Simplest Single-Ended OTA

\[ a_{\text{in}} = \frac{dV_{\text{out}}}{dV_{\text{in}}} \]

\[ A_{\text{in}} = \frac{V_{\text{out}} - V_{\text{out,\text{ref}}}}{V_{\text{in}} - V_{\text{in,\text{ref}}}} \]

Small Signal: \( a_{\text{in}} \)

Large Signal: \( A_{\text{in}} \)

Frequency Response

\[ \frac{V_{\text{out}}}{V_{\text{in}}} = 4kT \frac{1}{K_{\text{in}}} \left( g_{\text{in}} + g_{\text{out}} \right) \]

Noise

\[ \frac{V_{\text{noise}}^2}{M} = 4kT \frac{1}{K_{\text{in}}} \left( g_{\text{in}} + g_{\text{out}} \right) \]

\[ = 4kT \frac{1}{K_{\text{in}}} \left( 1 + \frac{g_{\text{out}}}{K_{\text{out}}} \right) \]

\[ = 4kT \frac{1}{K_{\text{in}}} \left( 1 + \frac{g_{\text{out}}^2}{K_{\text{out}}^2} \right) \]
### 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
  - $V_{id} = V_{ic}$, $V_{o+} = (V_{o+} + V_{o-})/2$
  - Still need to be careful with common mode

### 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

### Fully Differential Amplifier Gains

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

### Differential Input Stage Options

- (a) (b) (c)