EECS240 – Spring 2010

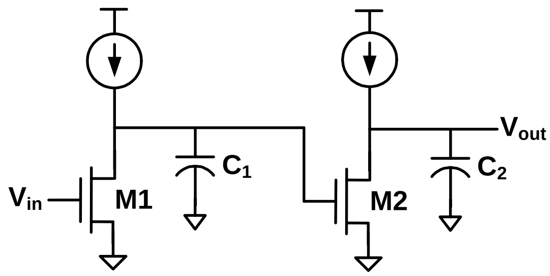
Lecture 16: Multistage Amplifiers

Elad Alon
Dept. of EECS

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!

Stability for Simple 2-Stage Amp



p1 =　　　　**p2 =**

- **Two closely spaced poles - is this circuit stable?**

2-Stage Stability cont'd

Compensation Techniques

- Many options – best one depends on situation at hand

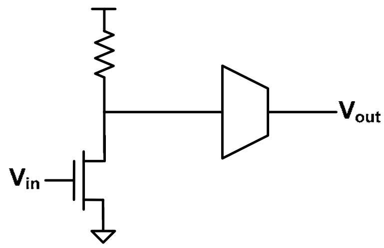
- Look at a few general categories:
  - Narrowbanding
  - Wideband input stage (pre-amp)
  - Miller

Narrowbanding

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

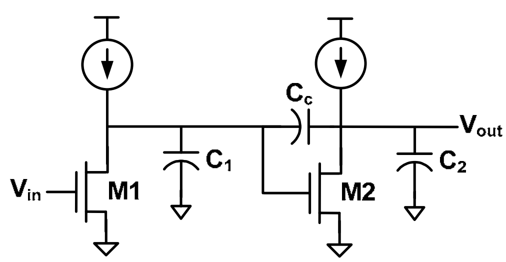
- Stability OK, but (feedback) bandwidth low
  - Example: offset cancellation

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

$$\omega_u \approx F\frac{g_{m1}}{C_c}$$

$$|p_2|, z >> \omega_u \quad \text{of } T(s)$$

$$\text{choose} \quad |p_2| \geq K\omega_u$$

$$C_c \geq KFC_2\frac{g_{m1}}{g_{m2}}$$

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

$$\frac{z}{|p_2|} \approx \frac{C_2}{C_c}$$

- **Higher K → higher C_c**
- **For fixed C_c, larger $C_L = C_2$ *lowers* phase margin**
- **Zero can add significant phase lag**
  - **Unless $g_{m2} >> Fg_{m1}$**

Nulling Resistor

$$z \rightarrow \frac{1}{\left(\frac{1}{g_{m2}} - R_Z\right)C_c}$$

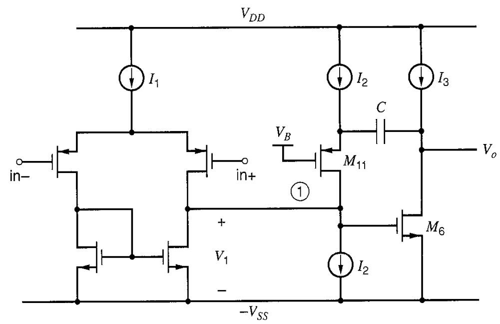
$$p_1, p_2: \quad \text{no change}$$

$$p_3 \approx -\frac{1}{R_z C_1}$$

- **R_z 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

- **Need a simplified model:**

Noise Analysis cont'd

$$v_o = \frac{1}{Fg_{m1}} \frac{1}{1 + \frac{s}{\omega_o Q} + \frac{s^2}{\omega_o^2}} \left(i_{n1} - i_{n2} \frac{sC_c}{g_{m2}} \right)$$

with

$$\omega_o^2 = \frac{Fg_{m1} g_{m2}}{C_c (C_c + C_L)}$$

$$\omega_o Q = \frac{Fg_{m1}}{C_c}$$

Total Noise at Output

$$\overline{v_{oT}^2} = \frac{k_B T}{C_c}\frac{\gamma}{F} + \frac{k_B T}{(C_c + C_L)}\gamma$$

$$\overline{v_{oT}^2} = \frac{k_B T}{C_c}\frac{\gamma}{F}\left(1 + \frac{F C_c}{C_c + C_L}\right)$$

- **Noise from first stage dominates**
- **Noise capacitor: C_c (NOT C_L!)**

2-Stage CMFB

2-Stage CMFB