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)
  - 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?
Miller Compensated Poles/Zeros

Phase Margin Engineering

\[
\omega_n \approx F \frac{g_{m1}}{C_c} \quad |p_2|, z >> \omega_n \quad \text{of } T(s)
\]

choose \[|p_2| \geq K \omega_n\]

\[
C_c \geq KFC_2 \frac{g_{m1}}{g_{m2}}
\]

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

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

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

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

• Need a simplified model:

\[
\nu_o = \frac{1}{F g_{m1}} \frac{1}{1 + \frac{s}{\omega_0 Q} + \frac{s^2}{\omega_0^2}} \left( i_{n1} - i_{n2} \frac{s C_i}{g_{m2}} \right)
\]

with

\[
\omega_0 = \frac{F g_{m2}}{C_i (C_{i} + C_L)}
\]

\[
\omega_0 Q = \frac{F g_{m1}}{C_i}
\]
Total Noise at Output

\[ \frac{\bar{v}_{oT}^2}{2} = \frac{k_B T}{C_c} \gamma F + \frac{k_B T}{(C_c + C_L)} \gamma \]

\[ \frac{\bar{v}_{oT}^2}{2} = \frac{k_B T}{C_c} \gamma \left( 1 + \frac{F C_c}{C_c + C_L} \right) \]

- Noise from first stage dominates
- Noise capacitor: \( C_c \) (NOT \( C_L \)!)
2-Stage CMFB