

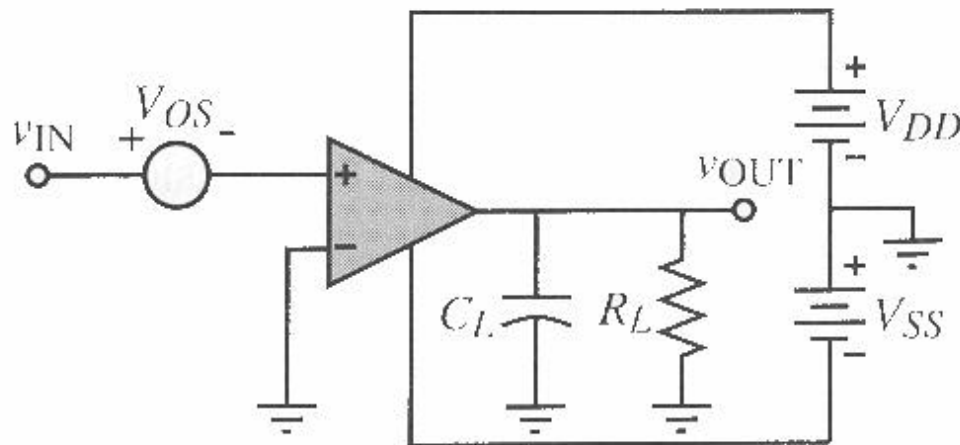
Simulation and Measurement of Op Amps

Simulation and measurement techniques

- The categories of op amp measurements and simulations discussed include: open-loop gain, open-loop frequency response (including the phase margin), input-offset voltage, common-mode gain, power-supply rejection ratio, common-mode input- and output-voltage ranges, open-loop output resistance, and transient response including slew-rate.
- Simulating or measuring the op amp in open loop configuration is one of the most difficult steps to perform successfully. The reason is the high differential gain of the op amp.

Open-loop mode with offset compensation

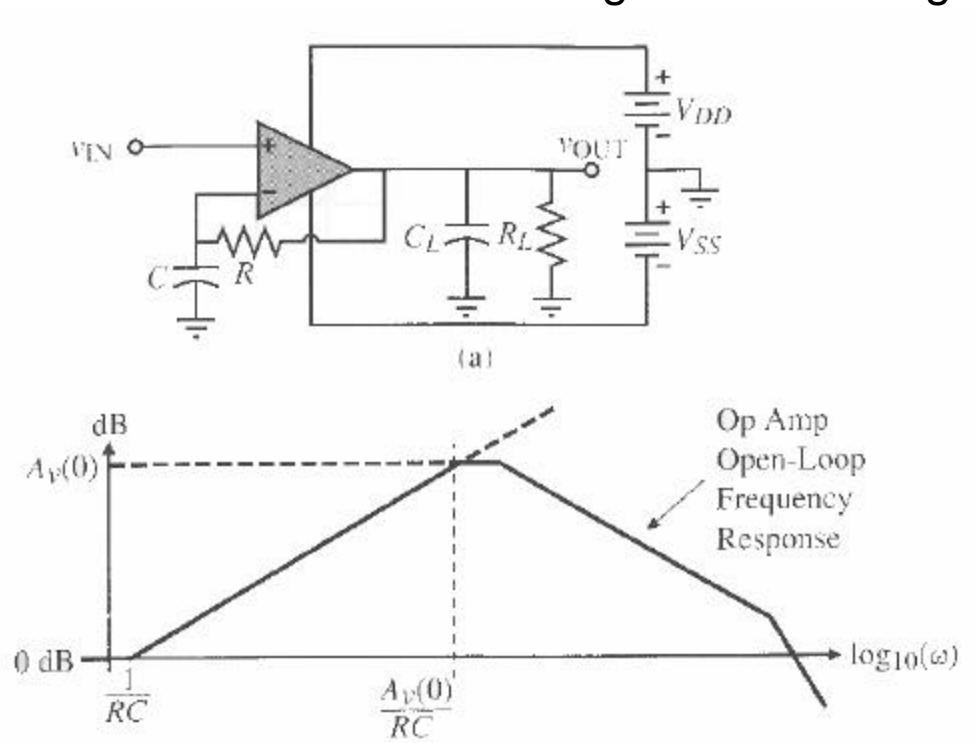
1) method:



V_{OS} is an external voltage whose value is adjusted to keep the dc value of v_{out} between the power-supply limits. Without V_{OS} the op amp will be driven to the positive or negative power supply for either the measurement or simulation cases. The method works in simulation but not in measurements

A method of measuring the open-loop characteristics with dc bias stability

- 2) A method more suitable for both measuring and simulating the open-loop gain is

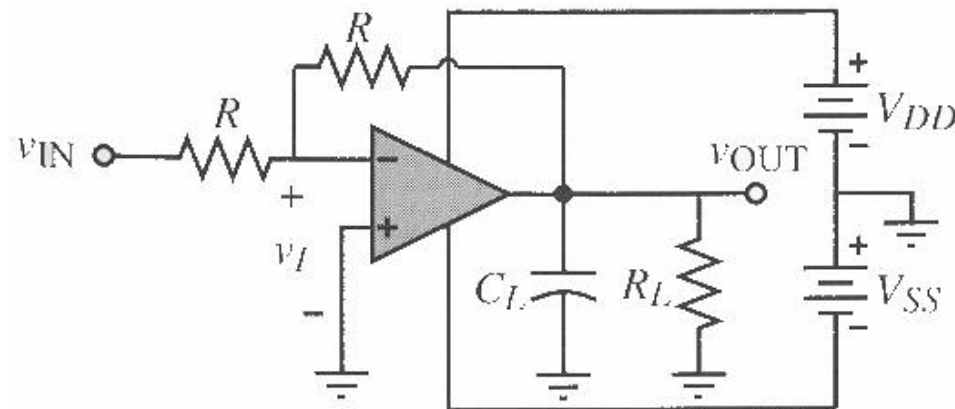


In this circuit it is necessary to select the reciprocal RC time constant a factor of $A_V(0)$ times less than the anticipated dominant pole of the op amp. Under these conditions, the op amp has total dc feedback, which stabilizes the bias.

- Simulation or measurement of the open-loop gain of the op amp will characterize the open-loop transfer curve, the open-loop output-swing limits, the phase margin, the dominant pole, the unity-gain bandwidth, and other open loop characteristics.
- The designer should connect the anticipated loading at the output in order to get meaningful results.

Configuration for simulating or measuring the open-loop frequency response for moderate-gain op amp

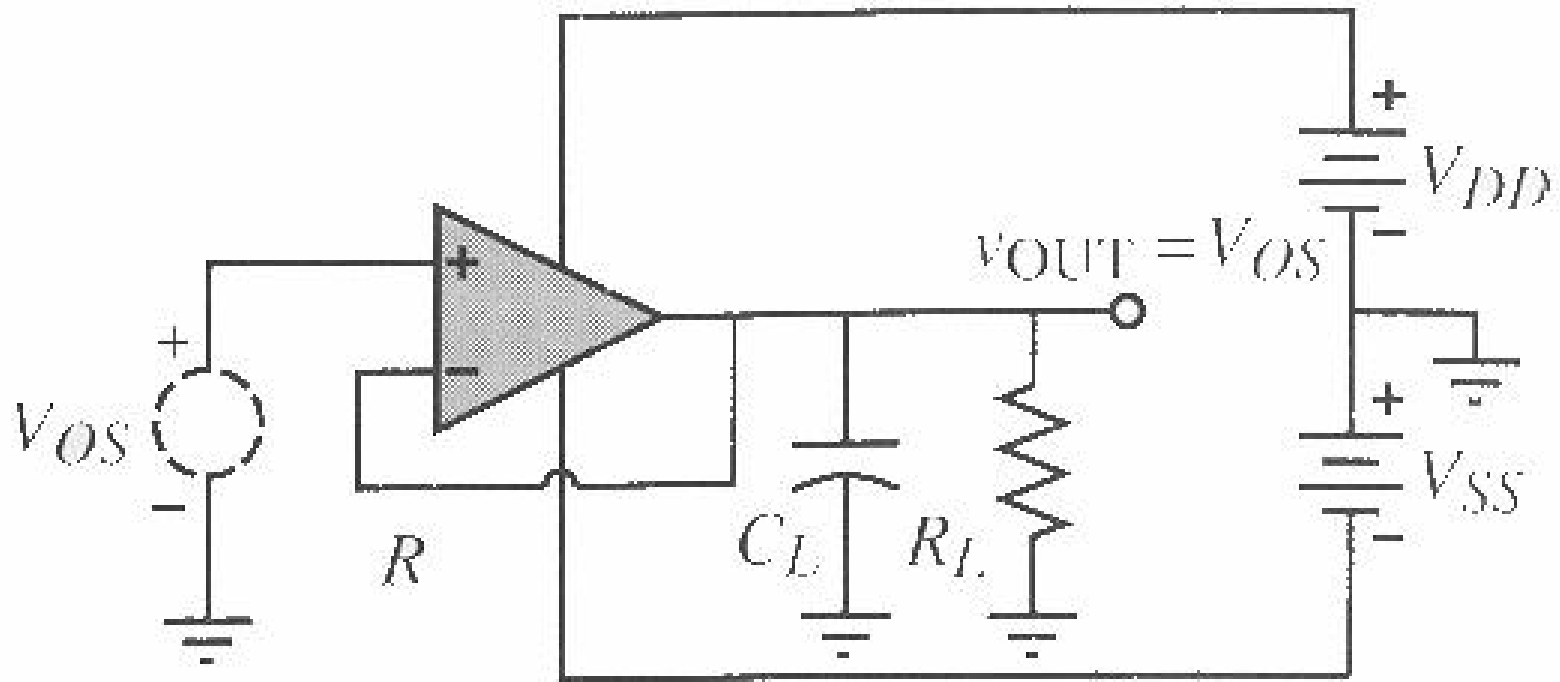
- In some cases, where the open-loop gain is not too large, the open-loop gain can be measured by applying v_{in} and measuring v_{out} and v_I . In this configuration R is large enough to not cause a dc current load on the output



DC input offset

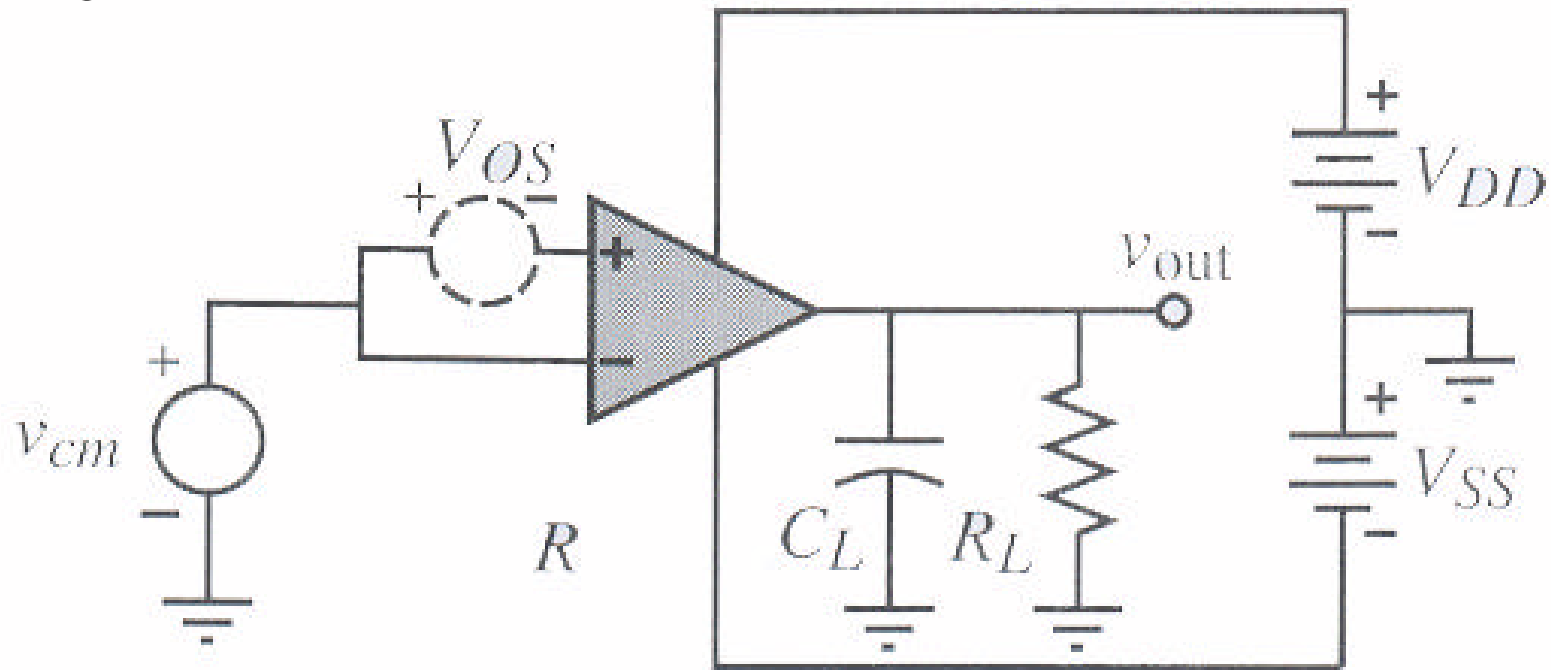
- If the dc input offset voltage is too small, it can be amplified by using a resistor divider in the negative feedback path. One must remember that V_{os} will vary with time and temperature and is very difficult to precisely measure experimentally.
- Interestingly enough, V_{os} cannot be simulated.
- The reason is that the input-offset voltage is not only due to the bias mismatch (systematic offset) but is due to device and component mismatches.
- Presently, most simulators do not offer the ability to predict device and component mismatch.

DC input offset



Common-mode gain

If V_{OS} fails to keep the op amp in the linear region, this configuration will gain, which is often the case in experimental measurements.

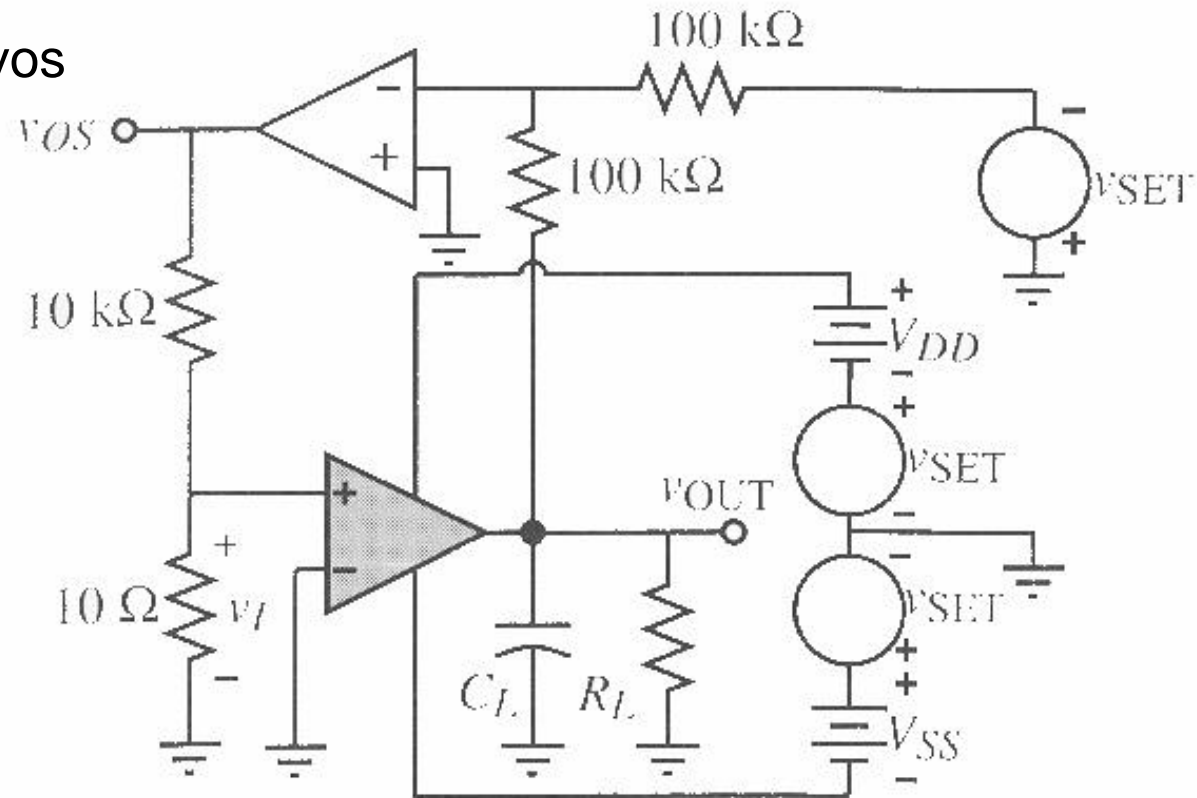


More often it can be derived from the CMRR and the open-loop gain

Circuit used to measure CMRR and PSRR

$$\text{CMRR} = 2000 / |V_{os1} - V_{os2}|$$

$$\text{CMRR} = 1000 v_{icm} / v_{os}$$

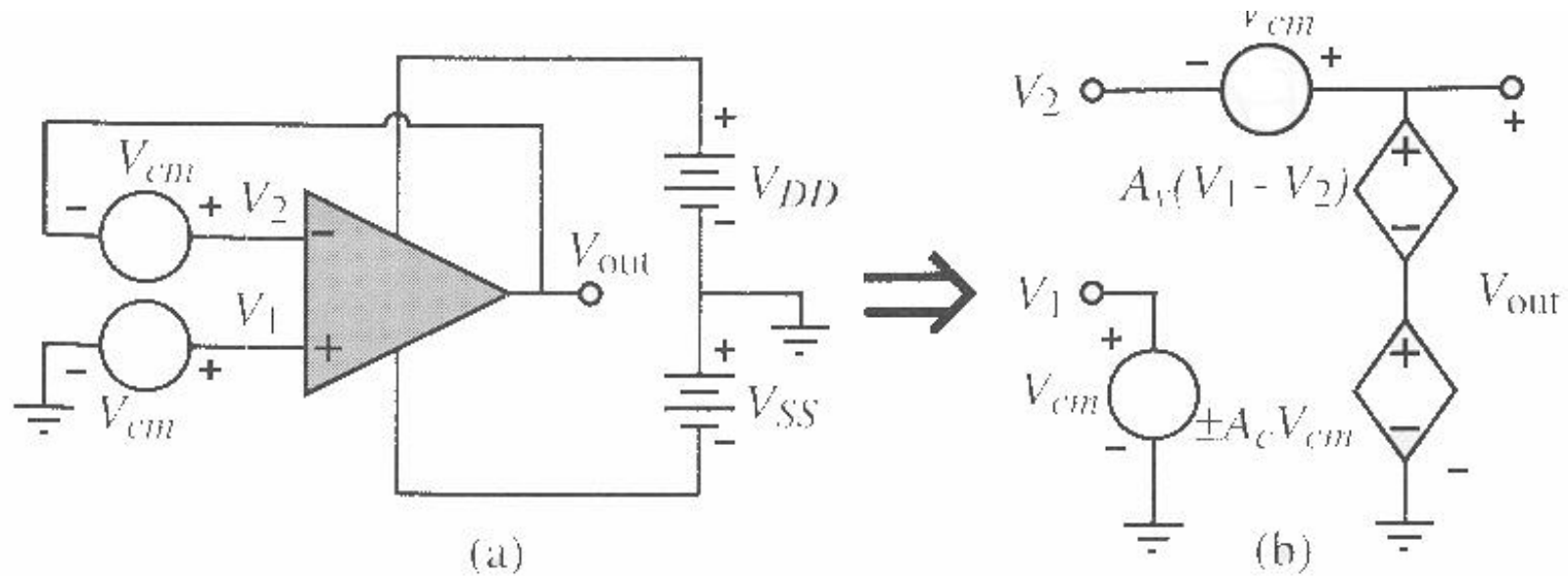


CMRR measurement

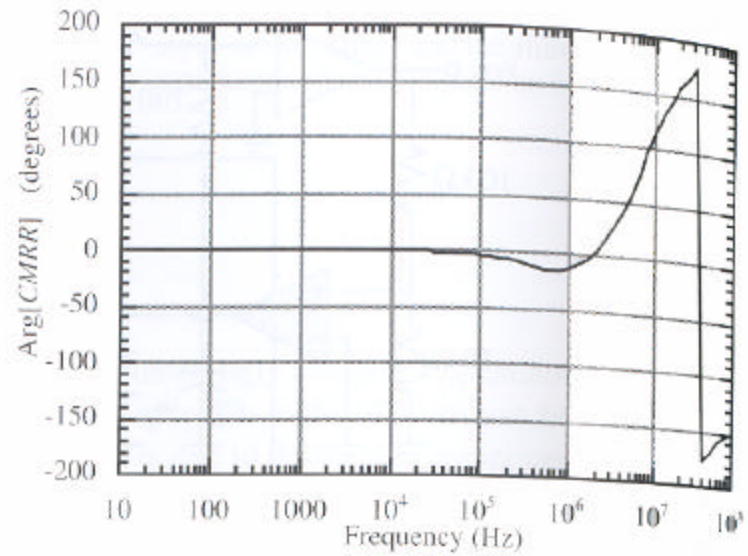
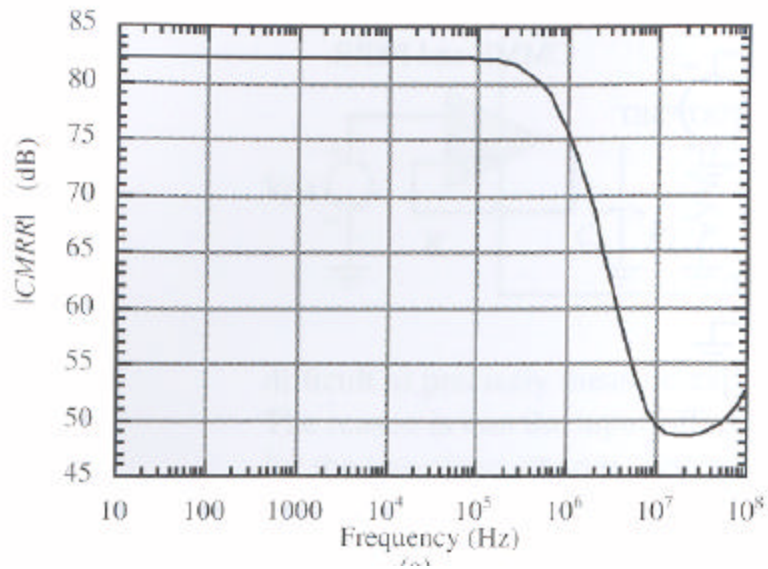
- Another way to measure CMRR would be to measure first the differential voltage gain in dB and then the common-mode voltage gain in dB by applying a common mode signal to the input.
- The CMRR in dB could be found by subtracting the common mode voltage in dB from the differential-mode voltage gain in dB.
- This can be performed automatically by a computer connected to the measurement setup.

Configuration for direct measurement of CMRR

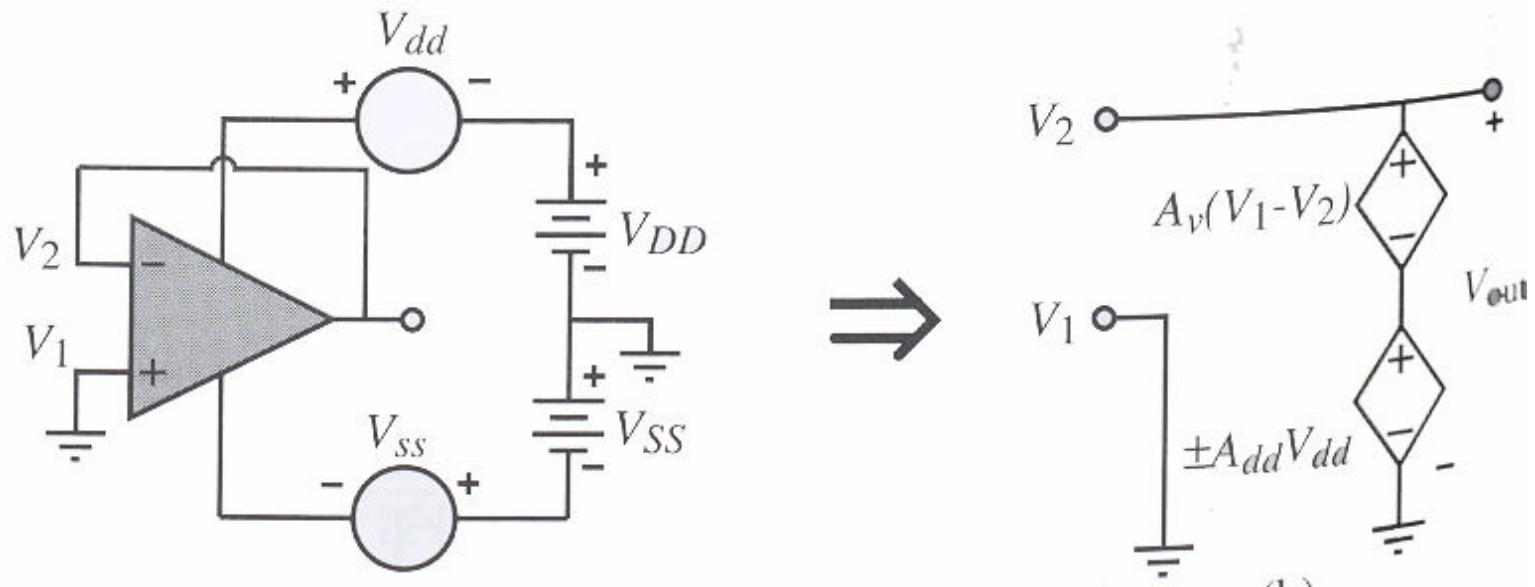
$$\frac{V_{out}}{V_{cm}} = \frac{\pm A_c}{1 + A_c - (\pm A_c / 2)} \cong \frac{|A_c|}{A_v} = \frac{1}{CMRR}$$



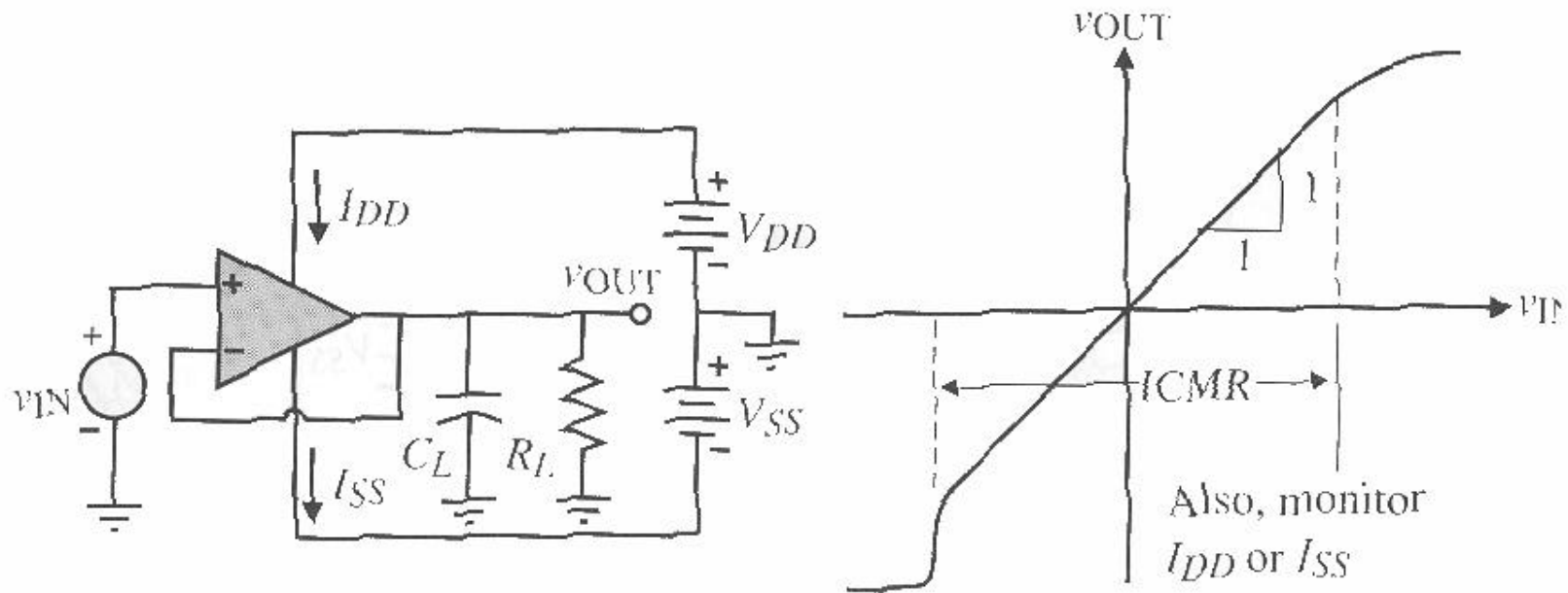
CMRR frequency response ($C_c=10\text{pF}$)



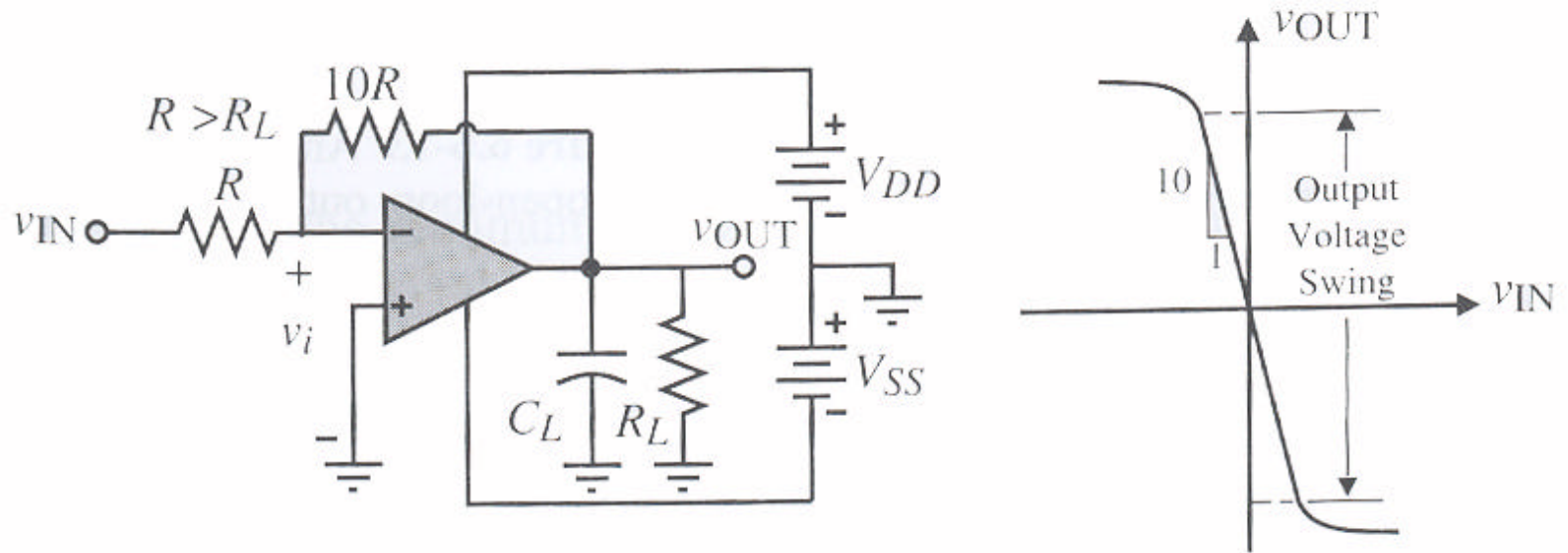
Configuration for direct measurement or simulation of PSRR



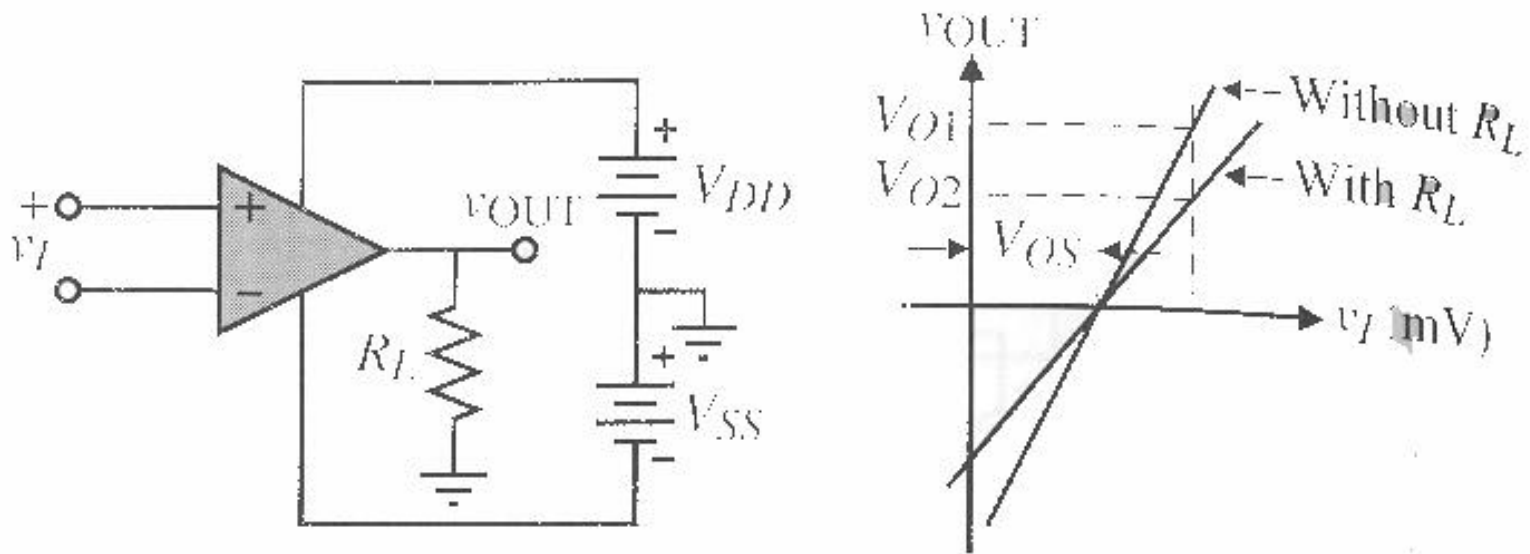
Measurement of the input common-mode voltage range



Measurement of the output voltage swing

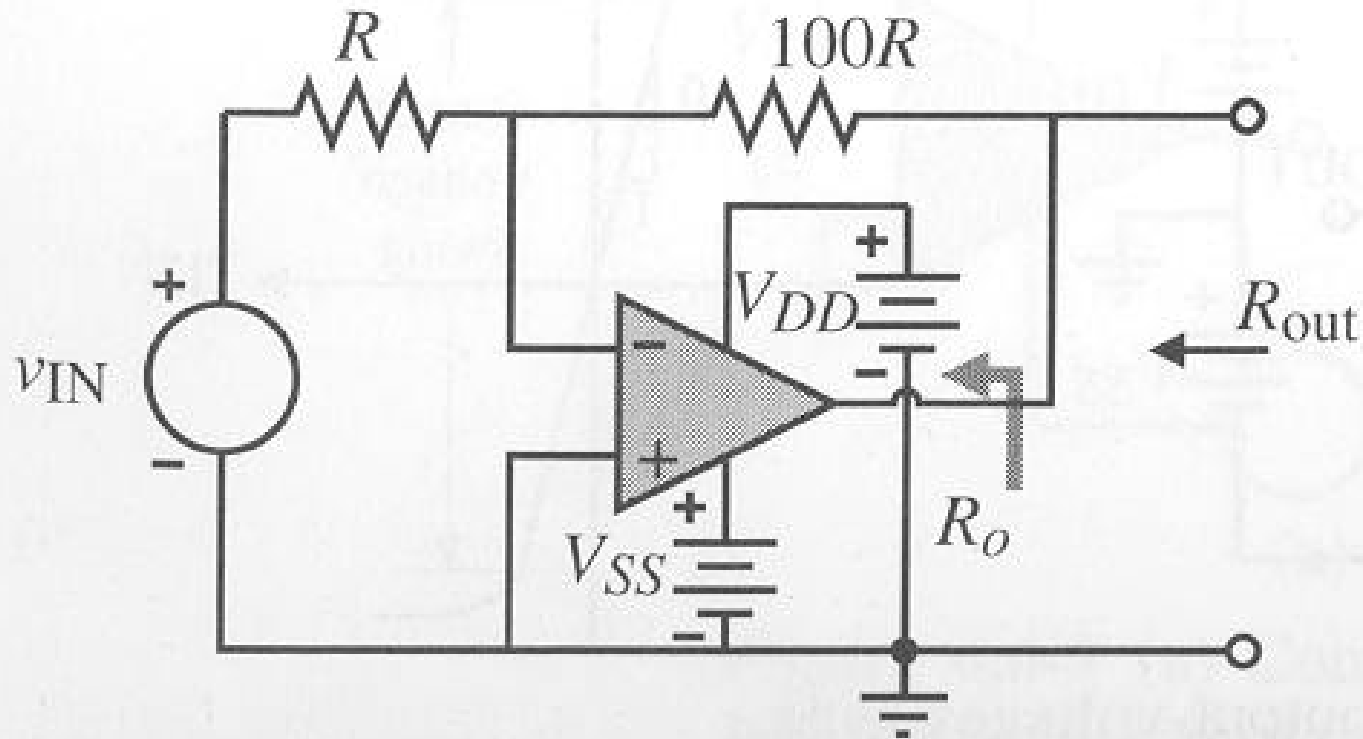


Measurement of the open-loop output resistance



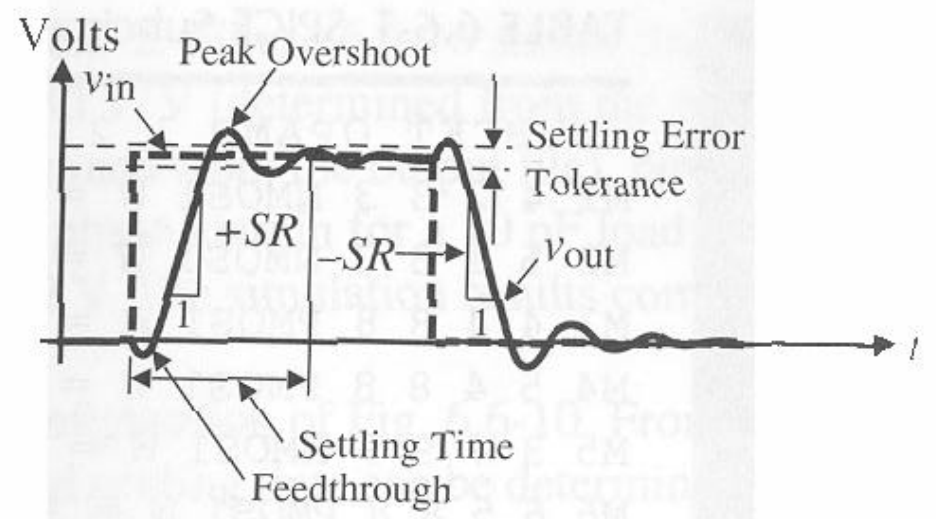
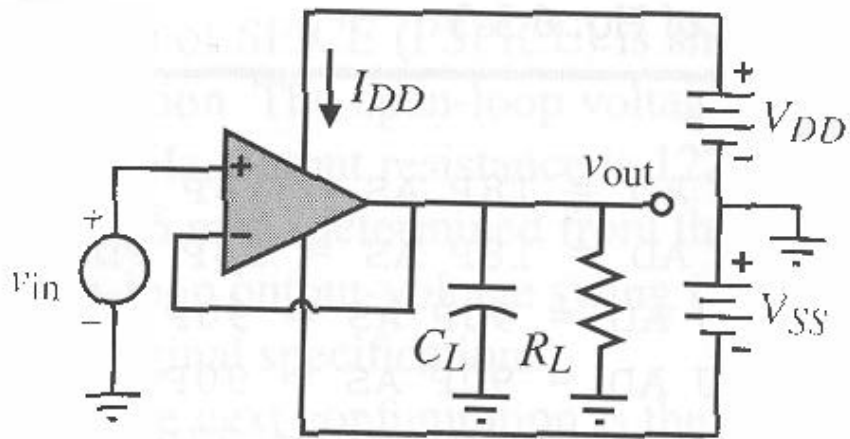
$$R_{out} = R_L \left(\frac{V_{O1}}{V_{O2}} - 1 \right)$$

An alternative method of measuring the open-loop output resistance

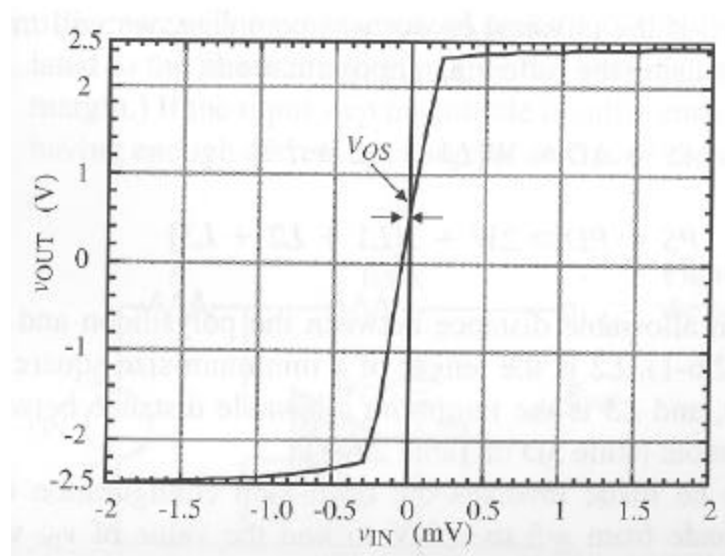
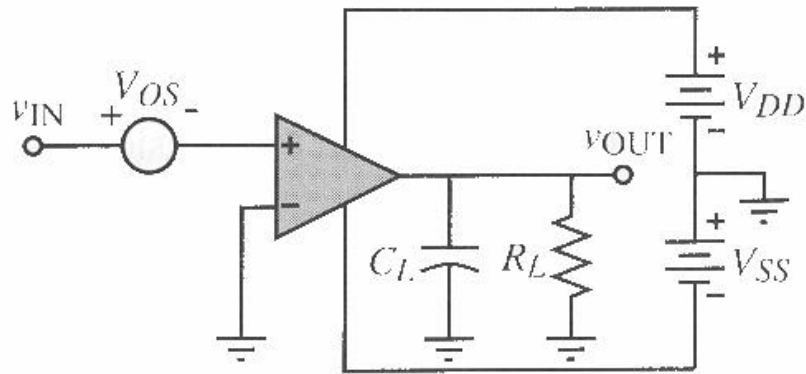


$$R_{out} = \left(\frac{1}{R_o} + \frac{1}{100R} + \frac{A_v}{100R_o} \right)^{-1} \cong \frac{100R_o}{A_v}$$

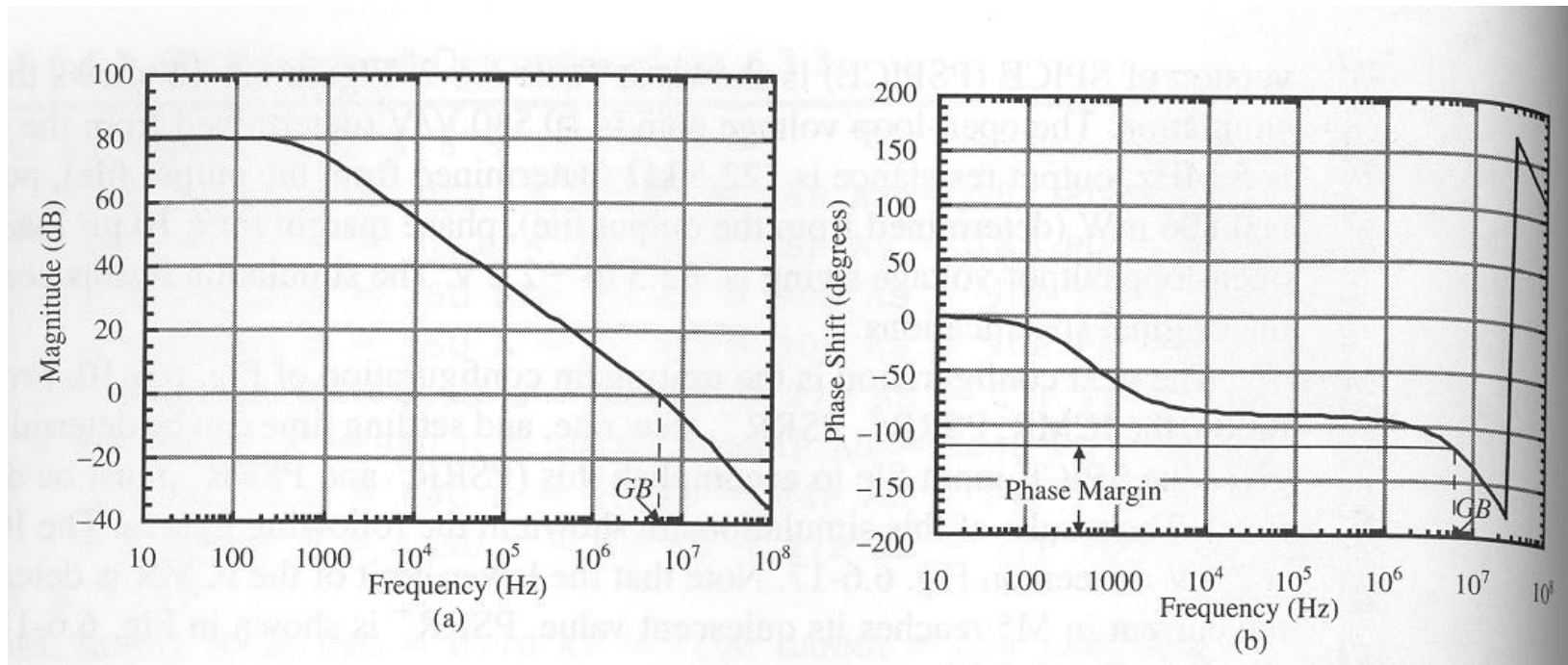
Measurement of slew rate (SR) and settling time



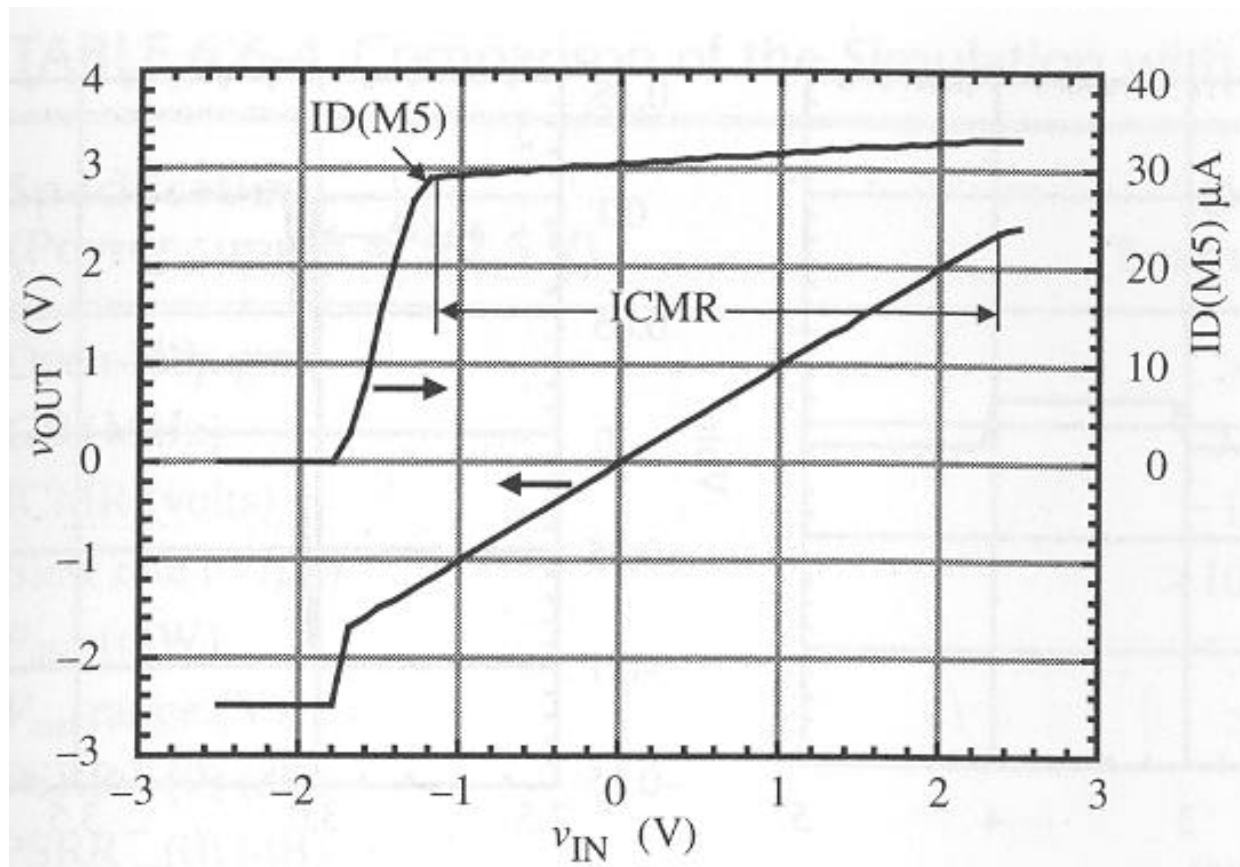
Open loop transfer characteristic



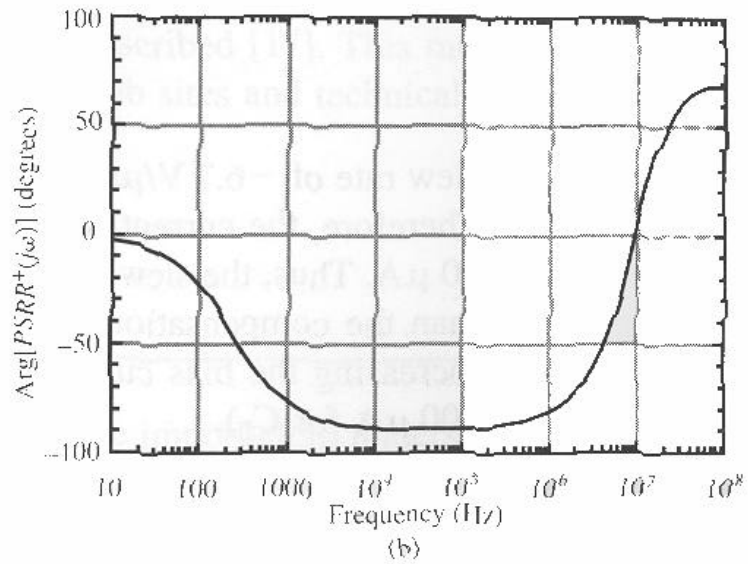
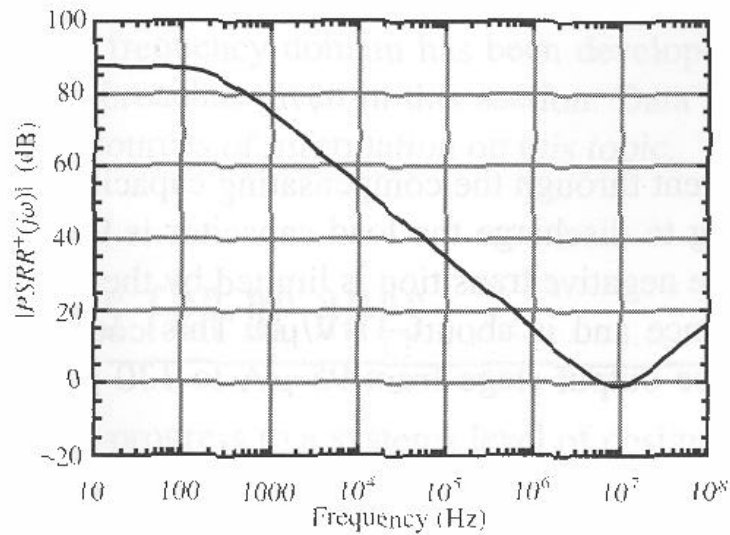
Open-loop transfer function magnitude and phase response



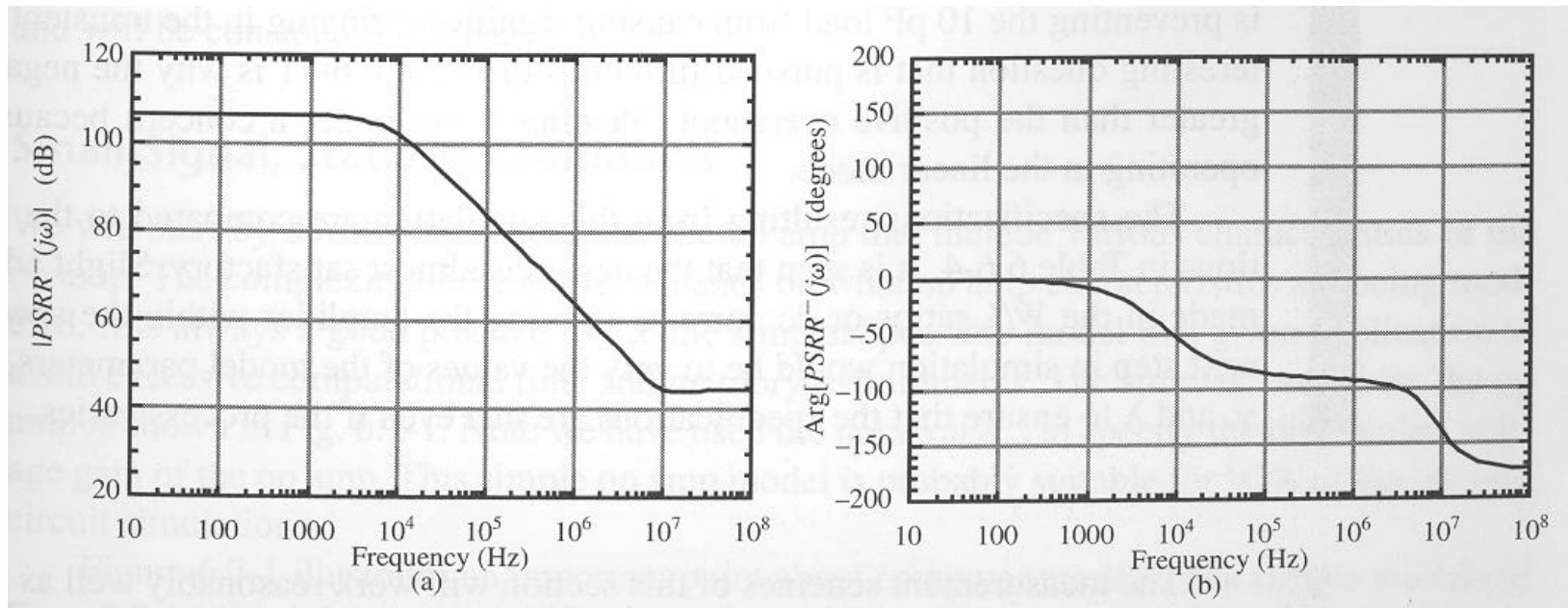
Input common-mode simulation



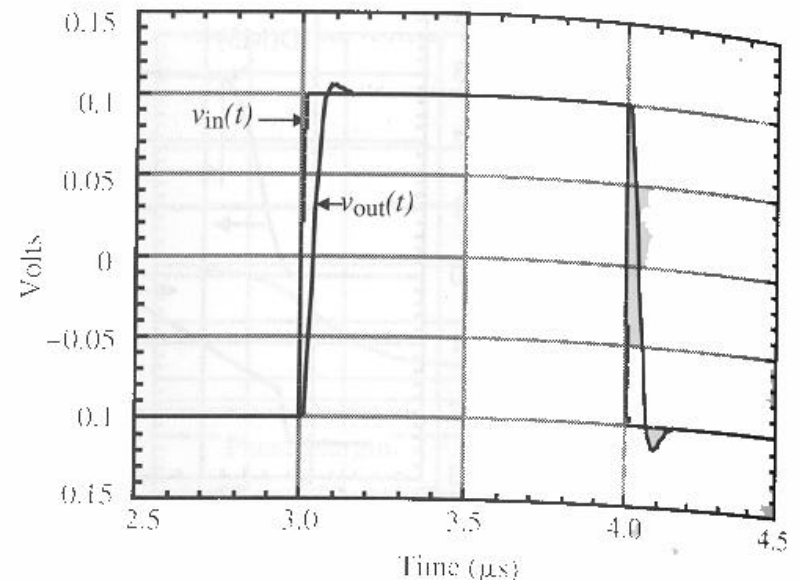
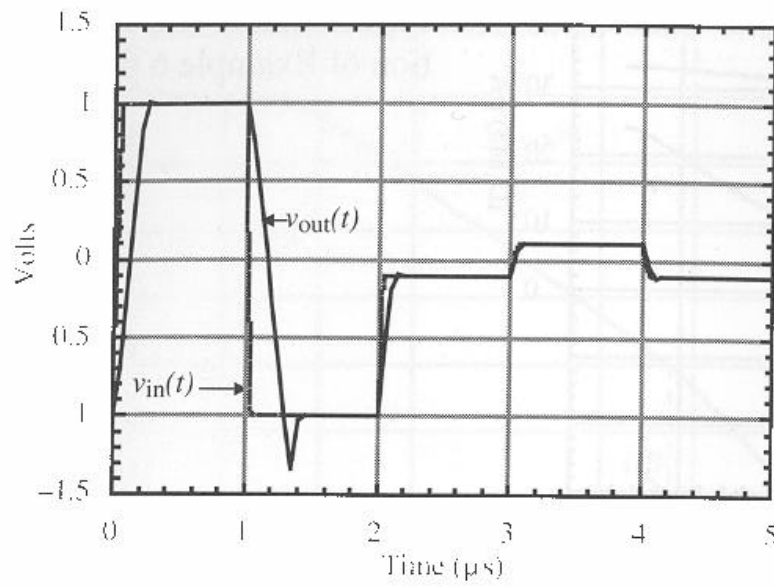
A PSRR+ magnitude and phase response



PSRR- magnitude and phase response

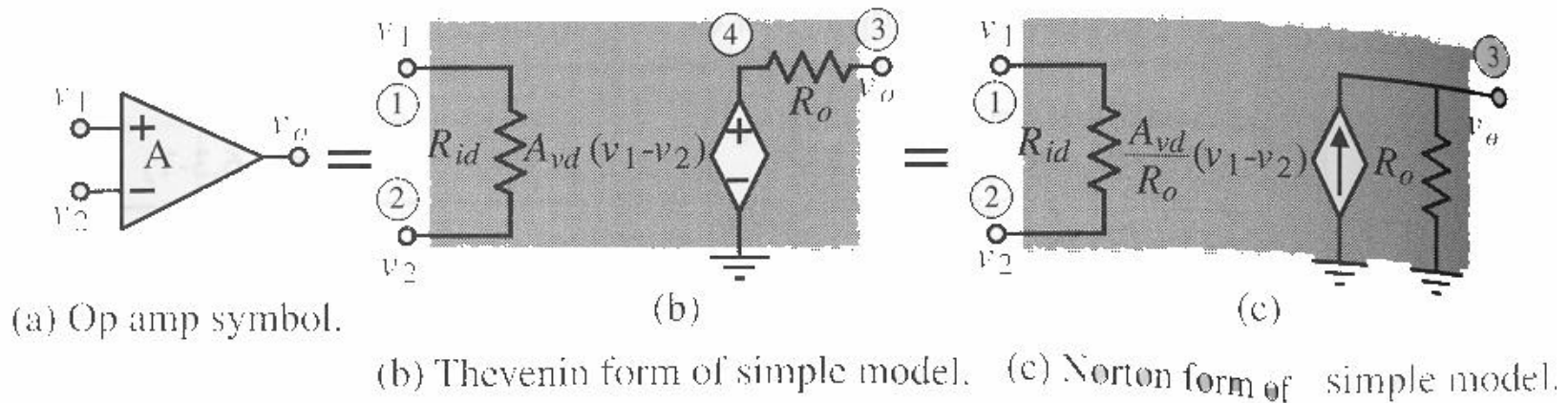


Unity gain transient response and unity-gain small-signal transient response

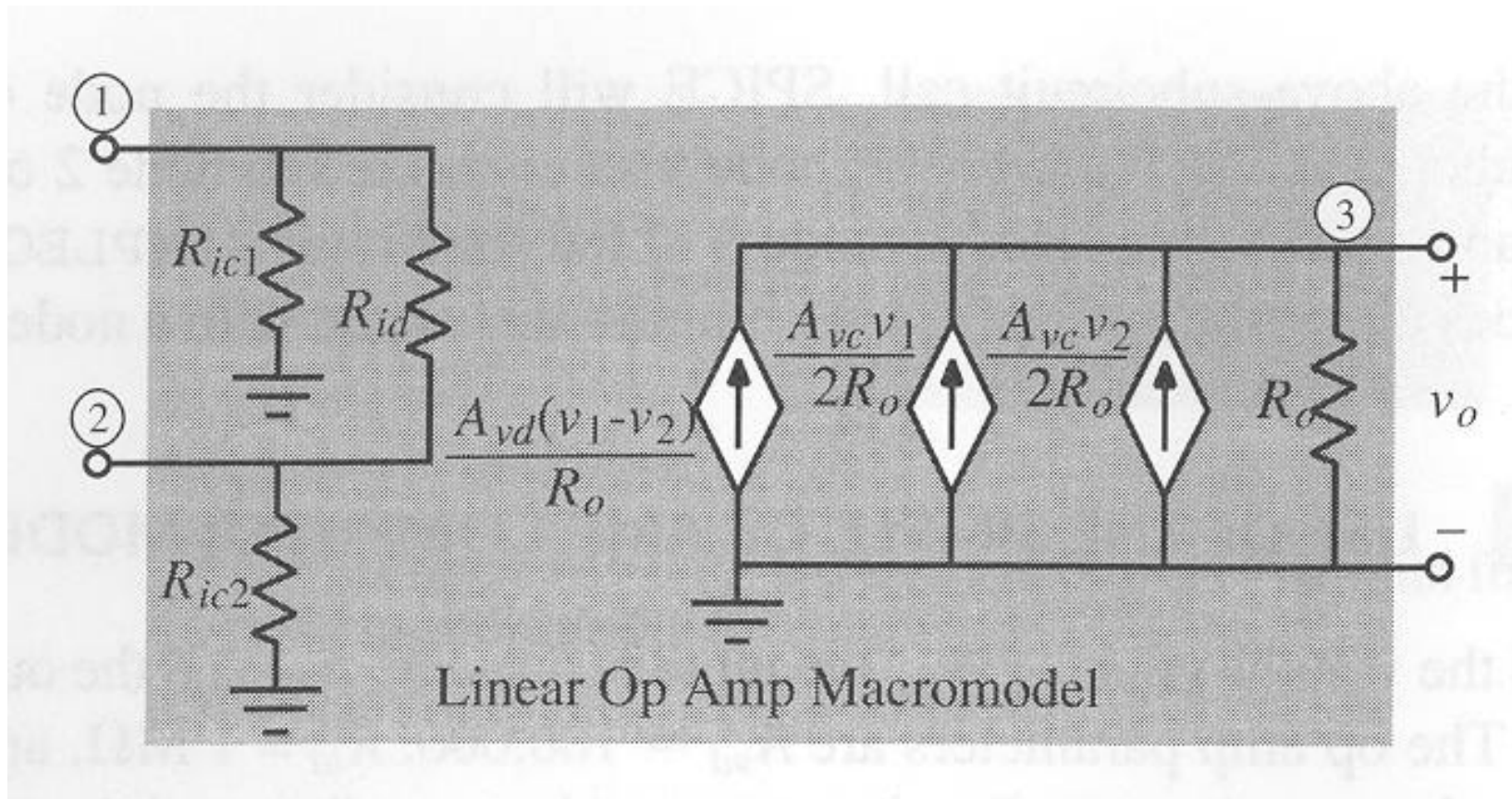


| Specification (Power supply = ± 2.5 V) | Design (Example 6.3-1) | Simulation (Example 6.6-1) |
|---|---------------------------|-------------------------------|
| Open-loop gain | > 5000 | 10,000 |
| GB (MHz) | 5 MHz | 5 MHz |
| ICMR (volts) | -1 to 2 V | +2.4 V, -1.2 V |
| Slew rate (V/ μ s) | > 10 (V/ μ s) | +10, -7 (V/ μ s) |
| P_{diss} (mW) | < 2 mW | 0.625 mW |
| V_{out} range (V) | ± 2 V | +2.3 V, -2.2 V |
| PSRR ⁺ (0) (dB) | — | 87 |
| PSRR ⁻ (0) (dB) | — | 106 |
| Phase margin (degrees) | 60° | 65° |
| Output resistance (k Ω) | — | 122.5 k Ω |

Macromodels for op amps



Op amp macromodel for separate differential and common mode gain frequency response



Op amp macromodel that limits the input and output voltages

