模拟集成电路 I
L12

主讲教师

张丽敏、纪小丽

南京大学电子科学与工程学院

纲要

- 运算放大器性能的仿真与测试

引言

Simulation and Measurement Considerations

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

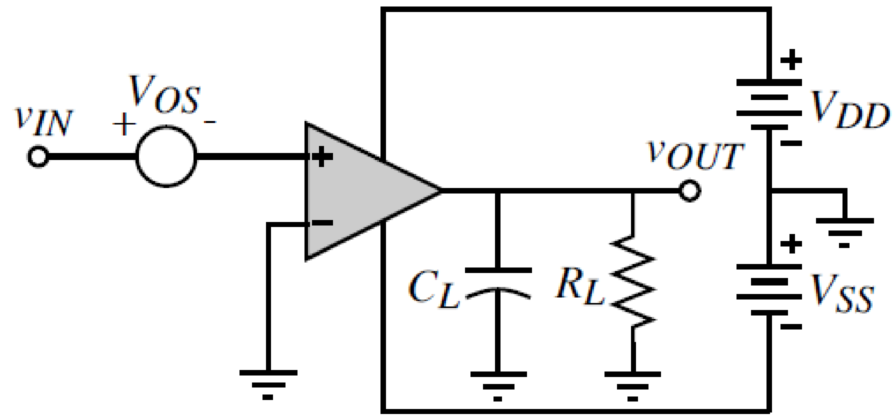
Differences between Simulation and Measurement:

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

开环传递函数

Simulating or Measuring the Open-Loop Transfer Function of the Op Amp

Circuit (Darkened op amp identifies the op amp under test):



Simulation:

This circuit will give the voltage transfer function curve. This curve should identify:

1.) The linear range of operation
2.) The gain in the linear range
3.) The output limits
4.) The systematic input offset voltage
5.) DC operating conditions, power dissipation
6.) When biased in the linear range, the small-signal frequency response can be obtained
7.) From the open-loop frequency response, the phase margin can be obtained ($F = 1$)

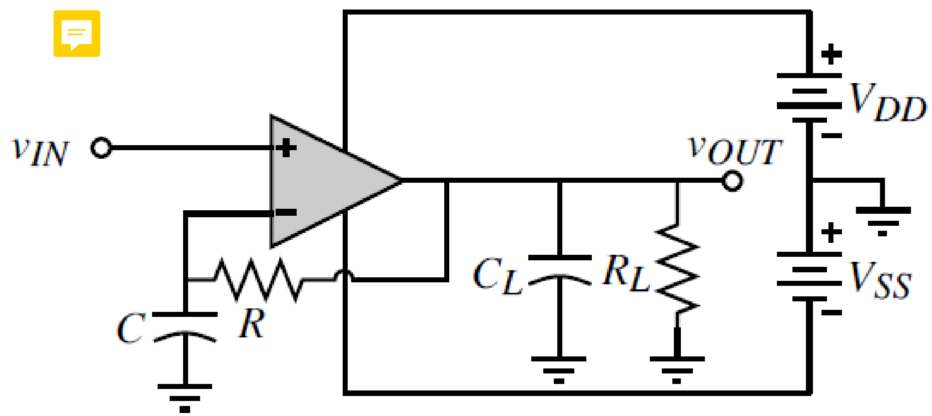
Measurement:

This circuit probably will not work unless the op amp gain is very low.

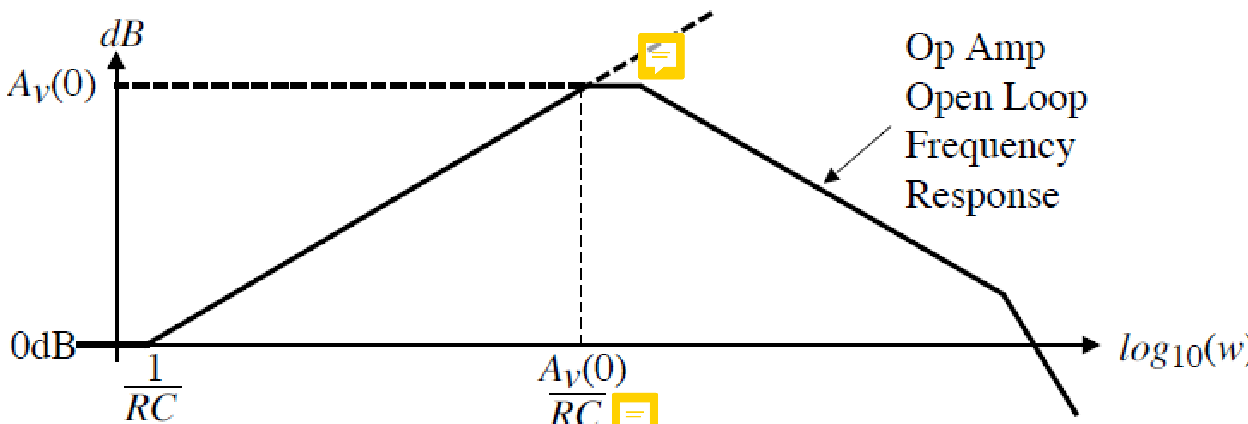
开环传递函数

A More Robust Method of Measuring the Open-Loop Frequency Response

Circuit:



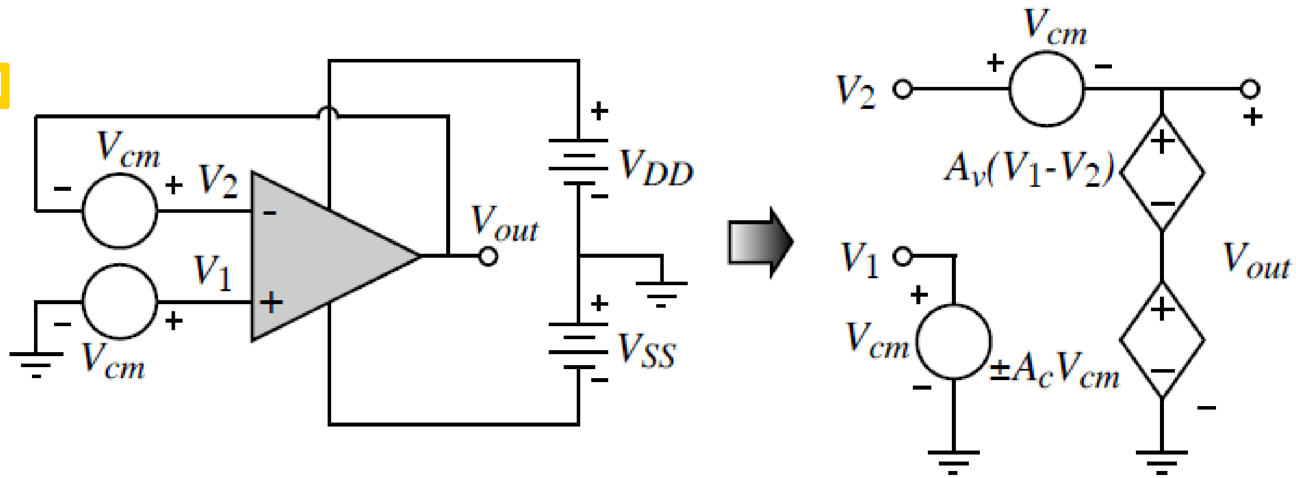
Resulting Closed-Loop Frequency Response:



Make the RC product as large as possible.

CMRR

None of the above methods are really suitable for simulation of *CMRR*. Consider the following:



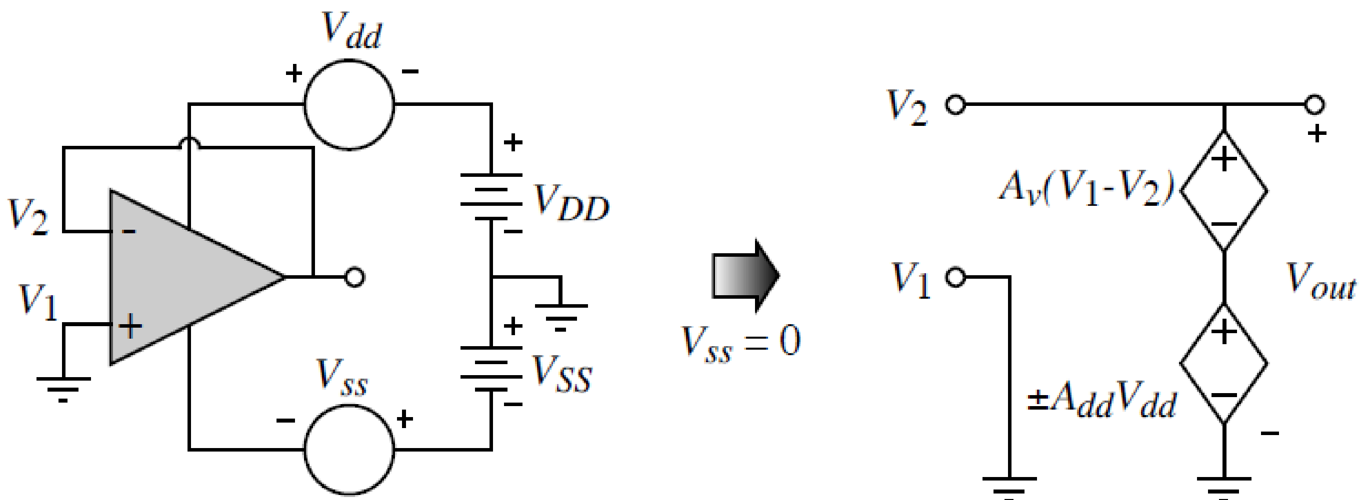
$$V_{out} = A_v(V_1-V_2) \pm A_{cm}\left(\frac{V_1+V_2}{2}\right) = -A_v V_{out} \pm A_{cm} V_{cm}$$

$$V_{out} = \frac{\pm A_{cm}}{1+A_v} V_{cm} \approx \frac{\pm A_{cm}}{A_v} V_{cm}$$

$$\therefore \quad \boxed{|CMRR| = \frac{A_v}{A_{cm}} = \frac{V_{cm}}{V_{out}}}$$

PSRR

Circuit:



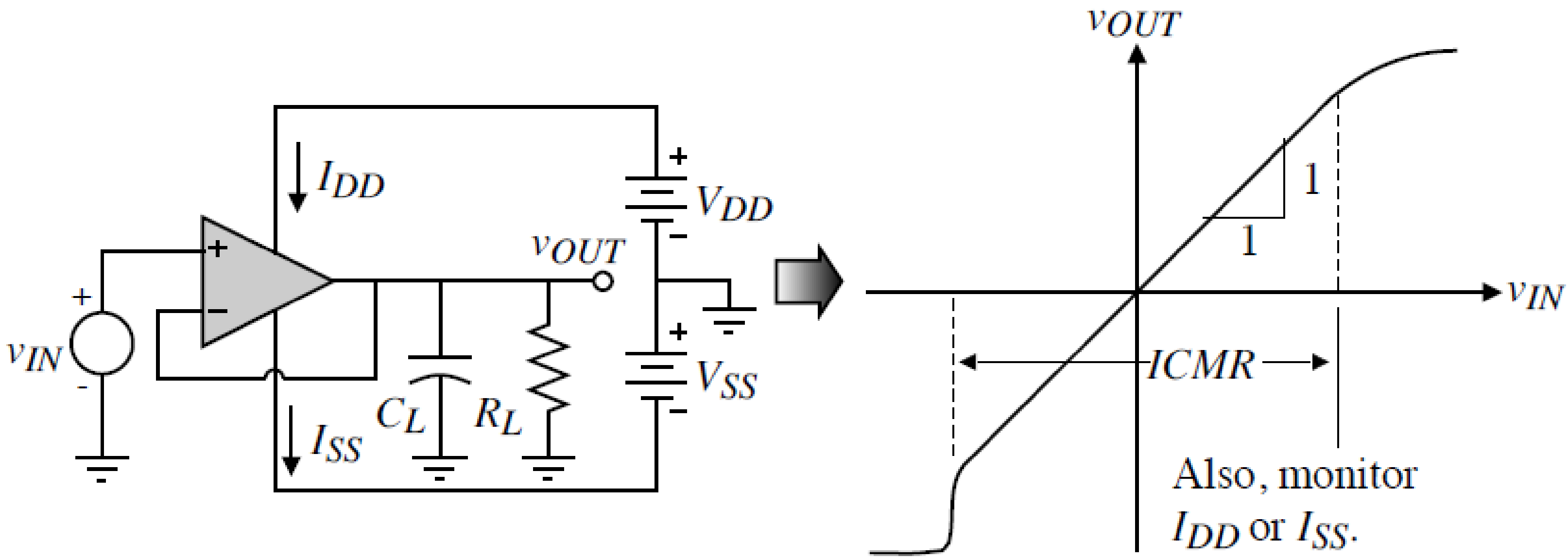
$$V_{out} = A_v(V_1-V_2) \pm A_{dd}V_{dd} = -A_v V_{out} \pm A_{dd}V_{dd}$$

$$V_{out} = \frac{\pm A_{dd}}{1+A_v} V_{dd} \approx \frac{\pm A_{dd}}{A_v} V_{dd}$$

$$\therefore \quad \boxed{PSRR^{+} = \frac{A_v}{A_{dd}} = \frac{V_{dd}}{V_{out}}} \quad \text{and} \quad \boxed{PSRR^{-} = \frac{A_v}{A_{ss}} = \frac{V_{ss}}{V_{out}}}$$

Works well as long as *CMRR* is much greater than 1.

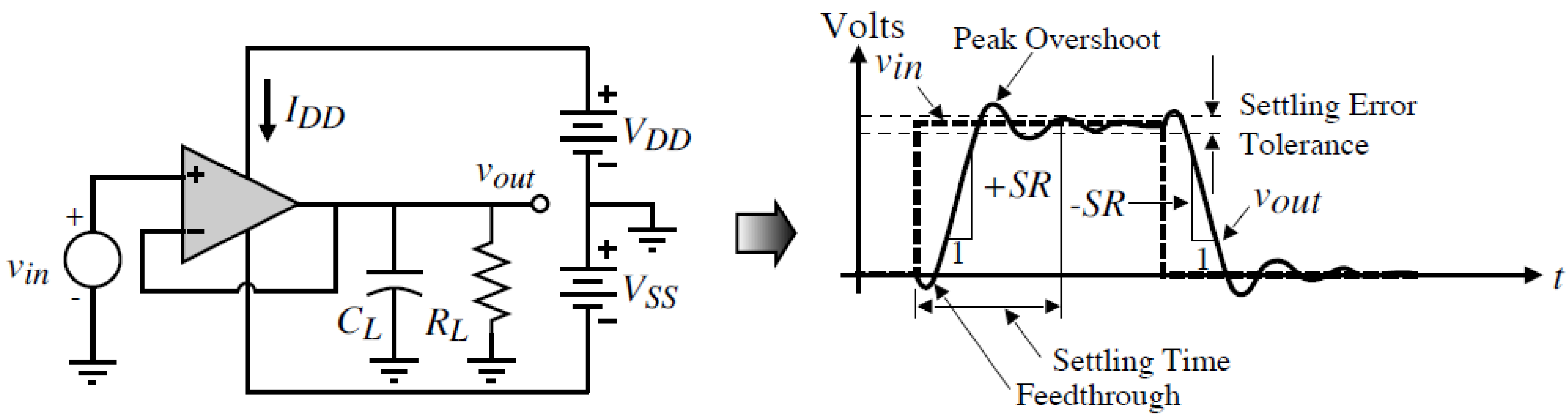
ICMR



Initial jump in sweep is due to the turn-on of M5.

Should also plot the current in the input stage (or the power supply current).

SR and Settling Time



If the slew rate influences the small signal response, then make the input step size small enough to avoid slew rate (i.e. less than 0.5V for MOS).

Phase Margin

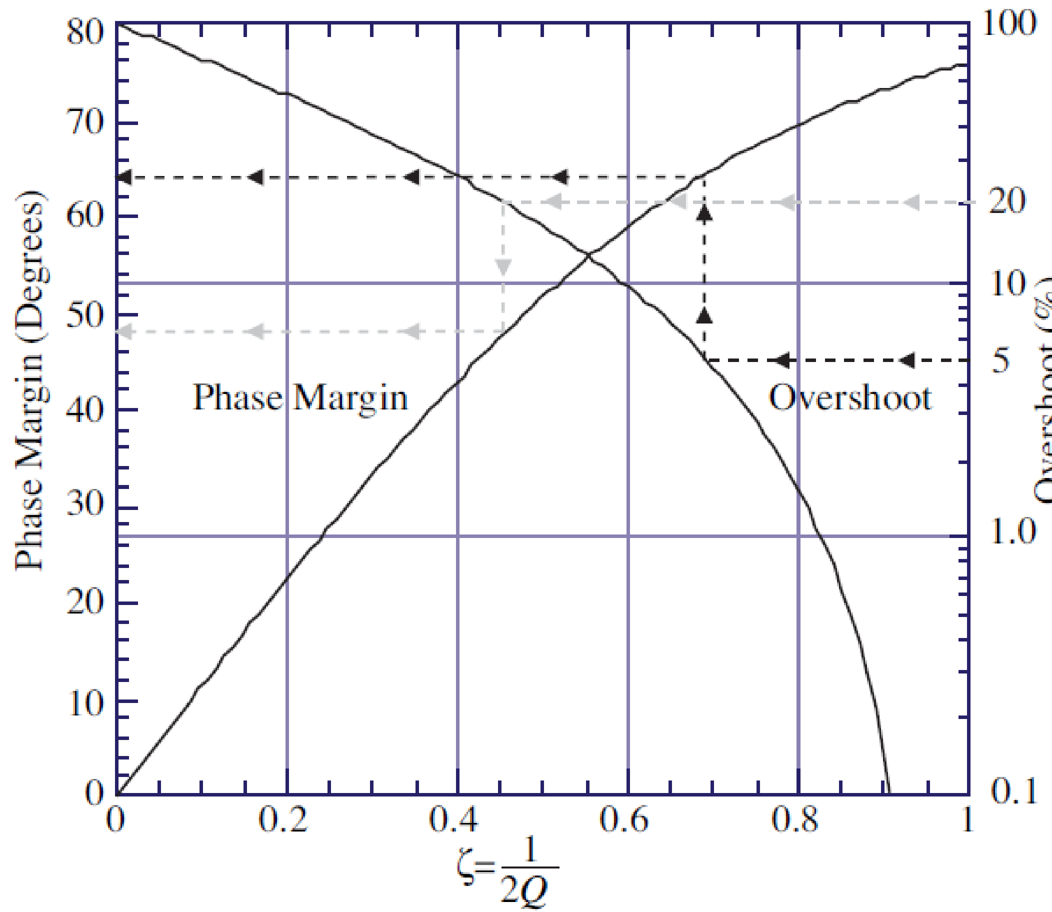
Phase Margin and Peak Overshoot Relationship

It can be shown (Appendix C of the text) that:

$$\text{Phase Margin (Degrees)} = 57.2958\,cos^{-1}\left[\sqrt{4\zeta^4+1} - 2\zeta^2\right]$$

Overshoot (%)

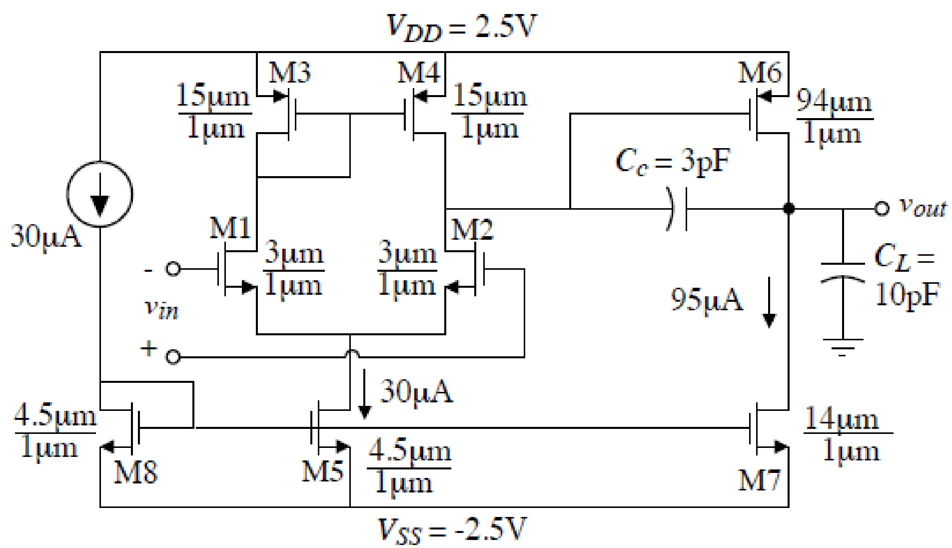
$$= 100\ exp\left(\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}\right)$$



For example, a 5% overshoot corresponds to a phase margin of approximately 64°.

Example

Example **Simulation of a Two-Stage CMOS Op Amp**

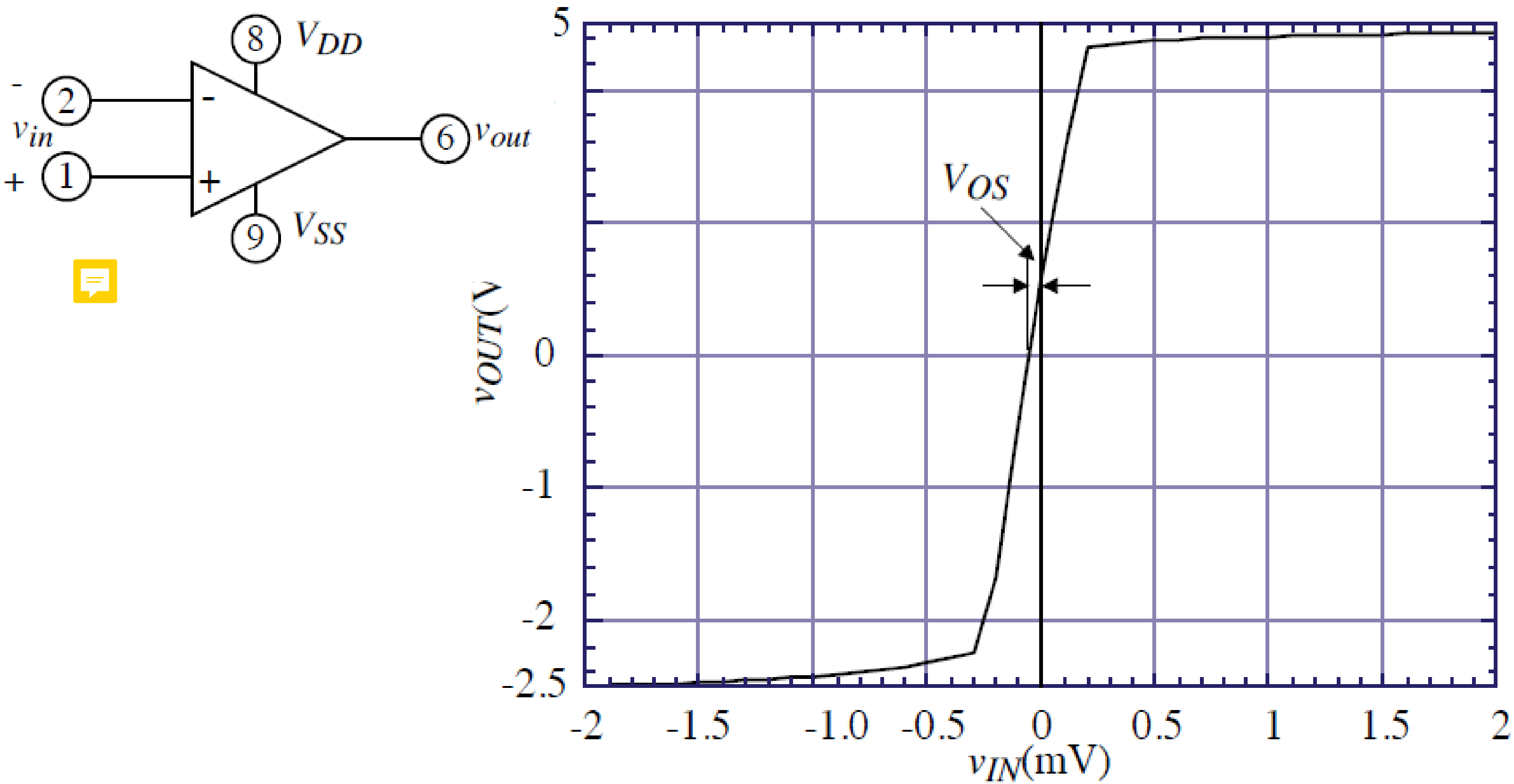


The specifications of this op amp are as follows where the channel length is to be 1μm and the load capacitor is C_L = 10pF:

A_v > 3000V/V	V_{DD} = 2.5V	V_{SS} = -2.5V
GB = 5MHz	SR > 10V/μs	60° phase margin
V_{out} range = ±2V	$ICMR$ = -1 to 2V	P_{diss} ≤ 2mW

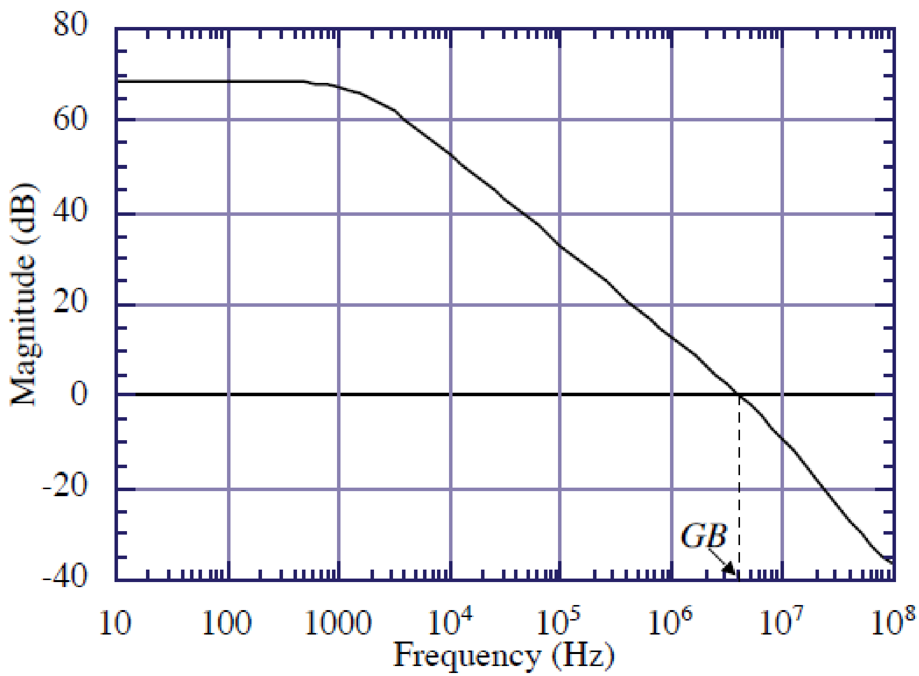
Example

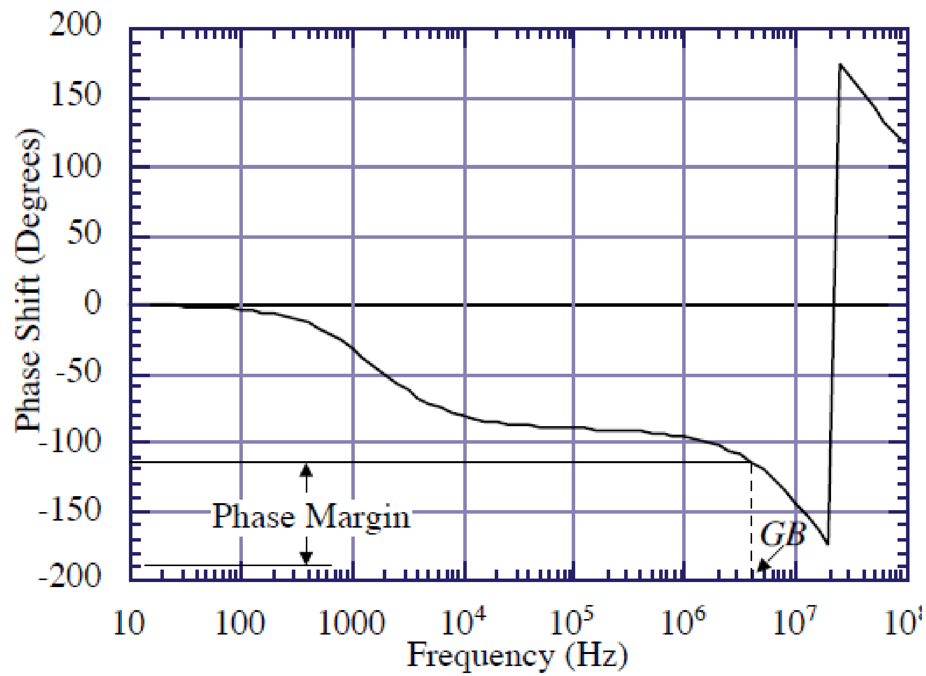
Open-loop transfer characteristic:



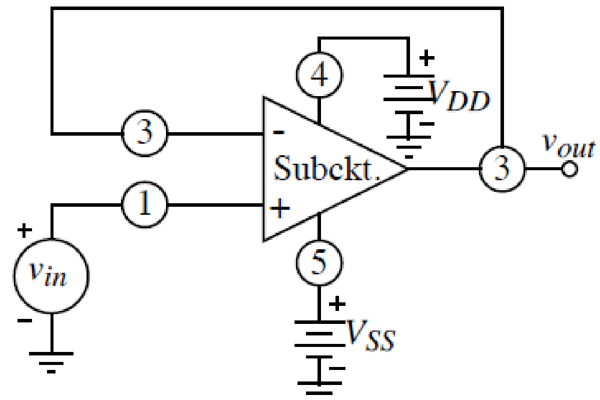
Example

Open-loop transfer frequency response:

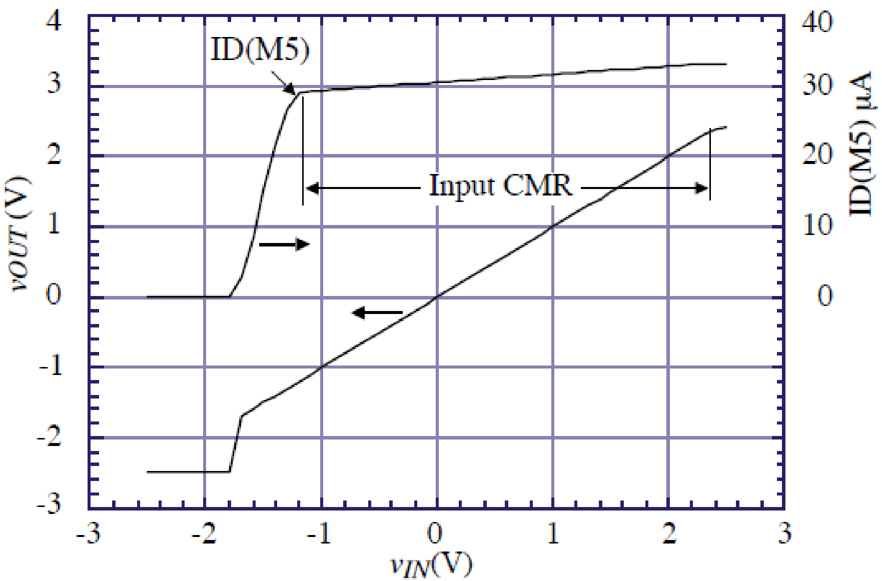




Example



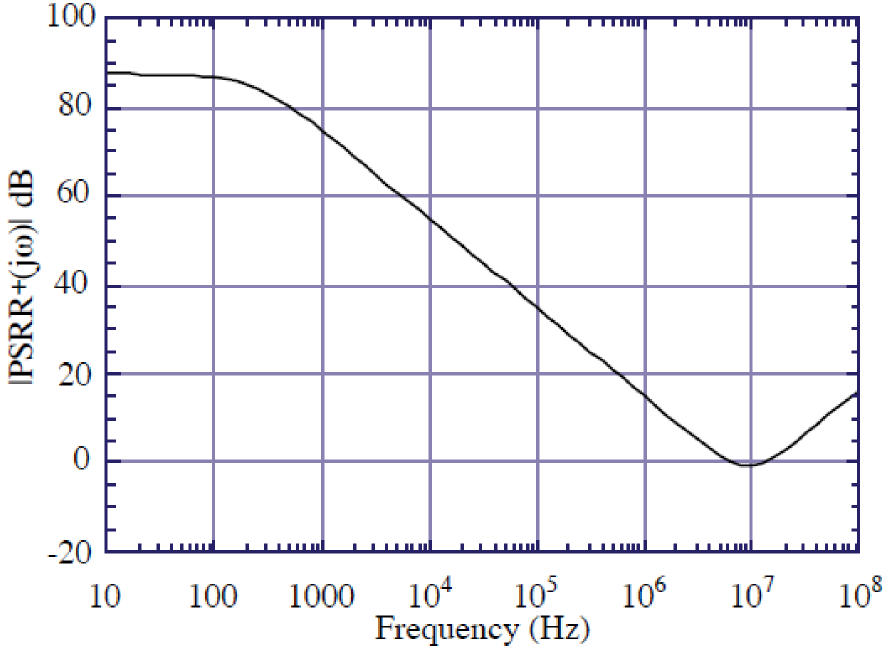
4
3
-
Subckt.
+
1
3
v_{out}
V_{DD}
5
V_{SS}
v_{in}

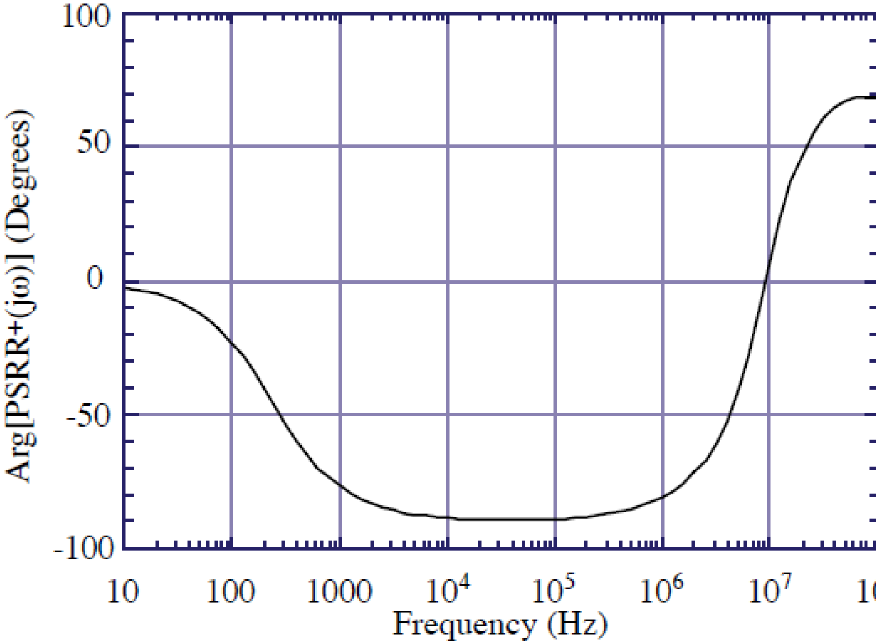


ID(M5)
Input CMR
vOUT (V)
ID(M5) μA
v_{IN}(V)
4
3
2
1
0
-1
-2
-3
40
30
20
10
0
-3
-2
-1
0
1
2
3

Example

Positive *PSRR*:

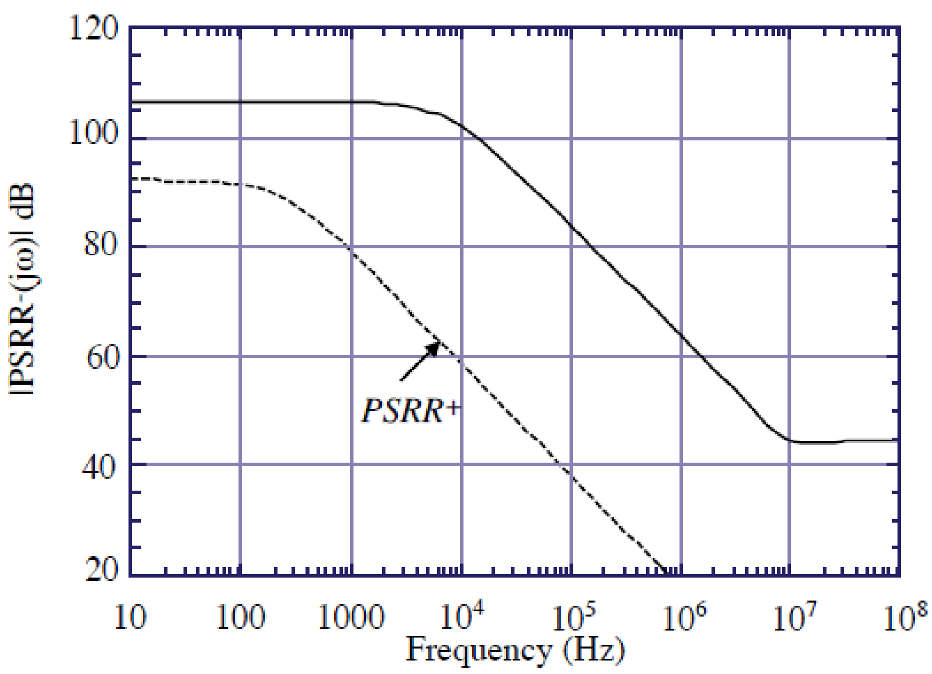


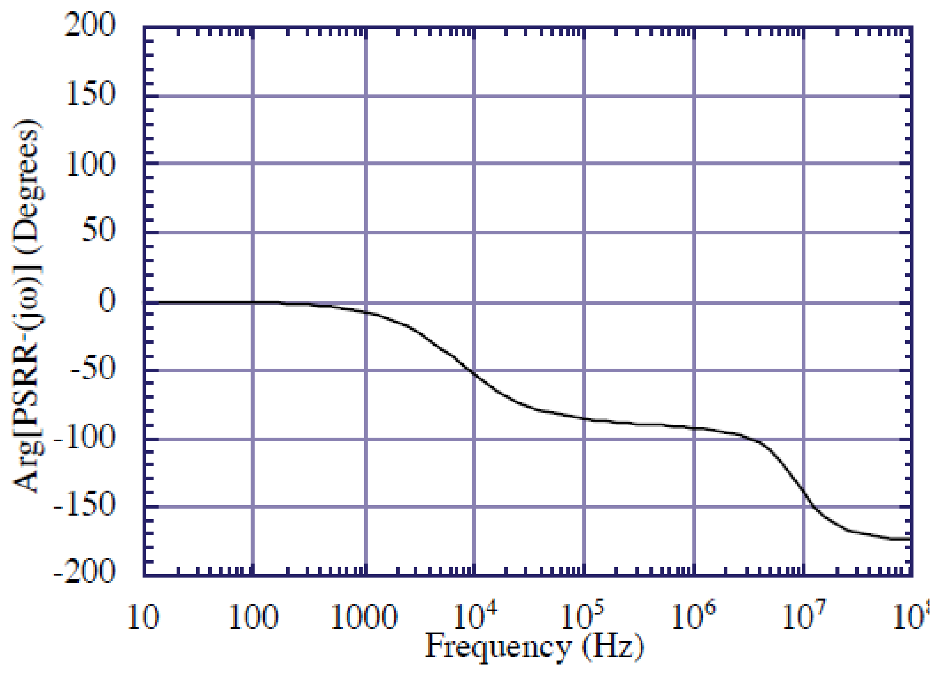


This $PSRR^+$ is poor because of the Miller capacitor. The degree of $PSRR^+$ deterioration will be better shown when compared with the $PSRR^-$.

Example

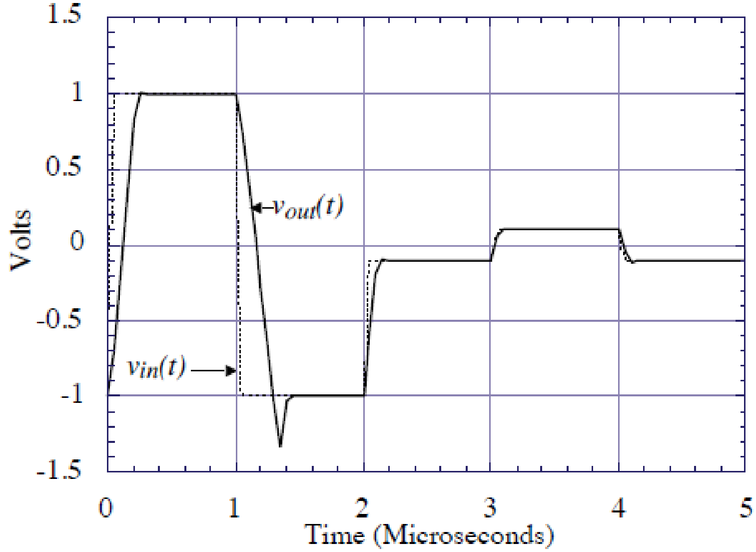
Negative *PSRR*:

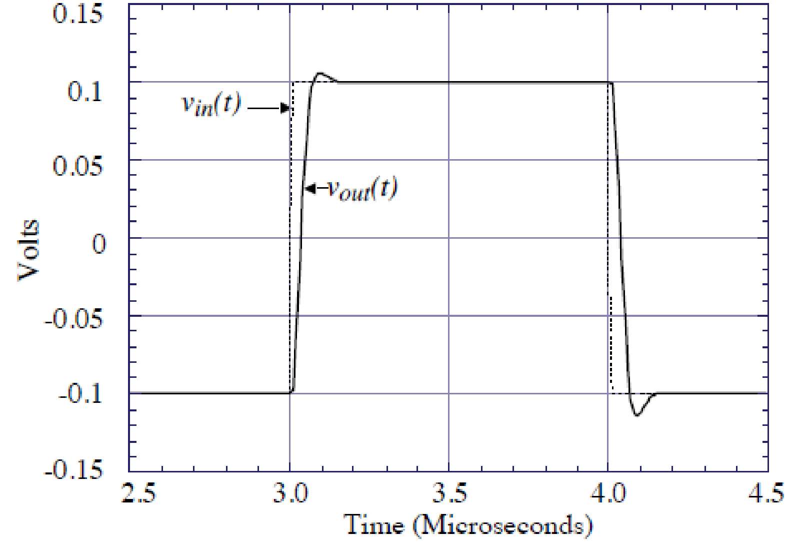




Example

Large-signal and small-signal transient response:

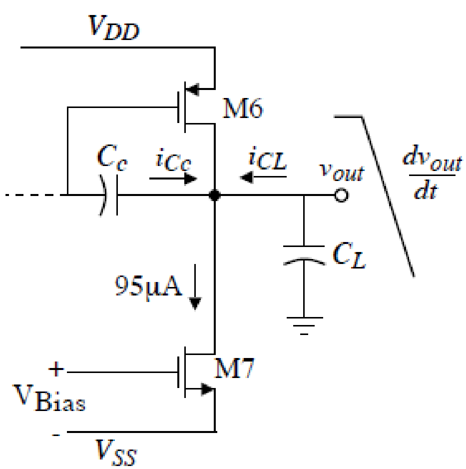




Why the negative overshoot on the slew rate?

If M7 cannot sink sufficient current then the output stage slews and only responds to changes at the output via the feedback path which involves a delay.

Note that $-dv_{out}/dt \approx -2\text{V}/0.3\mu\text{s} = -6.67\text{V}/\mu\text{s}$. For a 10pF capacitor this requires 66.7μA and only 95μA-66.7μA = 28μA is available for C_c. For the positive slew rate, M6 can provide whatever current is required by the capacitors and can immediately respond to changes at the output.



总结

SUMMARY

- Simulation and measurement of op amps has both similarities and differences
- Measurement of open loop gain is very challenging – the key is to keep the quiescent point output of the op amp well defined
- The method of stimulating the output of the op amp or power supplies and letting the input respond results in a robust method of measuring open loop gain, *CMRR*, and *PSRR*
- Carefully investigate any deviations or aberrations from expected behavior in the simulation and experimental results