Lecture 39

• Last time:
  – BiCMOS voltage amplifier: example of “dissection” technique for a complicated circuit

• Today:
  – Bias and output swing for BiCMOS voltage amp
  – Start open-circuit time constant analysis (back to Chapter 10)
DC Bias (Cont.)

Simplifying assumption: \( V_{GSn} = 1.5V = V_{SGp} \)

Cascode current supply and totem pole:

- diode connected devices set both source-gate and source-drain voltages
- select input bias voltage such that \( I_{D1} = I_{D9} \)
- devices \( M_1, Q_2, M_6, \) and \( M_7 \) must have same \( |V_{DS}| \) or \( V_{CE} \) as \( M_9, Q_{2B}, M_{6B}, \) and \( M_{7B} \) (2nd order effect) → sometimes called “replica biasing”

Output Swing: \( V_{OUT,MIN} \)

Minimum output voltage: \( M_{10}, M_3 \), and \( Q_2 \) are “suspects”

- \( M_{10} \) goes into triode when \( V_{OUT} = 0.5 \text{ V} \)
- \( M_3 \) goes into triode when \( V_{SD3} = 0.5 \text{ V} \)
  \[ V_{OUT} = 0.5 \text{ V} - 0.7 \text{ V} = 0.2 \text{ V} \]
- \( Q_2 \) goes into saturation when \( V_{CE2} = 0.1 \text{ V} \)
  or \( V_{BC2} = 0.6 \text{ V} \)
  \[ V_{OUT} = V_{B2} - V_{BC2} + V_{SG3} - V_{BE4} = 2 \text{ V} - 0.6 \text{ V} + 1.5 \text{ V} - 0.7 \text{ V} = 2.2 \text{ V} \]
Output Swing: $V_{OUT,MAX}$

Maximum output voltage: $Q_4$, $M_5$, and $M_6$ are “suspects”

$Q_4$ goes into saturation when $V_{CE4} = 0.1$ V $\Rightarrow V_{OUT} = 4.9$ V

$M_5$ goes triode when $V_{SD5} = 0.5$ V $\Rightarrow V_{OUT} = 3.8$ V

$M_6$ goes triode when $V_{SD6} = 0.5$ V $\Rightarrow$

$$V_{OUT} = V_{S6} - 0.5 \text{ V} + V_{SG3} - V_{BE4}$$

$$= 3.5 - 0.5 + 1.5 - 0.7 \text{ V} = 3.8 \text{ V}$$

Frequency Response of Multistage Amplifiers

We need a systematic technique rather than a bunch of qualitative results (e.g., CS suffers from Miller effect, CD and CG are wideband stages …)

Disappointing news: our analytical technique is capable of estimating only the dominant (lowest) pole … for a restricted class of amplifiers.
The Special Case

The transfer function can have \textit{no zeroes} and must have a \textit{dominant pole} $\omega_1 \ll \omega_2, \omega_3, \ldots, \omega_n$

$$H(j\omega) = \frac{H_o}{1 + j \omega b_1 + (j \omega)^2 b_2 + (j \omega)^3 b_3 + \ldots}$$

Factor denominator:

$$H(j\omega) = \frac{H_o}{(1 + j \omega / \omega_1)(1 + j \omega / \omega_2)\ldots(1 + j \omega / \omega_n)}$$

Approximating the Transfer Function

Multiply out denominator:

$$H(j\omega) \approx \frac{H_o}{(1 + j \omega / \omega_1)(1 + j \omega / \omega_2)\ldots(1 + j \omega / \omega_n)}$$

Since $\omega_1 \ll \omega_2, \omega_3, \ldots, \omega_n \Rightarrow$

$$b_1 \approx \frac{1}{\omega_1} + \frac{1}{\omega_2} + \ldots + \frac{1}{\omega_n} \approx \frac{1}{\omega_1}$$
How to Find $b_1$?


Result: $b_1$ is the sum of open-circuit time constants $\tau_i$ which can be found by considering each capacitor $C_i$ in the amplifier separately and finding its Thévenin resistance $R_{Ti}$

$$\tau_i = R_{Ti} C_i$$

$$b_1 = \sum_{i=1}^{n} R_{Ti} C_i$$

$$\omega_1 \approx \frac{1}{\sum_{i=1}^{n} R_{Ti} C_i}$$

Finding the Thévenin Resistance

1. Open-circuit all capacitors (i.e.; remove them)

2. For capacitor $C_i$, find the resistance $R_{Ti}$ across its terminals with all independent sources removed (voltages shorted, currents opened) … might need to apply a test voltage and find the current in some cases.

*Insight for design:* the bandwidth of the amplifier will be limited by the capacitor that contributes the largest $\tau_i = R_{Ti} C_i$ not necessarily the largest $C_i$