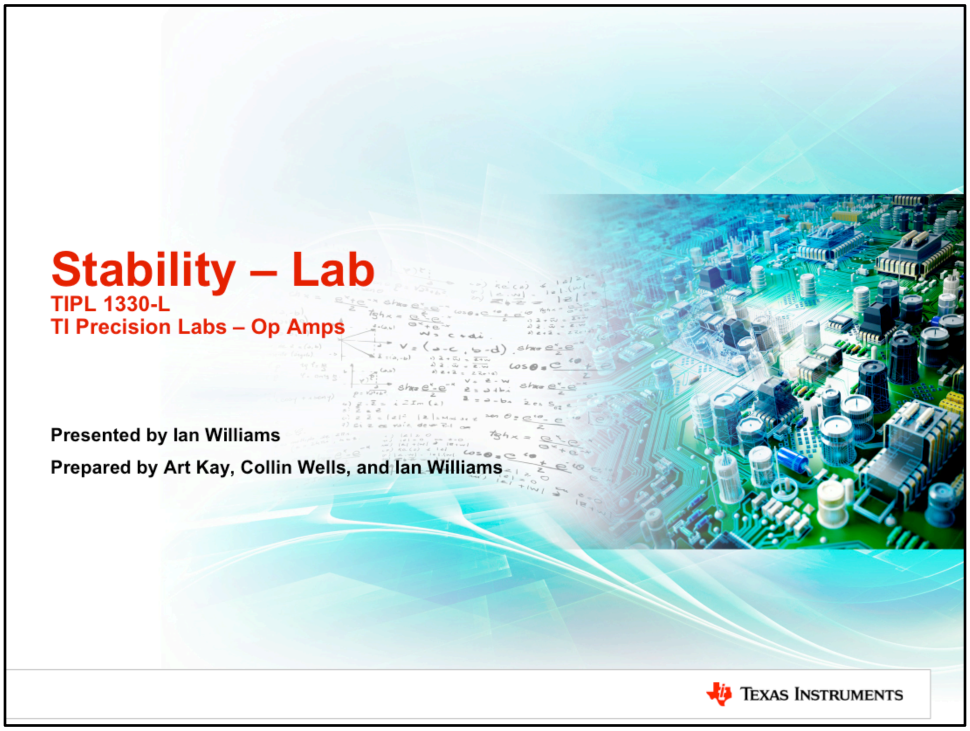
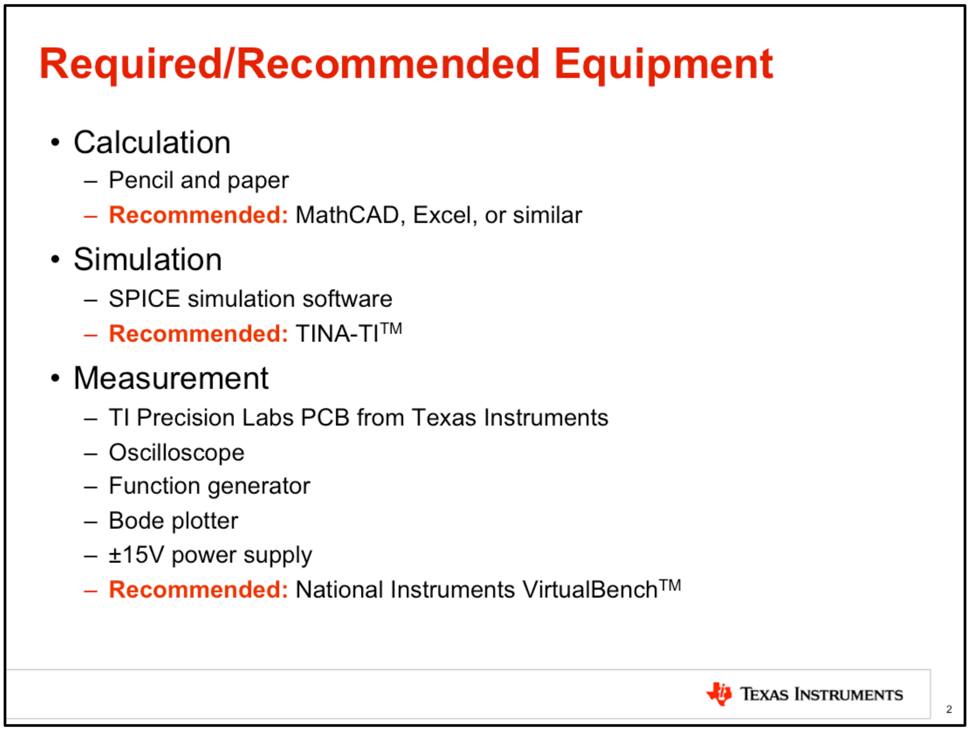


Hello, and welcome to the TI Precision Lab supplement for op amp stability.

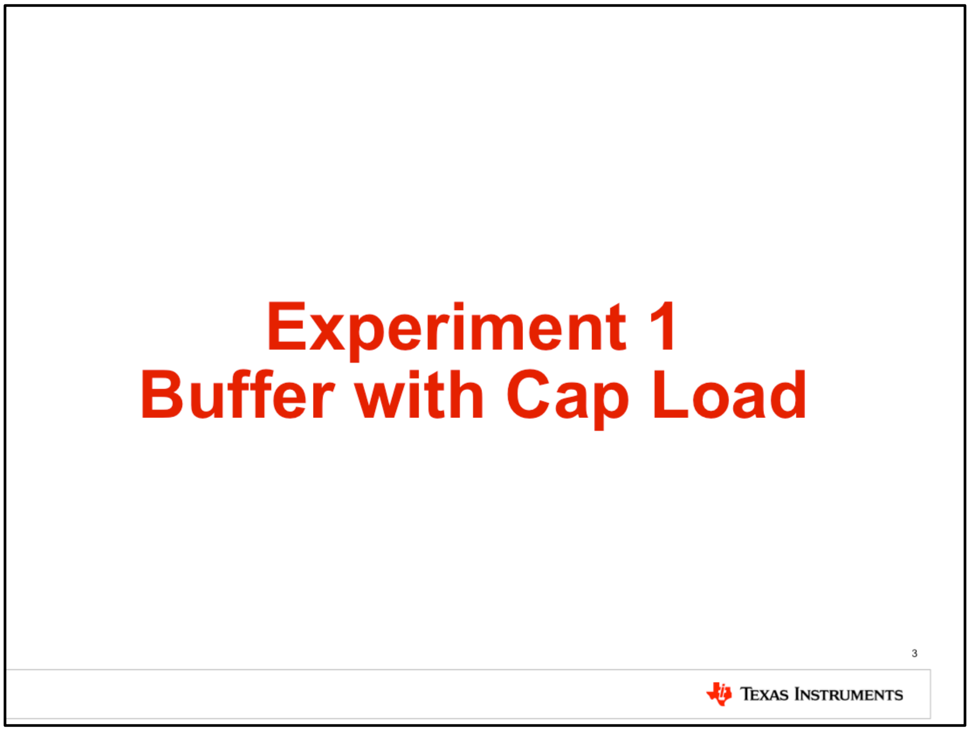
This lab will walk through detailed calculations, SPICE simulations, and real-world measurements that greatly help to reinforce the concepts established in the stability video series.



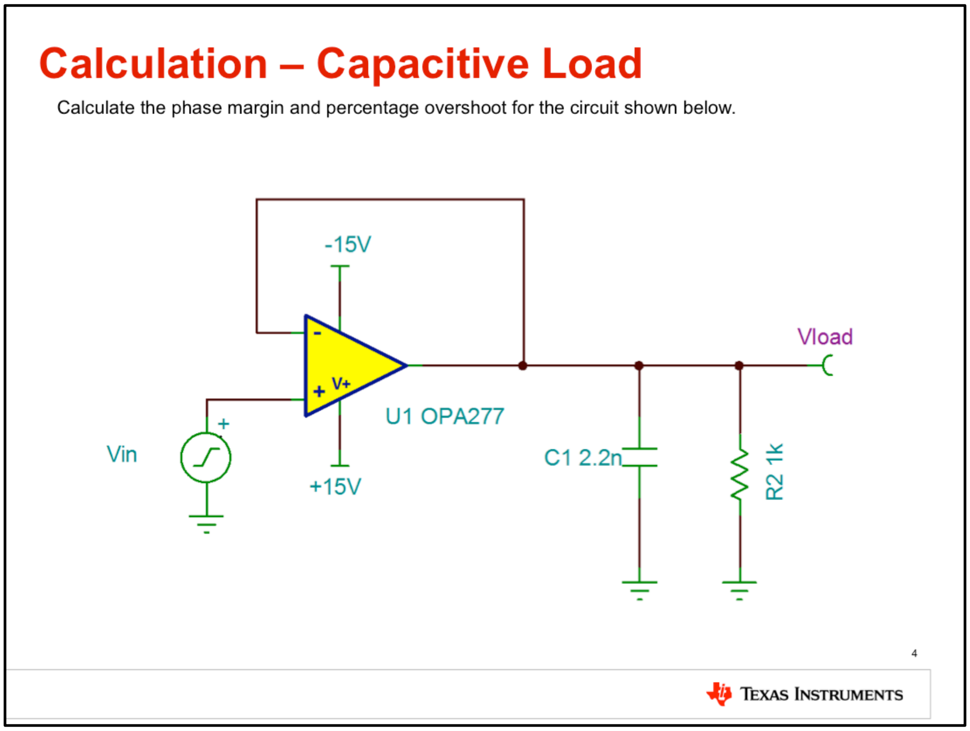
The detailed calculation portion of this lab can be done by hand, but calculation tools such as MathCAD or Excel can help greatly.

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, Bode plotter, and ±15V 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.

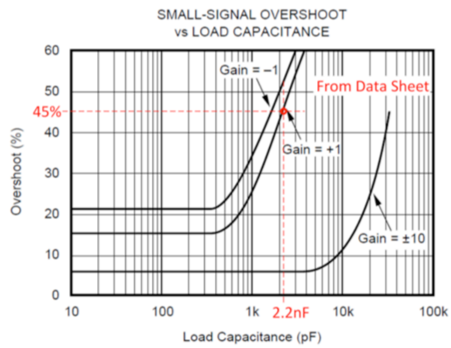


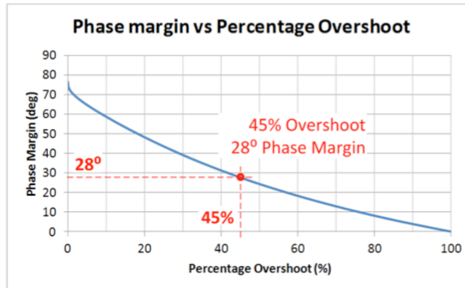
In experiment 1, we'll determine the phase margin, and therefore the stability, of a buffer circuit which is being used to drive a large capacitive load. We'll determine the phase margin by observing the transient overshoot as well as the AC transfer characteristic.



First, calculate the phase margin and percentage overshoot for the circuit shown here, using the techniques and equations given in the stability lecture. Use the plots given on the next slide.

Calculation – Capacitive Load





Answers	OPA277
Percent overshoot	45%
Phase margin	28°

5

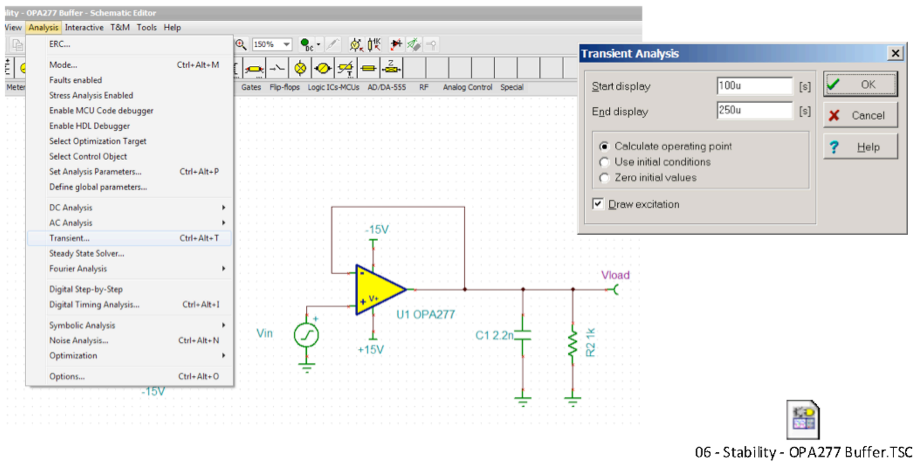
TEXAS INSTRUMENTS

This circuit uses the OPA277. In order to perform the calculations, you need to know the percent overshoot versus load capacitance for that device, shown on the top left. Then, use the plot on the right to determine the phase margin from that percentage overshoot.

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

Simulation Setup – Overshoot

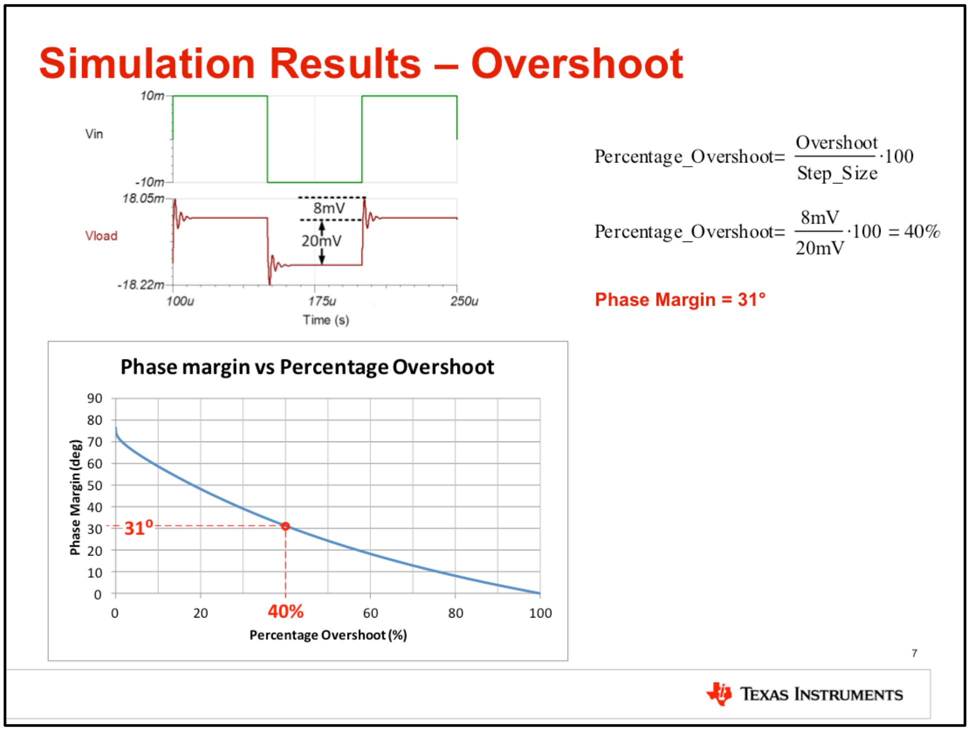
Click **Analysis → Transient** to run a transient simulation showing overshoot.
Run the analysis from 100µs to 250µs. The input is a 20mVpk, 10kHz square wave.



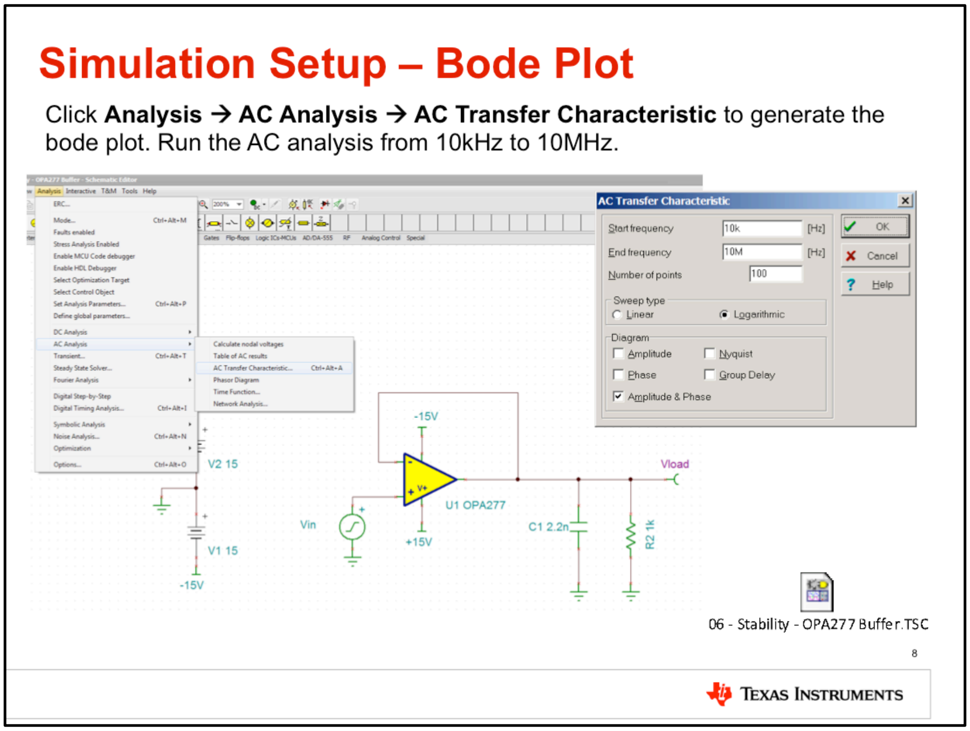
Texas Instruments

The next step is to run a SPICE simulation analysis for the transient overshoot.

The necessary TINA-TI simulation schematic is embedded in this slide set – simply double-click the icon to open it. To run the analysis, click Analysis → Transient, and run the analysis from 100us to 250us. The input is a 20mVpk, 10kHz square wave.

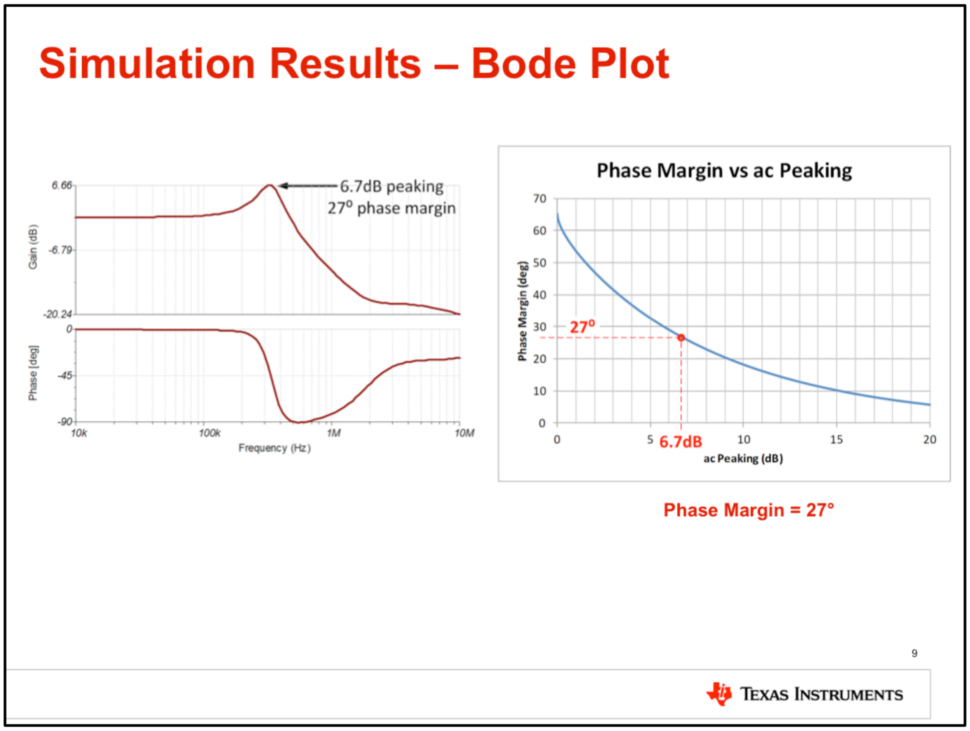


You should see a result similar to this. Use the simulated percentage overshoot of 40% to calculate the phase margin, which comes out to 31 degrees.

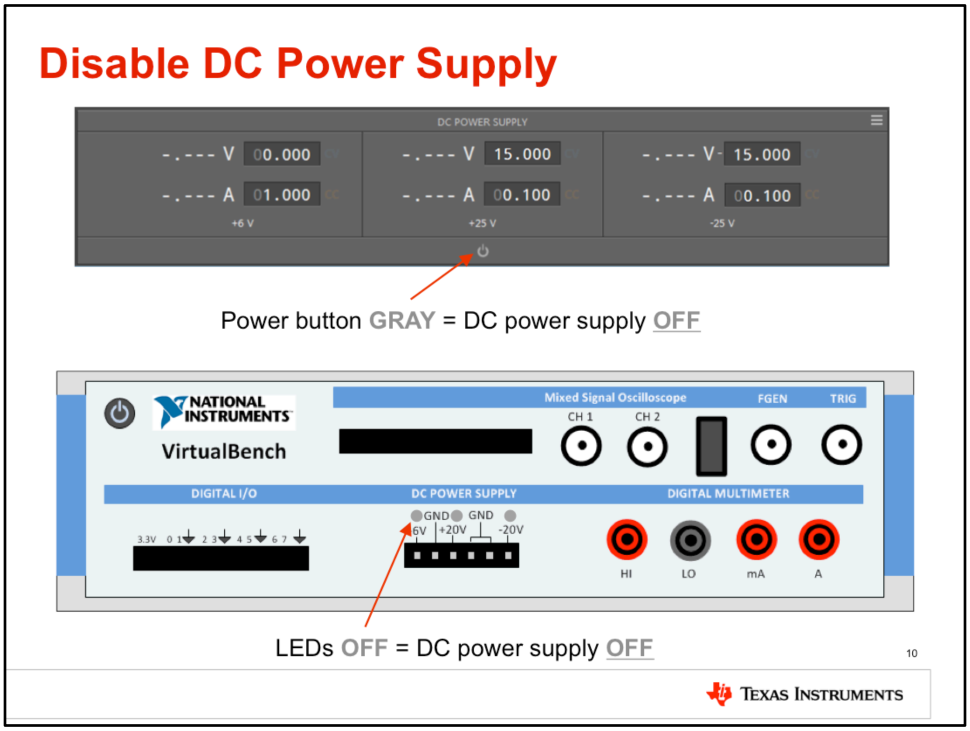


Next, run a SPICE simulation analysis for the AC transfer characteristic. This will allow us to see the op amp's AC peaking, which is another indicator of phase margin.

Use the same TINA-TI simulation schematic as before. To run the analysis, click Analysis → AC Analysis → AC Transfer Characteristic. Run the analysis from 10kHz to 10MHz.

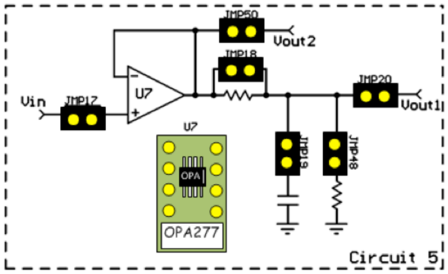


You should see a result similar to this. The 6.7dB of simulated AC peaking results in a phase margin of approximately 27 degrees.



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 ensure that the function generator is OFF.

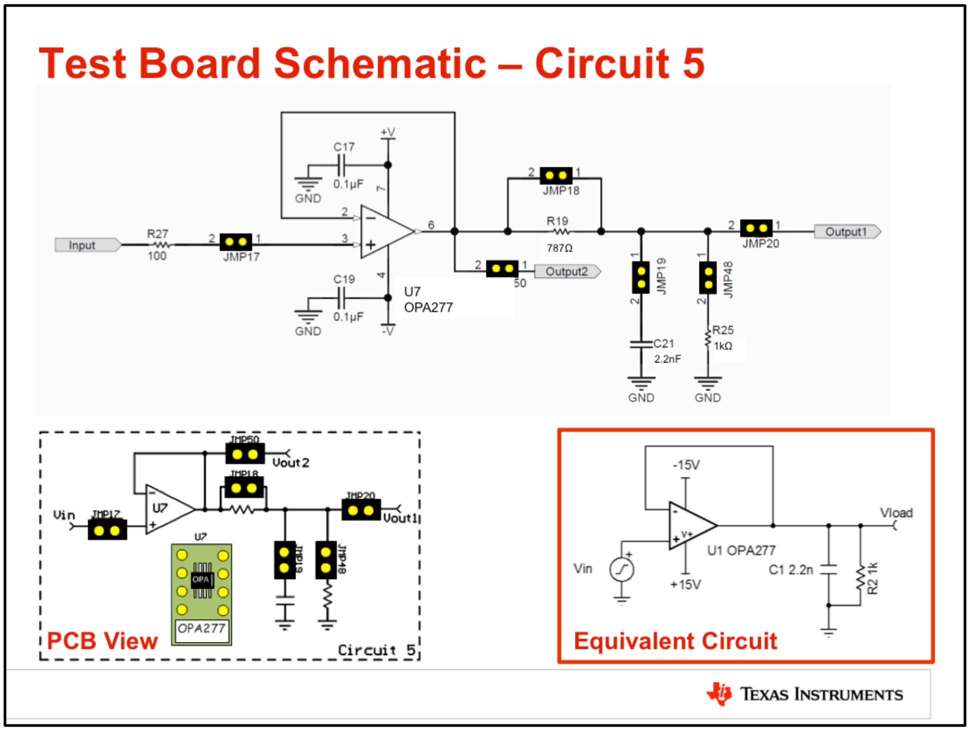
Test Board Setup – Jumpers



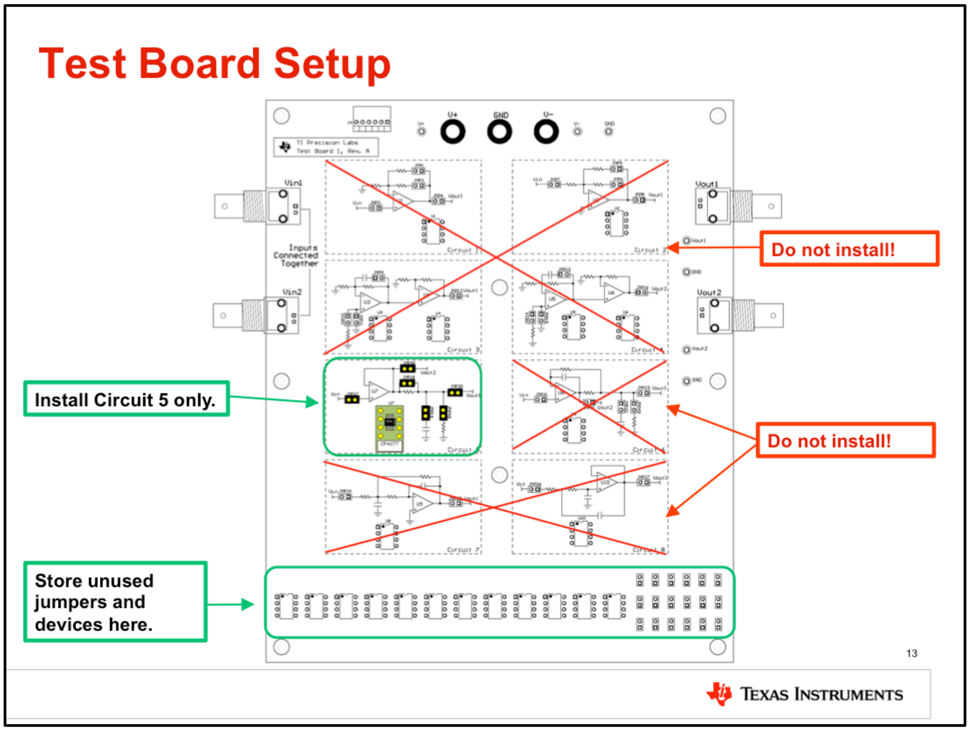
Jumper, Device	Description
JMP17	Connects input to U7
JMP18	Shorts isolation resistor. Riso = 0Ω
JMP19	Connects 2.2nF load capacitance
JMP20	Monitor output across load
JMP48	Connects 1kΩ load resistance
JMP50	Monitor directly at U7 output
U7	Install OPA277

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

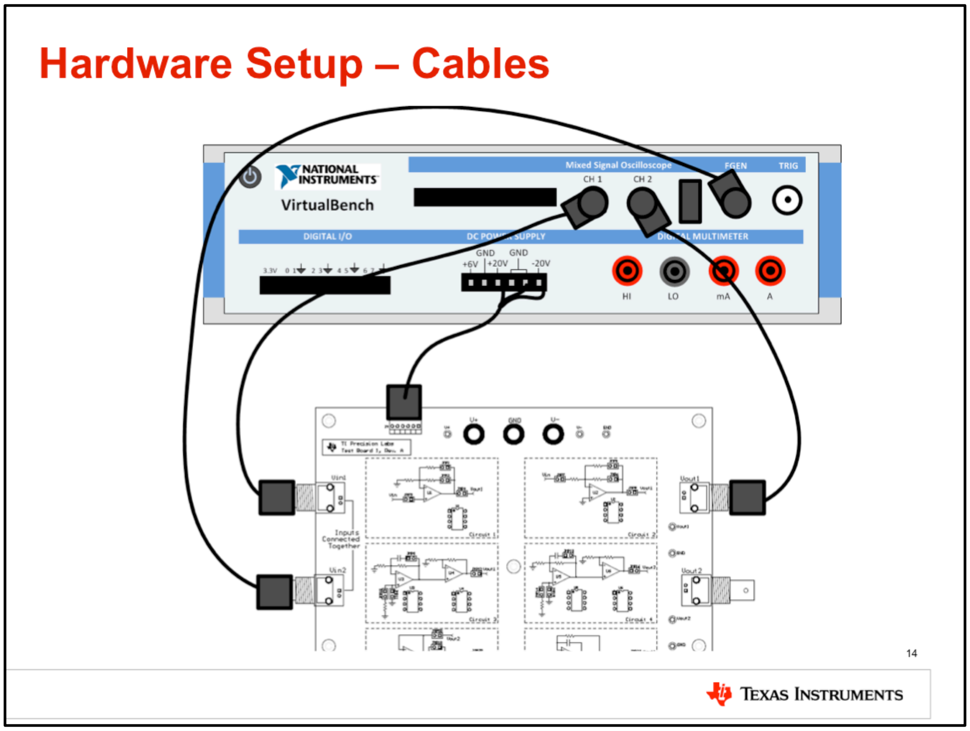
Install JMP17, JMP18, JMP19, JMP20, JMP48, and JMP50, as well as the OPA277 in socket U7.



This slide shows the full schematic for Circuit 5 on the TI Precision Labs test board. You will use this circuit to measure the stability of the OPA277.

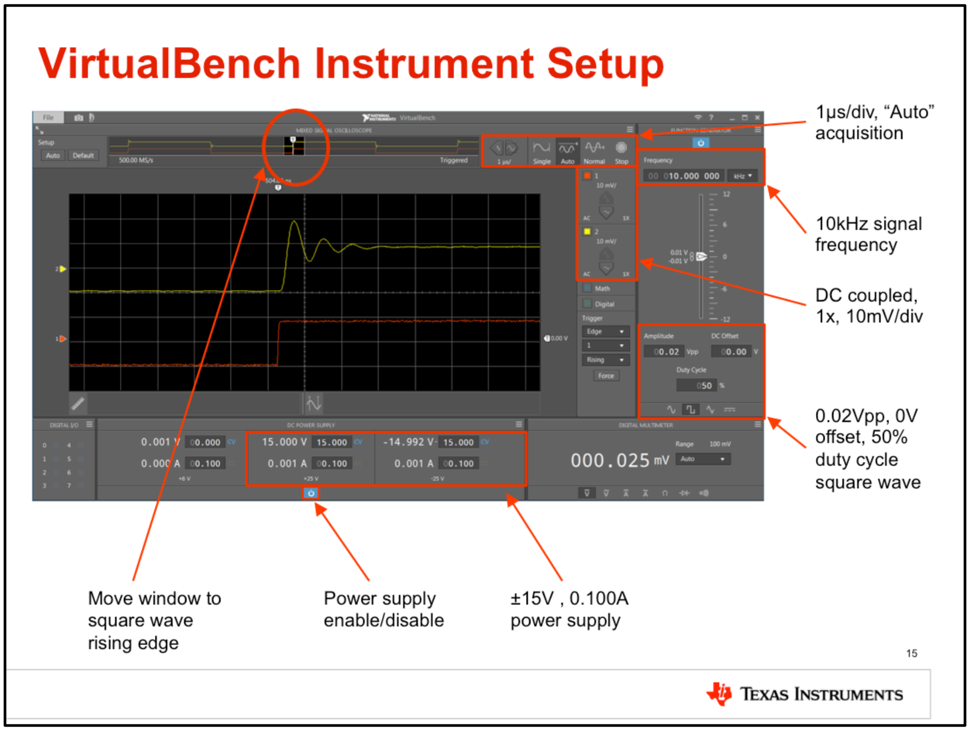


For the test board to function properly, it is important that you only install jumpers and devices in circuit 5. Do not install any jumpers or devices in any other circuits on the PCB! Remove any jumpers or devices from the unused circuits and store them in the storage area at the bottom of the test 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 Vin1 on the test board to VirtualBench oscilloscope channel 1, and Vin2 on the test board to the VirtualBench FGEN. Connect 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:

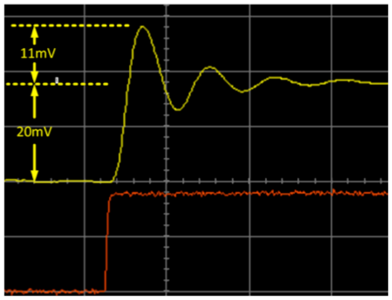
Set the time scale to 1us per division, with the acquisition mode set to "Auto." Enable channels 1 and 2 on the oscilloscope, and set them to 1x, DC-coupled mode, 10mV/div. Enable the function generator and setup the signal as follows:

10kHz frequency, 20mVpp, 0V offset, 50% duty cycle square wave.

Set the +25V power supply to +15V, 0.100A. Set the -25V power supply to -15V, 0.100A. Press the power button to turn on the power supply rails.

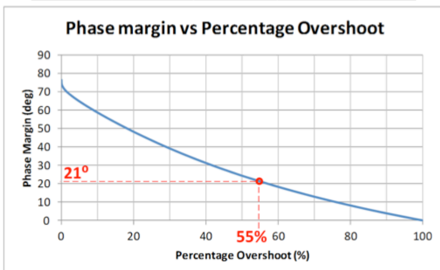
Move the display window to the rising edge of the square wave. This allows you to observe the overshoot and ringing of the op amp output.

Measurement Results – Overshoot



$$\text{Percentage\_Overshoot} = \frac{\text{Overshoot}}{\text{Step\_Size}} \cdot 100$$

$$\text{Percentage\_Overshoot} = \frac{11\text{mV}}{20\text{mV}} \cdot 100 = 55\%$$

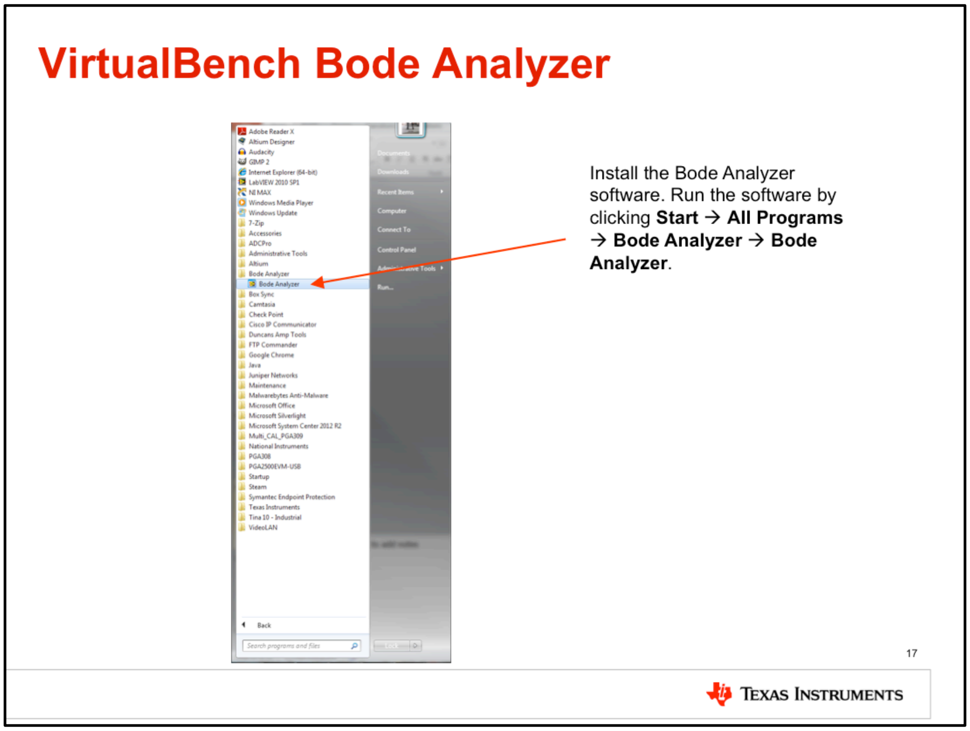


Answers	OPA277
Percent overshoot	55%
Phase margin	21°

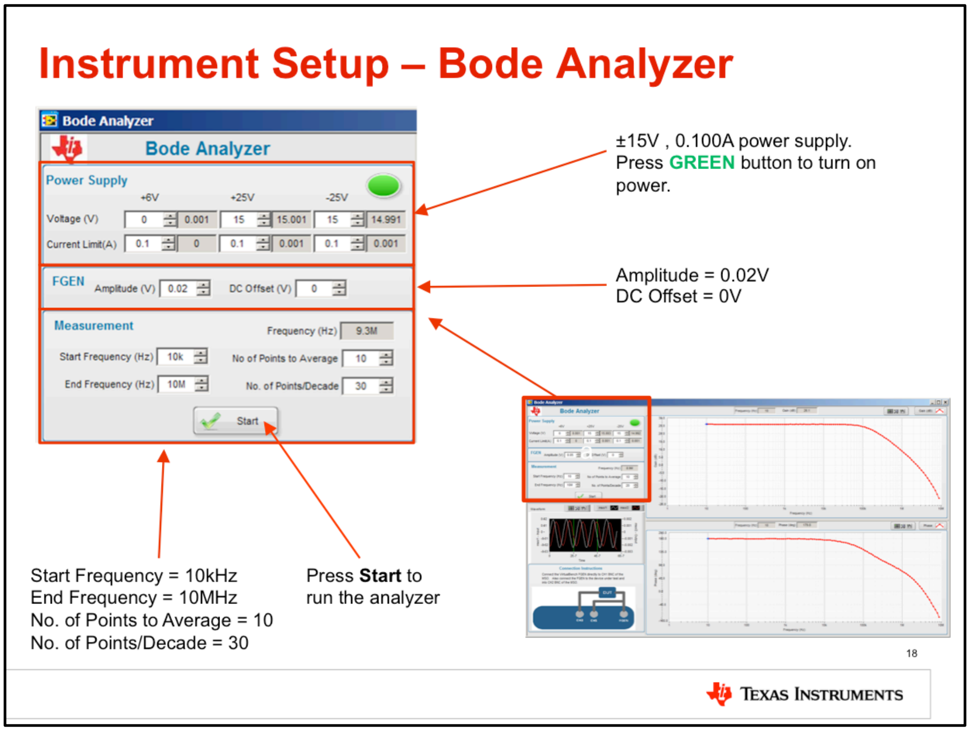
16

TEXAS INSTRUMENTS

Use cursors to measure the amount of overshoot. The expected measurement results are shown here. The measured overshoot of 55% results in a phase margin of 21 degrees. Your results may vary slightly.



This lab requires additional Bode analyzer software. Install the software, then run it by clicking Start → All Programs → Bode Analyzer → Bode Analyzer.

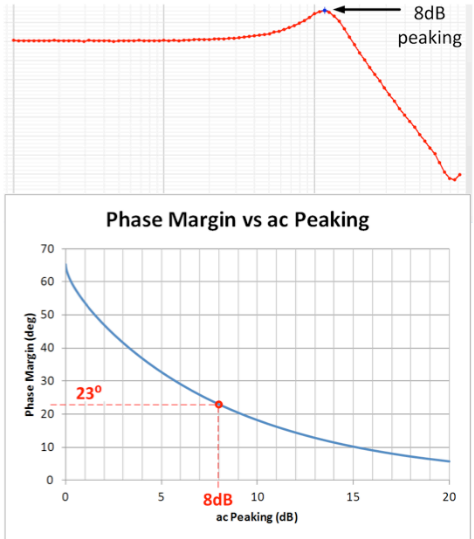


In the configuration panel, set the power supply to ±15V, 0.1A. Press the green button to turn on the power.

Set the FGEN amplitude to 0.02V, and DC offset to 0V.

Set the start frequency to 10kHz and the end frequency to 10MHz. Set the number of points to average to 10, and the number of points per decade to 30. Press “Start” to run the Bode analyer.

Measured AC Peaking – Bode Analyzer



Answers	OPA277
AC Peaking	8dB
Phase margin	23°

You should see a result similar to this. Enable the cursor, then drag the cursor to the maximum value to measure the AC peaking. In this measurement, AC peaking of 8dB resulted in a phase margin of 23 degrees. Your results may vary slightly.

Results Comparison

1. Compare the phase margin results from calculations, transient and AC response simulations, and transient and AC response measurements.

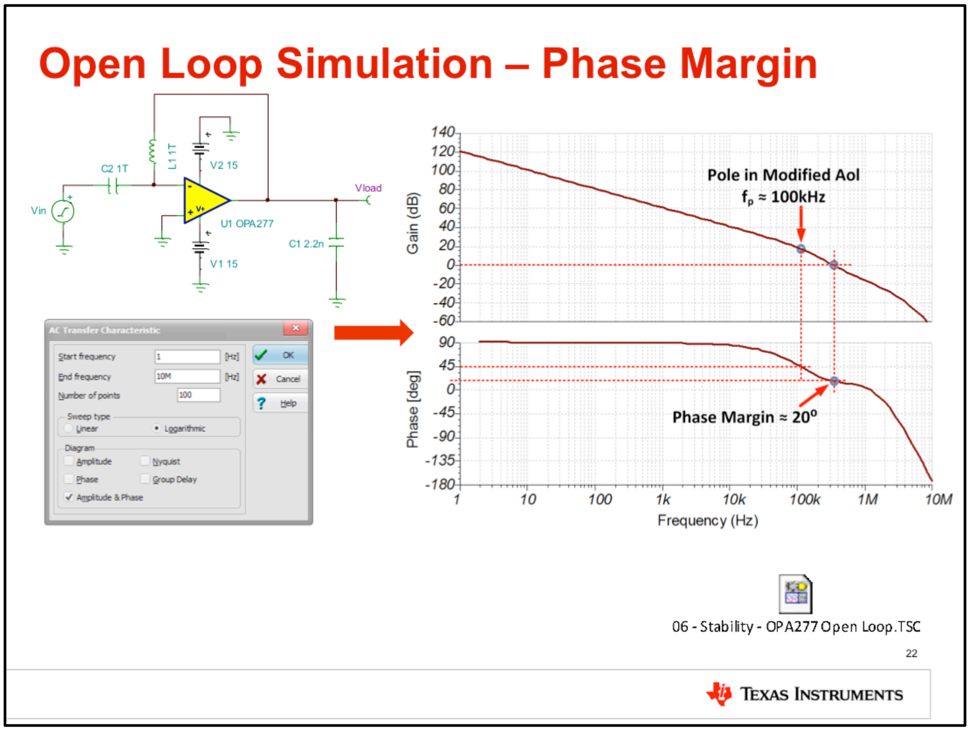
Test	Phase Margin
Calculated from data sheet	28°
Simulated from transient overshoot	31°
Simulated from AC peaking	27°
Measured from transient overshoot	21°
Measured from AC peaking	23°

20

Texas Instruments

Now, compare the phase margin results from your hand calculations, transient and AC response simulations, and transient and AC response measurements. While there is some slight variation to the results, the phase margin values compare very well at approximately 27 degrees.

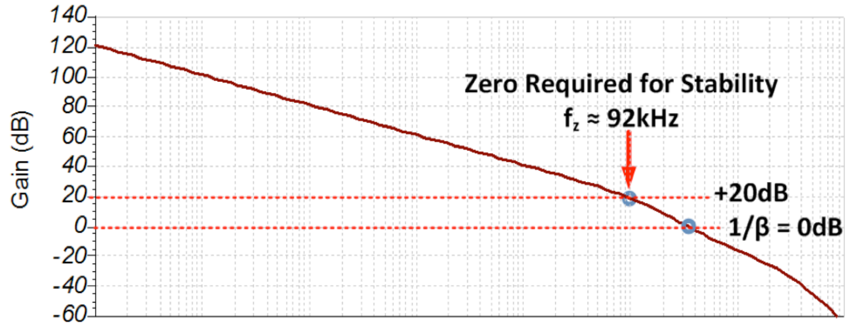
In experiment 2, we'll use an isolation resistor to increase the phase margin of the circuit from Experiment 1 and therefore improve its stability.



To determine the value of isolation resistor Riso, we must first know the open-loop AC response of the circuit. Here we show the TINA-TI simulation schematic and AC response results, which you can verify using the embedded file.

To measure the phase margin, find the frequency where the gain measures 0dB. Then, measure the phase at that same frequency, which in this example is 20 degrees.

Calculation – R_{ISO}



$$R_{iso} = \frac{1}{2 \cdot \pi \cdot f_z \cdot C_L} = \frac{1}{2 \cdot \pi \cdot 92kHz \cdot 2.2nF} = 786\ \Omega$$

R_{ISO} = 787 Ω (nearest standard value)

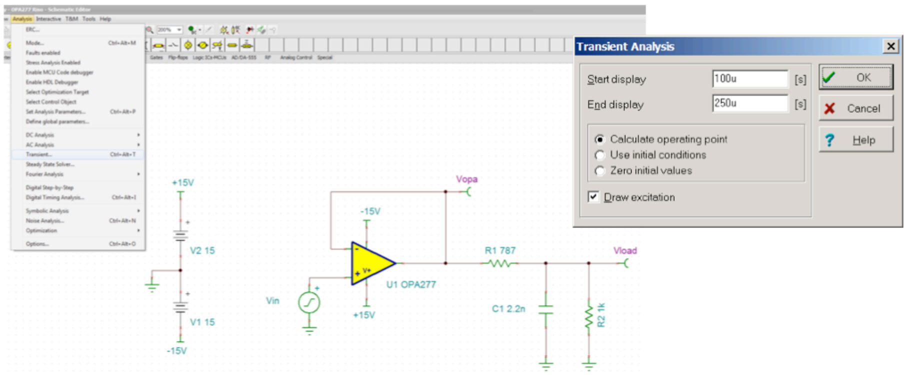
23

Texas Instruments

For best results, Riso should create a zero in the loop response 20dB greater than the frequency where the open-loop gain intersects with the closed-loop gain. This circuit is a buffer with a closed-loop gain of 0dB, so the zero should occur at 20dB. The open-loop gain is equal to 20dB at 92kHz. Use this value and the load capacitance to calculate Riso, which is 786 ohms in this example. 787 ohms is the nearest standard value resistance.

Simulation Setup – R_{ISO} Overshoot

Click **Analysis → Transient** to run a transient simulation, showing overshoot.
Run the analysis from 100µs to 250µs. The input is a 20mVpk, 10kHz square wave.



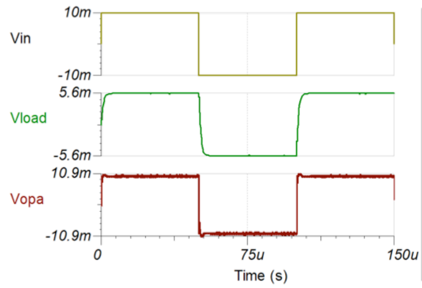
06 - Stability - OPA277 Riso.TSC

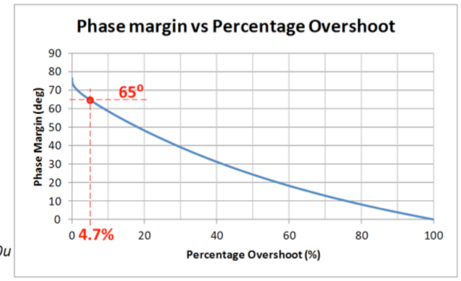
24

Texas Instruments

Let's now simulate the transient overshoot with Riso included in the circuit. As before, click Analysis → Transient to run the simulation. Run the analysis from 100us to 250us. The input is a 20mVpk, 10kHz square wave.

Simulation Results – R_{ISO} Overshoot





$$\text{Percentage\_Overshoot}=\frac{\text{Overshoot}}{\text{Step\_Size}}\cdot 100$$

$$\text{Percentage\_Overshoot}=\frac{0.93\text{mV}}{20\text{mV}}\cdot 100 = 4.7\%$$

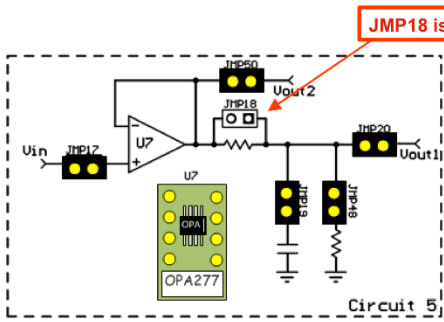
Phase Margin = 65°

25

TEXAS INSTRUMENTS

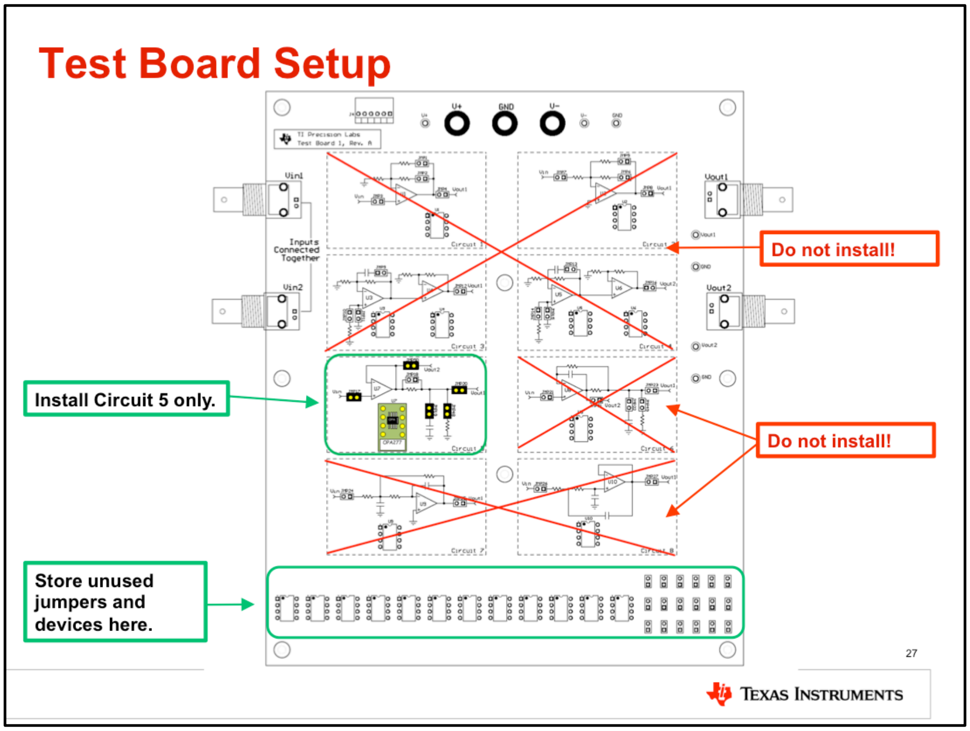
You should see results similar to this. With Riso added to the circuit, the overshoot was reduced to only 4.7%. This results in a phase margin of 65 degrees, indicating a stable circuit.

Test Board Setup – Jumpers

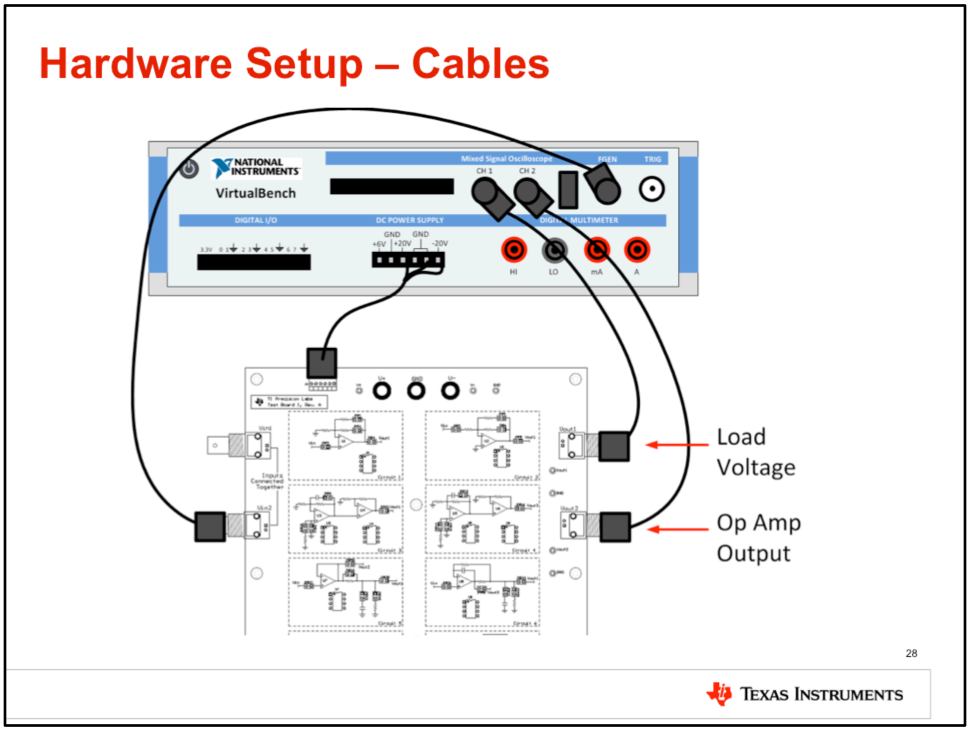


Jumper, Device	Description
JMP17	Connects input to U7
JMP18	**Removed to connect isolation resistor Riso = 787Ω**
JMP19	Connects 2.2nF load capacitance
JMP20	Monitor output across load
JMP48	Connects 1kΩ load capacitance
JMP50	Monitor directly at U7 output
U7	Install OPA277

Let's now re-run the overshoot measurement, this time with Riso. The jumper setup is almost the same. The only change is to remove JMP18, which connects the isolation resistor of 787 ohms.

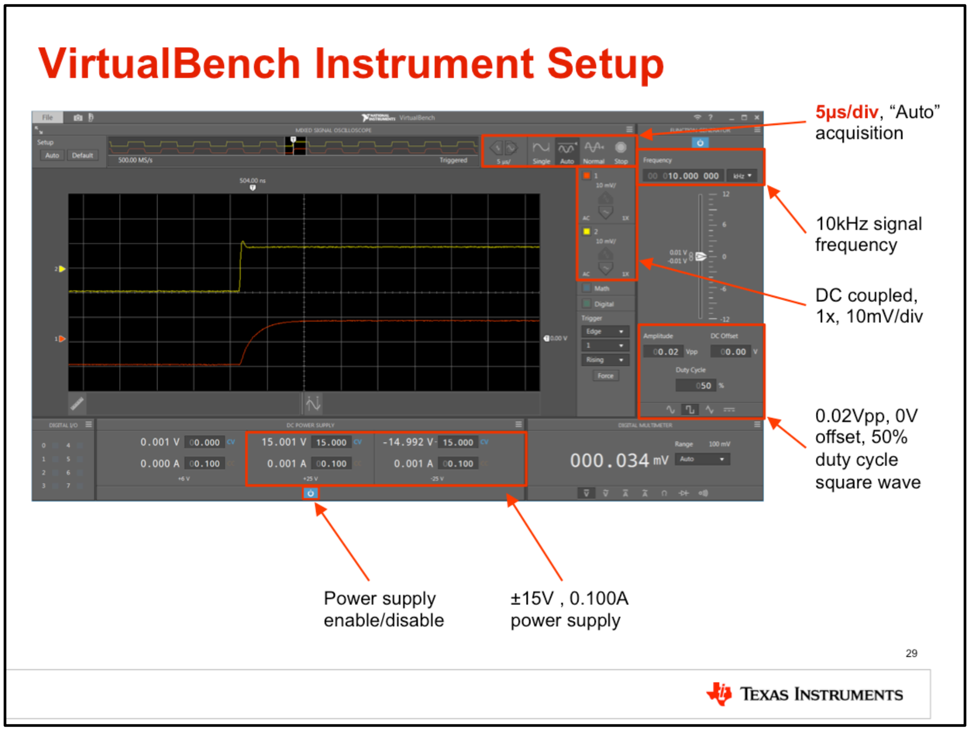


The test board setup remains the same as before. Install circuit 5 only, and store any unused jumpers and devices in the storage area at the bottom of the test board.



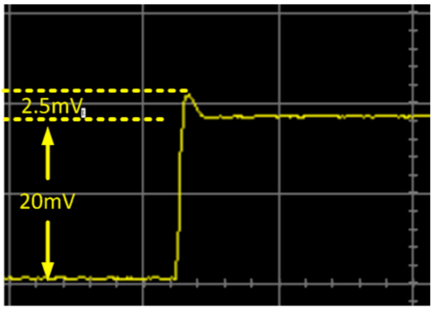
This slide gives the new connection diagram between the TI Precision Labs test board and the National Instruments VirtualBench. Connect the provided power cable to the DC power supply of the Virtual Bench and power connector J4 on the test board.

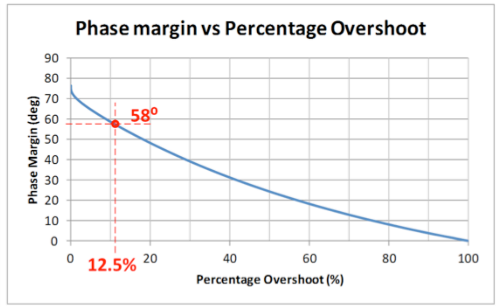
Connect Vin2 on the test board to the VirtualBench FGEN. Connect Vout1 on the test board to VirtualBench oscilloscope channel 1 to measure the load voltage, and connect Vout2 on the test board to VirtualBench oscilloscope channel 2 to measure the unloaded op amp output voltage.



The VirtualBench setup is almost the same as before. Only change the time scale to 5us/div. All other settings must remain the same.

Measurement Results – R_{ISO} Overshoot





$$\text{Percentage\_Overshoot} = \frac{\text{Overshoot}}{\text{Step\_Size}} \cdot 100$$

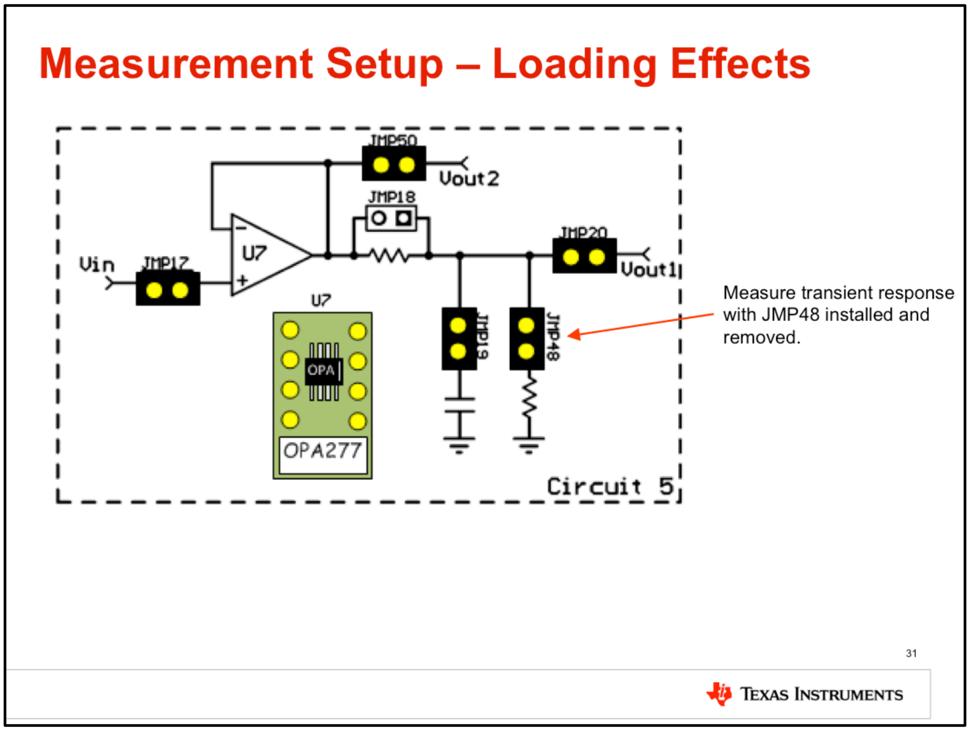
$$\text{Percentage\_Overshoot} = \frac{2.5\text{mV}}{20\text{mV}} \cdot 100 = 12.5\%$$

Phase Margin = 58°

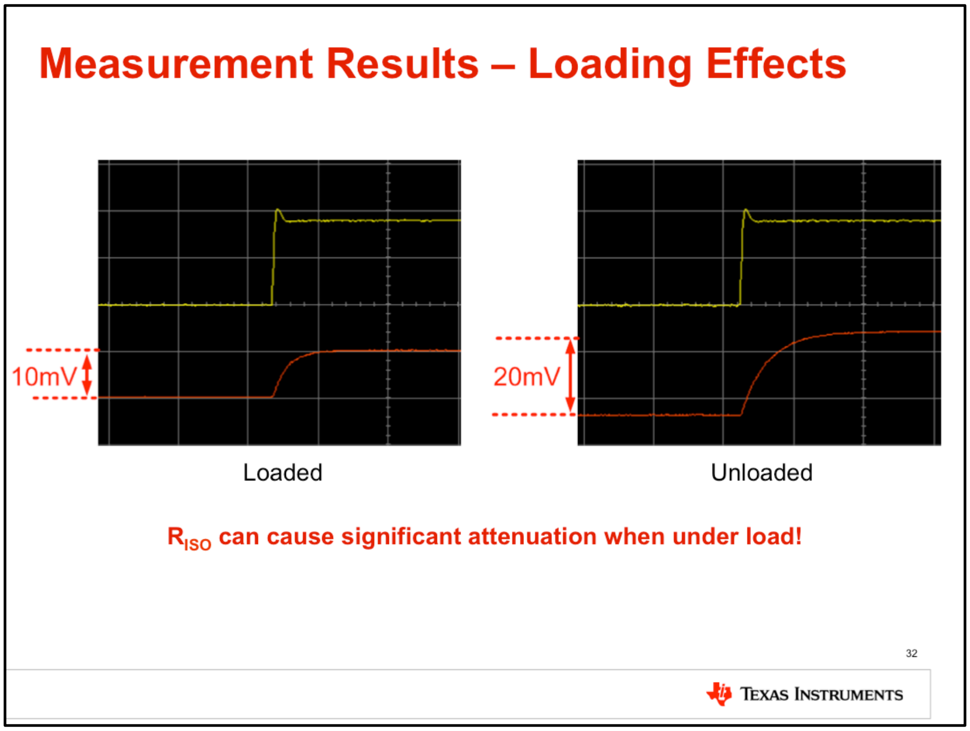
30

TEXAS INSTRUMENTS

Use cursors to measure the amount of overshoot. You should see results similar to this. With Riso, the measured unloaded output overshoot was reduced to 12.5%, resulting in a phase margin of approximately 58 degrees which indicates a stable circuit.



As an additional experiment, measure the transient response again with JMP48 installed and removed. This will connect and disconnect the 1k load resistor from the circuit.



As you can see, the load voltage changes dramatically if the circuit is loaded or unloaded! In fact, when loaded, the circuit with Riso shows attenuation of approximately 50%! This is simply due to the voltage divider effect of Riso and the load resistance.

Experiment 3
Dual Feedback

33

TEXAS INSTRUMENTS

For the final experiment, we'll analyze a circuit which uses Riso as well as a dual feedback network to achieve stability as well as output voltage accuracy.

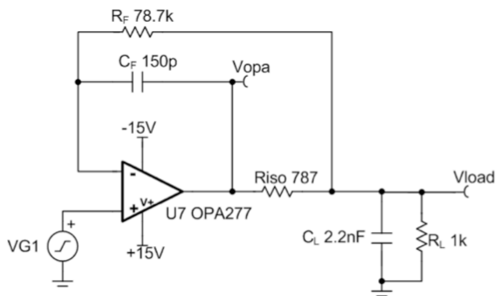
Calculation – Dual Feedback

$R_F \geq 100 \times R_{iso} = 100 \times 787\Omega = 78.7k\Omega$ **Choose R_F**

$$\frac{5 \times R_{iso} \times C_L}{R_F} \leq C_F \leq \frac{10 \times R_{iso} \times C_L}{R_F}$$ **Find the range of C_F**

$110pF \leq C_F \leq 220pF$

$C_F = 150pF$ **Select standard value of C_F**



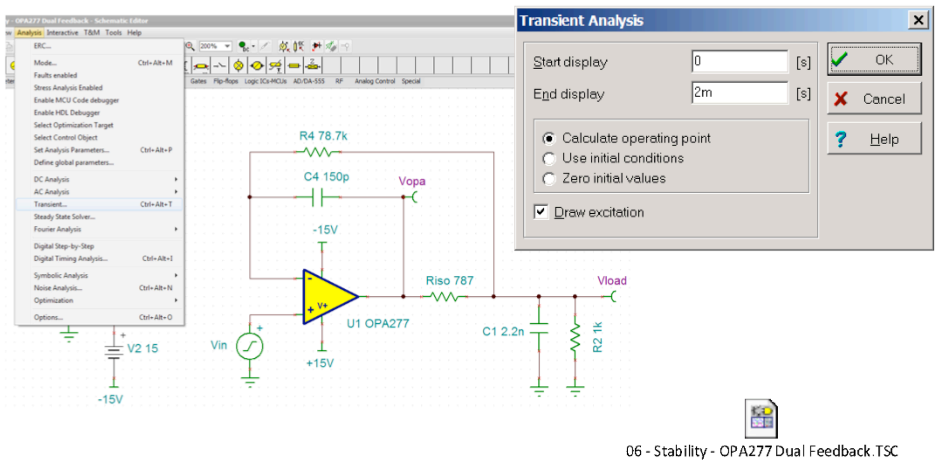
34

TEXAS INSTRUMENTS

To select the components of the dual feedback network, use the equations given on this slide. For this example, Rf was chosen to be 78.7k, and Cf was chosen to be 150pF.

Simulation Setup – Dual Feedback

Click **Analysis → Transient** to run a transient simulation showing overshoot.
Run the analysis from 0ms to 2ms. The input is a 1Vpk, 1kHz square wave.



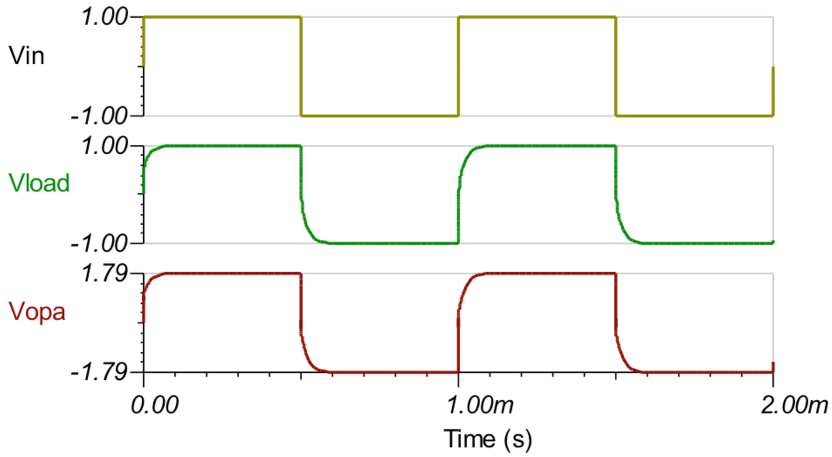
35

TEXAS INSTRUMENTS

Next, run a SPICE simulation analysis for the transient overshoot with dual feedback.

The necessary TINA-TI simulation schematic is embedded in this slide set – simply double-click the icon to open it. To run the analysis, click Analysis → Transient, and run the analysis from 0ms to 2ms. The input is a 1Vpk, 1kHz square wave.

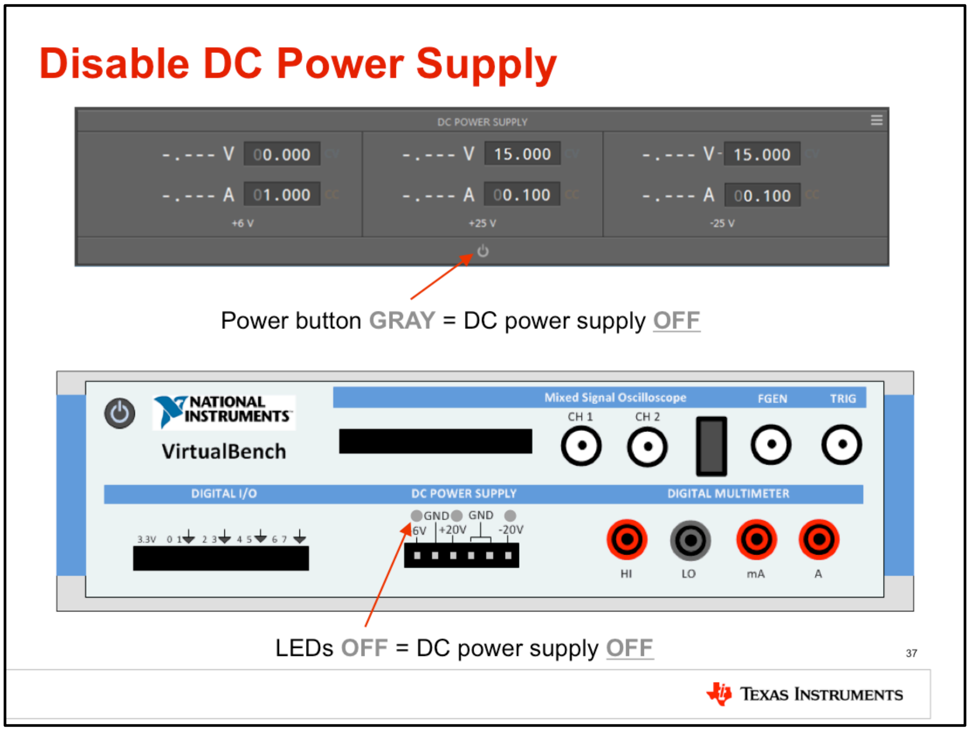
Simulation Results – Dual Feedback



36

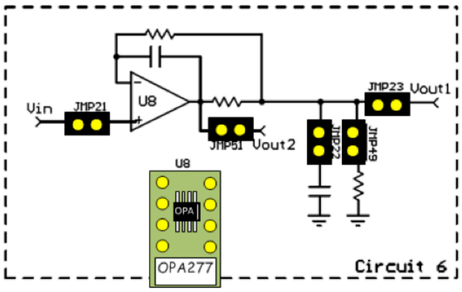
Texas Instruments

You should see results similar to this. As you can observe, in this configuration the loaded output voltage matches very well with the input. To achieve this, the unloaded output voltage Vopa must increase to compensate for the attenuation caused by Riso and the load resistance.



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 ensure the function generator is OFF.

Test Board Setup – Jumpers



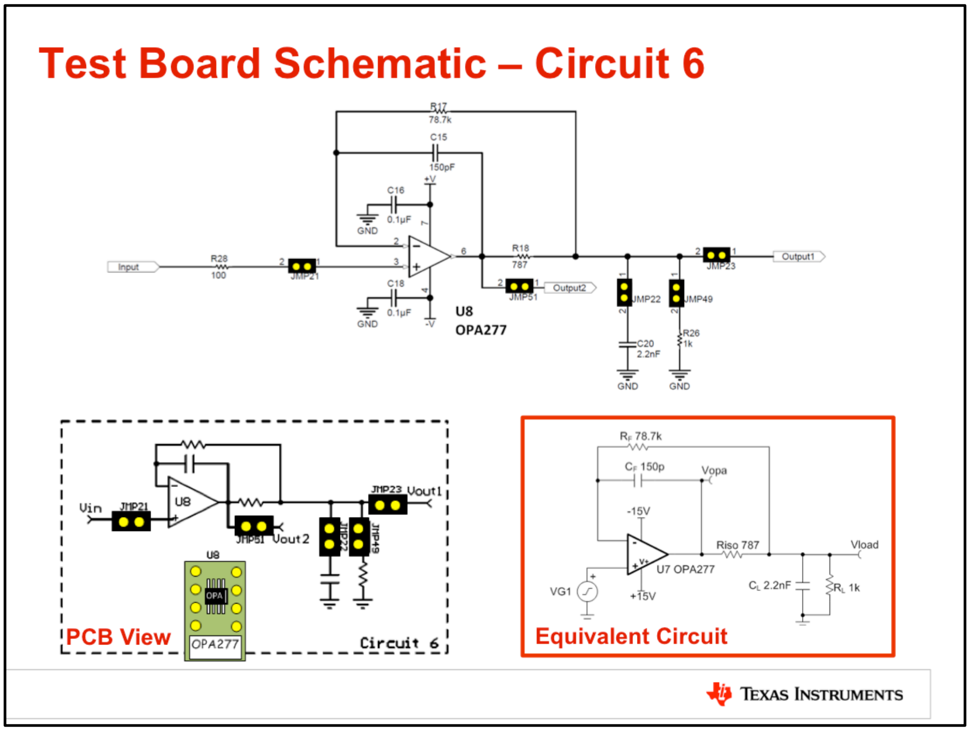
Jumper, Device	Description
JMP21	Connects input to U8
JMP22	Connects 2.2nF load capacitance
JMP23	Monitor across the load RC.
JMP49	Connects 1kΩ load resistance
JMP51	Monitor directly at U8 output.
U8	Install OPA277

38

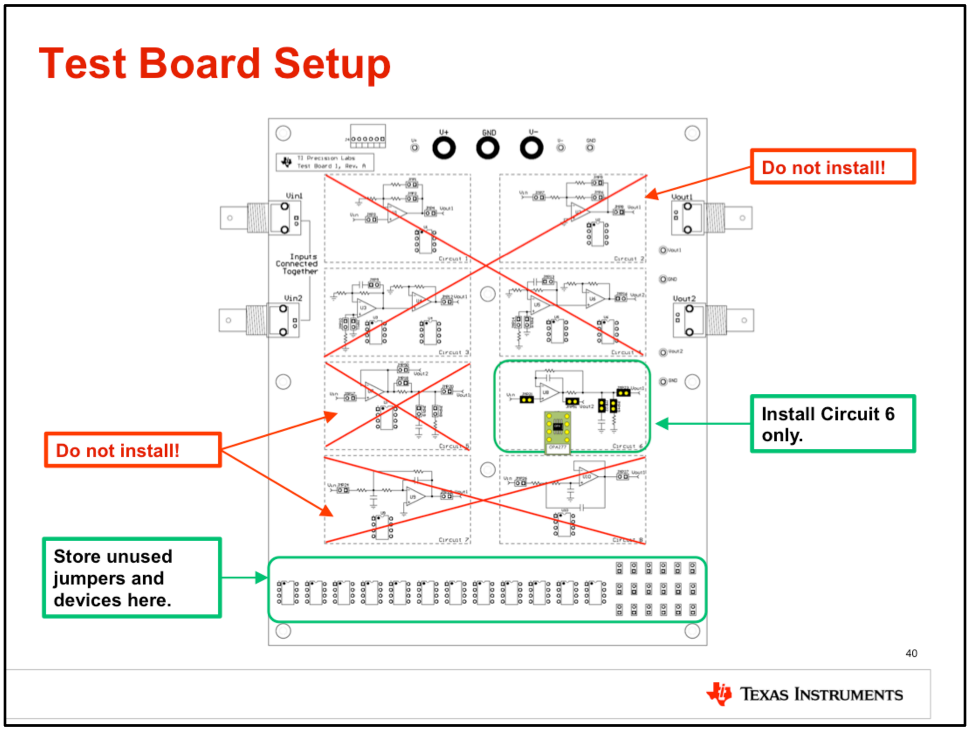
Texas Instruments

To prepare the test board for the measurement, install the jumpers and devices on circuit 6 as shown here.

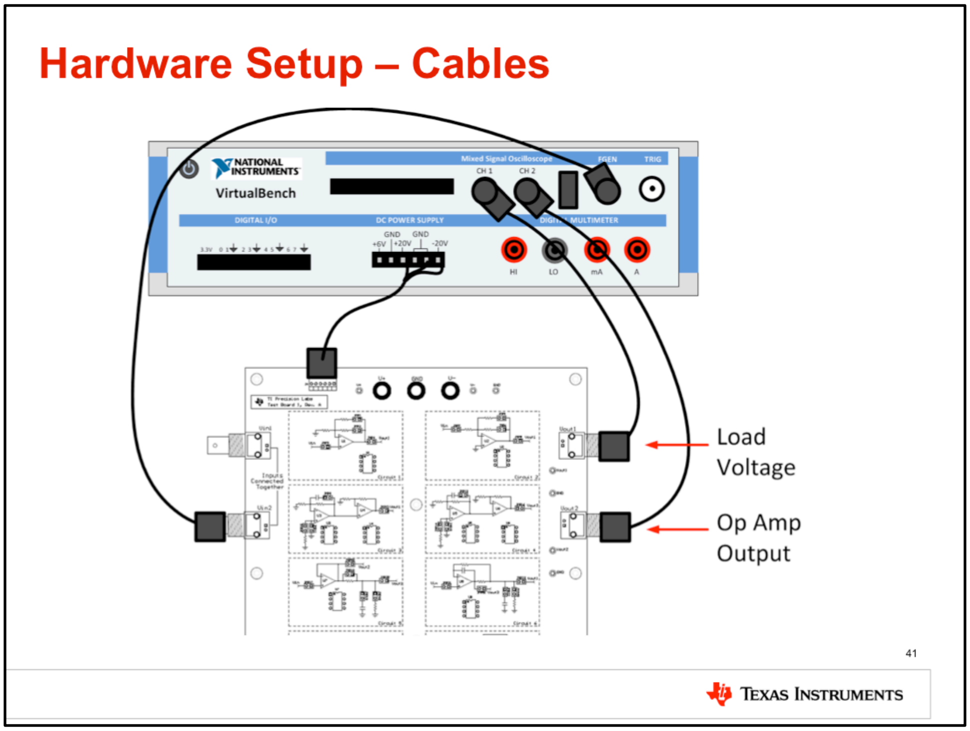
Install JMP21, JMP22, JMP23, JMP49, and JMP51. Install the OPA277 in socket U8.



This slide shows the full schematic for Circuit 6 on the TI Precision Labs test board. You will use this circuit to measure the transient behavior of the OPA277 in a dual-feedback configuration.

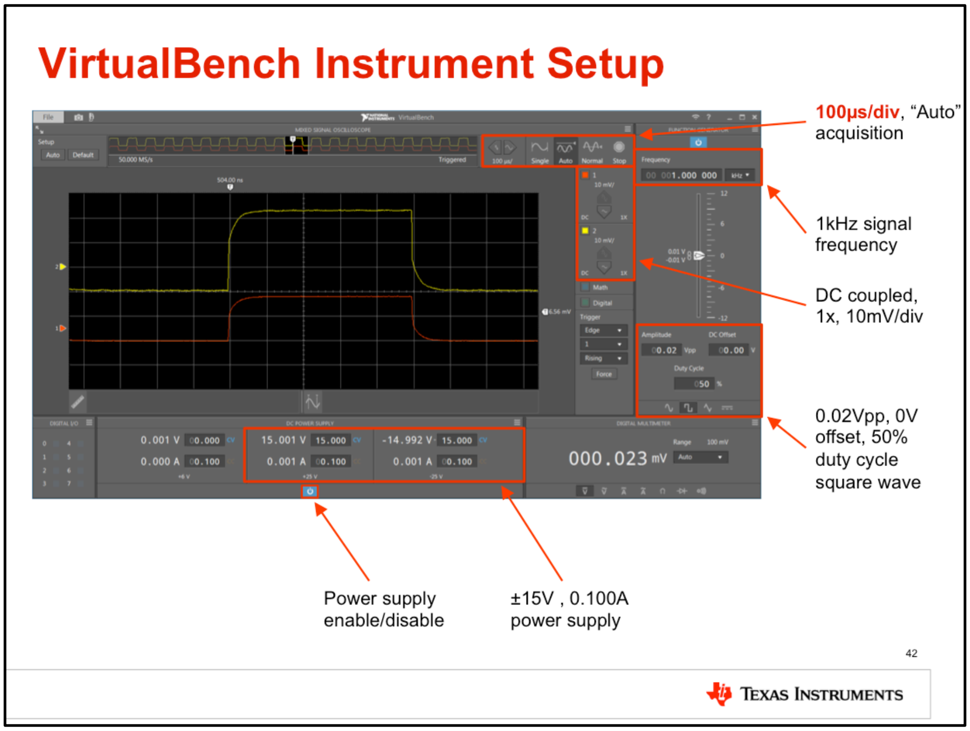


For the test board to function properly, it is important that you only install jumpers and devices in circuit 6! Do not install any jumpers or devices in any other circuits on the PCB! Remove any jumpers or devices from the unused circuits and store them in the storage area at the bottom of the test board.

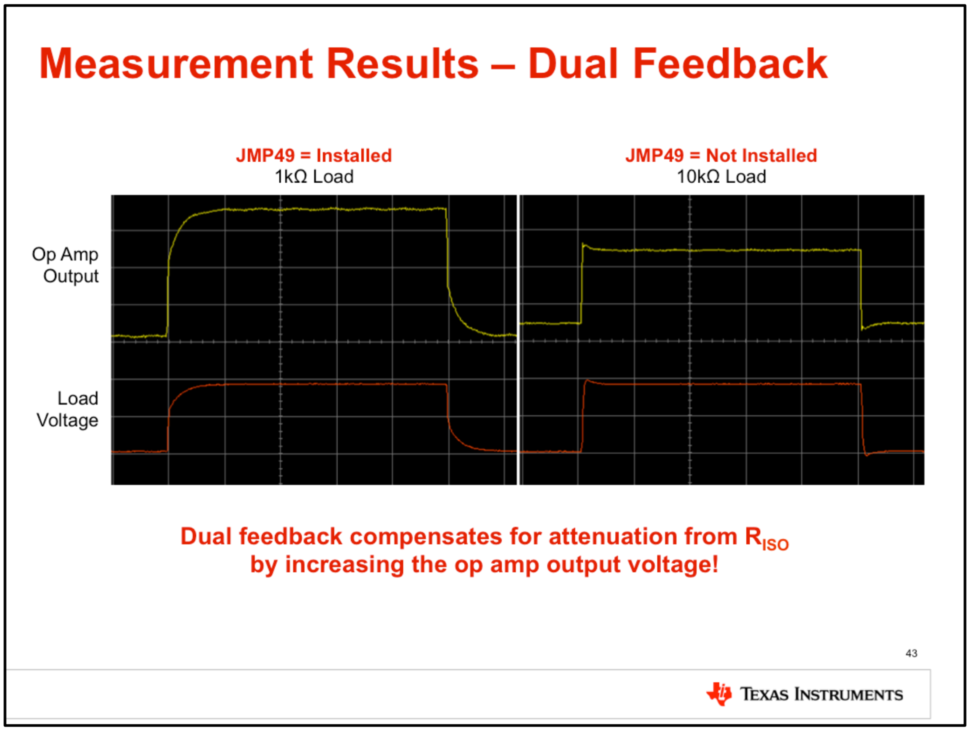


The cable connections are the same as in Experiment 2. Connect the provided power cable to the DC power supply of the Virtual Bench and power connector J4 on the test board.

Connect Vin2 on the test board to the VirtualBench FGEN. Connect Vout1 on the test board to VirtualBench oscilloscope channel 1 to measure the load voltage, and connect Vout2 on the test board to VirtualBench oscilloscope channel 2 to measure the unloaded op amp output voltage.



The VirtualBench setup is almost the same as before. Only change the time scale to 100us/div. All other settings must remain the same.



You should see results similar to this. As you can see, the load voltage remains accurate, even with changing load, due to the compensation provided by the dual-feedback network. The unloaded op-amp output voltage must increase as the load resistance decreases to minimize the output voltage divider effect.

That concludes this lab – thank you for your time!