LECTURE 3 – SIMULATION AND MEASUREMENT OF OP AMPS

Topics:

- Simulation versus measurement
- Different approaches to measure and simulate
    - Differential mode gain
    - Common mode rejection ratio
    - Power supply rejection ratio
    - Input offset voltage
    - Output voltage swing
    - Input common mode range
    - Slew rate and phase margin

What will I learn?

- How to do simulation and measurement of op amps

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Simulation vs. Measurement

Comparison:

Objectives:

- The objective of simulation is to verify and optimize the design.
- The objective of measurement is to experimentally confirm the specifications.

Similarity between Simulation and Measurement:

- Same goals
- Same approach or technique

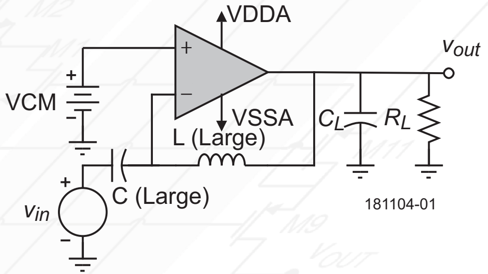
Differences between Simulation and Measurement:

- Simulation can idealize a circuit
  - All transistor electrical parameters are ideally matched
  - Ideal stimuli
- Measurement must consider all nonidealities
  - Physical and electrical parameter mismatches
  - Non-ideal stimuli
  - Parasitics

Differential Mode Gain

Low frequency gain, GB, and Phase Margin:

If the op amp has a large differential voltage gain, it cannot operate without negative feedback to establish the operating point.



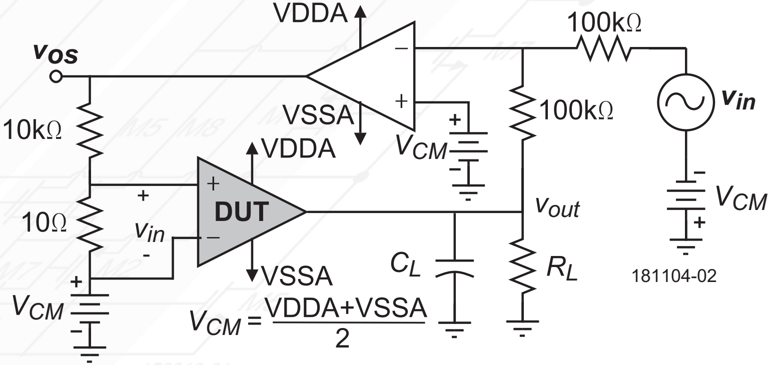
Simulation:

- L and C should be selected large enough so that $1/\sqrt{LC}$ is greater than the lowest frequency of interest.
- Some simulators (not NGSpice) have the ability to measure the open loop by inserting a voltage in series with the feedback loop.

Measurement:

Drive the output at the desired operating point and measure the input response.

$$\frac{v_{out}}{v_{in}} = \frac{v_{in}}{v_{OS}/1000} = 1000\times\frac{v_{in}}{v_{OS}}$$



Common Mode Rejection Ratio

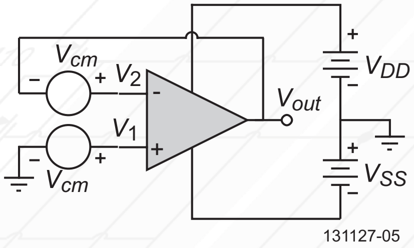
CMRR:

- Definition

$$CMRR = \left|\frac{A_{vd}}{A_{cm}}\right| = \frac{\left(\frac{v_{out}}{v_{id}}\right)}{\left(\frac{v_{out}}{v_{icm}}\right)}$$

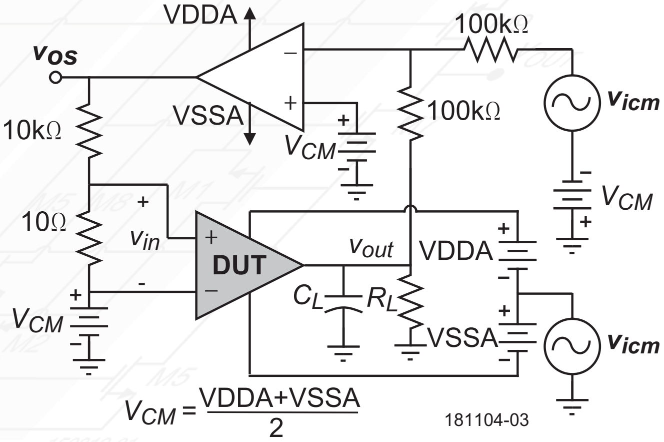
- Simulation

$$|CMRR| = \frac{V_{cm}}{V_{out}}$$



- Measurement

Works only if the op amp is perfectly matched.



$$CMRR = \frac{v_{out}/v_{in}}{v_{out}/v_{icm}} = \frac{v_{icm}}{v_{in}} = 1000 \times \frac{v_{icm}}{v_{OS}}$$

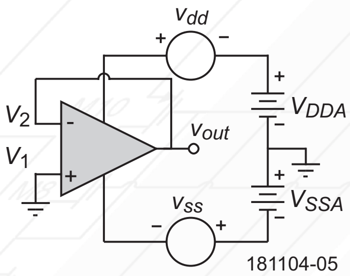
Power Supply Rejection Ratio

PSRR:

- Definition

$$PSRR^{+} = \left|\frac{A_{vd}}{A_{dd}}\right| = \frac{(v_{out}/v_{id})}{(v_{out}/v_{dd})} \quad \text{and} \quad PSRR^{-} = \left|\frac{A_{vd}}{A_{ss}}\right| = \frac{(v_{out}/v_{id})}{(v_{out}/v_{ss})}$$

- Simulation

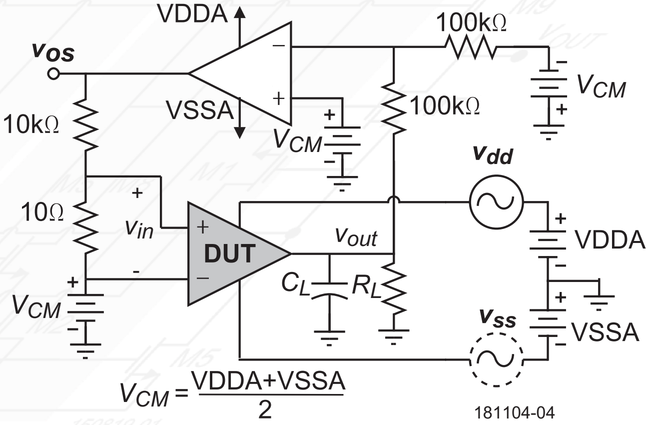


$$PSRR^{+} = \frac{A_v}{A_{dd}} = \frac{v_{dd}}{v_{out}} \quad \text{or} \quad PSRR^{-} = \frac{A_v}{A_{ss}} = \frac{v_{ss}}{v_{out}}$$

- Measurement

$$PSRR^{+} = \frac{v_{out}/v_{in}}{v_{out}/v_{dd}} = \frac{v_{dd}}{v_{in}} = 1000 \times \frac{v_{dd}}{v_{OS}}$$

$$PSRR^{-} = \frac{v_{out}/v_{in}}{v_{out}/v_{ss}} = \frac{v_{ss}}{v_{in}} = 1000 \times \frac{v_{ss}}{v_{OS}}$$

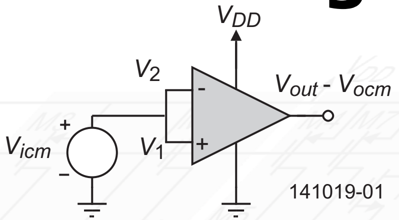


Input Offset Voltage

V_{OS}:

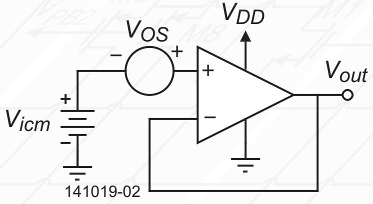
- Definition

$$V_{OS} = \frac{V_{out}(V_{in}=0)}{A_{vd}}$$



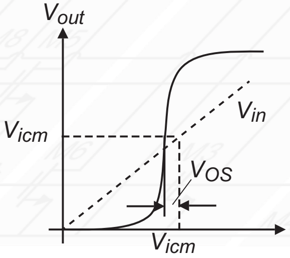
- Simulation/Measurement
  - Closed loop

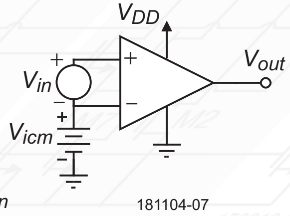
    Watch out for gain error masking the input offset voltage



$$V_{out} = \left(\frac{A_{vd}}{1+A_{vd}}\right)(V_{icm}+V_{OS}) \rightarrow V_{out} = V_{icm} + \left[\left(\frac{A_{vd}}{1+A_{vd}}\right)V_{OS} - \frac{V_{icm}}{1+A_{vd}}\right] = V_{icm} + "V_{OS}"$$

  - Open loop

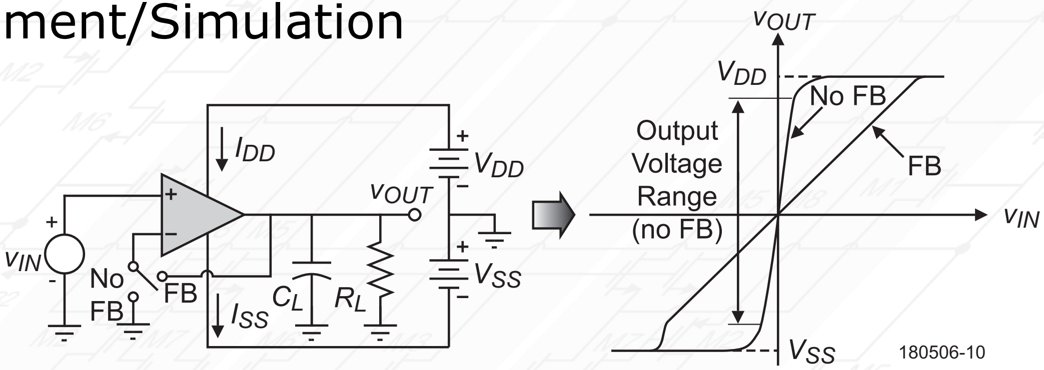




Output Voltage Swing

V_{out}(max) and V_{out}(min):

- Definition
  - The output voltage swing is the range of output voltages over which the slope of the transfer curve remains constant.
  - However, with feedback this range is extended because feedback linearizes the transfer function
- Measurement/Simulation



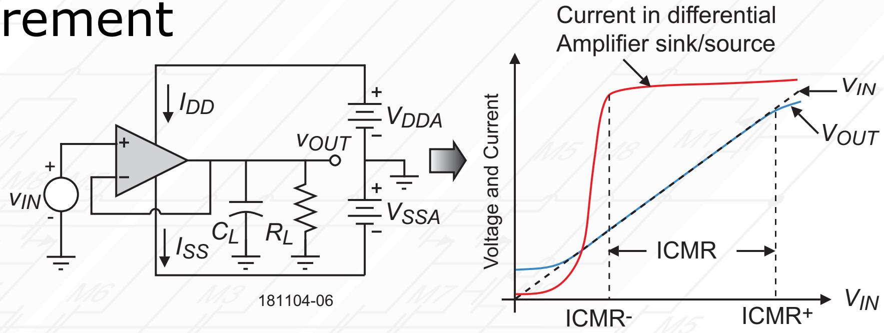
Input Common Mode Voltage Range

ICMR:

Definitions

1. ICMR is the range of input common-mode voltage over which the differential amplifier will continue to sense and amplify the difference signal with the same gain.
2. ICMR is the input common-mode voltage range over which all pertinent MOSFETs remain in the saturation region.

Simulation/Measurement



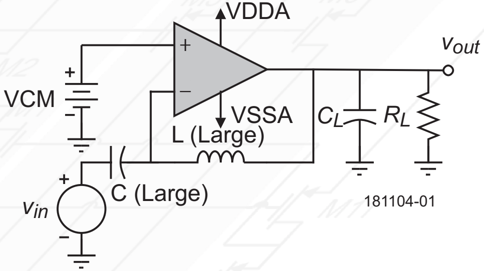
Also, plot the current in the input stage or the power supply current.

Input Common Mode Voltage Range – Cont'd

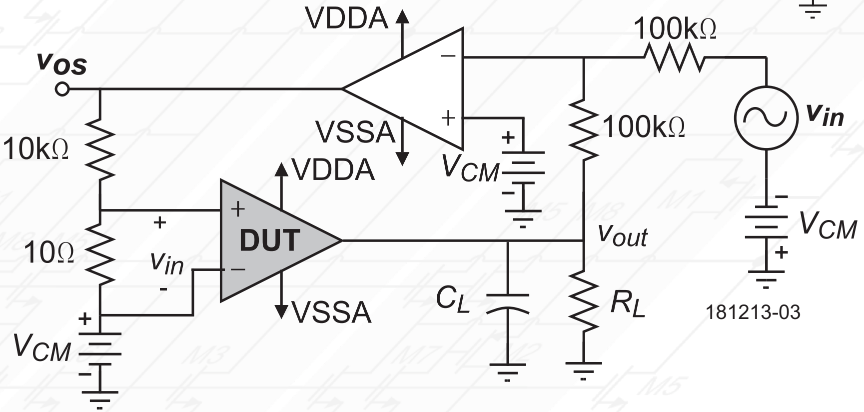
ICMR – An alternative approach:

Simulation:

Vary the input common mode voltage (VCM) and measure the open loop gain. When the gain goes below some predefined value (i.e. 20dB), this would define the upper and lower ICMR.



Measurement:

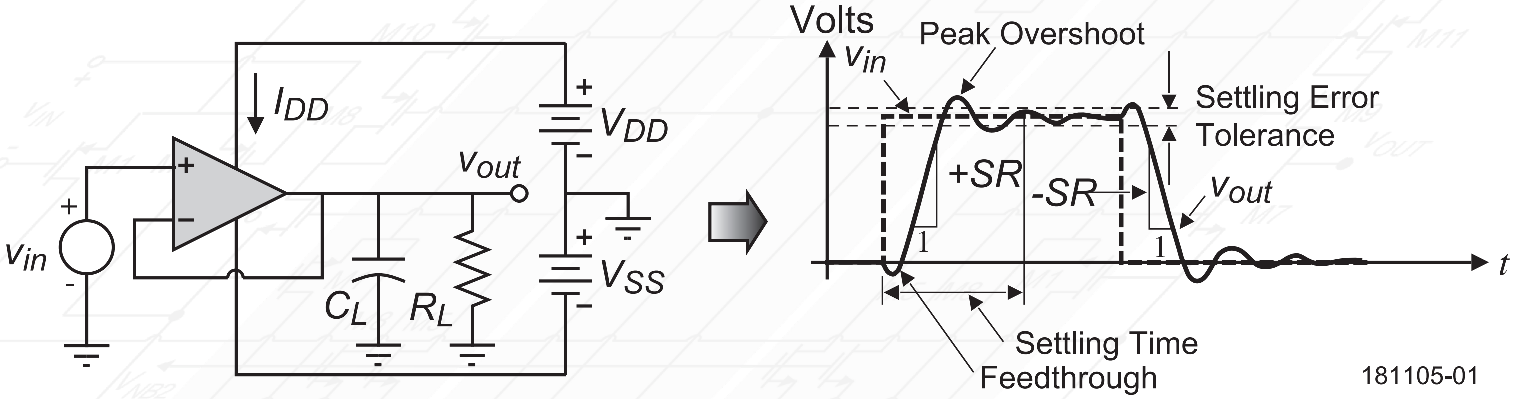


Slew Rate

SR:

Simulation/Measurement:

Put the op amp in the unity gain configuration and apply a positive and negative step within the ICMR range.

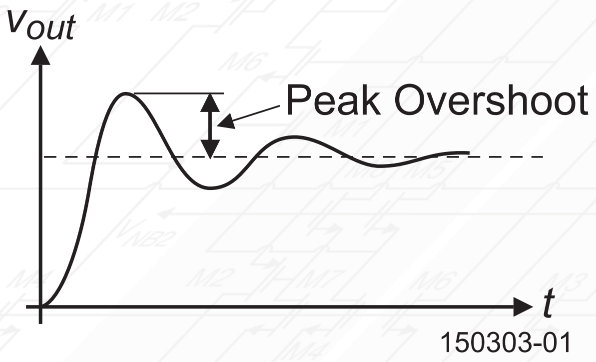


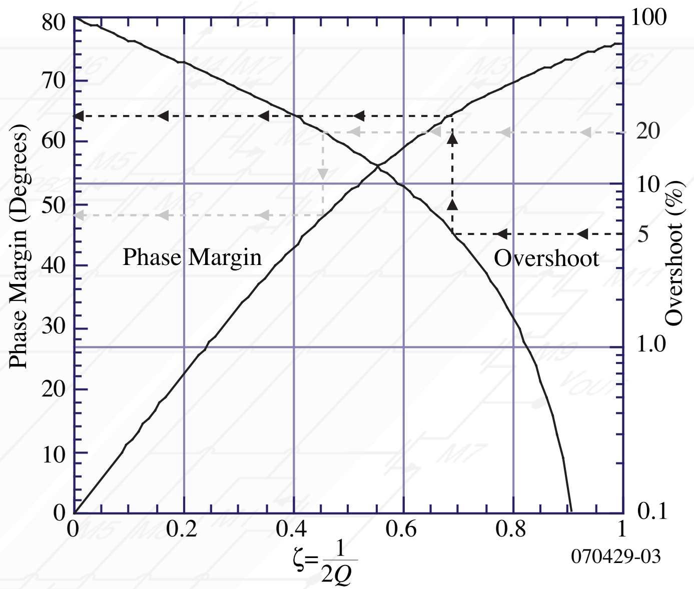
Phase Margin

PM:

Simulation/Measurement

If the unity gain configuration can be approximated as a low frequency pole and a pole at –GB, then for a non-slewing step response, the peak overshoot can be related to the phase margin.





$$PM(Deg) = 57.2958\cos^{-1}\left[\sqrt{4\zeta^4+1} - 2\zeta^2\right]$$

$$Overshoot\ (\%) = 100\exp\left(\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}\right)$$

Simulation and Measurement of Op Amps

Summary:

- Simulation versus measurement
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- Slew rate
- Phase margin