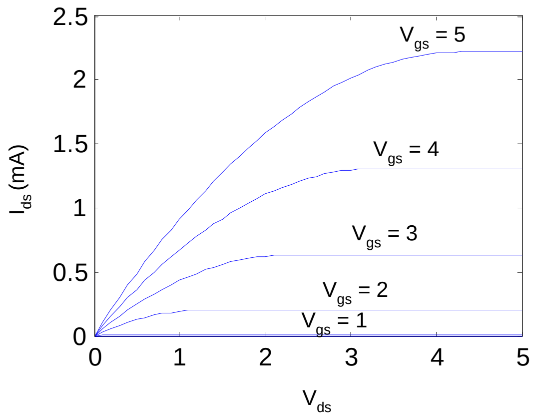
2.1

$$\beta = \mu C_{ox}\frac{W}{L} = (350)\left(\frac{3.9 \bullet 8.85\cdot 10^{-14}}{100\cdot 10^{-8}}\right)\left(\frac{W}{L}\right) = 120\frac{W}{L}\,\mu A/V^2$$



2.2 In (a), the transistor sees V_{gs} = V$_{DD}$ and $V_{ds} = V_{DS}$. The current is

$$I_{DS1} = \frac{\beta}{2}\left(V_{DD} - V_t - \frac{V_{DS}}{2}\right)V_{DS}$$

In (b), the bottom transistor sees $V_{gs} = V_{DD}$ and $V_{ds} = V_1$. The top transistor sees $V_{gs} = V_{DD} - V_1$ and $V_{ds} = V_{DS} - V_1$. The currents are

$$I_{DS2} = \beta\left(V_{DD} - V_t - \frac{V_1}{2}\right)V_1 = \beta\left((V_{DD} - V_1) - V_t - \frac{(V_{DS} - V_1)}{2}\right)(V_{DS} - V_1)$$

Solving for V_1, we find

$$V_1 = (V_{DD} - V_t) - \sqrt{(V_{DD} - V_t)^2 - \left(V_{DD} - V_t - \frac{V_{DS}}{2}\right)V_{DS}}$$

Substituting V_1 indo the I_{DS2} equation and simplifying gives $I_{DS1} = I_{DS2}$.

2.3 The body effect does not change (a) because $V_{sb} = 0$. The body effect raises the threshold of the top transistor in (b) because $V_{sb} > 0$. This lowers the current through the series transistors, so $I_{DS1} > I_{DS2}$.

2.4 $C_{permicron} = \varepsilon L/t_{ox}$ = 3.9 * 8.85e-14 F/cm * 90e-7 cm / 16e-4 μm= 1.94 fF/μm.

2.5 The minimum size diffusion contact is 4 x 5 λ, or 1.2 x 1.5 μm. The area is 1.8 μm^2 and perimeter is 5.4 μm. Hence the total capacitance is

$$C_{db}(0V) = (1.8)(0.42) + (5.4)(0.33) = 2.54\text{fF}$$

At a drain voltage of VDD, the capacitance reduces to

$$C_{db}(5V) = (1.8)(0.42)\left(1+\frac{5}{0.98}\right)^{-0.44} + (5.4)(0.33)\left(1+\frac{5}{0.98}\right)^{-0.12} = 1.78\text{fF}$$

2.6 Set the two parts of EQ (2.26) equal at $V_{ds} = V_{dsat.}$ Assume that EQ (2.27) is true and substitute it into (2.26) for $V_{dsat.}$, then simplify.

2.7 The new threshold voltage is found as

$$\phi_s = 2(0.026)\ln\frac{2\bullet 10^{17}}{1.45\bullet 10^{10}} = 0.85V$$

$$\gamma = \frac{100\bullet 10^{-8}}{3.9\bullet 8.85\bullet 10^{-14}}\sqrt{2\left(1.6\bullet 10^{-19}\right)\left(11.7\bullet 8.85\bullet 10^{-14}\right)\left(2\bullet 10^{17}\right)} = 0.75V^{1/2}$$

$$V_t = 0.7 + \gamma\left(\sqrt{\phi_s + 4} - \sqrt{\phi_s}\right) = 1.66V$$

The threshold increases by 0.96 V.

2.8 No. Any number of transistors may be placed in series, although the delay increases with the square of the number of series transistors.

2.9 The threshold is increased by applying a negative body voltage so $V_{sb} > 0$.

2.10 (a) $(1.2 - 0.3)^2 / (1.2 - 0.4)^2 = 1.26$ (26%)

(b) $$\frac{e^{\frac{-0.3}{1.4\bullet 0.026}}}{e^{\frac{-0.4}{1.4\bullet 0.026}}} = 15.6$$

(c) $v_T = kT/q = 34$ mV; $$\frac{e^{\frac{-0.3}{1.4\bullet 0.034}}}{e^{\frac{-0.4}{1.4\bullet 0.034}}} = 8.2$$; note, however, that the total leakage will normally be higher for both threshold voltages at high temperature.

2.11 The nMOS will be OFF and will see $V_{ds} = V_{DD}$, so its leakage is

$$I_{leak} = I_{dsn} = \beta v_T^2 e^{1.8} e^{\frac{-V_t}{nv_T}} = 69\,pA$$

2.12 If the voltage at the intermediate node is x, by KCL:

$$I_{leak} = \beta v_T^2 e^{1.8} e^{\frac{-V_t}{nv_T}}\left(1 - e^{\frac{-x}{v_T}}\right) = \beta v_T^2 e^{1.8} e^{\frac{-(x + V_t)}{nv_T}}$$

Now, solve for x using $n = 1$:

$$\left(1 - e^{\frac{-x}{v_T}}\right) = e^{\frac{-x}{nv_T}} \rightarrow x = v_T \ln 2$$

Substituting, the current is exactly half that of the inverter.

2.13 Assume $V_{DD} = 1.8$ V. For a single transistor with $n = 1.4$,

$$I_{leak} = I_{dsn} = \beta v_T^2 e^{1.8} e^{\frac{-V_t + \eta V_{DD}}{nv_T}} = 499\,pA$$

For two transistors in series, the intermediate voltage x and leakage current are found as:

$$I_{leak} = \beta v_T^2 e^{1.8} e^{\frac{-V_t + \eta x}{nv_T}}\left(1 - e^{\frac{-x}{v_T}}\right) = \beta v_T^2 e^{1.8} e^{\frac{\eta(V_{DD} - x) - V_t - x}{nv_T}}$$

$$e^{\frac{-V_t + \eta x}{nv_T}}\left(1 - e^{\frac{-x}{v_T}}\right) = e^{\frac{\eta(V_{DD} - x) - V_t - x}{nv_T}}$$

$$x = 69 \text{ mV};\ I_{leak} = 69 \text{ pA}$$

In summary, accounting for DIBL leads to more overall leakage in both cases. However, the leakage through series transistors is much less than half of that through a single transistor because the bottom transistor sees a small Vds and much less DIBL. This is called the *stack effect*.

For $n = 1.0$, the leakage currents through a single transistor and pair of transistors are 13.5 pA and 0.9 pA, respectively.