Fig. 1 shows three MOS current mirrors. The dc supply voltage is $V_{DD} = 12V$. All devices have identical characteristics, $K = (\mu_n C_{ox} / 2)(W/L) = 0.1mA/V^2$, $V_{tn} = 2V$, and $\lambda = 0.0125 \, 1/V$. You can neglect body-bias effects, i.e., you may assume that $\gamma \approx 0$.

a) Select $R$ in the current mirror 1.1 so that the output current is $I_o = 0.1mA$. State the assumptions you made.

b) Find the output resistance $R_{out}$ of the current mirror 1.1.

c) Find the minimum voltage $(V_o)_{min}$ such that the circuit operates as a current source, with the output resistance computed in b).

d) To increase the output resistance, the current mirror is modified as shown in 1.2. Repeat parts a), b) and c) for the current mirror 1.2. Then, do a .dc PSpice simulation and plot $I(V_o)$ for $0 \leq V_o \leq V_{DD}$ to verify your results for $(V_o)_{min}$ and for the output resistance. Turn in only the plots used to verify $(V_o)_{min}$ and $R_{out}$.

e) In part d) you will find that the current source 1.2 has a much higher output resistance than the current source 1.1, but that it also has a considerably higher $(V_o)_{min}$. To reduce $(V_o)_{min}$, the mirror 1.2 is modified further, as shown in 1.3. In 1.3, all devices are identical except that $M_7$ has a different $K$ (different $W/L$ ratio). Select $K_7$ of $M_7$ to obtain the minimum possible $(V_o)_{min}$. Then, repeat parts a), b), c) for the current mirror 1.3.

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Figure 1: Left to right: NMOS current mirrors 1, 2, 3.