[Problem 1]

The most efficient pull-down circuit is below. It can be derived by drawing the pull-up graph, and then the pull-down graph. Verify that the following truth table contains 32 (25) input combinations, and that the entries for \( f=0 \) and \( f=1 \) do not overlap.

There are three pull-up paths:
(1) \( p_3, p_5: a \ c \)
(2) \( p_3, p_4: b \ c \)
By combining these three pull-up paths, it becomes clear that the pull-up and pull-down together realize the desired function (Cn = complement of the carry function).

**Problem 4**

(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

\[
I_{DS2} = \beta \left( V_{DD} - V_t - \frac{V_{1}}{2} \right)\]

\[
V_{1} = \beta \left( V_{DD} - V_t \right) - \frac{\left( V_{DD} - V_t \right)^2 - \left( V_{DD} - V_t - \frac{V_{DS}}{2} \right) V_{DS}}{2}
\]

Solving for \( V_{1} \), we find

\[
V_{1} = \left( V_{DD} - V_t \right) - \sqrt{\left( V_{DD} - V_t \right)^2 - \left( V_{DD} - V_t - \frac{V_{DS}}{2} \right) V_{DS}}
\]

Substituting \( V_{1} \) into the IDS2 equation and simplifying gives \( IDS1 = IDS2 \).

(2.8)

The threshold is increased by applying a negative body voltage so \( V_{sb} > 0 \).

(2.22)

(a) 0; (b) 0.6; (c) 0.8; (d) 0.8