Lecture 25

- Last time:
  - Cascode: merged CS/CG cascade
  - Cascode current supplies

- Today:
  - Cascode transconductance amplifier: full design

Improved Current Sources

Goal: increase $r_{oc}$

Approach: look at amplifier (?) output resistance results

… to see topologies that boost resistance

- Drawback of Cascode $I$-Source
  Minimum output voltage for all transistors saturated:
  $$V_{OUT,MIN} = V_{DS4,SAT} + V_{S4} = V_{DS4,SAT} + V_{GS2}$$
CG Cascade: Sharing a Supply

First stage has no current supply of its own → its output resistance is modified

Amplifier Topology

Goals: $R_{in}$ and $R_{out}$ should be maximized
Common source – common gate cascode makes sense
Share the current supply

Amplifier Schematic

Note that the backgate connection for $M_2$ is not specified: ignore $g_{mb}$

Current Supply Design

Output resistance goal requires large $r_{ac}$ → use cascode current source
Totem Pole Voltage Supply

DC voltages must be set for the cascode current supply transistors $M_3$ and $M_4$, as well as the gate of $M_2$.

Why include $M_{2B}$?

Complete Amplifier Schematic

Goals:
\[ g_{m1} = 1 \text{ mS}, \quad R_{out} = 10 \text{ M\Omega} \]

Device Sizes

$M_1$: select $W/L_1 = 200/2$ to meet specified $g_{m1} = 1 \text{ mS}$

\[ \Rightarrow \text{find } V_{BIAS} = 1.2 \text{ V} \]

Cascade current supply devices: select $V_{SG} = 1.5 \text{ V}$

\[ (W/L)_A = (W/L)_{M4} = (W/L)_B = 64/2 \]

$M_2$: select $W/L_2 = 50/2$ to meet specified $R_{out} = 10 \text{ M\Omega}$

\[ \Rightarrow \text{find } V_{GS2} = 1.4 \text{ V} \]

Match $M_2$ with diode-connected device $M_{2B}$.

Assuming perfect matching and zero input voltage, what is $V_{OUT}$?
Two-Port Model

Find output resistance $R_{out}$

$\lambda_n = \frac{1}{20}\, V^{-1}$, $\lambda_n = \frac{1}{50}\, V^{-1}$ at $L = 2\, \mu m$ →

$r_{on} = \frac{100\, \mu A}{20\, V^{-1}} = 200\, k\Omega$, $r_{off} = 500\, k\Omega$

$g_{n2} = \frac{2I_{ds}}{V_{GS2} - V_{th}} = \frac{2(100\, \mu A)}{1.4V - 1V} = 500\, \mu S$

$g_{n3} = \frac{2(-I_{ds})}{V_{SG3} + Vp} = \frac{2(100\, \mu A)}{1.5V - 1V} = 400\, \mu S$

$R_{out} = r_{on} \| r_{ds} (1 + g_{n2} R_{ds}) = r_{on} (1 + g_{n3} R_{S3}) \| r_{ds} (1 + g_{n2} r_{ds})$

Voltage Transfer Curve

Open-circuit voltage gain: $A_v = \frac{v_{out}}{v_{in}} = -g_m R_{out}$

\[ v_{OUT} = \frac{v_{IN}}{A_v} \]

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\[ 4 \quad 3 \quad 2 \quad 1 \quad 0 \]

\[ 0 \quad 1 \quad 2 \quad 3 \quad 4 \quad v_{IN} \]