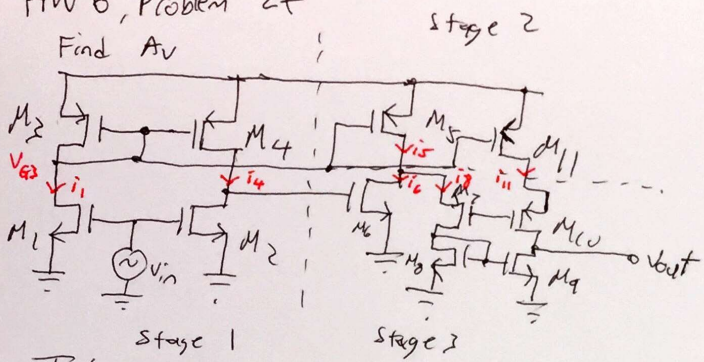
HW 6, Problem 2f

Find A_V

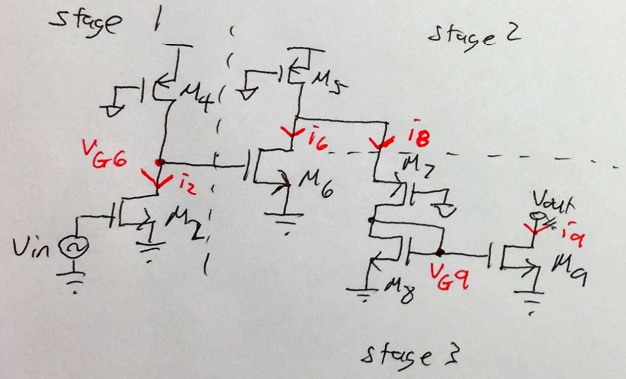


$R_{out} = (r_{ds9}) \| (r_{ds10} + r_{ds11} + g_{m10} r_{ds10} r_{ds11})$

Idea: We know $G_M = \frac{i_{out}}{v_{in}}$, so we want to find the current from M_1/M_2 to the output node. We will use superposition to find the contributions from M_1 and M_2 seperately.

Part I: M_1 off, M_2 on (superposition)

Simplified Circuit:



Since M_1 is off, $I_1 = 0$, gate voltage for $M_3/M_4/M_5/M_{11} = 0$

Stage 1: $i_2 = g_{m2} \cdot V_{in}$

$r_{V_{G6}} = r_{ds4} \| r_{ds2}$

$V_{G6} = i_2 \cdot r_{V_{G6}} = (g_{m2})(r_{ds4} \| r_{ds2}) V_{in}$

Stage 2: $i_6 = g_{m6} \cdot V_{G6}$

$i_8 = -i_6$

Stage 3: $V_{G9} = \frac{1}{g_{m9}} \cdot i_8$

$i_9 = g_{m9} \cdot V_{G9} = -\frac{g_{m9}}{g_{m8}} i_6 = \boxed{-\left(\frac{g_{m9}}{g_{m8}}\right)(g_{m6})(g_{m2})(r_{ds4} \| r_{ds2}) V_{in}}$ ← i_{M2}

Part II : M_1 on, M_2 off (superposition)

Find $V_{G3} = V_{G4} = V_{G5} = V_{G11}$

$i_1 = g_{m1} V_{in}$

$V_{G3} = g_{m1} V_{in} \left(\frac{1}{g_{m3}} \| r_{ds1}\right) \simeq \frac{g_{m1}}{g_{m3}} V_{in}$

a. Find current contribution due to M_4

$i_4 = \frac{g_{m4}}{g_{m3}} \cdot i_1$ ← stage 1

$V_{G6} = +i_4 \cdot (r_{ds4} \| r_{ds2})$

$i_6 = g_{m6} \cdot V_{G6}$

$i_8 = -i_6$, $V_{G9} = \frac{1}{g_{m8}} \cdot i_8$ } stage 3

$I_{M1,A}$

$i_9 = \frac{g_{m9}}{g_{m8}} i_8 = \boxed{-\frac{g_{m9}}{g_{m8}} \cdot g_{m6} \frac{g_{m4}}{g_{m3}} \cdot (r_{ds4} \| r_{ds2}) \cdot g_{m1} \cdot V_{in}}$

b. Find current contribution due to M_5

$i_5 = V_{G3} g_{m5}$

$i_8 = i_5$

$V_{G9} = \frac{1}{g_{m8}} i_8$

$I_{M1,B}$

$i_9 = \frac{g_{m9}}{g_{m8}} i_8 = \boxed{\frac{g_{m9}}{g_{m8}} \cdot g_{m5} \cdot \frac{g_{m1}}{g_{m3}} V_{in}}$

c. Find current contribution due to M11

$i_{11} = V_{G3} g_{m11} = \boxed{-g_{m11} \cdot \frac{g_{m1}}{g_{m3}} V_{in}}$ ← $I_{M1,C}$

$G_M =$ [illegible] $\boxed{I_{M2} + I_{M1A} + I_{M1B} + I_{M1C}}$