Why use Multi-Stage Amplifiers?

- Single-stage amplifier:
  - Generally have to trade between swing and gain
  - (Need cascodes and/or large $V_{\text{min}}$ 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?

Narrowbanding

- Narrowbanding
  - Lower one of the poles
  - Or introduce a new one

  - Stability OK, but (feedback) bandwidth often low
    - Example: offset cancellation
Pre-amp

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

Phase Margin Engineering

\[ a_k = \frac{F}{C \omega} \]

- Higher K \( \rightarrow \) higher \( C \)

\[ C \geq KFC \frac{g_{m2}}{g_{m1}} \]

- For fixed \( C_m \), larger \( C_2 \) lowers phase margin

\[ \frac{z}{\omega} = \frac{1}{g_{m2}} \frac{g_{m1}}{C_2} \]

- Zero can add significant phase lag
  - Unless \( g_{m2} > g_{m1} \)

Nulling Resistor

\[ z \approx \frac{1}{g_{m2}} \left( \frac{1}{R} - \frac{1}{R} \right) C_2 \]

- \( R \) limits feedforward current at high frequency
  - Pushes feedforward zero to higher frequency
  - Adds new pole \( p_3 \)

Nulling Resistor Implementation
Cascode Compensation (Ahuja)

- No RHP zero
- But cost in power can be high
  - \((I_2\) needs to slew \(C_C))\)

Cascode Compensation (Ribner)

Noise Analysis cont’d

\[
V_n = \frac{1}{F_{B,\omega}} \left( \frac{1}{\omega Q} \right) \left( \frac{\omega Q}{\omega Q + \omega_0^2} \right) \left( \frac{\omega_0^2}{\omega_0^2} \right)
\]

with

\[
\omega_0^2 = \frac{F_{B,\omega} S_{\omega}}{C(C + C_0)}
\]

\[
\omega Q = \frac{F_{B,\omega} S_{\omega}}{C_1}
\]

Total Noise at Output

\[
V_{n1} = \frac{k T}{C_F \gamma} \left( \frac{k T}{C_F (C_0 + C_L)} \right) \gamma
\]

\[
V_{n2} = \frac{k T}{C_F} \gamma \left( \frac{F C_0}{C_0+C_L} \right)
\]

- Noise from first stage dominates
- Noise capacitor: \(C_C\) (NOT \(C_L\))

Noise Analysis

- Need a simplified model:

2-Stage CMFB
2-Stage CMFB