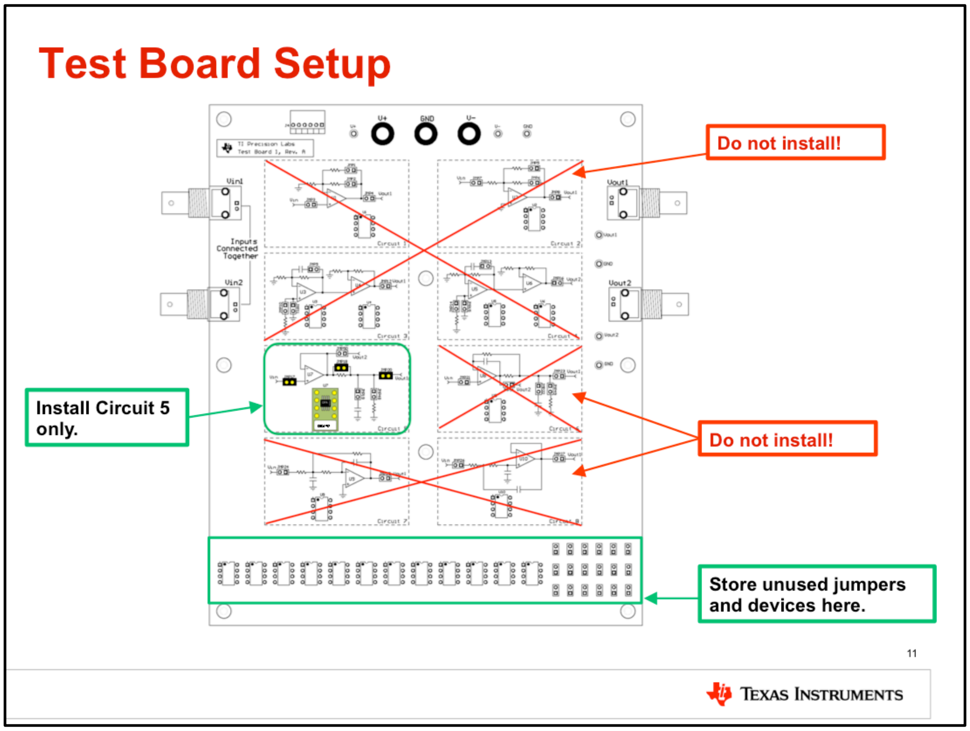
Texas Instruments

To prepare the test board for the measurement, install the jumpers and devices on circuit 5 as shown here.

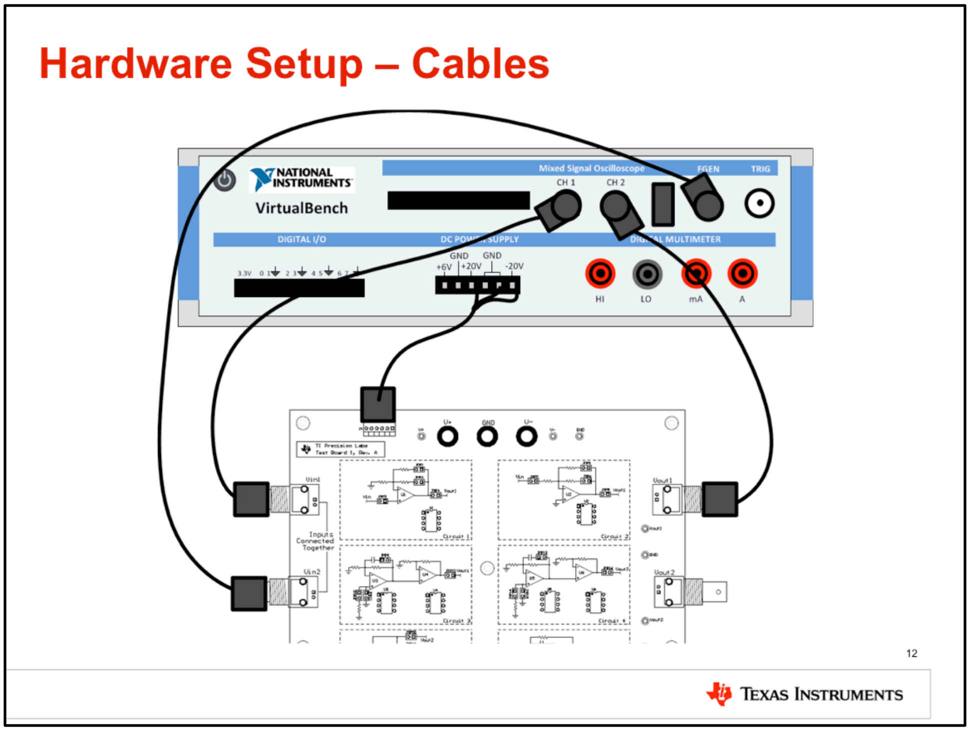
Install JMP17, JMP18, and JMP20, as well as the OPA140 in socket U7.



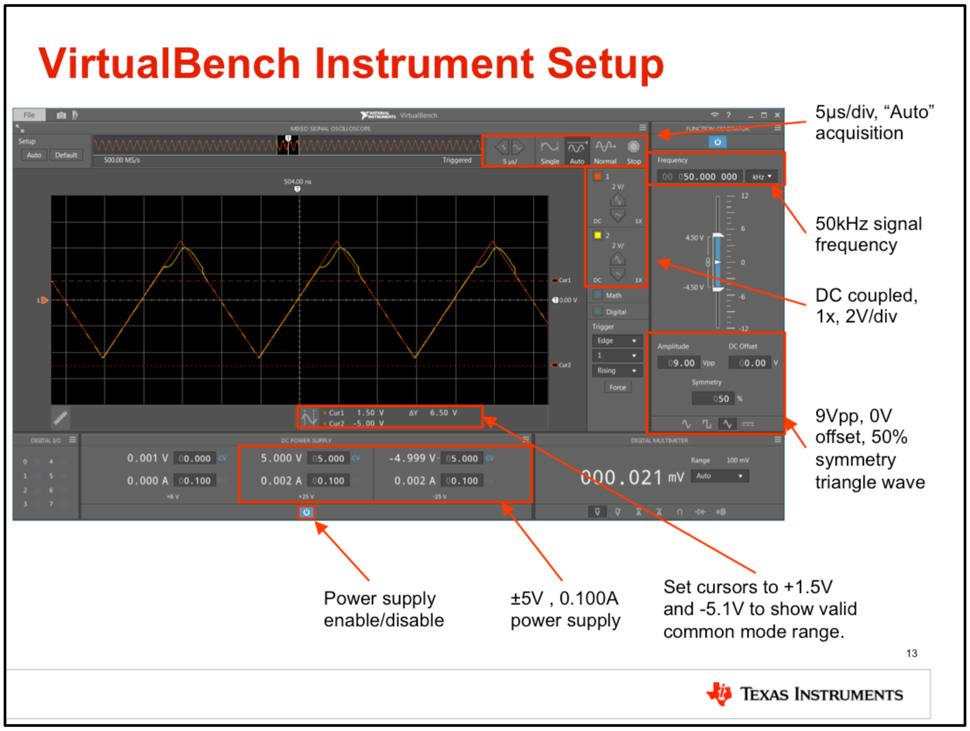
This slide shows the full schematic for Circuit 5 on the TI Precision Labs test board. You will use this circuit to measure the effect of input and output voltage range limitations on the OPA140.



For the test board to function properly, it is important that you only install jumpers and devices in circuit 5. Do not install any jumpers or devices in any other circuits on the PCB! Remove any jumpers or devices from the unused circuits and store them in the storage area at the bottom of the test board.



This slide gives the connection diagram between the TI Precision Labs test board and the National Instruments VirtualBench. Connect the provided power cable to the DC power supply of the Virtual Bench and power connector J4 on the test board. Connect Vin2 on the test board to VirtualBench channel FGEN, or function generator. Then connect Vin1 on the test board to VirtualBench oscilloscope channel 1, and Vout1 on the test board to VirtualBench oscilloscope channel 2.



Next apply power to the National Instruments VirtualBench and connect it to your computer with a USB cable. The hardware should be detected as a virtual CD drive, and you can run the VirtualBench software directly from the drive. Once the software opens, configure the software as follows:

Set the time scale to 5us per division, with the acquisition mode set to "Auto." Enable channels 1 and 2 on the oscilloscope, and set them to 1x, DC-coupled mode, 2V/div. Enable the function generator and setup the signal as follows:

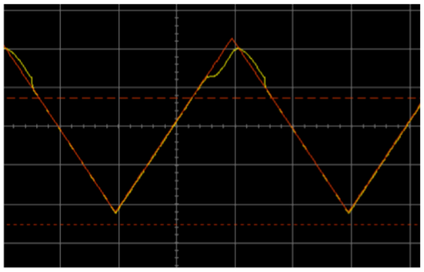
50kHz frequency, 9Vpp, 0V offset, 50% symmetry triangle wave.

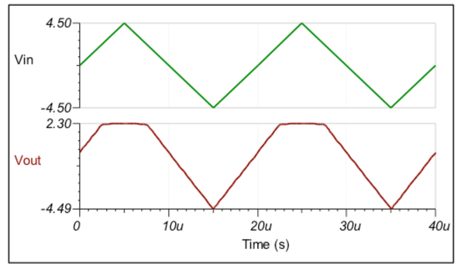
Enable the cursors and set them to +1.5V and -5V to show the valid input common mode range.

Set the +25V power supply to +5V, 0.100A. Set the -25V power supply to -5V, 0.100A. Press the power button to turn on the power supply rails.

Measurement Results – Voltage Follower

1. Compare TINA-TI™ simulation results to measured results.





2. Use the cursors on the VirtualBench and TINA-TI™ tool to measure the voltage where Vout becomes limited (clipped). Compare this to your calculation.

Answer (calculation):	clipped at +1.5V
Answer (simulation):	clipped at +2.3V
Answer (measurement):	visible distortion above +2.5V

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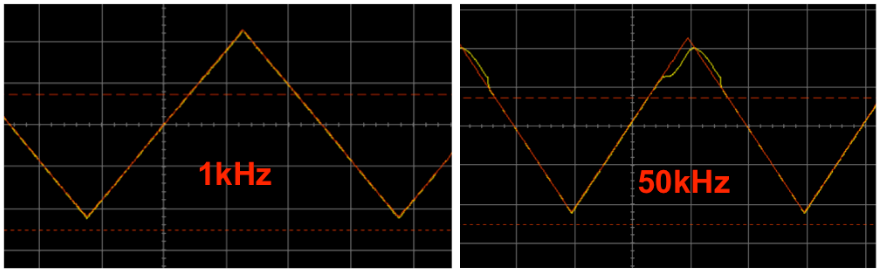
TEXAS INSTRUMENTS

The expected measurement results are shown here. Compare the oscilloscope display of the VirtualBench to the simulation results from TINA-TI. Also, use the cursors on the VirtualBench and TINA-TI tool to measure the voltage where Vout becomes limited, or clipped. Compare this to your calculation.

The results have already been entered into the table to allow you to check your results. You may have different results in your experiment.

Extra Experiment: 1kHz vs. 50kHz Input

3. Change the triangle waveform frequency to 1kHz and compare the common mode range to the 50kHz wave. Change the time scale to 200µs/div.



4. What conclusion do you draw from the measurement?

The 1kHz waveform does not show the common mode limitation, but the 50kHz waveform does. This device is actually “rail-to-rail” for low frequencies, but common mode performance ~2V from the positive rail degrades at higher frequencies.

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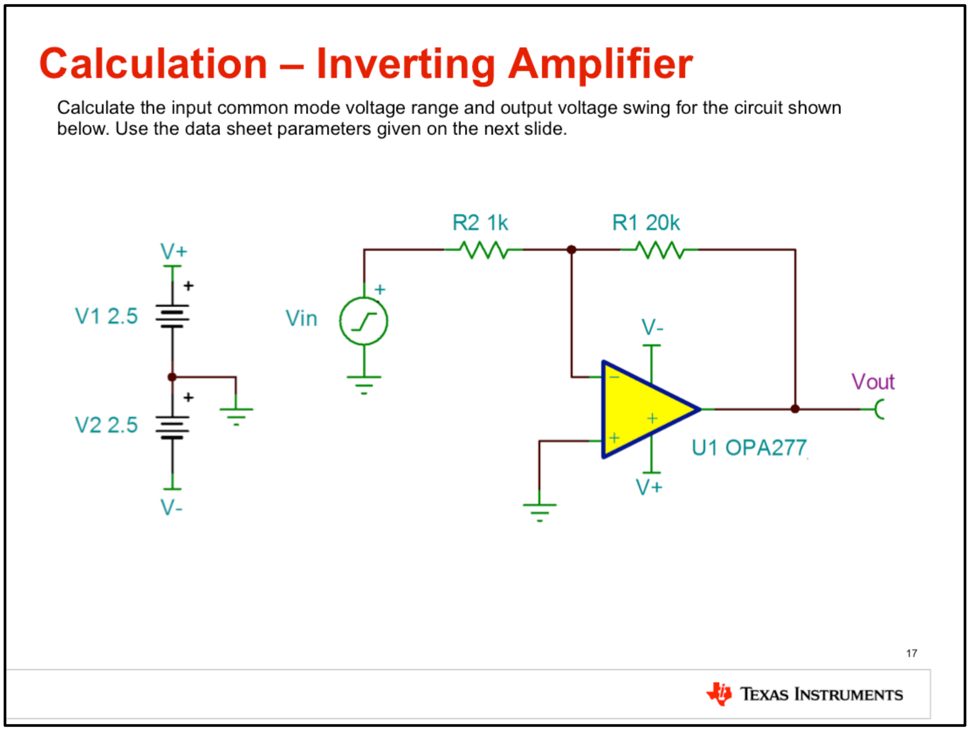
TEXAS INSTRUMENTS

As an extra experiment, you can change the input signal frequency to 1kHz, and change the time scale to 200us/div. Now compare the common mode range to the previous 50kHz input signal. What conclusion do you draw from the measurement?

As you can see, there is no noticeable distortion or clipping with the 1kHz signal. This is because the OPA140 is actually “rail-to-rail” for low frequencies, but at higher frequencies the common mode performance degrades at about 2V from the positive rail.

In experiment 2, we'll determine the effects of input and output limitations in an inverting amplifier circuit with gain.

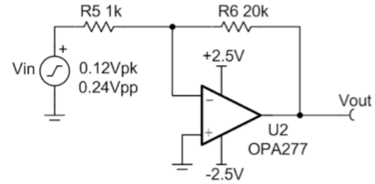


First, calculate the input common mode voltage range and output voltage swing for this inverting amplifier circuit, using the techniques and equations given in the input/output limitations lecture. Use the data sheet parameters given on the next slide.

Calculation – Inverting Amplifier

PARAMETER (data sheet)		CONDITION	OPA277			
			MIN	TYP	MAX	UNIT
Input Voltage Range	V_{CM}		(V-) +2		(V+) –2	V
Voltage Output	Vo	RL = 10kΩ	(V-) +0.5		(V-) –1.2	V
Voltage Output		RL = 2kΩ	(V-) +1.5		(V-) –1.5	

Answers	Min	Max
Common Mode Input Range	-0.5V	0.5V
Output Swing Range	-2.0V	1.3V



With a 0.24Vpp (0.12Vpk) input signal, is the circuit limitation caused by input common mode range or output voltage swing?

Answer:	The output wants to be ± 2.4Vpk. This violates both the negative and positive output swing limit. There's no issue with the input common mode range.

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Texas Instruments

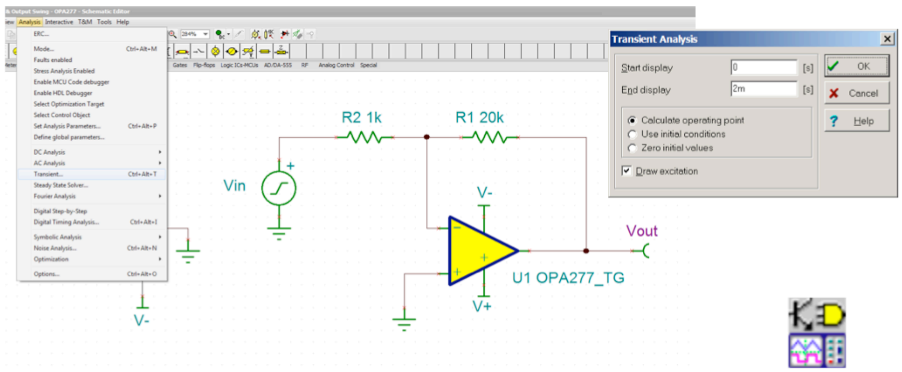
This circuit uses the OPA277. In order to perform the calculations, you need to know the input voltage range and voltage output swing values for that device. Those values are given here.

Enter your answers in the table in the middle of the slide. The solutions are already provided to allow you to check your work.

Also answer the question at the bottom of the slide. Again, the solution is already provided.

Simulation Setup – Inverting Amplifier

Click **Analysis → Transient** to show the common mode limitations for the OPA277. Run the analysis from 0ms to 2ms. The input is a 120mVpk, 1kHz triangle wave.



1130-L – Input and Output Limitations - OPA277.TSC

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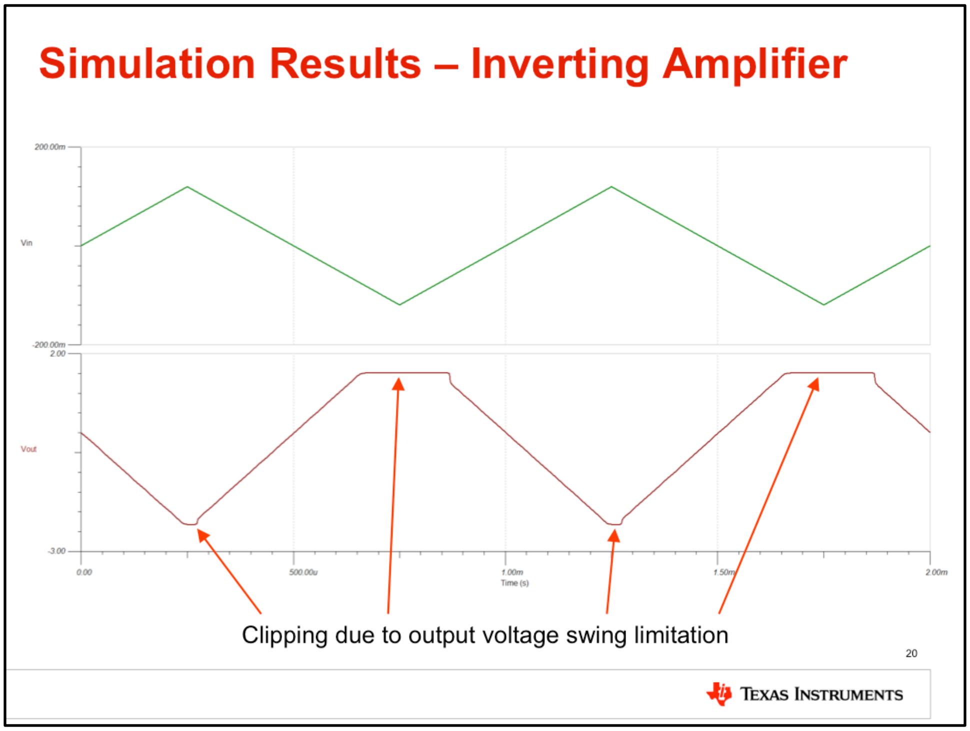
TEXAS INSTRUMENTS

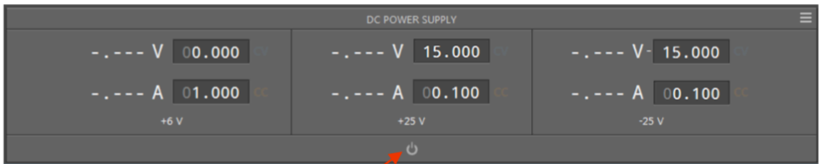
Run a SPICE simulation as before, but now using this inverting amplifier circuit with the OPA277.

The necessary TINA-TI simulation schematics are embedded in this slide set – simply double-click the icon to open them. Click Analysis → Transient and run the transient from 0ms to 2ms. The input signal to this circuit is a 120mVp, 1kHz triangle wave.

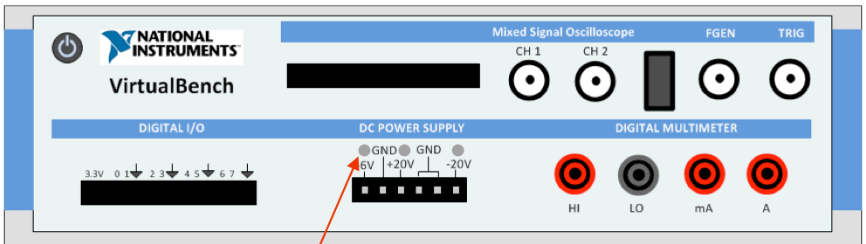


You should see a result similar to this. Vin is a triangle wave, as expected, but Vout clips at both the positive and negative ends of the triangle wave due to output voltage swing limitations.

Disable DC Power Supply



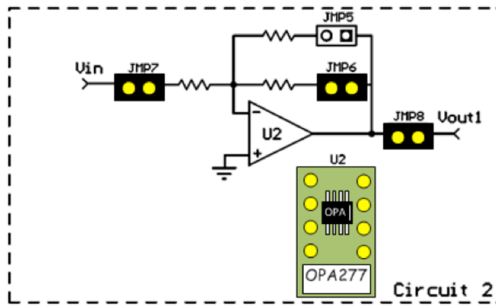
Power button GRAY = DC power supply OFF



LEDs OFF = DC power supply OFF

Make sure to disable the DC power supply before setting up the test PCB! In the VirtualBench software, click the power button in the DC Power Supply area to turn off the power. Check the front panel of the VirtualBench unit to make sure the LEDs are OFF! Also make sure the function generator is OFF!

Test Board Setup – Jumpers



Jumper, Device	Description
JMP6	Connect Rf = 20kΩ for a gain of 20V/V
JMP7	Connect input to signal source
JMP8	Connect Circuit 2 output to Vout1
U2	Install OPA277

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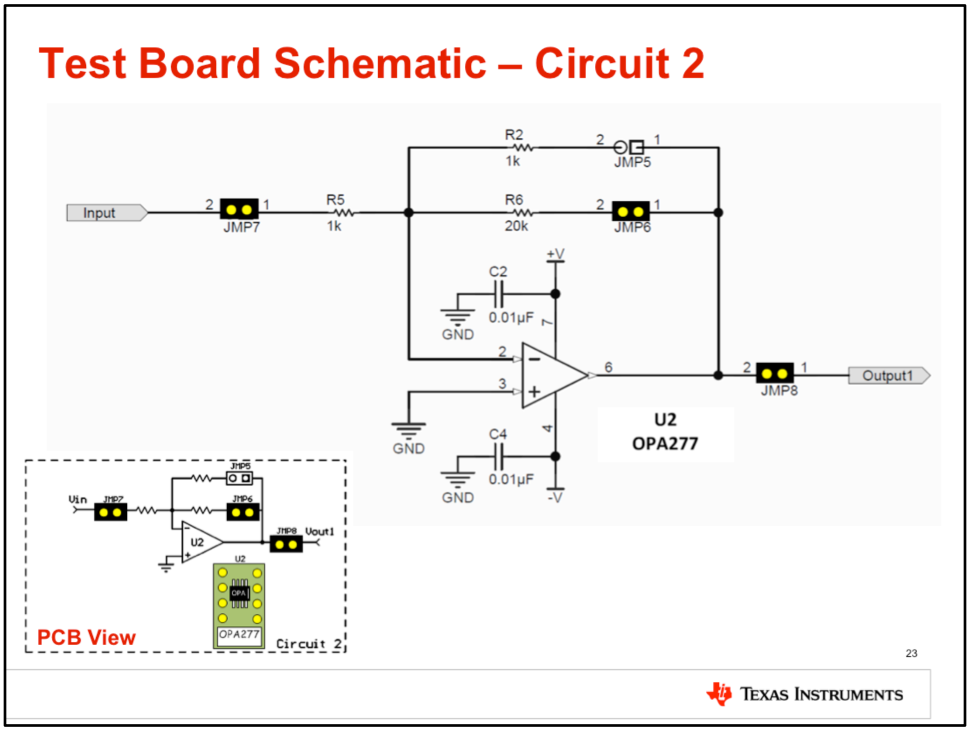
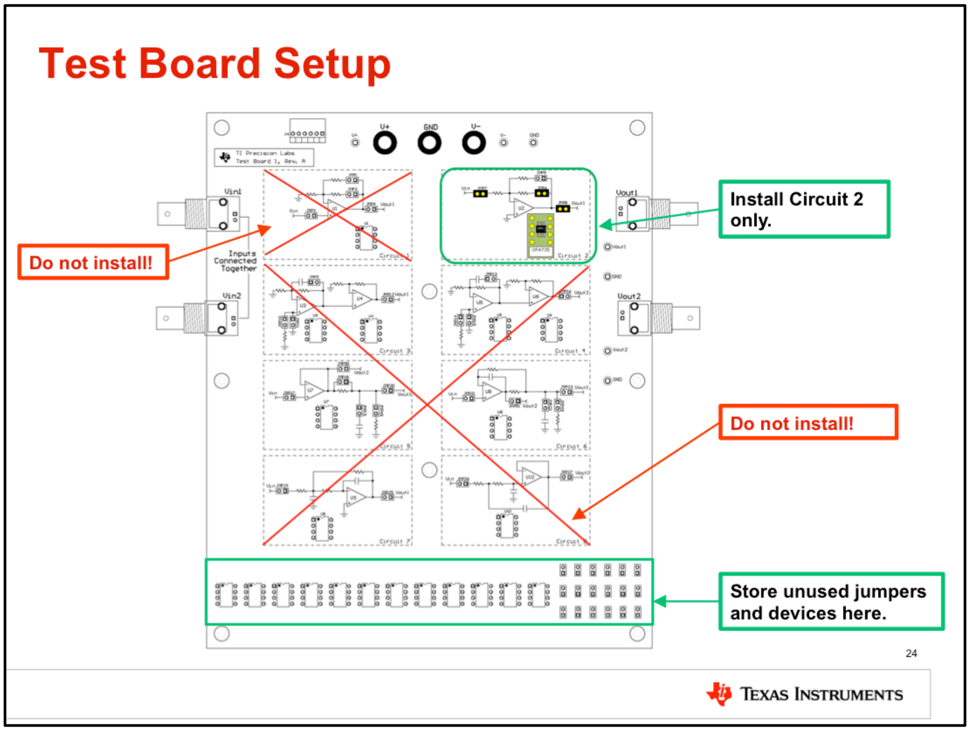
TEXAS INSTRUMENTS

To prepare the test board for the measurement, install the jumpers and devices on circuit 2 as shown here.

Install JMP6, JMP7, and JMP8, as well as the OPA277 in socket U2.

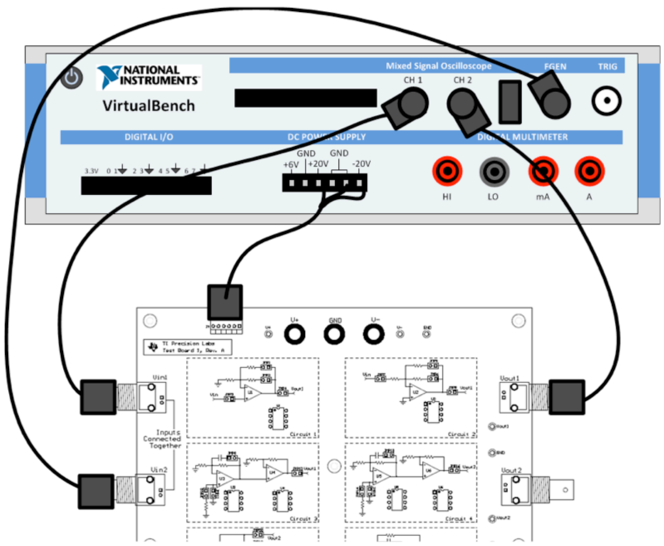


This slide shows the full schematic for Circuit 2 on the TI Precision Labs test board. You will use this circuit to measure the effect of input and output voltage range limitations on the OPA277.



For this measurement, only circuit 2 is used. Do not install any jumpers or devices in any other circuits on the PCB! Remove any jumpers or devices from the unused circuits and store them in the storage area at the bottom of the test board.

Hardware Setup – Cables



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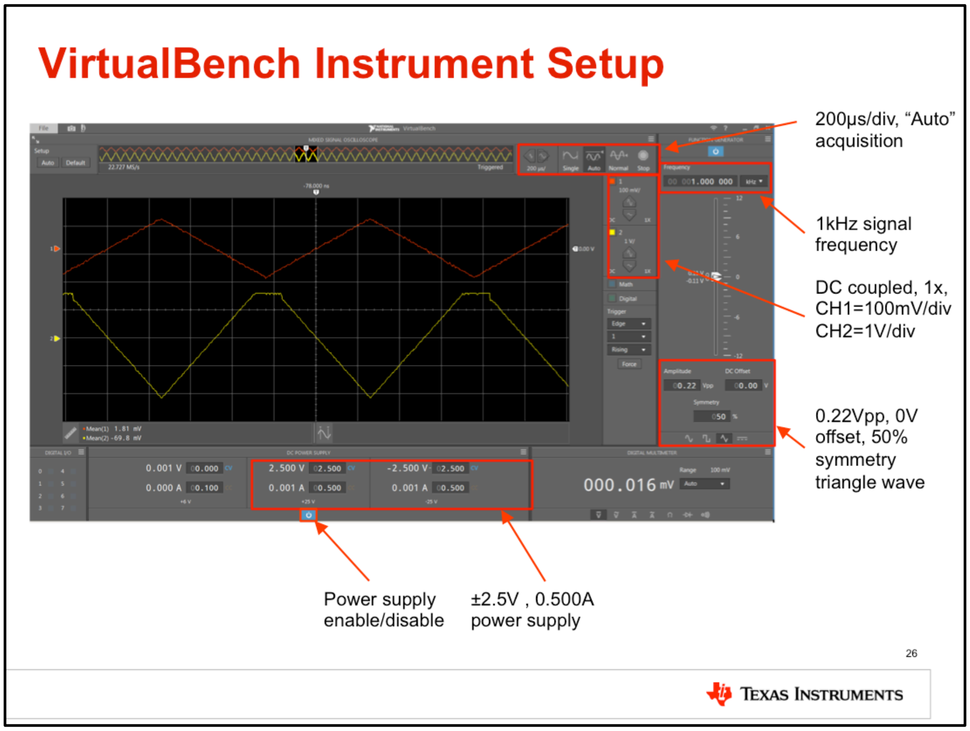
Texas Instruments

The cable connections to the VirtualBench are exactly the same as in experiment 1. No changes are necessary.



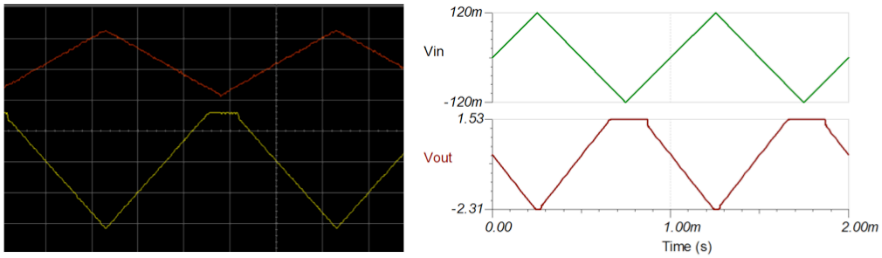
The VirtualBench instrument setup is very similar to experiment 1. Make the following changes:

Set the vertical scale of CH1 to 100mV/div. Keep the vertical scale of CH2 at 1V/div.

Set the function generator to a 0.22Vpp, 0V offset, 50% symmetry triangle wave at 1kHz.

Measurement Results – Inverting Amplifier

1. Compare TINA-TI™ simulation results to measured results.



2. Use the cursors on the VirtualBench and TINA-TI™ tool to measure the voltage where Vout becomes limited (clipped). Compare this to your calculation.

Answer (calculation):	clipped at -2.0V and +1.3V
Answer (simulation):	clipped at -2.31V and +1.53V (it may distort before the clip)
Answer (measurement):	clipped at -2.40V and +1.59V (it may distort before the clip)

Compare the TINA simulation results to your measured results. The shape of the output waveform should look very similar, with hard clipping at the top of the waveform. Your device may or may not clip at the bottom of the waveform.

That concludes this lab – thank you for your time!