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!
Stability for Simple 2-Stage Amp

Two closely spaced poles - is this circuit stable?

2-Stage Stability cont’d
Compensation Techniques

- Many options – best one depends on situation at hand

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

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

Miller Compensation

- Very common form of compensation
  - Why is this “pole splitting” good?
Alternative Explanation

- $C_c$ forms another feedback loop
  - $1/F = 1/(sC_c)$
  - Low freq: $1/F > A_{v0}$
  - High freq: CL gain reduced

Miller Compensated Poles/Zeros
Phase Margin Engineering

\[ \omega_u \approx \frac{F}{C_c} \frac{g_{m1}}{g_{m2}} \]

\[ |p_2| \geq K \omega_u \]

- Higher \( K \) → higher \( C_c \)

- For fixed \( C_c \), larger \( C_L = C_2 \) lowers phase margin

\[ \frac{z}{\omega_u} = \frac{1}{F} \frac{g_{m2}}{g_{m1}} \]

\[ \frac{z}{|p_2|} \approx \frac{C_2}{C_c} \]

Nulling Resistor

\[ z \rightarrow \frac{1}{\left( \frac{1}{g_{m2}} - R_z \right) C_c} \]

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

\[ p_1, p_2 : \text{ no change} \]

\[ p_3 \approx -\frac{1}{R_z C_1} \]
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
Total Noise at Output

2-Stage CMFB
2-Stage CMFB