Why use Multi-Stage Amplifiers?

- Single-stage amplifier:
  - Generally have to trade between swing and gain
  - (Need cascodes and/or large $V_{min}$ for current sources)

- Multi-stage amplifier:
  - Higher gain without sacrificing swing
  - (Gain-boosted cascode is multi-stage amplifier in disguise)

- Challenge: stability!

Compensation Techniques

- Many options – best one depends on situation at hand

- Look at a few general categories:
  - Narrowbanding
  - Wideband input stage (pre-amp)
  - Miller

Stability for Simple 2-Stage Amp

- Two closely spaced poles - is this circuit stable?
Pre-amp

- Build a pre-amp with bandwidth much higher than 2nd stage
- Usually limits achievable pre-amp gain

Phase Margin Engineering

\[ a_k \approx \frac{F_{\text{ni}}}{C_C} \]
\[ |p_i| \gg |a_k| \text{ of } T(s) \]

choose \[ |p_i| \gg K a_k \]
\[ C_i \geq KFC \frac{F_{\text{ni}}}{R_{\text{in}}} \]

- Higher \( K \) \( \rightarrow \) higher \( C_i \)
- For fixed \( C_i \), larger \( C_1 = C_2 \) lowers phase margin

\[ \frac{z}{a_k} = \frac{1}{\frac{1}{R_{\text{in}}} C_1} \]
\[ \frac{z}{|p_i|} = \frac{C_1}{C_i} \]

Nulling Resistor

\[ z \rightarrow \frac{1}{\left( \frac{1}{R_{\text{in}}} - R_f \right) C_i} \]

- \( R_f \) limits feedforward current at high frequency
- Pushes feedforward zero to higher frequency
- Adds new pole \( p_z \)

Nulling Resistor Implementation
Cascode Compensation (Ahuja)

• No RHP zero
• But cost in power can be high
  • ($I_i$ needs to slew $C_c$)

Noise Analysis cont’d

\[ V_n = \frac{1}{\beta F_i} \left( \frac{1}{aQ} + \frac{1}{\beta aO} \right) \left( \frac{I_{in}}{I_{bias}} + \frac{I_{c}}{I_{bias}} \right) \]

with

\[ aO = \frac{F_{trans}}{C_c (C_i + C_f)} \]

\[ aQ = \frac{F_{trans}}{C_i} \]

Total Noise at Output

\[ v_{nT} = \frac{kT}{C_i} \left( \frac{1}{F} + \frac{kT}{C_i} \right) \gamma \]

\[ v_{nT} = \frac{kT}{C_f} \left( \frac{1}{F} + \frac{FC_c}{C_i (C_i + C_f)} \right) \gamma \]

• Noise from first stage dominates
• Noise capacitor: $C_c$ (NOT $C_i$)

Noise Analysis

• Need a simplified model:
2-Stage CMFB