Name:_____ Student Number:_____

There are 100 points over 3 problems on 3 additional pages.

Be sure to **state** any assumptions made and **check** them when possible.

Useful units and constants

Definition of electron volt: $1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$

Electronic charge: $q = 1.6 \times 10^{-19}\ \text{C}$

Boltzmann constant: $k = 8.62 \times 10^{-5}\ \text{eV/K} = 1.38 \times 10^{-23}\ \text{J/K}$

Thermal voltage at room temperature: $kT / q = 0.0259\ \text{V}$

Relative permittivity of silicon: $\varepsilon_r = 11.7$

Relative permittivity of SiO_2: $\varepsilon_r = 3.9$

Permittivity of free space: $\varepsilon_0 = 8.854 \times 10^{-14}\ \text{F/cm}$

Silicon intrinsic carrier density at room temperature: $n_i = 10^{10}/\text{cm}^3$

Band gap for silicon: $E_G = 1.12\ \text{eV}$

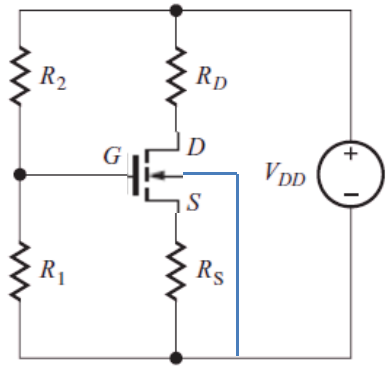
1. (32 points) Design a four-resistor bias network for an NMOS transistor with $R_D = R_S$ to give a Q-point (i_{DS}, v_{DS}) of (0.25 mA, 2 V) with $V_{DD} = 5$ V. Use $K_n' = 50\ \mu A/V^2$, $V_{TO} = 0.8$ V, and (W/L) = 2/1. Ignore channel length modulation effect.

(a) (5 points) What are the values of R_D and R_S?

(b) (12 points) What is the ratio R_1/R_2 to give the desired biasing for $\gamma = 0$? What is transistor mode?

(c) (5 points) What value of R_1 would make the current through R_1 equal to 5% of drain current.

(d) (10 points) Repeat (b) if body effect parameter is $\gamma = 0.6\ V^{1/2}$ and $2\varphi_F = 0.7$ V.



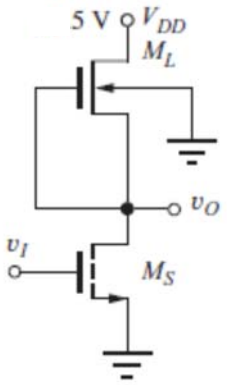
2. (36 points) An NMOS depletion load inverter design is shown in the figure below. Use K_n' = 20 μA/V^2 for both devices. $V_{TO}{}^S$ = 1.0 V and $V_{T0}{}^L$ = -1.0 V. Neglect the body effect.

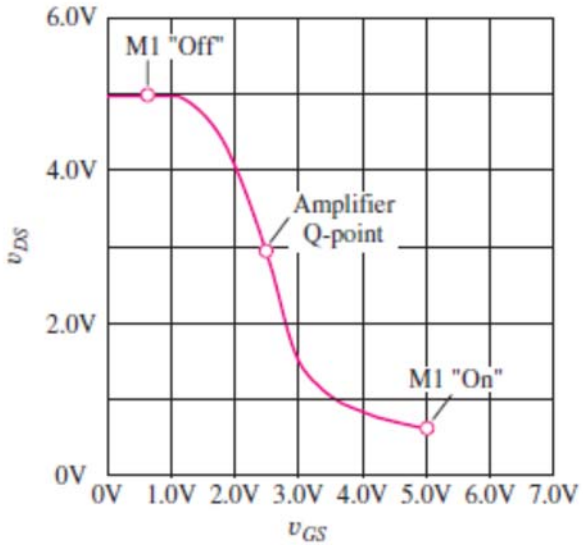
(a) (12 pts) If $(W/L)_S$ = (1/1), find the value of $(W/L)_L$ to give V_L = 0.7 V. Neglect channel length modulation effect (λ = 0).

(b) (6 pts) How should the aspect ratios of the MOSFETs be changed to make the maximum power consumption of the inverter 4 mW, with V_H and V_L kept unchanged.

(c) (8 pts) If channel length modulation was significant, would V_L increase/decrease/stay the same? Explain.

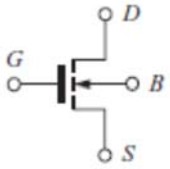
(d) (10 pts) Estimate the noise margins based on the voltage transfer characteristic provided.



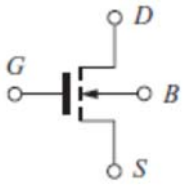


3. (32 points) Use $K_{n,p}$= 100 μA/V^2, γ = 0, and λ = 0. The on voltages of body pn junctions are 0.7 V.

(a) (10 points) $V_S = V_B$ = 2 V. V_D = 3 V. V_{T0}=0.5V. The current **into** terminal D is 2 mA. What is V_G?



(a) (12 points) The current **into** terminal D is -2 mA. V_{T0}=0.5V. $V_S = V_B = V_G$ = 0V. Find V_D and current **into** terminal S.



(b) (10 points) This transistor is a depletion mode PMOS devices with V_{TO} = 0.5 V. $V_S = V_B$ = 0 V, V_G = -1 V, and V_D = -2 V. What mode is device operating in? What is current **into** terminal D?