Simplest Single-Ended OTA
DC Input/Output, Gain

Gain, Output Range

- Small Signal:
\[ a_{vo} = \frac{dV_{out}}{dV_{in}} \]

- Large Signal:
\[ A_{vo} = \frac{V_{out} - V_{out_{o}}}{V_{in} - V_{in_{o}}} \]
Frequency Response

\[ \text{Noise Response} \]

\[ \overline{\frac{v_{eq}^2}{\Delta f}} = 4k_B T \gamma \left( \frac{1}{g_{m1}^2} \left( g_{m1} + g_{m2} \right) \right) \]

\[ = 4k_B T \gamma \left( \frac{1}{g_{m1}} \left( 1 + \frac{g_{m2}}{g_{m1}} \right) \right) \]

\[ = 4k_B T \gamma \left( \frac{1}{g_{m1}} \left( 1 + \frac{V^+}{V^2} \right) \right) \]

\[ a_f \]
Differential Input?

- Why use a differential input?
  - Diff. version has extra device(s) – more power, noise, etc.
- Real reason is systematic offset
  - All voltages are relative
  - Inherent asymmetry to get single-ended $V_{out}$
    - "common-mode" sensitivity

Fully Differential Circuits

- Fully differential circuits: complete symmetry
  - $V_{id} = V_{i+} - V_{i-}$
  - $V_{ic} = (V_{i+} + V_{i-})/2$
  - $V_{od} = V_{o+} - V_{o-}$
  - $V_{oc} = (V_{o+} + V_{o-})/2$
- Still need to be careful with common mode
Fully Differential Amplifier Gains

- Input
  - $V_{id}$
  - $V_{ic}$

- Output
  - $V_{od}$
  - $V_{oc}$

- Gains
  - $A_{dm}$
  - $A_{dcm}$
  - $A_{cdm}$
  - $A_{cm}$

PSRR, CMRR, ...

- $A_{dm} = \frac{v_{od}}{v_{id}} \to \infty$
- $A_{YDD} = \frac{v_{od}}{V_{DD}} \to 0$
- $CMRR = \left| \frac{A_{dm}}{A_{cdm}} \right| \to \infty$
- $A_{cm} = \frac{v_{oc}}{v_{ic}} \to 0$
- $A_{YSS} = \frac{v_{od}}{V_{SS}} \to 0$
- $PSRR_{YDD} = \left| \frac{A_{dm}}{A_{YDD}} \right| \to \infty$
- $A_{cdm} = \frac{v_{od}}{v_{ic}} \to 0$
- $PSRR_{YSS} = \left| \frac{A_{dm}}{A_{YSS}} \right| \to \infty$

- Any “terminals” are inputs
  - May not be a node in the circuit – could be e.g. temperature

- Typical metrics: CMRR, PSRR
  - Careful with how you use these
CMRR Example

Differential Input Stage Options

(a) (b) (c)