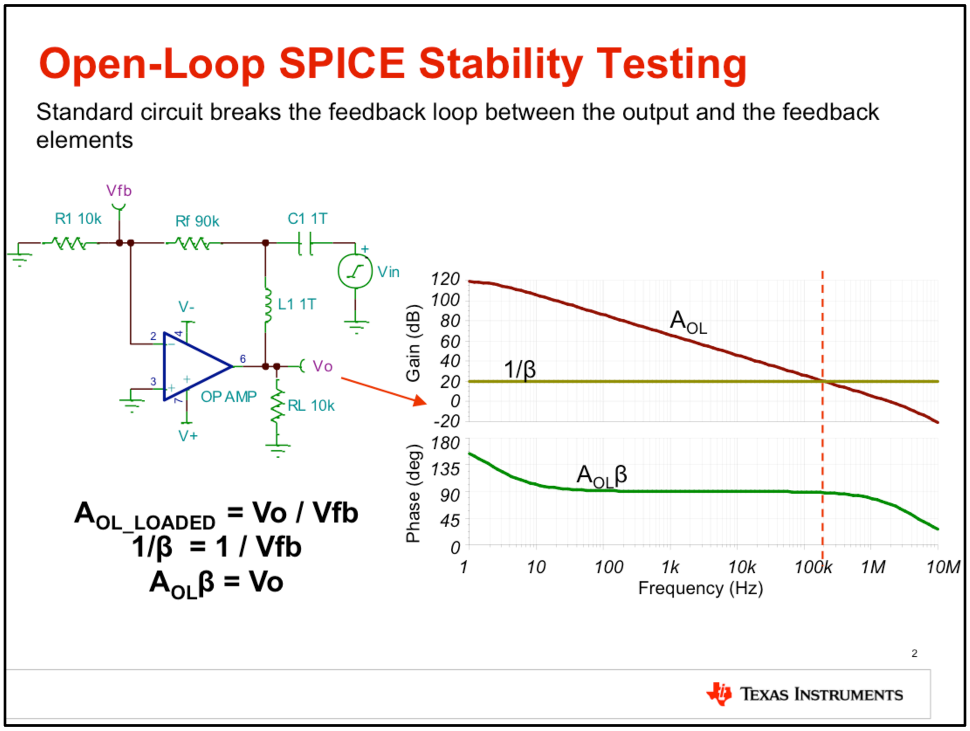
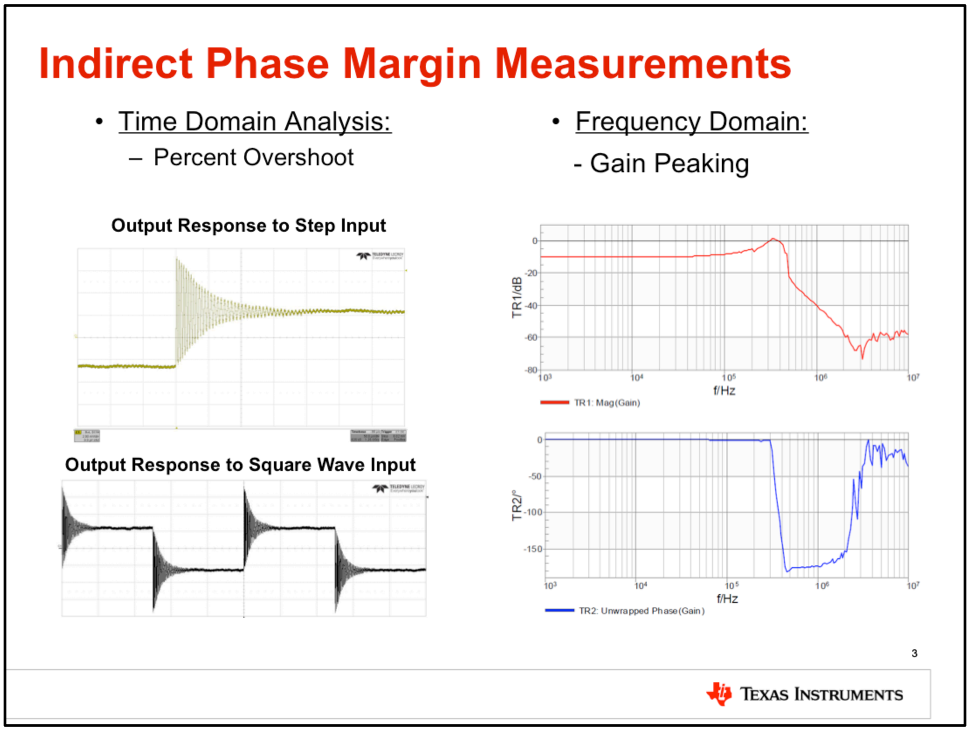
Hello, and welcome to part four of the TI Precision Labs on op amp stability. The previous videos have focused on understanding and measuring the phase margin and rate of closure of circuits using SPICE.

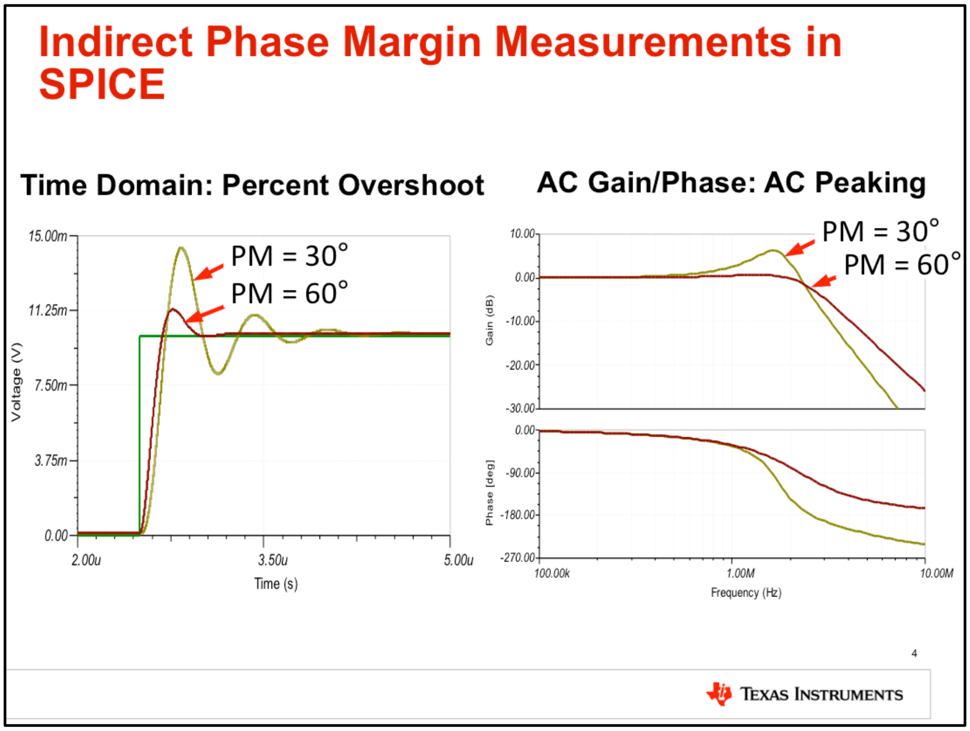
This video will explain how to perform indirect phase margin measurements in SPICE and on the bench through time domain and ac frequency domain measurements.



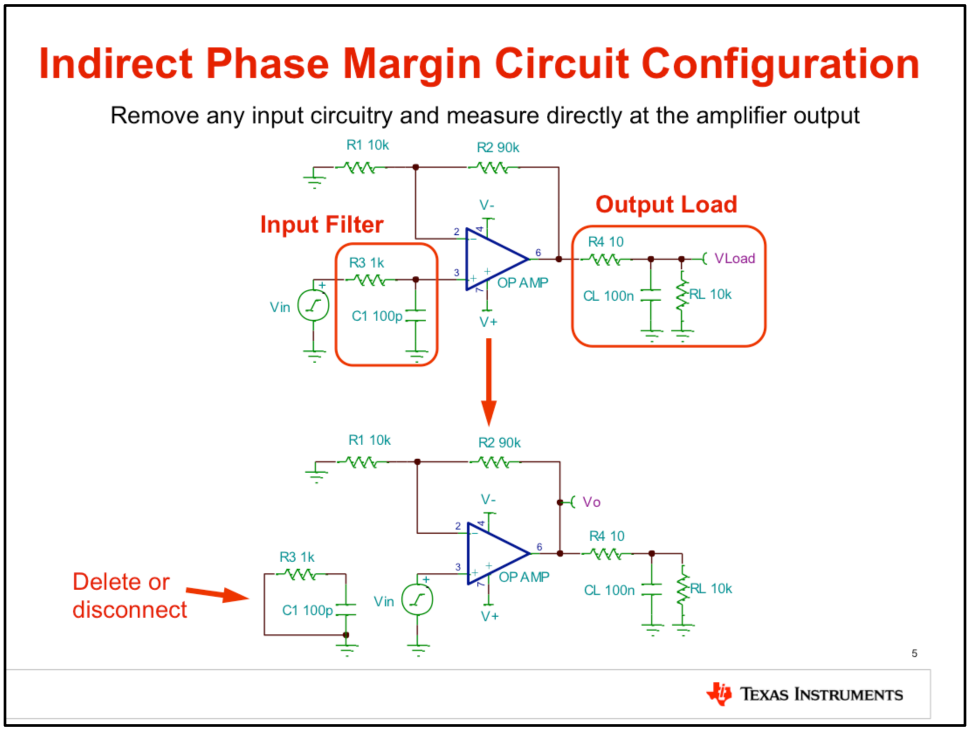
While the phase margin and rate of closure measurements discussed in the previous video are possible in SPICE, it is rarely practical to make open-loop measurements while testing circuits in the lab.



Luckily, there are two fairly easy-to-run tests that can be used to indirectly measure the phase margin of a circuit. The first is to measure the output percent overshoot in response to a step or square wave input. This test can be run using a standard lab function generator and oscilloscope. The second test is to measure the gain peaking in the ac frequency domain. This measurement can be performed on some advanced oscilloscopes, but generally requires a gain / phase analyzer.

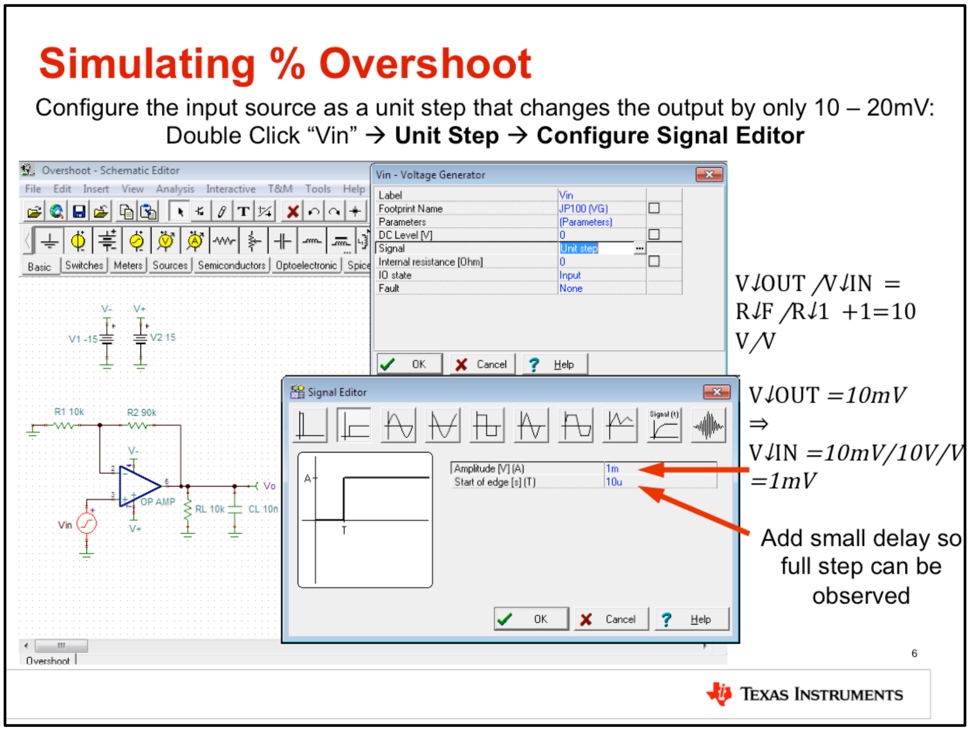


As shown in these SPICE simulations, the magnitude of the percent overshoot and ac gain peaking directly correlate to the phase margin of the circuit. Circuits with lower phase margins exhibit a classic underdamped output response with significant percent overshoots relative to the input step size and ringing. Low phase margins also result in noticeable ac peaking when measuring the closed loop ac gain and phase characteristics of the circuit.



Circuit modifications are occasionally required before indirect phase margin measurements can be made. First, all indirect phase margin measurements must be made directly at the output of the amplifier, not at after any output filtering. However, be sure to leave all output loading connected to the amplifier to test its effects on the stability of the circuit.

Input filtering must be removed completely from the circuit so the input step or ac signal is applied directly at the non-inverting input of the amplifier. In SPICE, this is fairly simple and involves disconnecting the input filter and moving the input source. On the bench, this may require minor PCB rework so the input filter is disconnected and a signal can be applied directly to the non-inverting input.



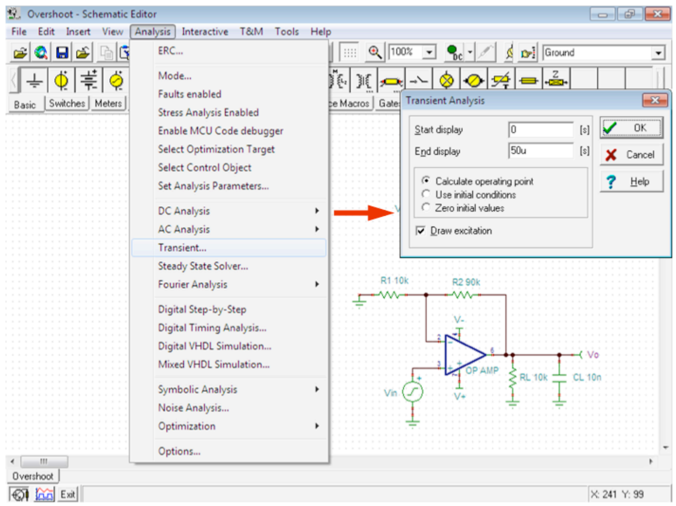
The next slides detail how to simulate percent overshoot and ac gain peaking in SPICE. The same basic principles can be applied to bench testing as well.

To simulate the percent overshoot, first configure the input signal to be a "Unit Step" with an amplitude that causes the output to change by only 10 to 20 millivolts. If the output is required to drive a capacitive load, output signals larger than 10 to 20mV can result in large-signal behavior which may mask small-signal stability issues.

Therefore, using the gain of the circuit, calculate the proper input step level so the output changes by only 10 to 20 mV. Add a small delay to the start of the edge of the step so the entire step can be observed then click "OK" to save the input source configuration.

Simulating % Overshoot

Run a transient analysis over the appropriate frequency range:
Click **Analysis → Transient → Configure the Start and Stop Times**



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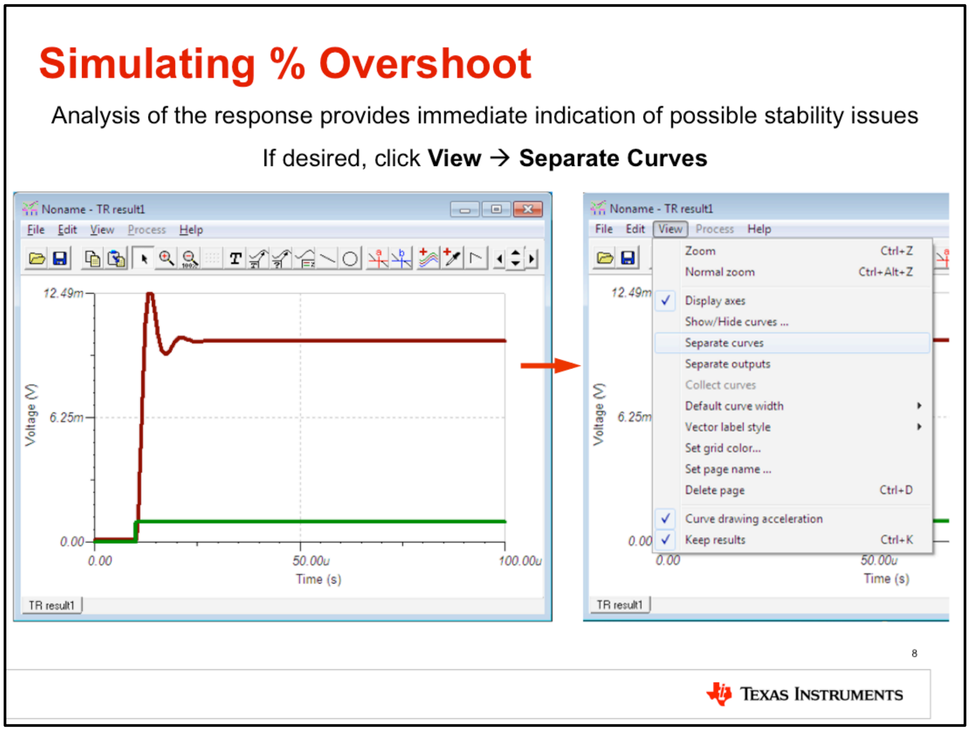
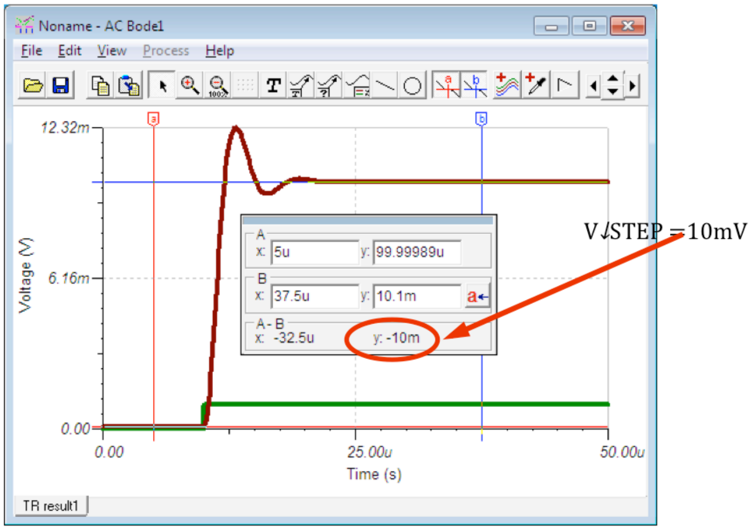
With the input step properly configured, click the "Analysis" menu and select transient response. Configure the start and stop times and then press "OK" to run the simulation.



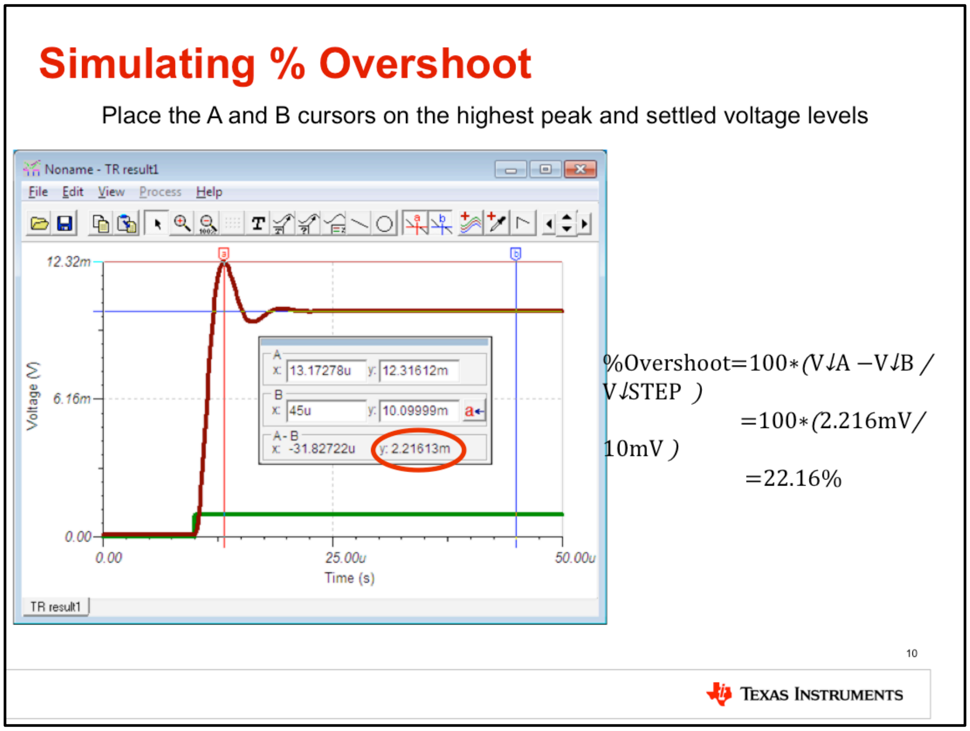
Without performing any measurements, it is usually possible to identify whether or not a circuit has a stability issue based on if the circuit looks over damped, critically damped, or under damped. If desired, the curves can be separated or the input can be deleted.

Simulating % Overshoot

Verify the output step size by placing cursors before the step and after the output settles

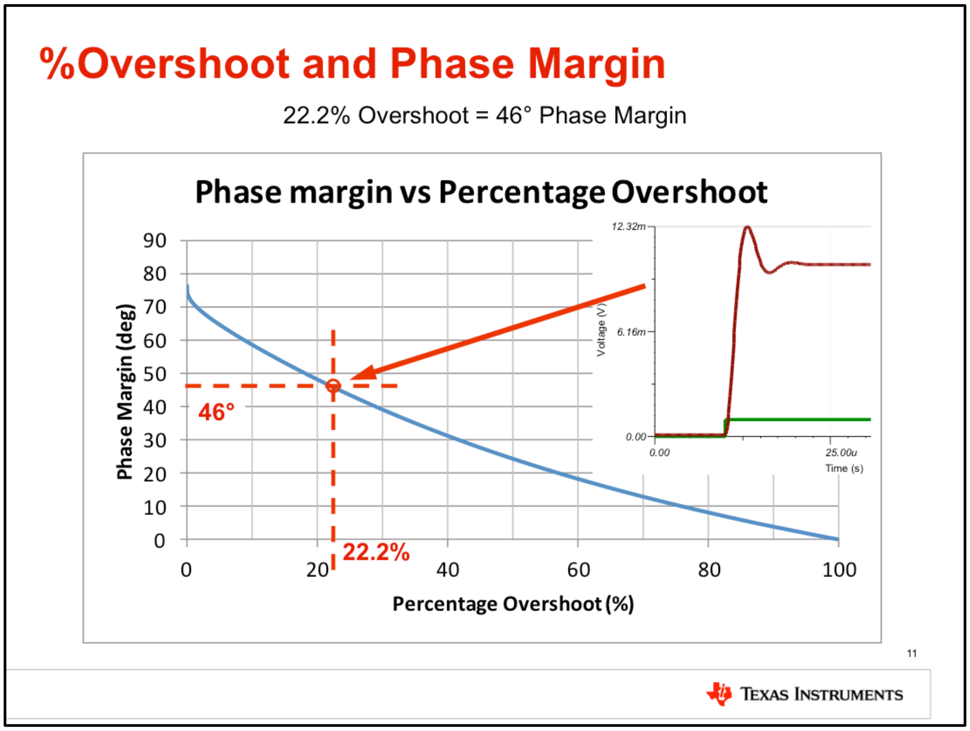


Before measuring the % overshoot, let's verify the output step size. Place the A cursor at the output's initial value. Then place the B cursor at the output's settled final value. Take note of the delta-Y value in the cursor display and ensure that the output step size is correct. In that case, the output matches the desired output step of 10mV.



To measure the % overshoot, place the A cursor on the highest peak voltage in the overshoot. Place the B cursor on the settled output voltage level. Again, the delta-Y value in the cursor display will show the absolute overshoot. Use the equation on the right to calculate the percent overshoot.

In this circuit, the measured % overshoot was 22.16%. We can use this value to calculate the phase margin!

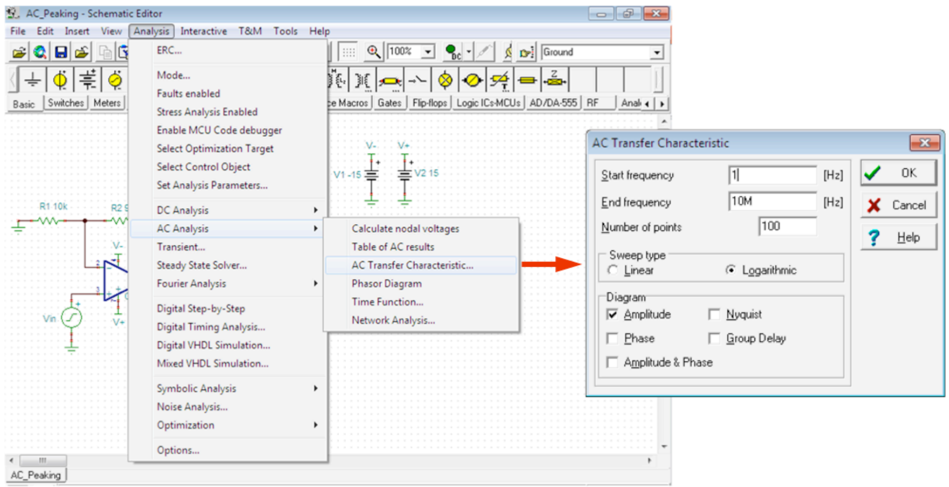


This curve displays the phase margin vs % overshoot, based on their mathematical relationship to each other through the damping factor. Find the x-axis coordinate for the 22.2% overshoot measurement and then draw a line straight up until it intersects the phase margin vs % overshoot curve. Draw a horizontal line at this point to the y-axis to determine the phase margin.

The 22.2% overshoot correlates to roughly 46 degrees of phase margin, which is barely above the recommended 45 degrees of phase margin.

Simulating AC Gain Peaking

Run an AC transfer characteristic analysis over the appropriate frequency range:
Click **Analysis → AC Analysis→ AC Transfer Characteristic**



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TEXAS INSTRUMENTS

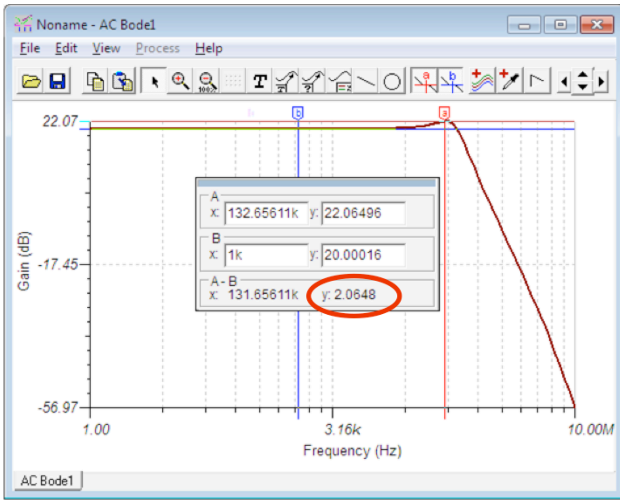
To simulate the ac gain peaking of a circuit, simply connect an input source directly to the non-inverting input of the amplifier. The dc level of the source will affect the operating region of the circuit, which may impact the ac results, but the signal source configuration type as a step or sine wave is not taken into consideration for this simulation.

From the “Analysis” menu, select AC Analysis, then AC Transfer Characteristic. Configure the start and end frequencies to include the circuit operating frequency range, then click “OK” to run the simulation.

For bench testing of ac gain peaking, configure the input source to a level that allows the output to operate within the linear operating region of the amplifier and run the gain / phase measurement over the circuit operating frequency.

Simulating AC Gain Peaking

Place the A and B cursors on the peak and flat gain levels



$$\text{Peaking(dB)} = \text{Gain}_A - \text{Gain}_B = 22.065 - 20 = 2.065\text{dB}$$

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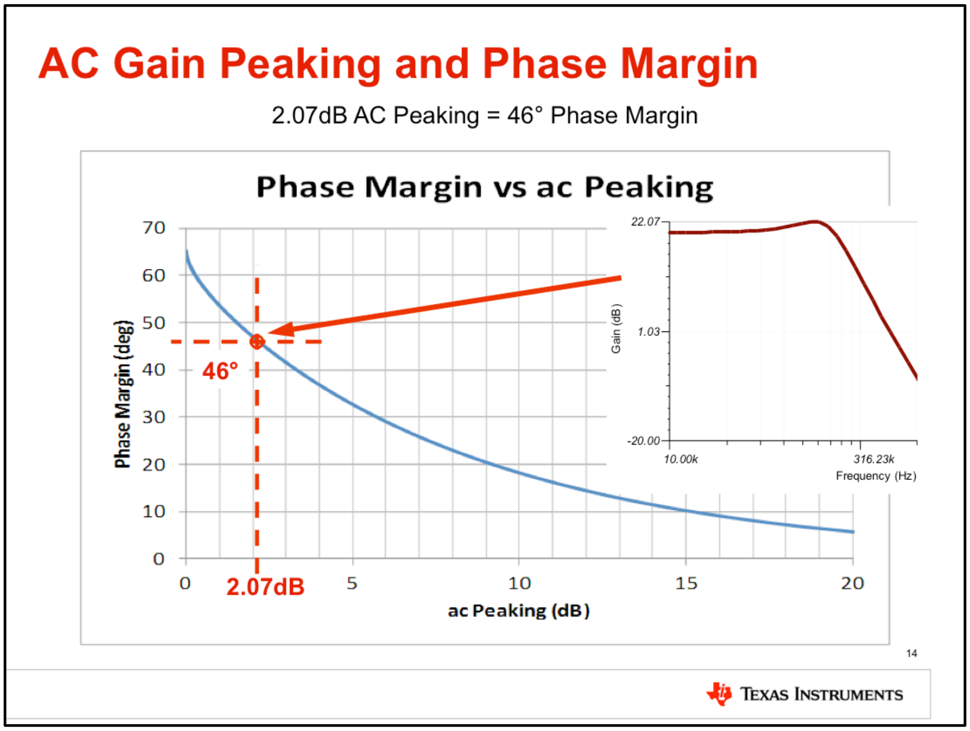
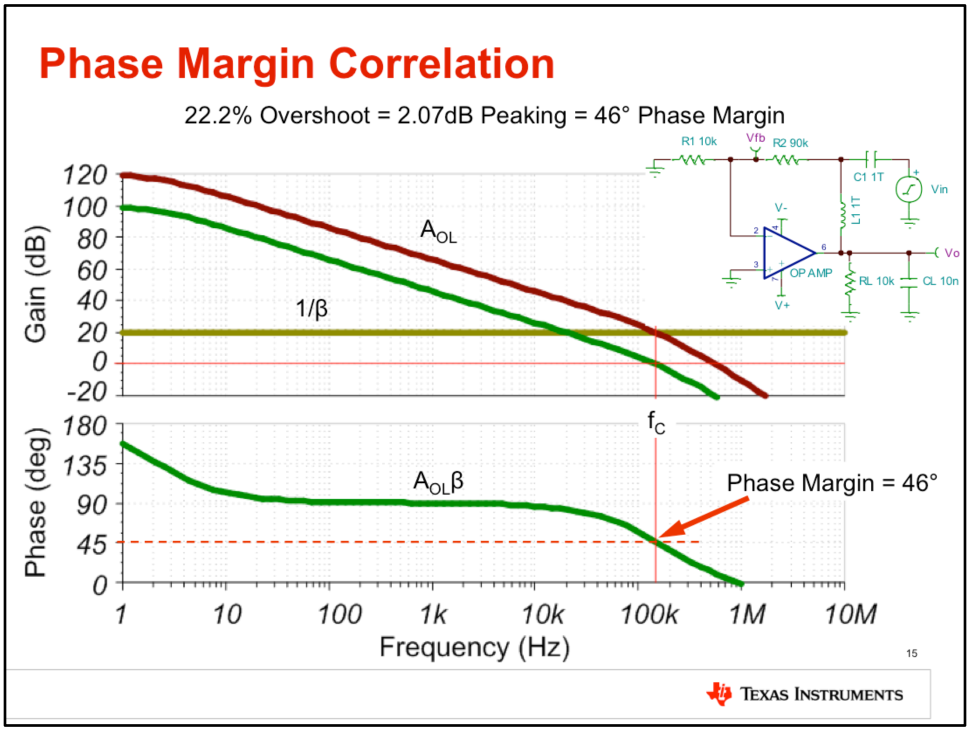
TEXAS INSTRUMENTS

To measure the ac gain peaking of the response, place the A cursor on the highest peak of the output response at the frequency where the loop is closed. Place the B cursor on the flat region of the response to measure the closed-loop gain. The ac peaking in dB is simply the difference of these gain values. In this circuit the measured ac gain peaking was 2.065dB.



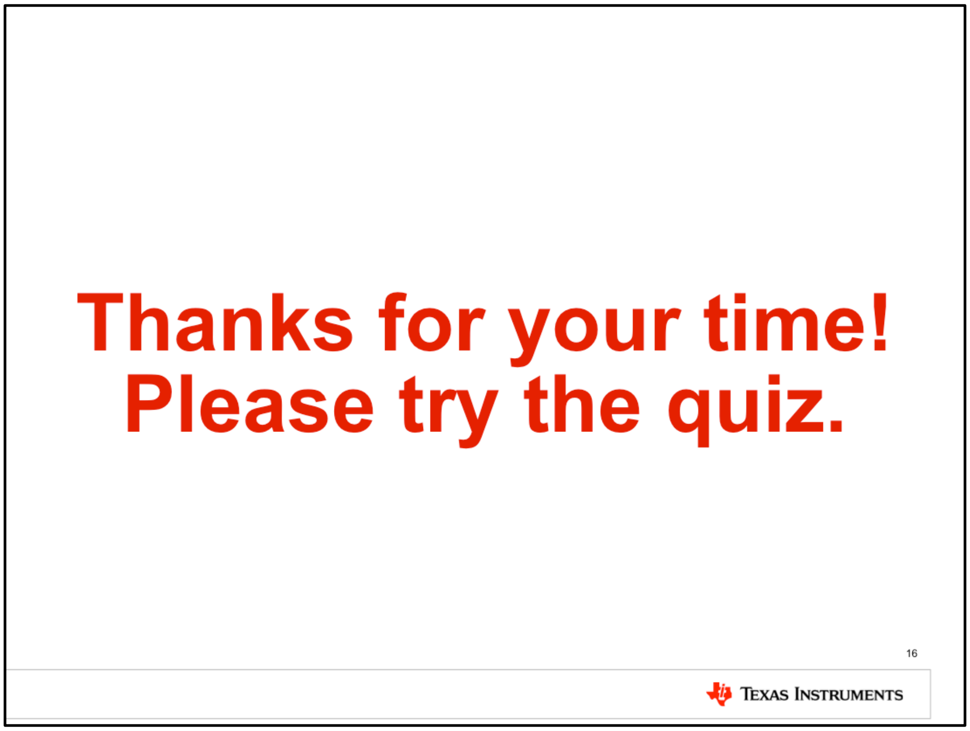
The phase margin versus ac gain peaking curve is show here. To determine the phase margin, first find the x-axis coordinate for the 2.07dB of ac gain peaking, and then draw a line straight up until it intersects the phase margin vs ac gain peaking curve. Draw a horizontal line at this point to the y-axis to determine the phase margin.

The 2.07db of ac gain peaking correlates to 46 degrees, matching the phase margin from the % overshoot measurements.



The open-loop phase margin measurement method shown in the previous video was used to directly measure the phase margin of the circuit. This allows us to verify the accuracy of our results from the indirect phase margin measurements.

As shown, the measured phase margin was 46 degrees, matching the phase margin measured through the % overshoot and ac gain peaking methods. Therefore, the indirect methods provide a quick way to accurately test the stability of a circuit on the bench or in SPICE.



In summary, this video discussed the theory and measurement methods for making indirect phase margin measurements using % overshoot and ac gain peaking tests. The video focused on simulating these tests, but the same theory can be applied to making indirect phase margin measurements on the bench.

While the indirect methods will provide indication to whether or not there is a stability issue in the circuit, the root cause of the stability issue can't be determined from these tests. Therefore if the results of the indirect stability tests indicate a stability issue with the circuit, it's recommended that a full open-loop rate of closure simulation is performed to determine if the issue is due to the output loading or feedback of the amplifier circuit.

Thank you for time! Please try the quiz to check your understanding of this video's content.

Stability 4

Multiple Choice Quiz

TI Precision Labs – Op Amps

Quiz: Stability 4

1. (T/F) It is practical to make open-loop measurements on most circuits being tested in the lab

a. True
b. False

2. (T/F) It is possible to indirectly measure the phase margin of a circuit through transient and frequency domain behavior.

a. True
b. False

3. (T/F) The circuit phase margin is ______ proportional to the magnitude of %overshoot and ac peaking.

a. Indirectly
b. Directly

4. (T/F) Output loading should be removed from the circuit before performing indirect stability methods.

a. True
b. False

Quiz: Stability 4

5. (T/F) Input filtering should be removed from the circuit before performing indirect stability methods.

a. True
b. False

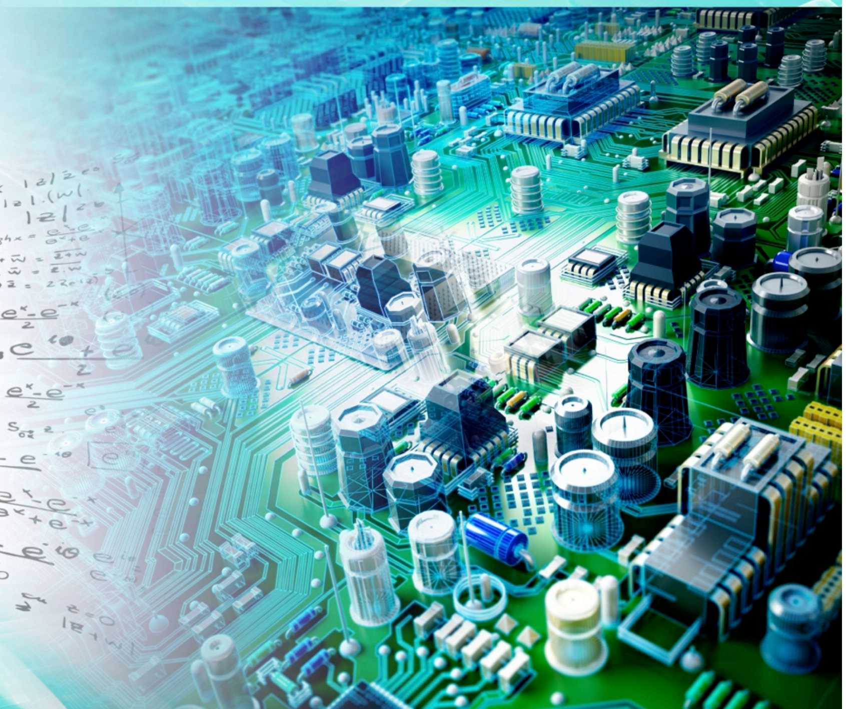
6. (T/F) Indirect stability testing can directly indicate the root cause of a circuit stability issue.

a. True
b. False

Stability 4

Multiple Choice Quiz: Solutions

TI Precision Labs – Op Amps



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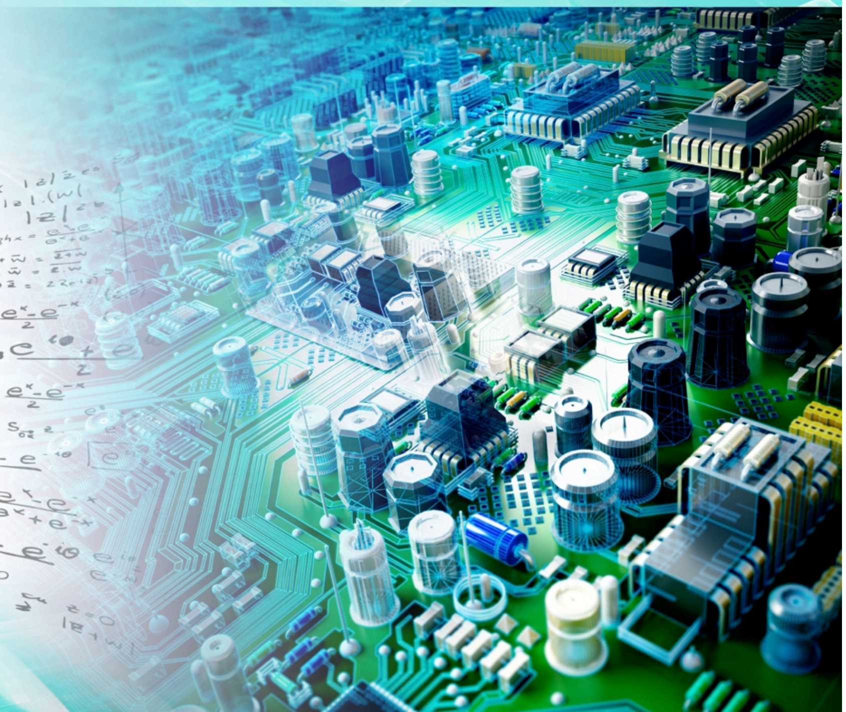
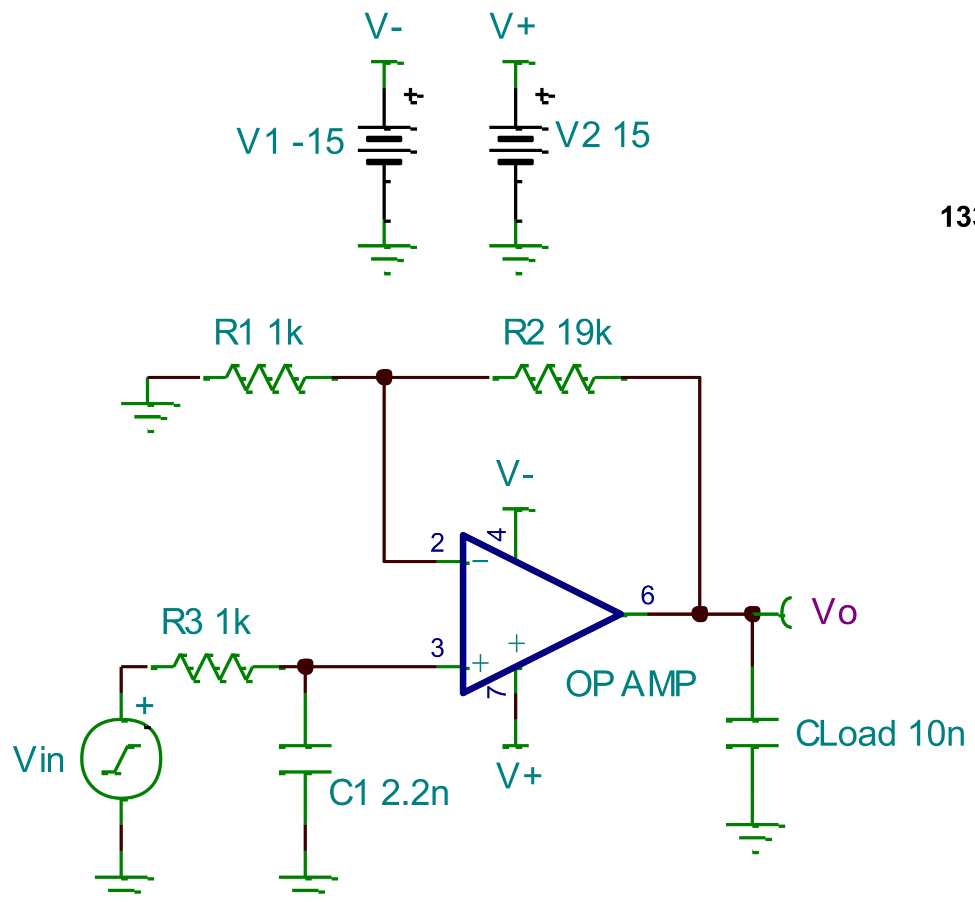
Stability 4

Exercises

TI Precision Labs – Op Amps

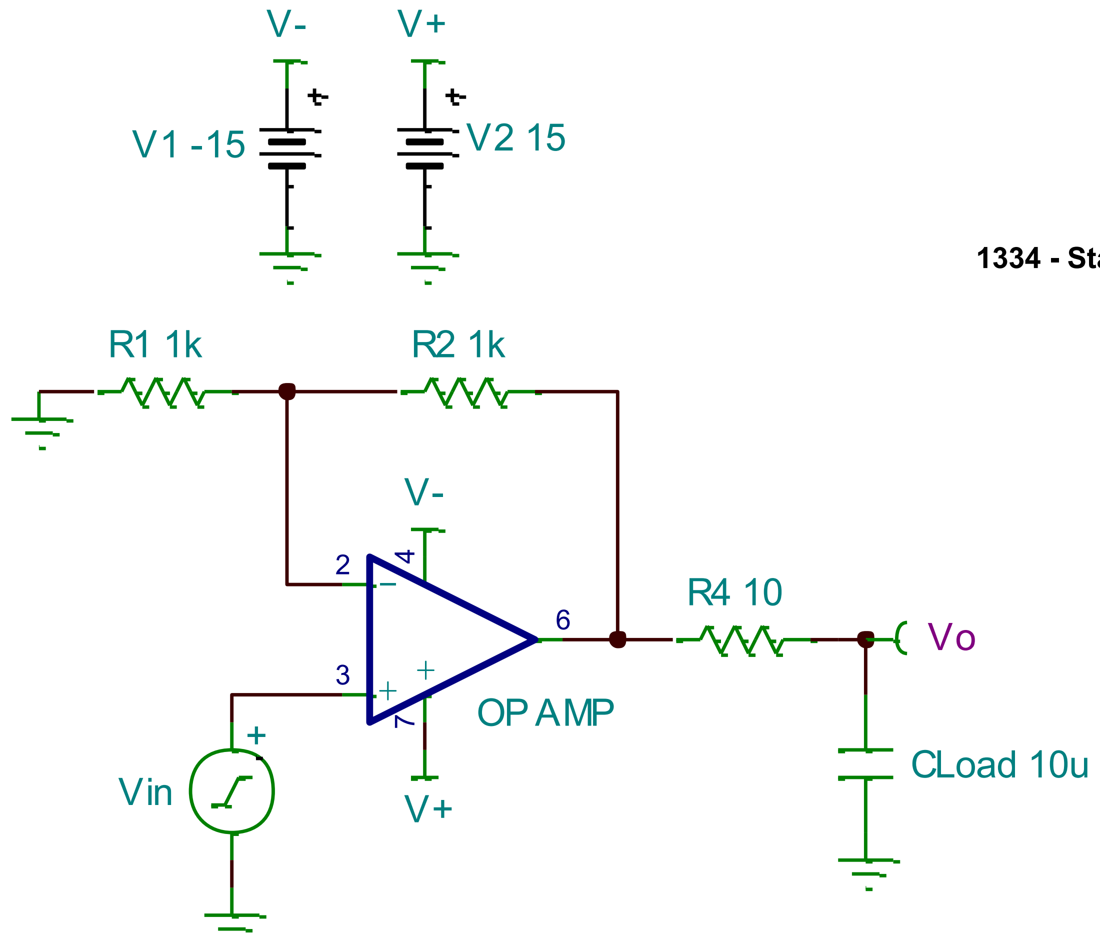


1. **Simulate the percent overshoot and ac gain peaking for the following circuit. Based on these indirect measurements, what is the Aolβ phase margin?**



1334 - Stability 4 - Problem 1.TSC

2. Simulate the percent overshoot and ac gain peaking for the following circuit. Based on these indirect measurements, what is the Aolβ phase margin?

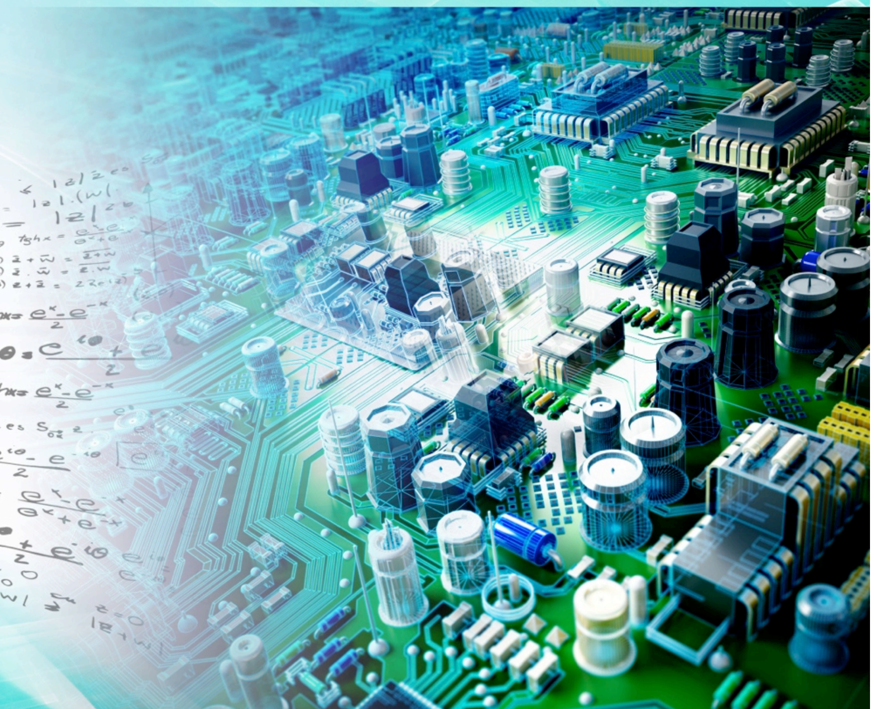


1334 - Stability 4 - Problem 2.TSC

Stability 4

Solutions

TI Precision Labs – Op Amps



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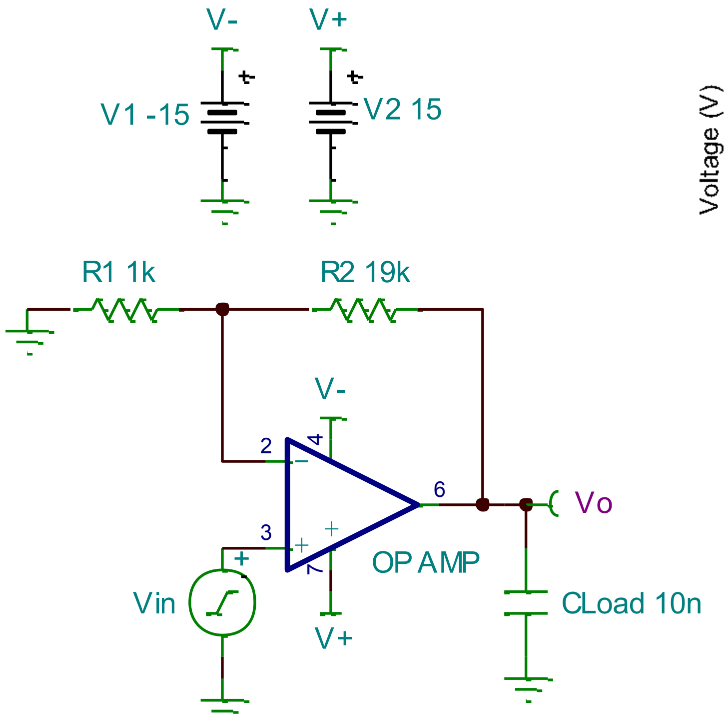

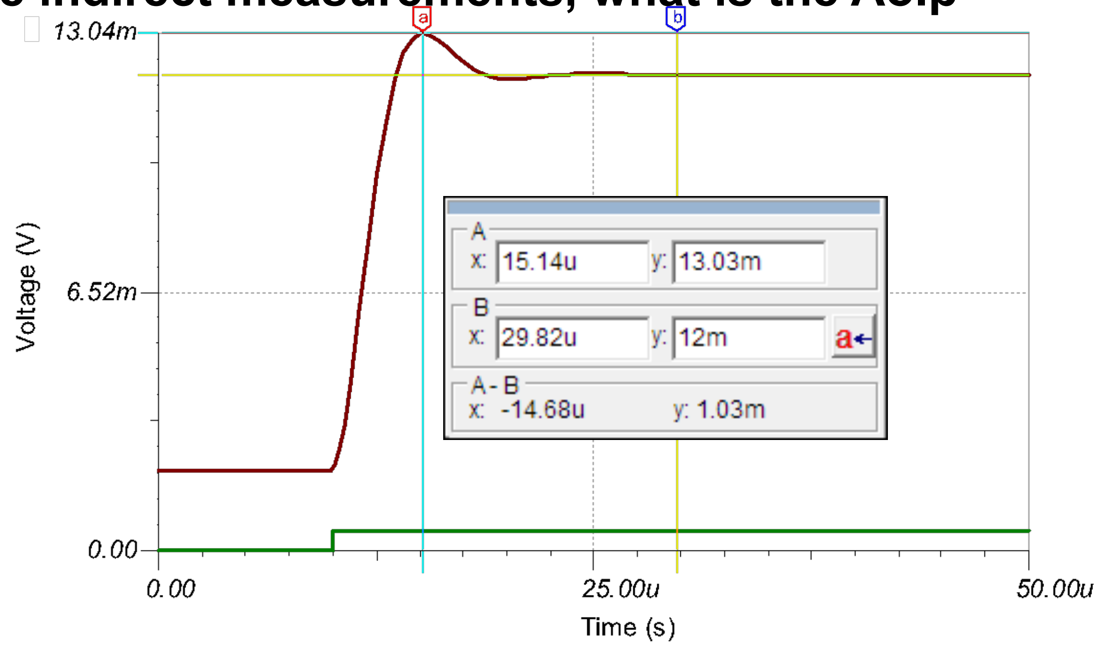

Vo/Vin = 1+(19/1) = 20V/V
Vo = 10mV
Vin = 500µV

1334 - Stability 4 - Problem 1 -Solution.TSC

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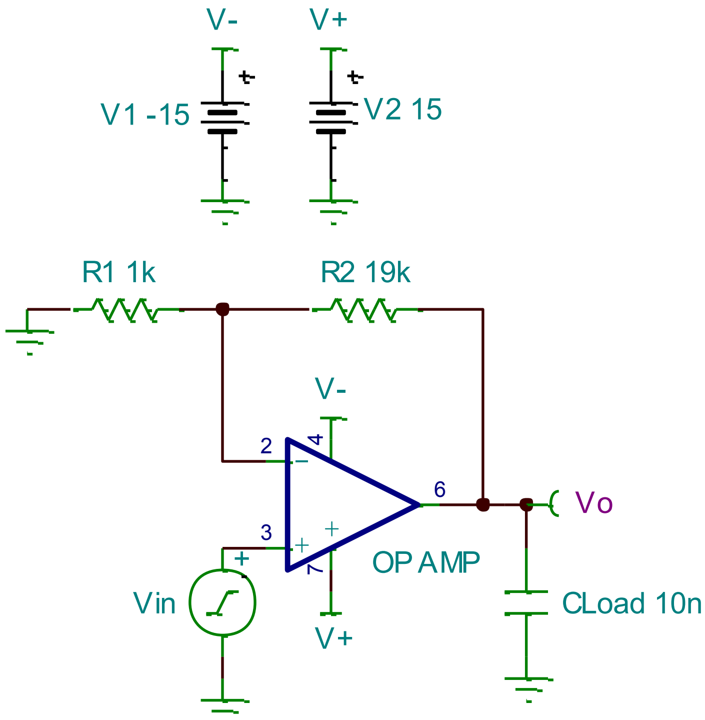

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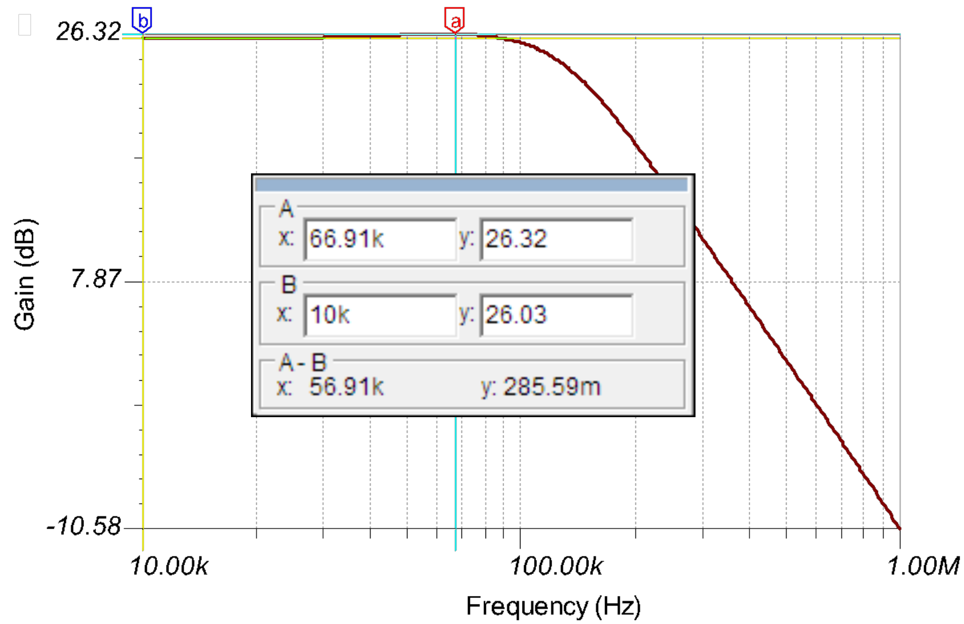

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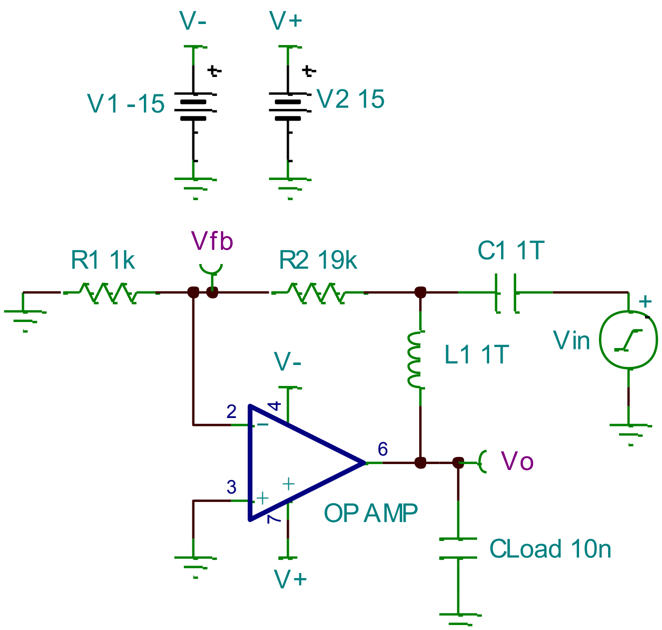
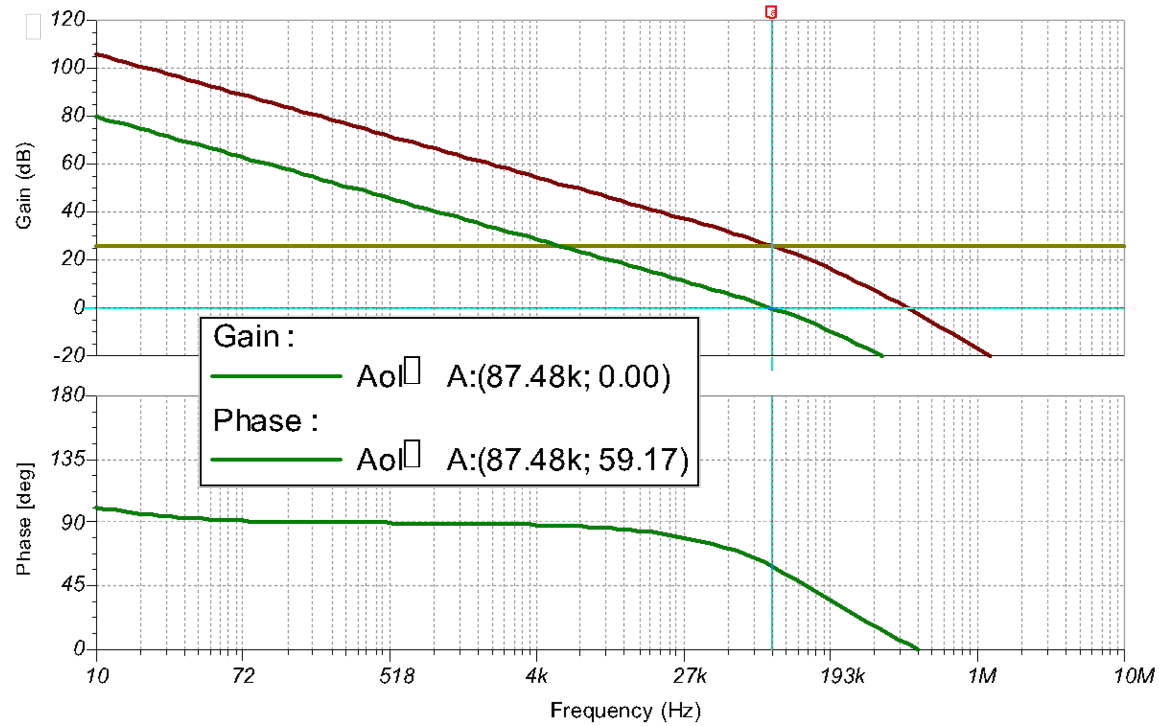
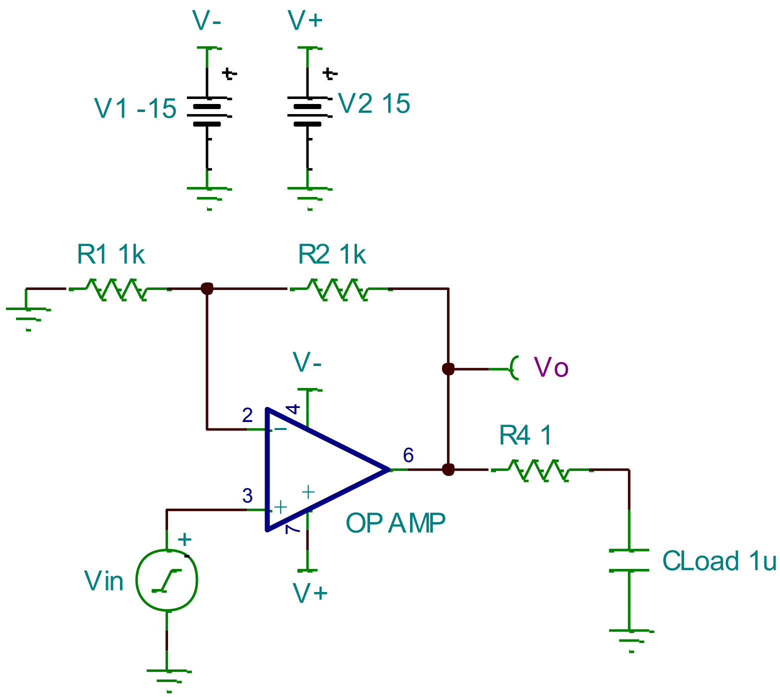
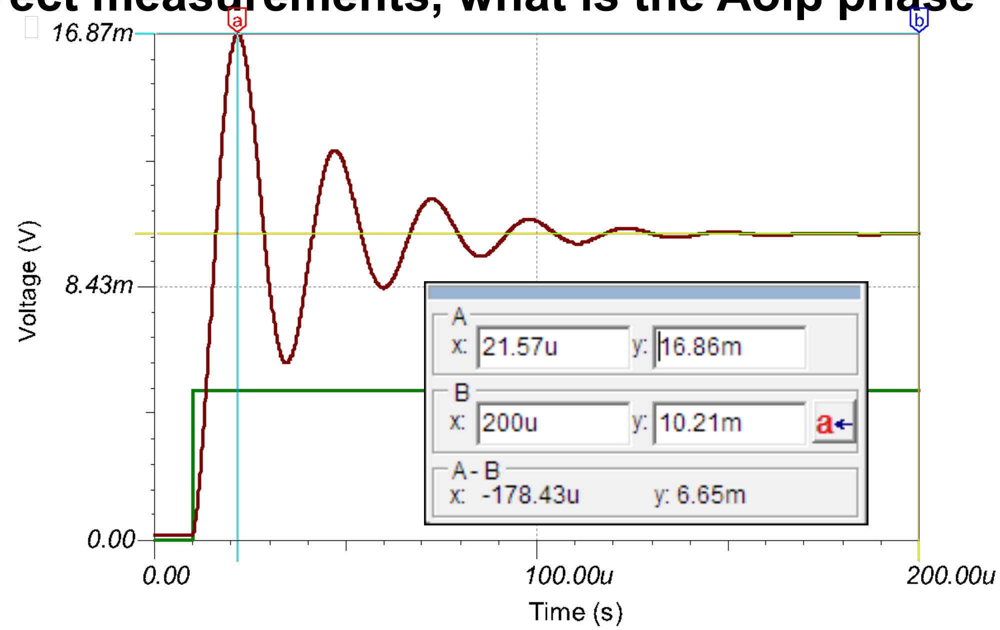




1334 - Stability 4 - Problem 1 - Solution2.TSC

2. Simulate the percent overshoot and ac gain peaking for the following circuit. Based on these indirect measurements, what is the Aolβ phase margin?





Vo/Vin = 1+(1/1) = 2V/V
Vo = 10mV
Vin = 5mV

1334 - Stability 4 – Problem 2 - Solution.TSC

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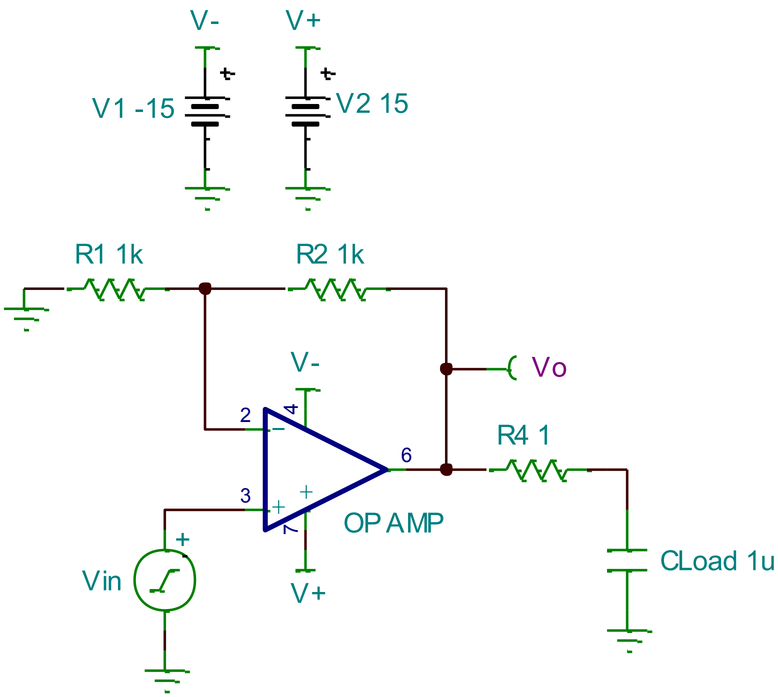

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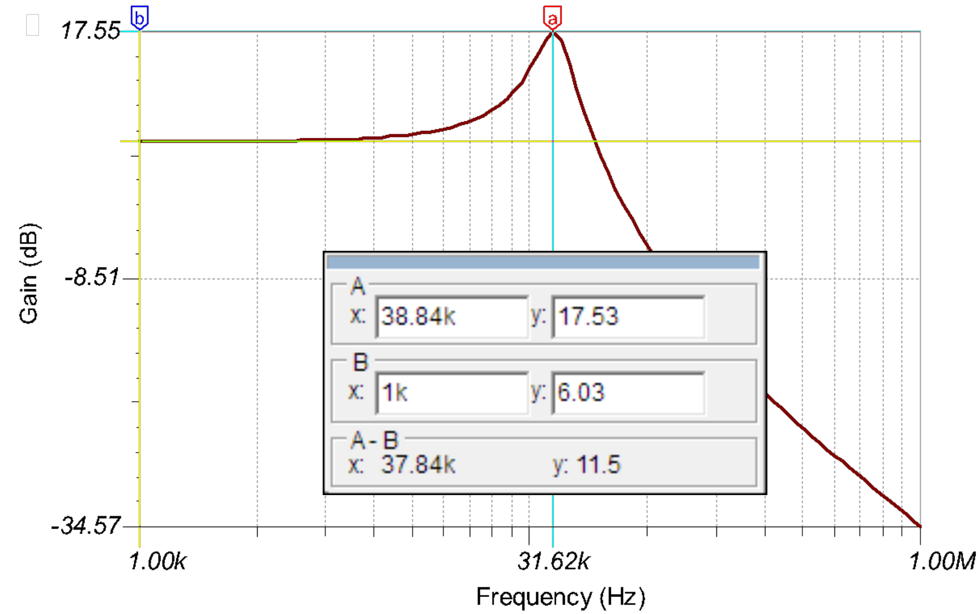

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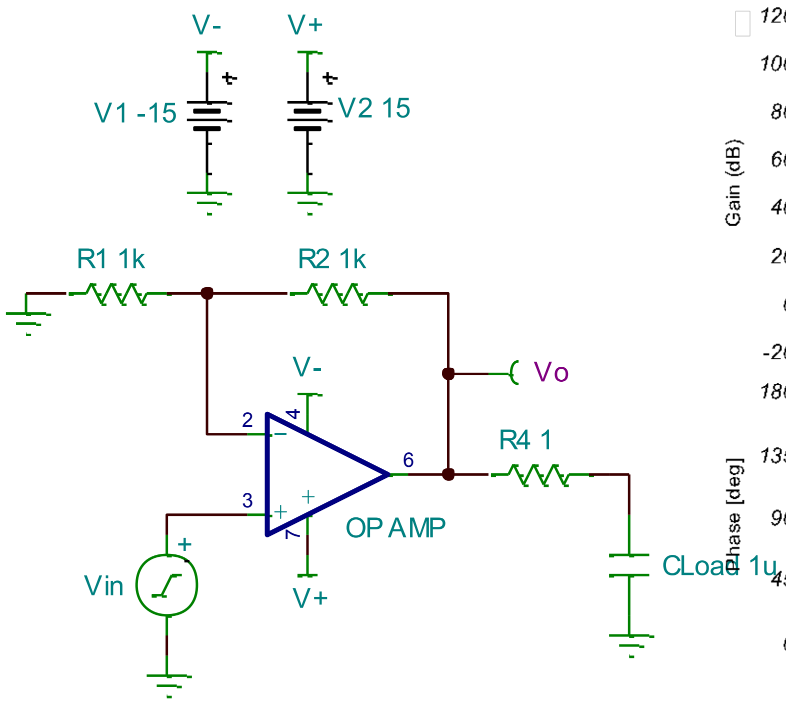

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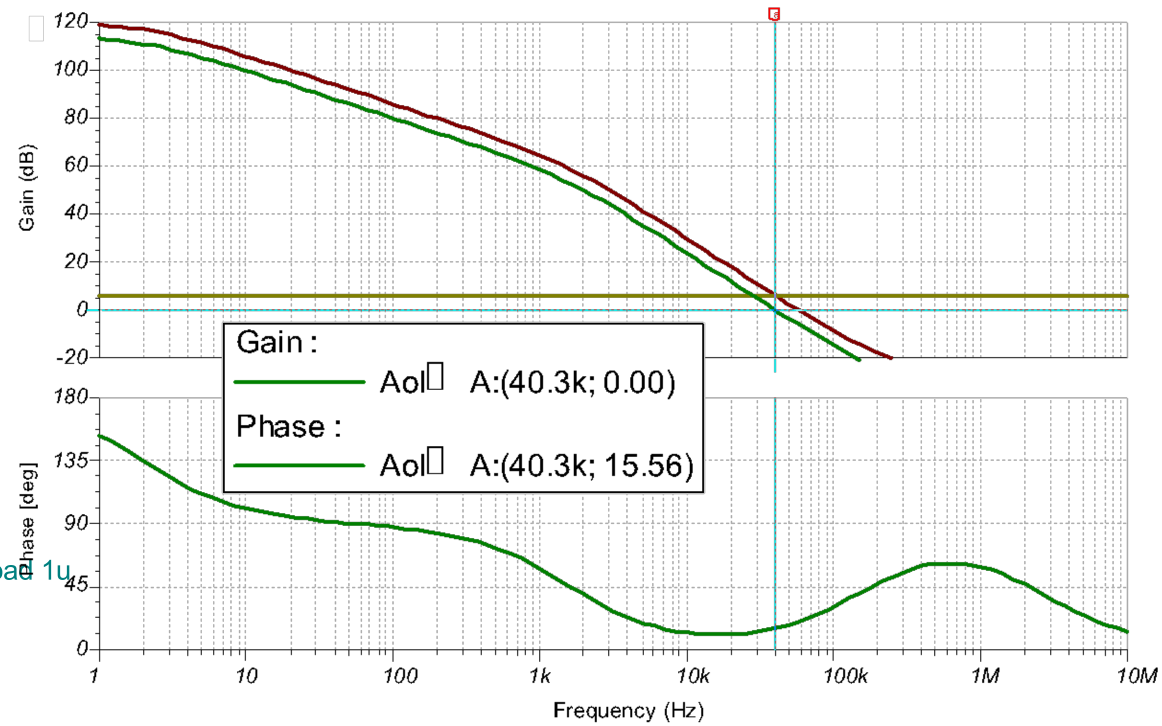

1334 - Stability 4 - Problem 2 -Solution2.TSC