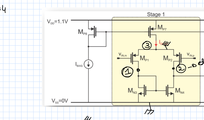
calculate V_{GV}, g_m, I_{DS} and L for each transistor → 1, 2, 3, 4, 6

take $V_{tp1} = V_{tp2}$ and $V_{tn3} = V_{tn4}$

specs: $C_L = 5\,pF$

DC gain = 50dB

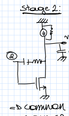
f_{GBW} = 17 MHz



changes sign of zero from RHP to LHP due to Miller

right hand plane

Stage 2:



→ common source

$\Rightarrow A_{V2} = g_{m2} \cdot r_{out2} = \frac{V_{out}}{V_{GS}}$

$V_{out} = r_{ops} \cdot I$

$= r_{ops} \cdot (V_{DS} \cdot r_{ds2} + V_{GS} \cdot g_{m2})$

$= r_{ops} \cdot (V_{DS}(r_{ds2} + \cancel{V_{GS}} \cdot g_{m2})$

$\hookrightarrow V_{GS} \cdot g_{m2} V_{DS} >> V_{DS} \cdot r_{ds2}$

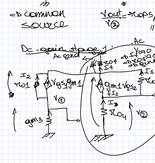
$V_{GS} = V_{DS}$

$V_{out} = r_{ops} \cdot g_{m2}$

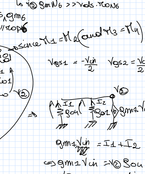
$\Rightarrow A_{V2} = r_{ops} \cdot g_{m2}$

DC-gain stage 1

assume $V_{t1} = V_{t2}$ (and $V_{t3} = V_{t4}$)



$V_{GS1} = \frac{-V_{in}}{2}$ $V_{GS2} = \frac{V_{in}}{2}$



$g_{m1} \cdot V_{in} = I_1 + I_2$

$\Leftrightarrow g_{m1} \cdot V_{in} = V_{DS4} - V_{DS1}$

$\Rightarrow V_{DS} = -\frac{g_{m1} \cdot V_{in}}{g_{ds4} + g_{ds1}}$

$\Rightarrow A_{V1} = -r_{ops} \cdot g_{m1} \Rightarrow A_V = \frac{g_{m1} \cdot r_{ds5}}{g_{ds4} + g_{ds1}}$ $r_{ds5} = r_{ds6}$

$\Rightarrow$ DC-gain = 50dB $\Rightarrow$ DC = 100 000 $= \frac{g_{m1} \cdot g_{m6}}{(g_{ds4} + g_{ds1})(g_{ds6} + g_{ds5})}$

Gain Bandwidth

$f_{GBW} = |A_V \cdot p_d|$ → $p_d = p_{②}$ → due to pole splitting

dominant pole = $P_{②}$

$= \frac{g_{mp1}}{2\pi C_M}$

$C_M >> C_{gs4}, C_L, \ldots$

$\frac{1}{C_M} = \frac{1}{g_m} = \frac{C_M \cdot g_m}{g_m \cdot C_M}$

$\Rightarrow \frac{g_m \cdot C_M}{C_M + g_m}$

$\Rightarrow p_d = \frac{g_{ds4} + g_{ds2}}{C_M} = \frac{g_{ds4} + g_{ds2}}{\frac{g_m C_M}{C_M + g_m}} = \frac{g_{ds4} + g_{ds2}}{\frac{g_m C_M}{C_M + g_m}}$

$\Rightarrow f_{GBW} = \frac{g_{m1} \cdot g_{m6}}{g_{ds6}(g_{ds4} + g_{ds2})} = \frac{g_{ds4} + \overset{g_{ds2}}{g_{ds2}}}{\frac{g_m C_M}{C_M + g_m}} \left(\frac{g_{m6}}{g_{ds6} + g_{ds5}}\right)$

$= \frac{g_{m1}}{\frac{g_{ds4} + g_{ds2}}{g_{ds4} + g_{ds2}}} \cdot \frac{1}{\frac{g_m C_M}{C_M + g_m}} = g_{m1}\left(\frac{C_M + g_m}{g_m C_M}\right) = 17\,000 \cdot 2\pi$

$\begin{cases} \frac{g_{m1}(C_M + g_m)}{g_m C_M} = 2\pi \cdot 17\,000 \\ \frac{g_{m1} \cdot g_{m6}}{(g_{ds4} + g_{ds2})(g_{ds6} + g_{ds5})} = 100\,000 \end{cases}$

take $V_{GV} = 0$ for all → use DC-gain to choose $\frac{g_{m1}}{g_{ds1}}$ and $\frac{g_{m6}}{g_{ds6}}$ → get g_{ds4} and g_{ds} from other plots

all equations:

$\begin{cases} \cancel{\frac{g_{m1}(C_M + g_m)}{g_m C_M} = 2\pi \cdot 17\,000} \\ \frac{g_{m1} \cdot g_{m6}}{(g_{ds4} + g_{ds2})(g_{ds6} + g_{ds5})} = 100\,000 \\ f_{GBW} = \frac{g_{mp1}}{2\pi C_M} = \frac{g_{ds4} + g_{ds2}}{2\pi C_M} \\ P_{②} = \frac{g_{m6}}{C_L} \Rightarrow \text{if } 3\,f_{GBW} = 3 \cdot 17 \cdot 10^3 \cdot 2\pi \\ C_M = \frac{C_L}{n} \quad n = 3 \ldots 5 \end{cases}$

→ design parameters:

- take $n = 4 \Rightarrow C_M = \frac{C_L}{n} = \frac{5\,pF}{4} = 1{,}25\,pF = C_M$ $\quad M_1 = M_2$, $M_3 = M_4$
- take $g_{ds4} << g_{ds1}$ and $g_{ds6} \Rightarrow g_{ds5}$

$\Rightarrow \frac{g_{m1}}{g_{ds1}} \cdot \frac{g_{m6}}{g_{ds6}} = 100\,000$

$g_{m6} = 3 \cdot 17 \cdot 10^3 \cdot 2\pi \cdot C_L$

$17 \cdot 10^3 \cdot 2\pi \cdot C_M = g_{ds4} + g_{ds2}$

$\Rightarrow \begin{cases} C_M = 1{,}25\,pF \\ M_1 = M_2 \text{ en } M_3 = M_4 \\ \frac{g_{m1}}{g_{ds1}} \cdot \frac{g_{m6}}{g_{ds6}} = 223{,}87 \\ g_{ds4} << g_{ds1} \text{ and } g_{ds5} << g_{ds6} \\ g_{m6} = 3 \cdot 17 \cdot 10^3 \cdot 2\pi \cdot 5 \cdot 10^{-12} = 1{,}6022 \cdot 10^{-6} \\ g_{ds4} + g_{ds2} = 17 \cdot 10^3 \cdot 2\pi \cdot 1{,}25\,pF \end{cases}$

→ reduce exciting to M_1 and M_4 (p, p → n)

$\Rightarrow g_{ds4} = 17 \cdot 10^3 \cdot 2\pi \cdot 1{,}25\,pF - g_{ds2} = 1{,}335 \cdot 10^{-7}$

assume $V_{GV} = 0$

from V_{GV} for pmos → choose gain first stage ≈ 30, second stage ≈ 2

$\Rightarrow V_{GV} = 0 \Rightarrow \frac{g_{m1}}{g_{ds1}} = 44{,}746$ $\quad g_{ds}L = 300\,nm$

$\Rightarrow g_{m1} = 5{,}9736 \cdot 10^{-6}$

$\Rightarrow \frac{g_{m6}}{g_{ds6}} \approx \frac{223{,}87}{44{,}746} \approx 5 \Rightarrow$ take 8 for reasonign

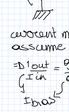
$\Rightarrow \frac{g_{m6}}{g_{ds6}} = 7{,}98426$ $\quad g_{ds}L = 600\,nm$

$\Rightarrow g_{ds6} = 2{,}0042 \cdot 10^{-7}$

$\frac{g_{m1}}{I_{ds1}} = 20{,}6083 \Rightarrow I_{ds1} = 2{,}8986 \cdot 10^{-7}$

$\frac{g_{m6}}{I_{ds6}} = 10{,}8885 \Rightarrow I_{ds6} = 1{,}4715 \cdot 10^{-7}$

M_{n3} and M_{n4}:



→ from M p1

current mirrors:
assume same width

$\Rightarrow \frac{I_{out}}{I_{in}} = \frac{g_m}{g_{m1}} = \frac{L_1}{L_2}$

$\Rightarrow \frac{I_{DS7}}{I_{DS5}} = \frac{I_{DS7}}{I_{DS8}} = \frac{L_8}{L_7}$

→ choose $L_8 = 100\,nm$?

$\Rightarrow L_7 = \frac{L_8}{\frac{I_{DS7}}{I_{DS8}}} = 2{,}5\,nm$

For DC in node 2:
all current from M_2 to M_4

$\Rightarrow I_{D4} = I_{D2}$

$\Rightarrow \frac{g_{m4}}{I_{D4}}$ with $g_{ds4} << g_{ds2}$

$\Rightarrow$ choose $L = 200\,nm$

$\Rightarrow \frac{g_{m4}}{g_{ds4}} = 34{,}4 \Rightarrow$ keep g_{ds} small enough

$\frac{g_{m4}}{I_{DS}} = 25{,}7 \Rightarrow g_{m4} = 7{,}4454 \cdot 10^{-6}$

$g_{ds4} = \frac{g_{m4}}{34{,}4} = 1{,}295 \cdot 10^{-7} \rightarrow << 10^{-7} \Rightarrow$ not correct

$\Rightarrow$ choose $L = 600\,nm$

$\Rightarrow g_{m4} = \frac{g_{m4}}{L} \cdot I_{DS} = 3{,}15 \cdot 10^{-6}$

$\Rightarrow g_{ds4} = \frac{g_{m4}}{8{,}13} = 5{,}82 \cdot 10^{-7}$

$\Rightarrow$ choose $V_{GV} = -0{,}2V \Rightarrow g_{ds4} = 3{,}07 \cdot 10^{-8} \Rightarrow$ from graph

$\Rightarrow g_{ds4} << g_{ds2}$

$g_{m4} = 8{,}13$ $\quad g_{ds}L = 200\,nm$

$\Rightarrow g_{m4} = 34{,}47 \cdot g_{ds4} = 1{,}153 \cdot 10^{-7}$

$R_{M4} =$ → not 52 ?

$V_{in,min,max} = V_{t2} - V_{t1} - |V_{tp1}| + V_{GS1} + V_{GS2}$ $\quad V_{GS}$ from $\frac{g_m}{g_{ds}}$ or $\frac{g_m}{I_{DS}}$ graphs

$= V_{t2} - V_{t1} - |V_{tp1}| - 0{,}2V + V_{GS}$

$= V_{t2} - 0{,}2V - |V_{tp1}| + 0{,}2V + V_{GS}$

$= V_{t2} - 0{,}2V - |V_{tp1}| + V_{GS}$

$-0{,}15 - 0{,}2V - |0{,}35| + 0{,}2 + V_{GS}$

$= -0{,}2V + V_{GS}$?

$V_{in,cm,min} = V_{GS1} + V_{GS2} + V_{t1}$

$= -0{,}15V + V_{GS}$? $= 0{,}35V$?

$V_{in,cm,max} = -0{,}15 + 0{,}2$

dominant pole = $P_{②}$

$f_{GBW} = \frac{g_{mp1}}{2\pi C_M}$

- pole ② output → pole ④

$\Rightarrow P_{②} = \frac{g_{m6}}{C_L} \Rightarrow$ if $3\,f_{GBW}$

→ others negligible

get g_{m6} →

→ high gain → bang transistors (high) → most gain in first stage, so this doesn't have a too high output capacitance

→ weak inversion: width probably too high

also lower saturation

→ go for moderate inversion / lower inversion ($V_{GS} = 0V$?) → 1.1V over 2 transistors

→ for strong inversion → I_{DS} is high for good g_{m6}

- $C_M = \frac{C_L}{n}$ $\quad n = 3 \ldots 5$

choose C_M

→ g_{mp1} from GBW

→ start sizing from the output