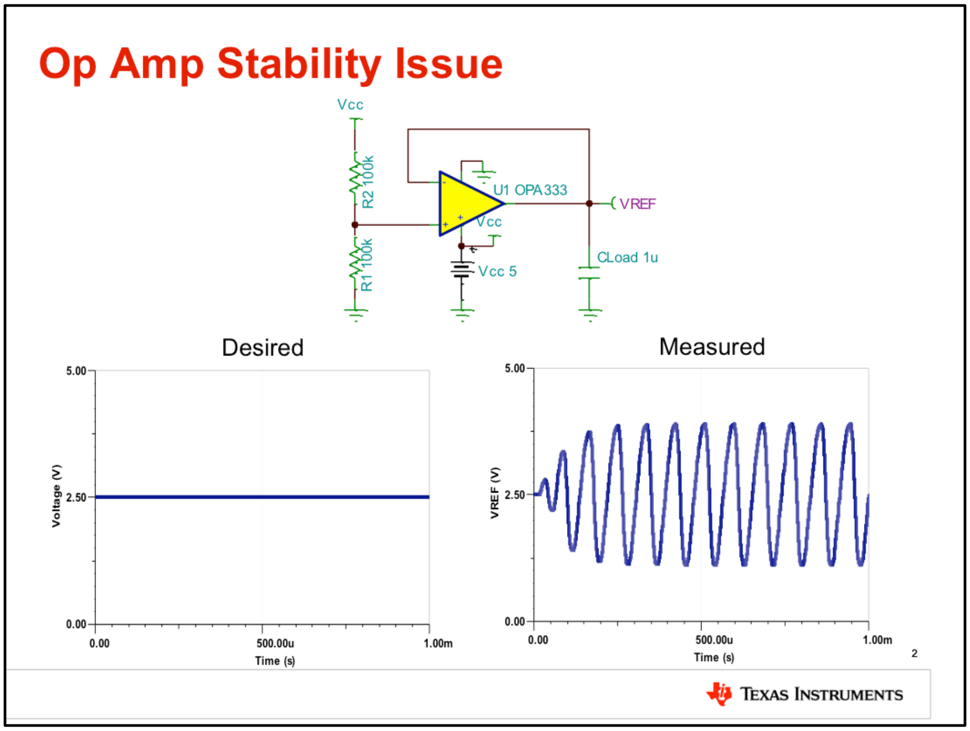
Hello, and welcome to part 1 of the TI Precision Labs on op amp stability. In this video we will discuss the common causes of op-amp stability issues as well as how to identify stability issues in the lab using common equipment.

The following videos in the series will provide a review of Bode plots, basic stability theory, and how to simulate op amp stability in SPICE. The remaining videos will address specific compensation techniques with detailed analysis of the solutions.

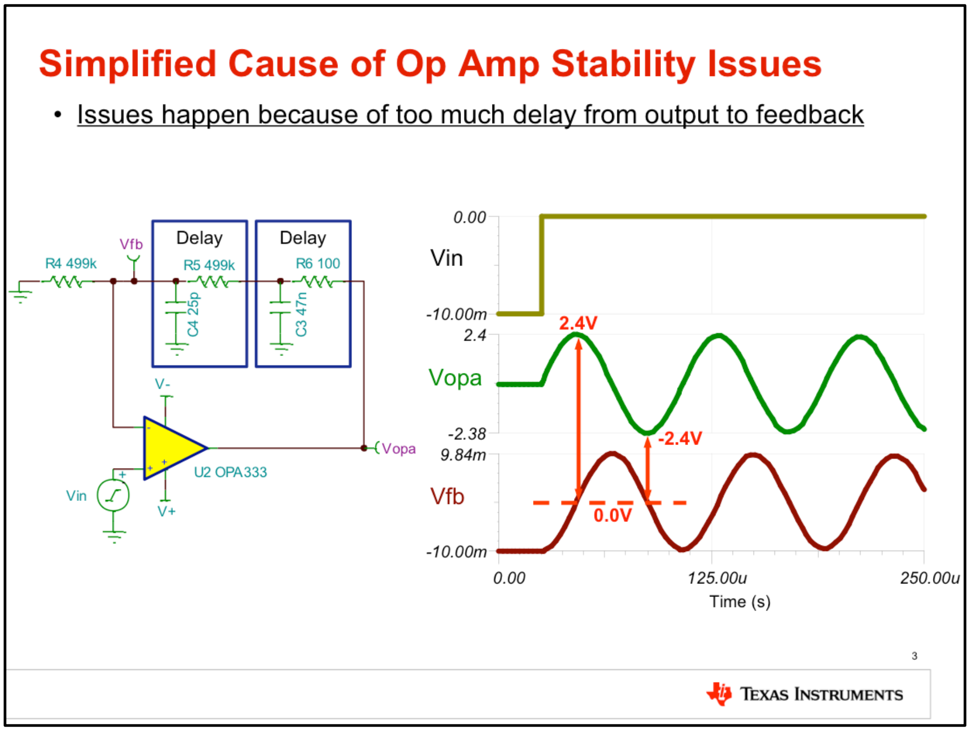
Before proceeding with the op amp stability series the lectures and problem sections for Op-Amp Bandwidth one through three should be completed. The bandwidth series thoroughly discusses several key concepts used in stability theory that will only briefly be reviewed in the stability video series.



Here is an example of what can happen if a circuit's stability is not verified before going to production. An op amp circuit that is unstable will have an unpredictable or unexpected output with poor transient performance. This typically results in large overshoots and ringing when changes occur on the input or load, but may also result in sustained oscillations. Often stability problems are caused by connecting a capacitor to the output or to the inverting input of the amplifier.

This op amp supply-splitter circuit was designed to deliver a constant 2.5 V dc output for the reference voltage in a system. However, the unstable design resulted in a sustained output oscillation, which has turned the DC reference voltage into a sine wave!

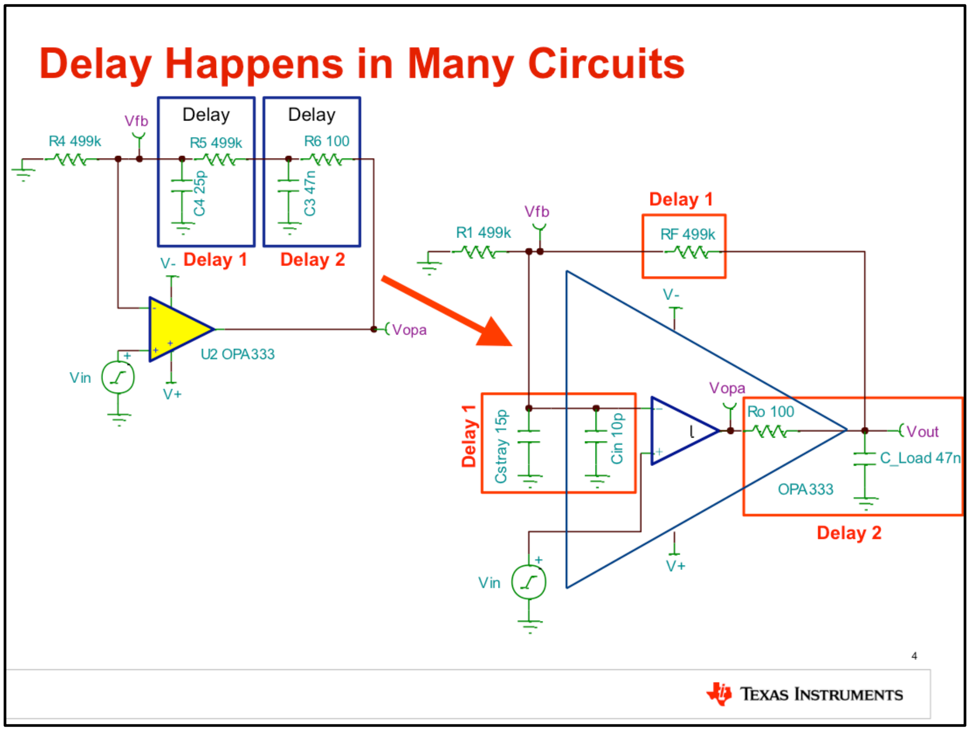
Even though this circuit is meant to operate with a dc input and output, transient disturbances on the input, power-supplies, or on the output may cause the amplifier to begin to oscillate. Therefore, we recommend checking every op amp circuit for stability regardless of the closed loop signal frequency of operation.



Too much delay between the amplifier output and the inverting feedback node is a straightforward way to visualize the root cause of op amp stability issues.

The effects of feedback delay are displayed in the example shown by observing the voltages at the amplifier output, Vopa, and inverting input, Vfb, when a step is applied to the input, Vin. When Vin changes, Vopa responds in an effort to set Vfb equal to Vin which will reestablish the “virtual short” between the inputs.

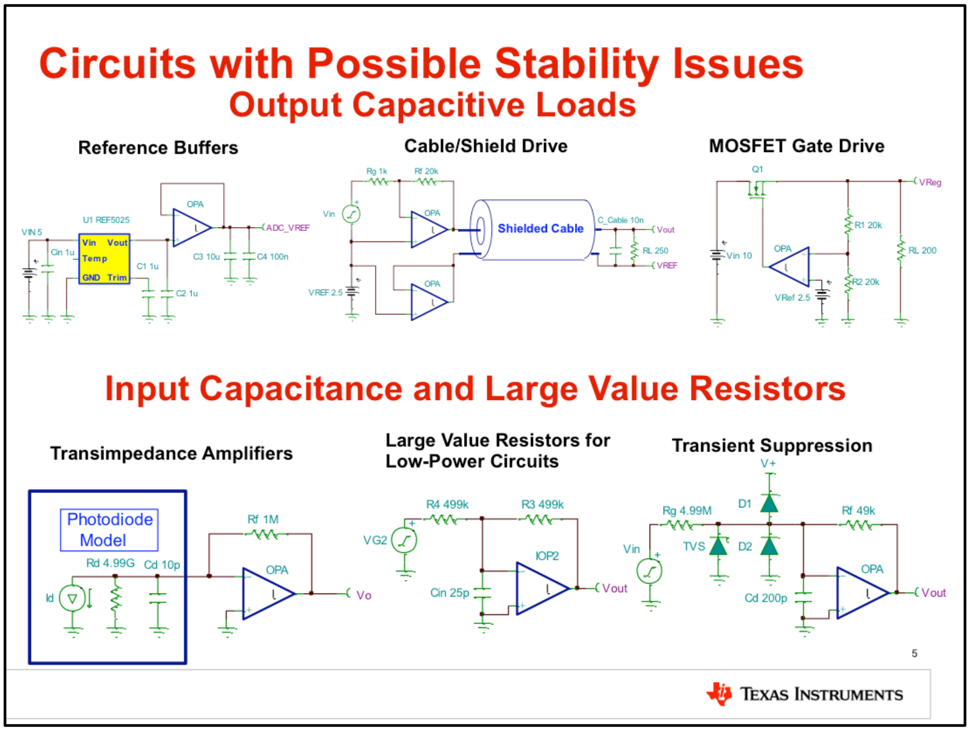
However, the feedback delay results in an erroneous voltage at Vopa by the time Vfb equals Vin. As a result Vfb continues to rise and overshoots the input voltage causing Vopa to reverse directions. Depending on the severity of the delay the output may settle, or may result in a sustained oscillation as shown here.



While the op amp circuit with the RC delay elements in the feedback path looks strange and unrealistic, many standard op amp circuits inadvertently create the same situation when external circuit components interact with non-ideal op-amp properties.

For example an op amp's open-loop output impedance, Ro, frequently interacts with the circuit load capacitance, Cload, to form a delay. Another delay is commonly formed when the feedback resistance, RF, interacts with the parallel combination of the op amp input capacitance, Cin, and any stray PCB capacitance.

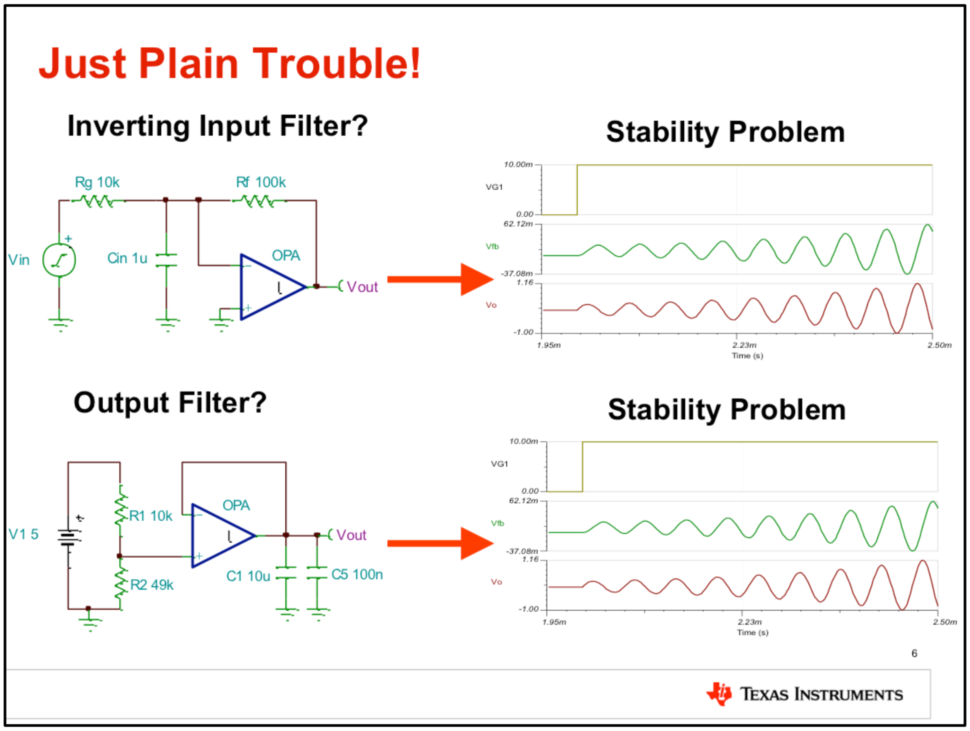
The delay caused by either of these situations can result in stability issues if not properly taken into consideration..



So, without further ado, here are the most common circuits and applications involved in op amp circuit stability issues. These circuits all create unwanted delay from the output to the feedback node and can be divided into two distinct groups based on the issue they cause in the op amp control loop.

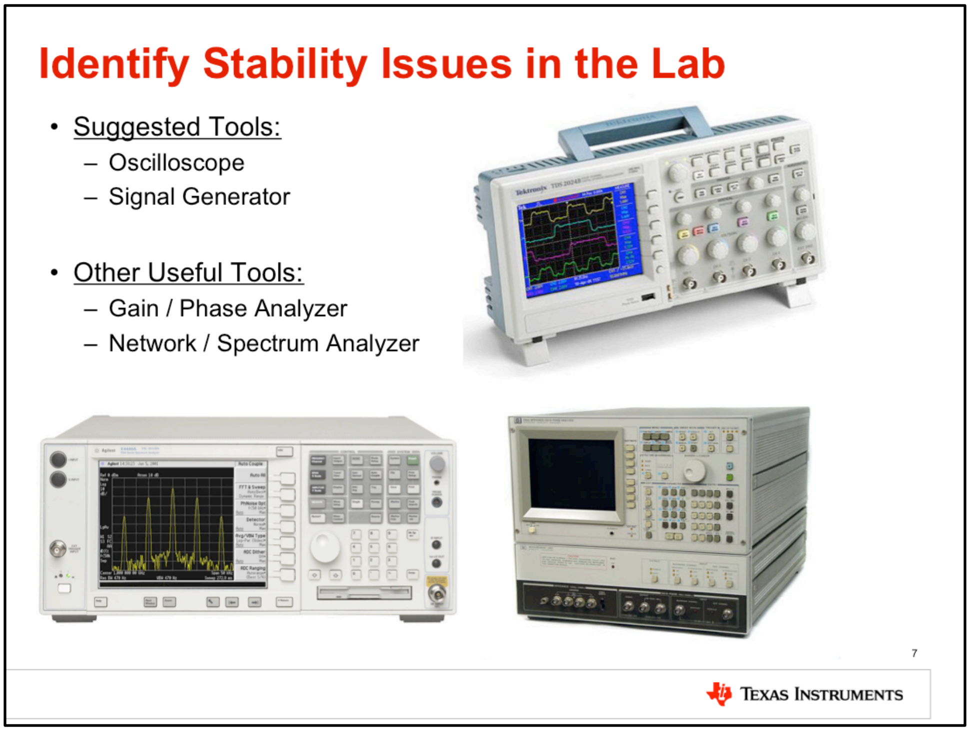
The first, and most common group of circuits are those that disturb the open-loop gain of the amplifier circuit by presenting a capacitive load, either directly or due to parasitic elements, on the output of the amplifier. Examples of these circuits include voltage reference buffers, cable/shield drive circuits, and MOSFET drive circuits.

The second group of circuits disturb the feedback network of the amplifier circuit due to interaction between the input capacitance and large valued feedback resistors used in the circuit. Common examples of these circuits include transimpedance amplifiers, circuits designed for low-power operation, and circuits that feature transient suppression elements on the inverting input.



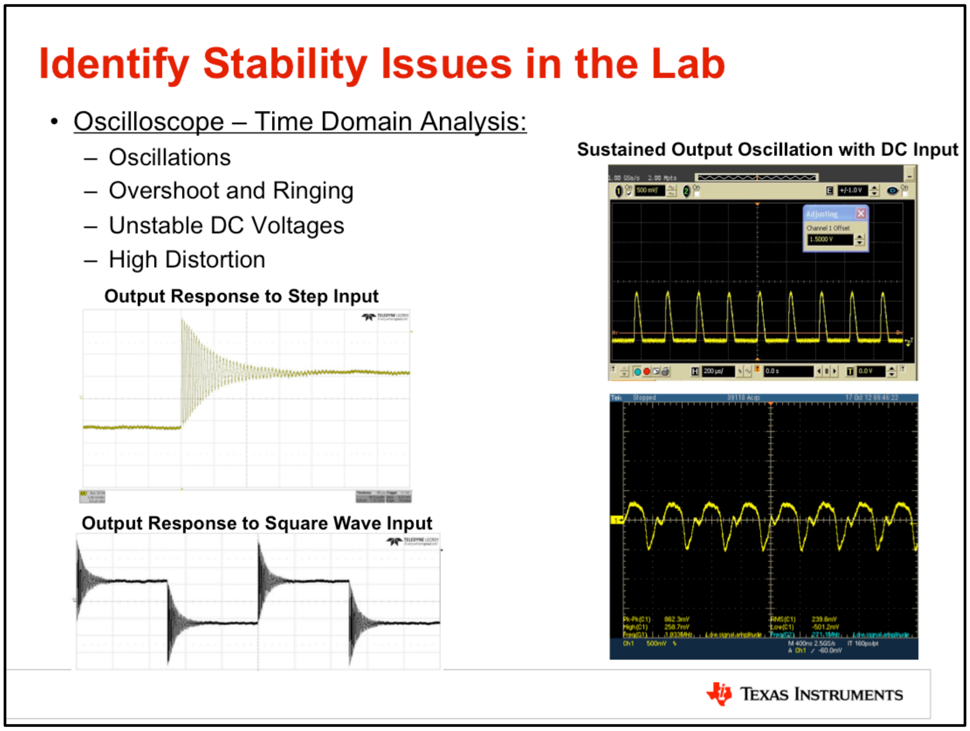
These two circuits are "Just Plain Trouble!" They will almost always have issues and should generally be avoided.

Attempting to filter the signal at the inverting input or output by directly placing a capacitor on those nodes will directly create the two most common causes of op amp stability issues. These designs are more likely to behave as oscillators as they are to do what was desired of them. If you see either of these circuits being designed make sure they are thoroughly analyzed for stable operation before taking them to production.



Although solving op amp stability issues takes practice and experience, identifying them in the lab is generally straightforward.

An input step signal generator and an oscilloscope are all that is required. The input step could come from a DAC that's already in the system or from an external function generator. If they are available, gain/phase analyzers and network/spectrum analyzers can also be used to help identify stability issues.



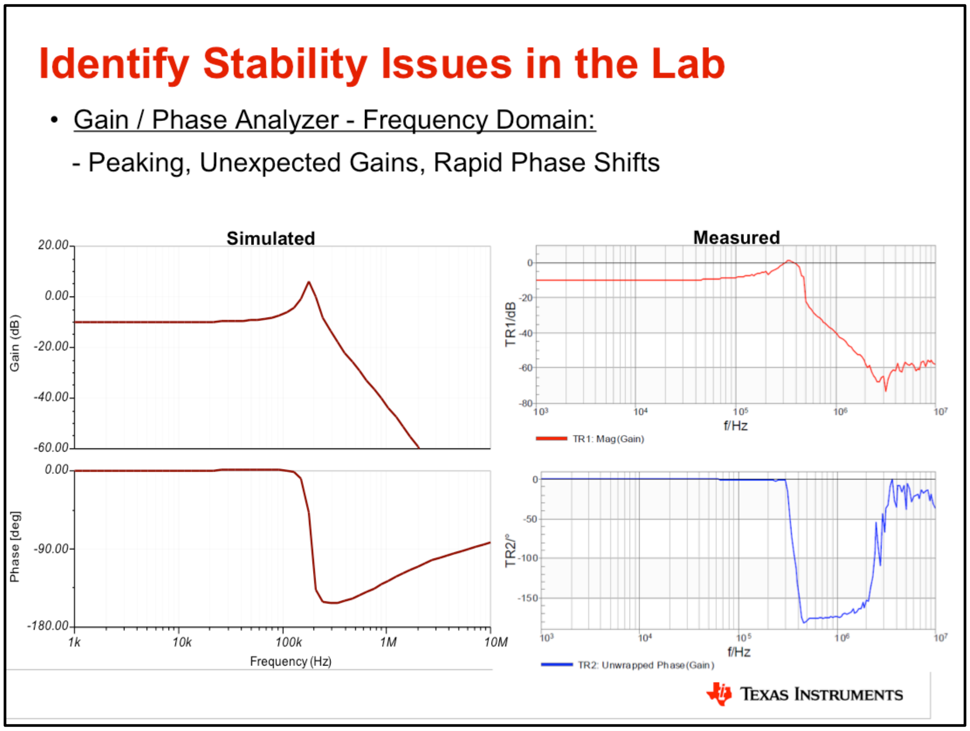
Here are some images of output signals from unstable circuits taken with common lab oscilloscopes.

A circuit with a dc output may look stable when first observed on an oscilloscope until the loop is disturbed when a small-signal step or square wave is applied to the input. An unstable circuit's output will overshoot the input signal and will then ring back and forth until the output settles out.

The magnitude of the overshoot and the duration of the ringing directly relate to the severity of the of stability issue. Circuits with minor stability issues may feature modest overshoots with minimal ringing. More severe stability issues will result in overshoots equal to or greater than the input signal with significant ringing as shown in these examples.

The most severe stability issues can result in sustained output oscillations without having to apply a signal to the input to disturb the loop. These circuits can produce a wide variety of strange looking output signals which may not always be pure sine-waves as possibly expected.

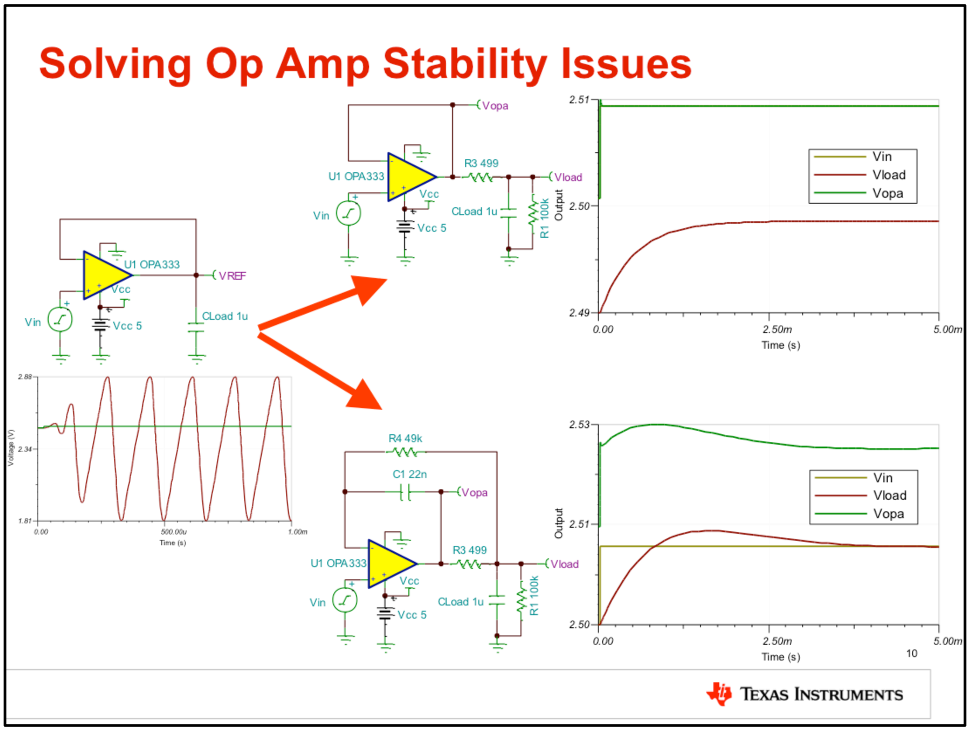
Although not featured here, unstable dc outputs and higher than expected distortion readings can be more subtle signs of a stability issue.



In addition to oscilloscopes, gain/phase analyzers can be used to measure the frequency response of a circuit which can also be used to identify stability issues. These results compare a circuit's simulated gain/phase response versus the measured response.

Gain peaking, rapid phase shifts in the frequency domain, or unexpected gains are all indicators of circuit stability issues.

When trying to measure the gain and phase of an unstable circuit it is common for the measured response to appear jagged or not clean and may be difficult to measure over the full frequency range. Watch for those more subtle signs of stability as well.



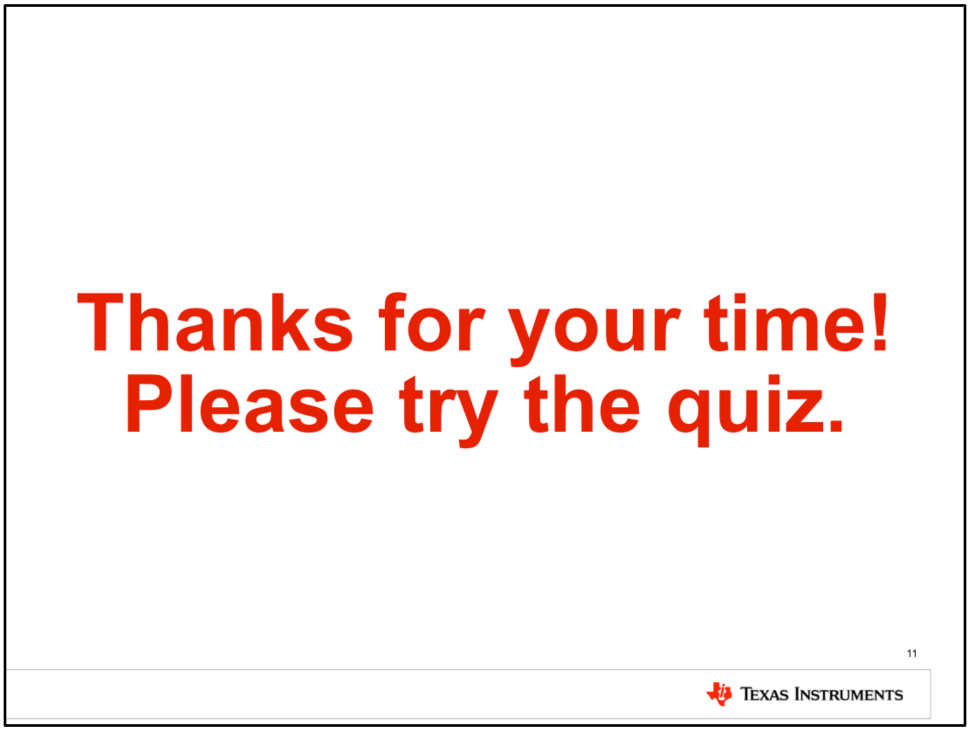
The objective of this series is to understand the different op amp stability compensation techniques, how to select the best method for a given application, and how to design the circuit with optimal component values.

As shown here, the supply-splitter circuit from earlier can be compensated multiple ways depending on the final application requirements. Two examples of which are shown here.

This technique uses an isolation resistor, Riso, to compensate the circuit at the expense of DC accuracy due to the voltage drop across Riso.

This technique pulls Riso back into the feedback loop, allowing the op amp to eliminate the voltage drop across Riso at the expense of settling time.

We'll explore the different methods to stabilize circuits after we review the necessary theory to understand, simulate, and compensate a feedback network.



In summary, this video discussed op amp stability issues, common circuits that cause stability issues, and how to identify stability issues in the lab.

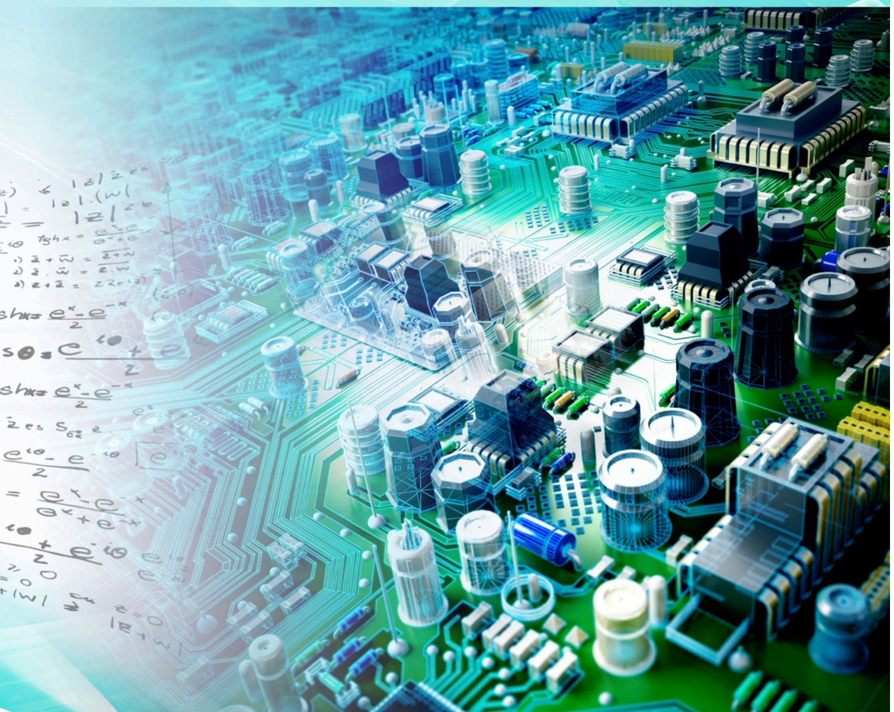
Stay tuned for the next videos which will cover Bode plots, basic stability theory, simulating op-amp stability in SPICE, and common compensation techniques.

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

Stability 1

Multiple Choice Quiz

TI Precision Labs – Op Amps



Quiz: Stability 1

1. What are some possible signs of an unstable op amp circuit?

a. Oscillations
b. Large overshoot and ringing
c. Unpredictable or Unexpected Response
d. All of the above.

2. (T/F) Many common circuits inadvertently cause delay in the feedback network resulting in stability issues.

a. True
b. False

3. What are some possible causes amplifier instability?

a. Capacitance on the amplifiers output.
b. Capacitance on the amplifiers inverting input.
c. Large value feedback resistors.
d. All of the above.

Quiz: Stability 1

4. Which common application is most likely to have a stability issues? Photodiode Transimpedance Amplifier

a. Low-Noise Gain Stage
b. Summing Amplifier
a. Integrator

5. Amplifiers with stability problems are_____.

a. Only sensitive to transients on the input.
b. Sensitive to transients on the input, output, and the power supplies.

6. (T/F) Amplifiers with dc inputs (e.g. reference buffer) will not have stability issues.

a. True
b. False

Quiz: Stability 1

7. Describe a common setup used for stability testing.

a. Monitor the amplifier output with an oscilloscope and apply a sinusoidal input signal.
b. Monitor the amplifier output with an oscilloscope and apply a square wave input signal.
c. Monitor the amplifier output with an oscilloscope and apply a triangle wave input signal.

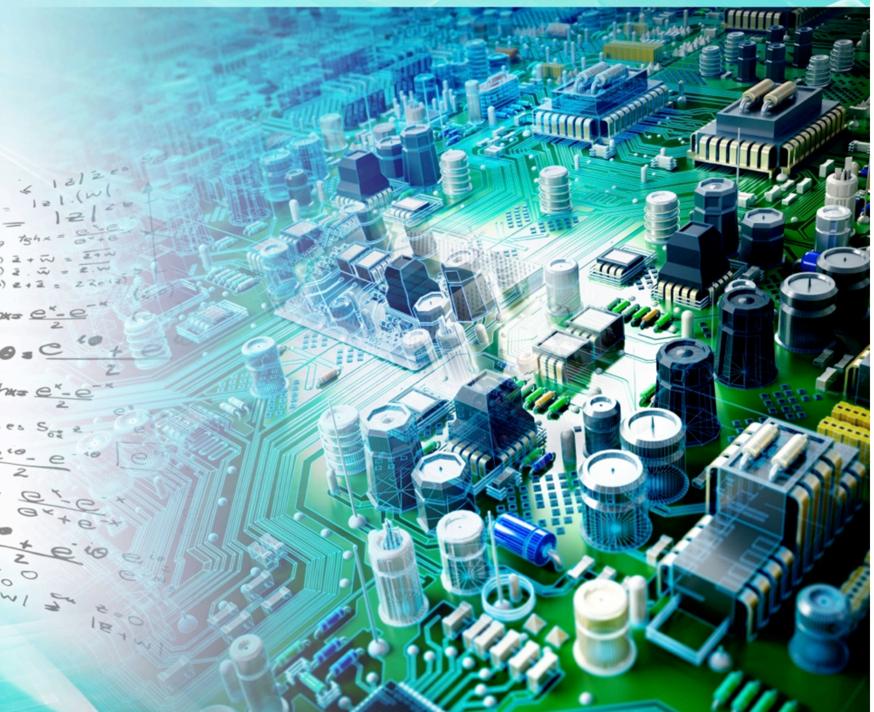
8. How can a gain / phase analyzer be used to test for stability?

a. AC gain peaking
b. Rapid phase shifts
c. Unexpected gains
d. All of the above

Stability 1

Multiple Choice Quiz: Solutions

TI Precision Labs – Op Amps



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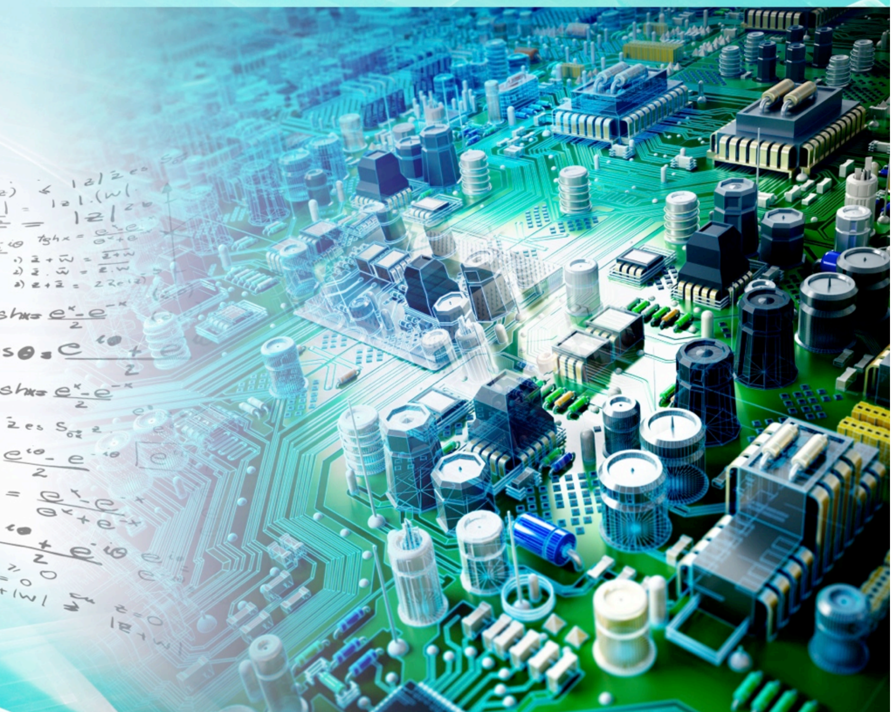
Stability 1

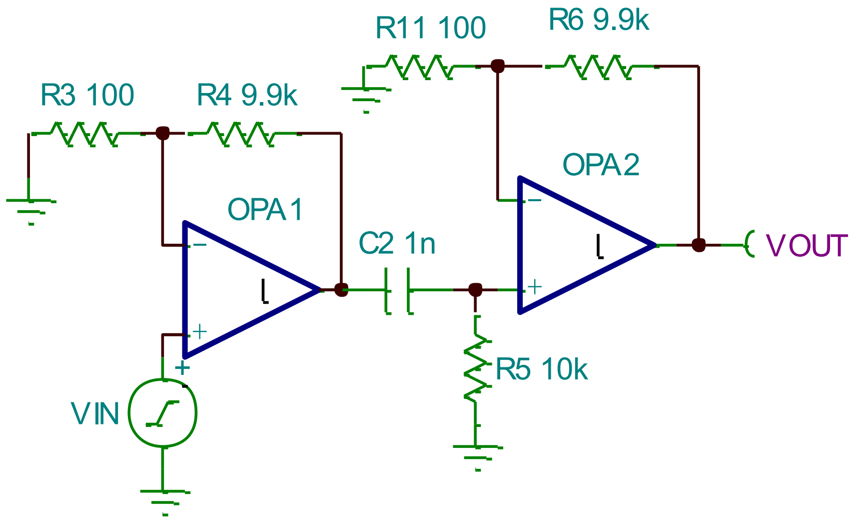
Exercises

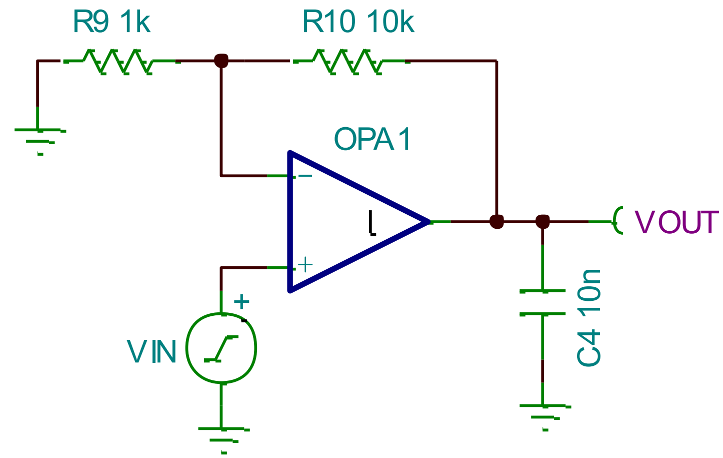
TI Precision Labs – Op Amps

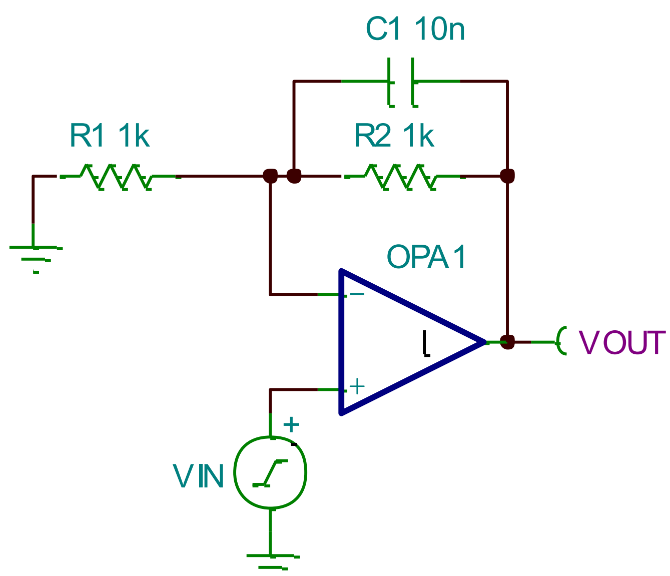


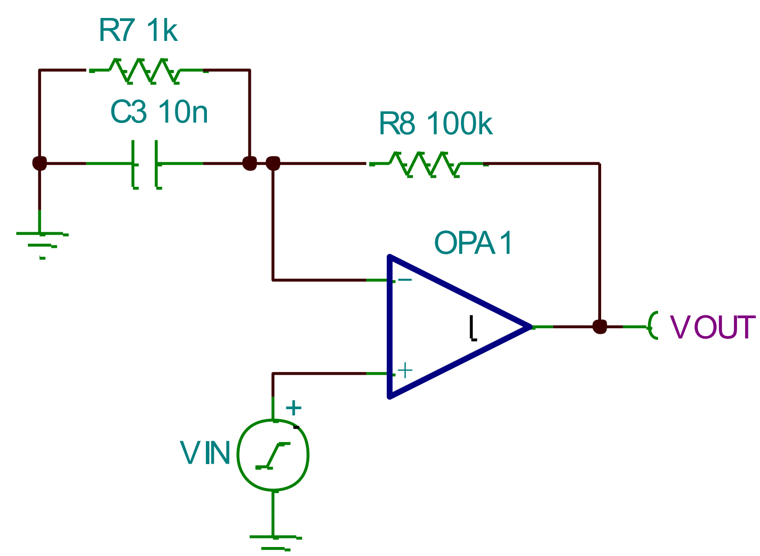
Texas Instruments

1. Which of these circuits are likely to have stability issues?

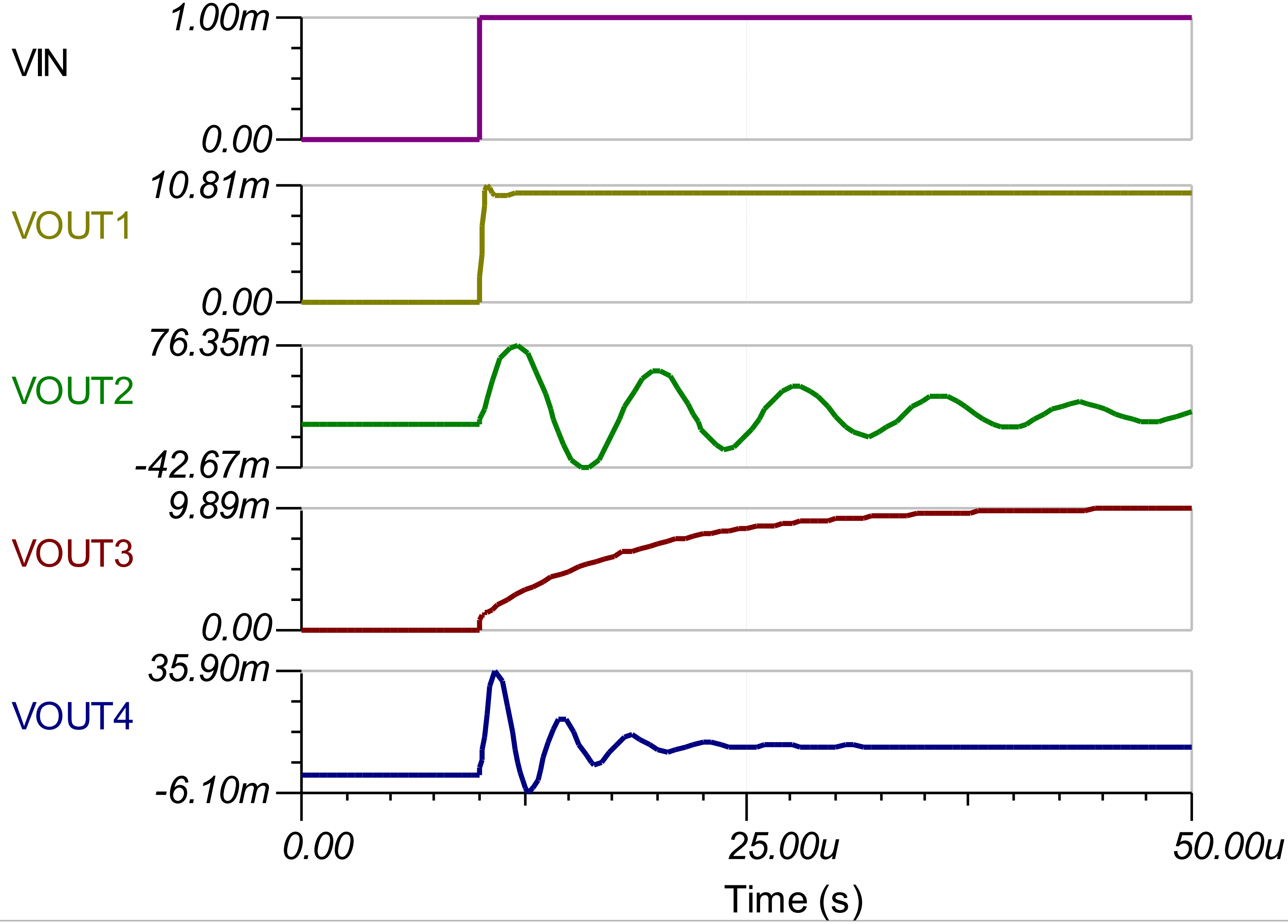




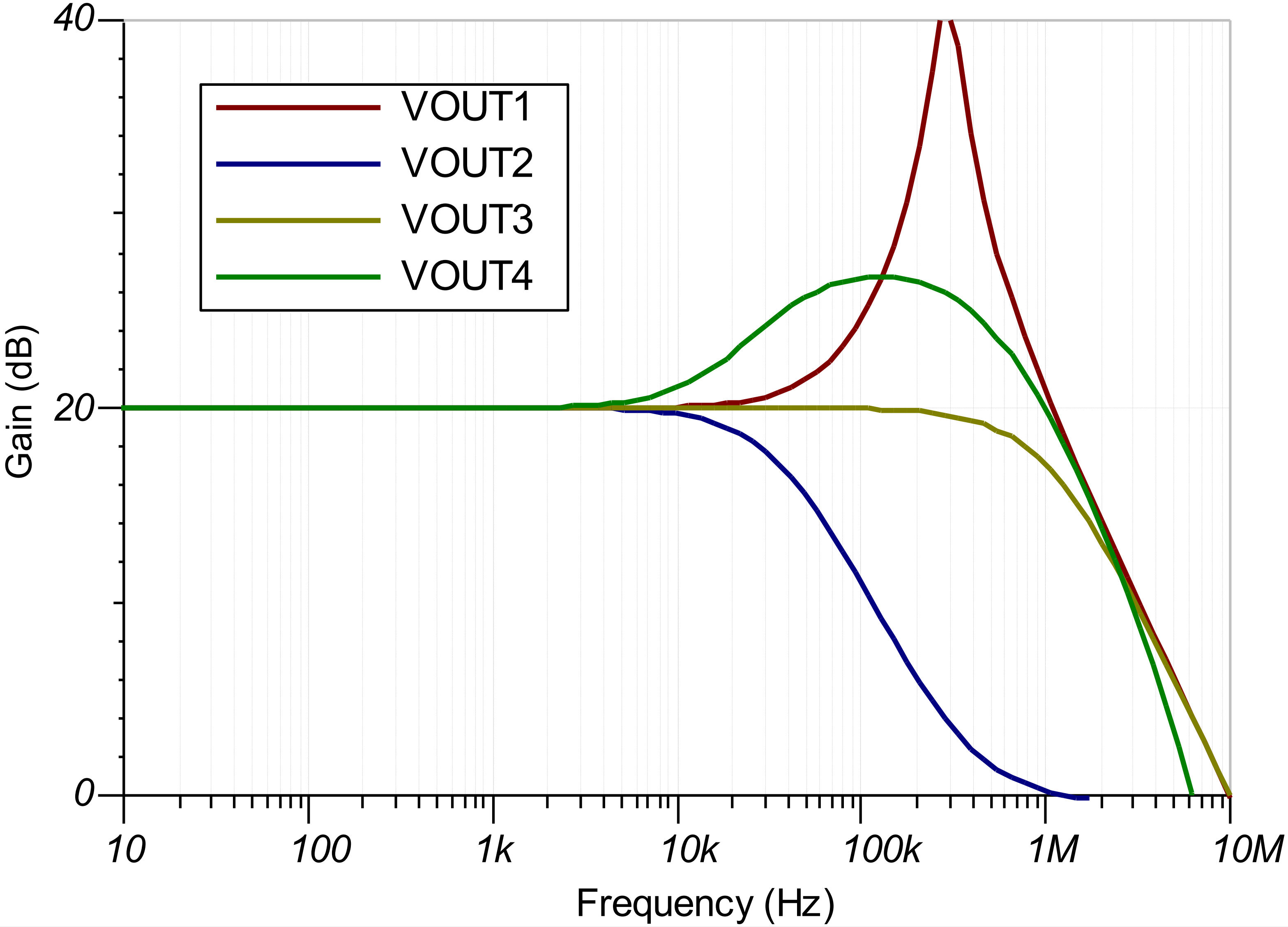




2. Which of the output responses to step inputs correspond to unstable circuits



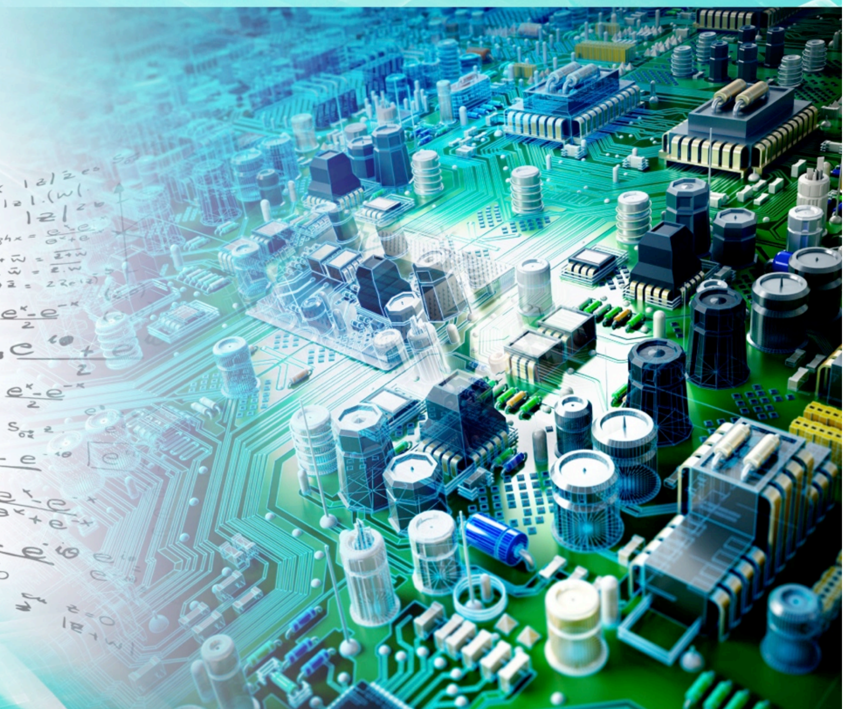
3. Which of the following four output AC transfer functions correspond to unstable circuits?



Stability 1

Solutions

TI Precision Labs – Op Amps



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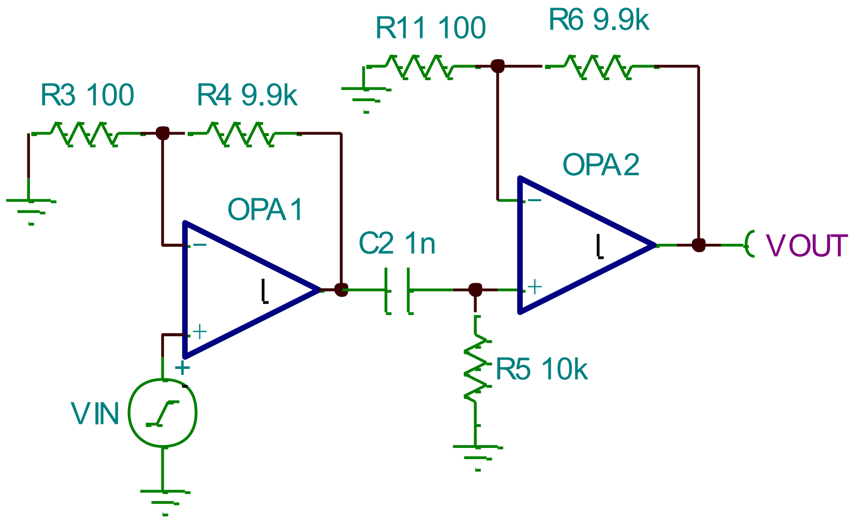

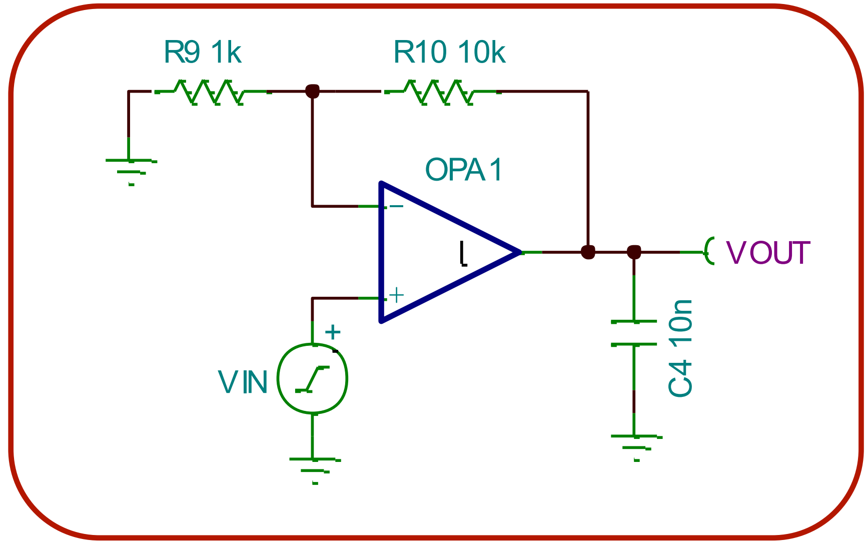

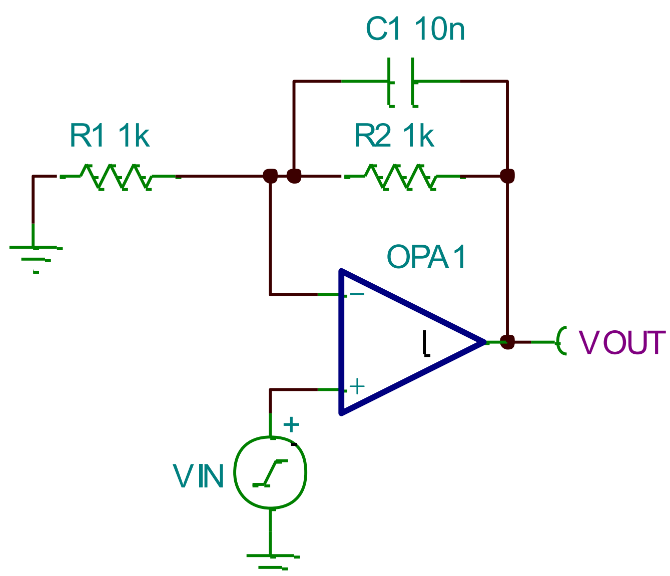

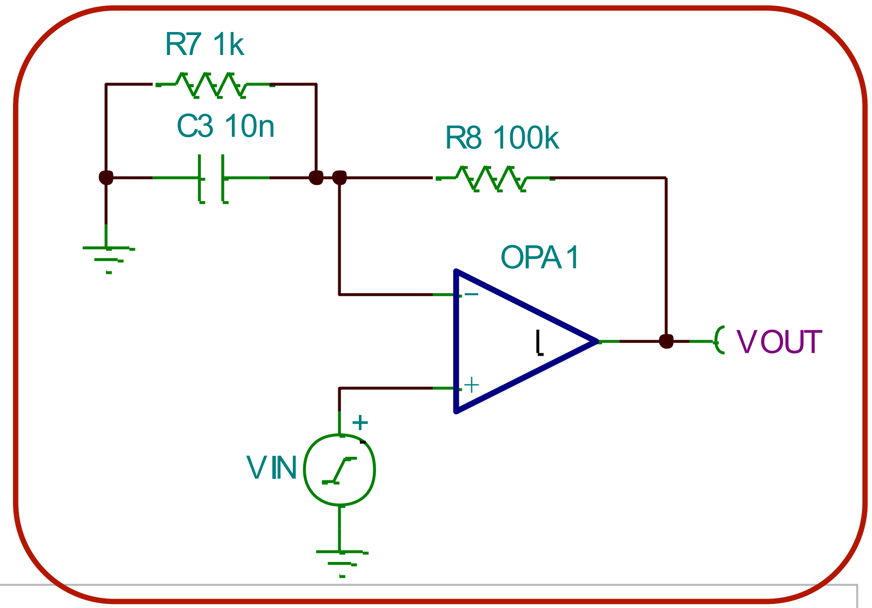

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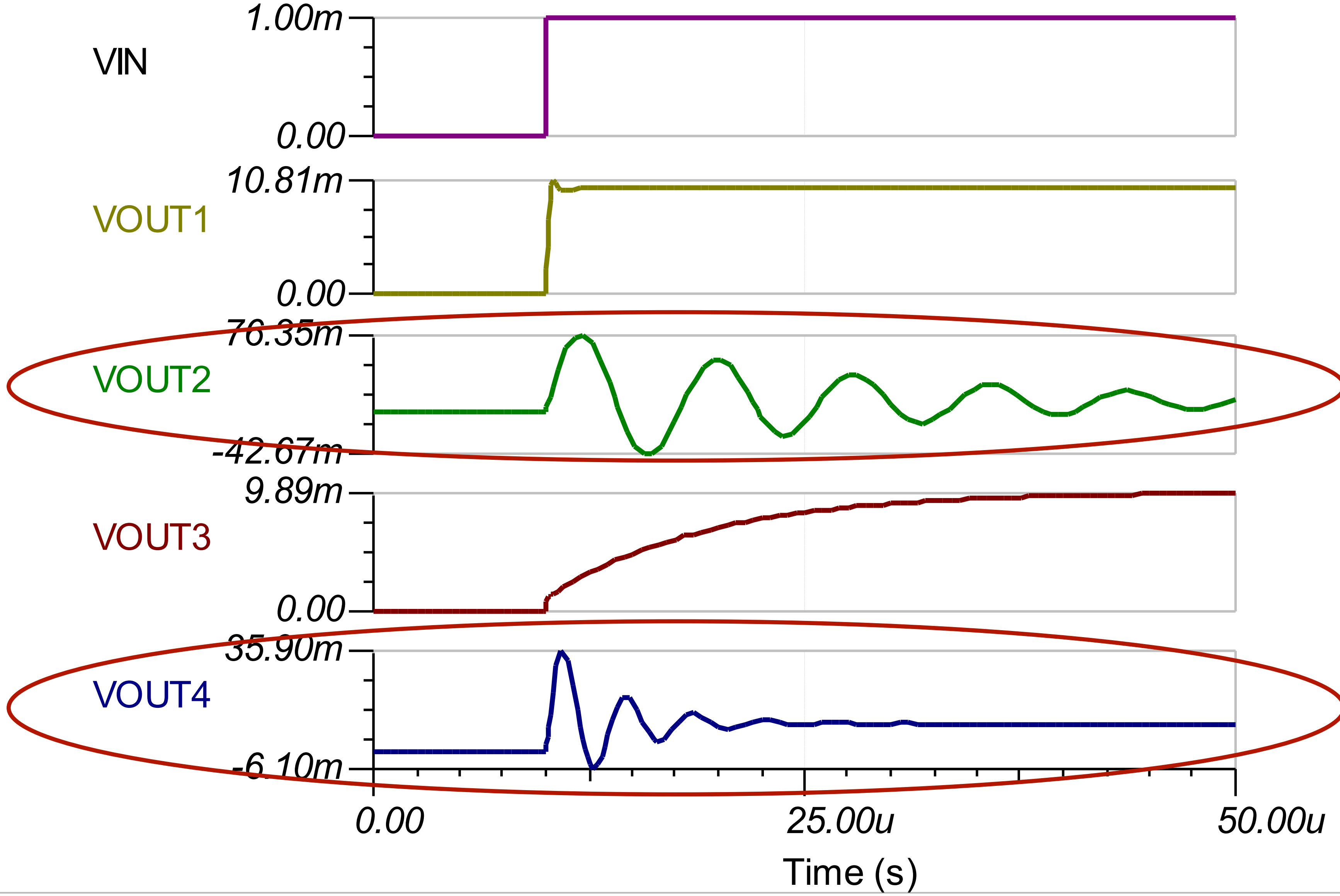

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