Simplest Single-Ended OTA
**DC Input/Output, Gain**

\[ V_{out} = V_{in} \frac{A_{vo}}{A_{th}} \]

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

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

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**Gain, Output Range**
**Frequency Response**

![Frequency Response Graph](image)

**Noise**

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

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

\[
= 4k_B T \gamma \frac{1}{g_{m1}} \left( 1 + \frac{V^*}{V^*_{\text{ref}}} \right)_{n_f}
\]
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 $V_{\text{out}}$
  - “common-mode” sensitivity

![Differential Input Circuit Diagram]

Fully Differential Circuits

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

![Fully Differential Circuit Diagram]
Fully Differential Amplifier Gains

### Input
\[ V_{id} \]

### Output
\[ A_{dm} \]
\[ A_{dcm} \]
\[ A_{cm} \]
\[ A_{cdm} \]
\[ V_{od} \]
\[ V_{oc} \]

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### PSRR, CMRR, ...

- 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

\[
A_{dm} = \frac{v_{od}}{v_{id}} \rightarrow \infty \\
A_{dcm} = \frac{v_{od}}{V_{DD}} \rightarrow 0 \\
A_{cm} = \frac{v_{oc}}{v_{ic}} \rightarrow 0 \\
A_{cdm} = \frac{v_{od}}{v_{ic}} \rightarrow 0 \\
CMRR = \frac{|A_{dm}|}{|A_{dcm}|} \rightarrow \infty \\
PSRR_{VDD} = \frac{|A_{dm}|}{|A_{dcm}|} \rightarrow \infty \\
PSRR_{VSS} = \frac{|A_{dm}|}{|A_{dcm}|} \rightarrow \infty
\]
CMRR Example

Differential Input Stage Options

(a) (b) (c)
PSRR Example

Baluns