Simplest Single-Ended OTA
DC Input/Output, Gain

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**

**Noise**

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

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

\[
= 4kT \gamma \frac{1}{g_{m1}} \left( 1 + \frac{V_1^*}{V_2^*} \right)
\]

\[
\Delta f
\]

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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
  - $V_{id} = V_{i+} - V_{i-}$  \quad $V_{ic} = (V_{i+} + V_{i-})/2$
  - $V_{od} = V_{o+} - V_{o-}$  \quad $V_{oc} = (V_{o+} + V_{o-})/2$
- Still need to be careful with common mode
**Fully Differential Amplifier Gains**

Input                      Output

\[ V_{id} \rightarrow A_{dm} \rightarrow V_{od} \]
\[ V_{ic} \rightarrow A_{dcm} \rightarrow V_{oc} \]

\[ A_{cm} \]

**PSRR, CMRR, …**

\[ A_{dm} = \frac{v_{od}}{v_{id}} \rightarrow \infty \]
\[ A_{vdd} = \frac{v_{od}}{v_{DD}} \rightarrow 0 \]

\[ CMRR = \left| \frac{A_{dm}}{A_{vdd}} \right| \rightarrow \infty \]

\[ A_{cm} = \frac{v_{oc}}{v_{ic}} \rightarrow 0 \]
\[ A_{vss} = \frac{v_{od}}{v_{SS}} \rightarrow 0 \]

\[ PSRR_{vDD} = \left| \frac{A_{dm}}{A_{vDD}} \right| \rightarrow \infty \]
\[ PSRR_{vSS} = \left| \frac{A_{dm}}{A_{vSS}} \right| \rightarrow \infty \]

- All “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) \[ V_{i+} \quad V_{i-} \]

(b) \[ V_{i+} \quad V_{i-} \quad \downarrow \]

(c) \[ V_{i+} \quad V_{i-} \quad \uparrow \]