Chapter 3.

[3.1] The resistance of the line is given by $R_{line} = R_s n$ where the number of squares can be divided into "normal" straight line contributions and corners. Let n_c be the contribution of a corner square. The number of square is given by tracing the line from A to B as

$$n = 15 + n_c + 12 + n_c + 14 + n_c + 4 + n_c + 22 + n_c + 9 = 76 + 56n_c = 79.125$$

so

$$R = 25(79.125) = 1,978.125\Omega$$

[3.2]The line resistance is $R_{line} = R_s n$. Fdor the polysilicon line

$$R_{line} = 25\left(\frac{275}{0.5}\right) = 1375\Omega$$

while the metal line is

$$R_{line} = 0.08\left(\frac{32.4}{0.8}\right) = 3.24\Omega$$

which is the smallest.

[3.3](a) The sheet resistance is

$$R_s = \frac{\rho}{t} = \frac{(4\times10^{-6})}{(1200\times10^{-8})} = 0.33\Omega$$

(b) The number of squares is given by

$$n = \frac{125}{0.6} = 156.25 \text{ squares}$$

so that the line resistance is

$$R_{line} = (0.33)(156.25) = 52.08\Omega$$

[3.4]We have units of the RC product of

$$RC = [\Omega][F] = \left[\frac{V}{A}\right]\left[\frac{C}{V}\right] = \left[\frac{C}{A}\right] = \left[\frac{C}{\frac{C}{\text{sec}}}\right] = [\text{sec}]$$

which shows that τ has units of sec as stated.

[3.5] (a) Use the line resistance formula

$$R_{line} = (25)\left(\frac{40}{0.5}\right) = 2k\Omega$$

(b) The line capacitance is

$$C_{line} = \frac{\varepsilon_{ox}(wl)}{T_{ox}} = \frac{(3.9)(8.854\times10^{-14})(0.5\times10^{-4})(40\times10^{-4})}{1000\times10^{-8}} = 6.906 \text{ fF}$$

(c) The line time constant is

$$\tau = R_{line}C_{line} = (2000)(6.906\times10^{-15}) = 13.81 \text{ ps}$$

[3.6] (a) For n-type material,

$$n_{n0} \approx N_d = 4\times10^{17}\text{cm}^{-3}$$

(b) The hole density is

$$p_{n0} = \frac{n_i^2}{n_n} = \frac{(1.45\times10^{10})^2}{(4\times10^{17})} = 525.6 \text{ cm}^{-3}$$

(c) The electron mobility is

$$\mu_n = 92 + \frac{1380-92}{1+\left(\frac{4\times10^{17}}{1.3\times10^{17}}\right)^{0.81}} = 433 \text{ cm}^2/\text{V-sec}$$

while the hole mobility is

$$\mu_p = 47.7(92) + \frac{495-47.7}{1+\left(\frac{4\times10^{17}}{1.6\times10^{14}}\right)^{0.76}} = 135.9 \text{ cm}^2/\text{V-sec}$$

The mobility is then given by

$$\sigma = q(\mu_n n + \mu_p p) \approx q\mu_n n_n = 27.71 \ [\Omega\text{-cm}]$$

since the majority electron concentration dominates.

[3.7] $N_a > N_d$, so the material is p-type. The majority carrier density is

$$p_{p0} \approx N_d - N_d = 5.98\times10^{18}\text{cm}^{-3}$$

and the minority carrier density is

$$n_{p0} = \frac{n_i^2}{p_{p0}} = \frac{(1.45\times10^{10})^2}{(5.98\times10^{18})} = 35.2 \text{ cm}^{-3}$$

[3.8] (a) We have carrier densities of

$$p_{p0} \approx N_d = 4\times10^{14}\text{cm}^{-3} \qquad n_{p0} \approx \frac{n_i^2}{p_{p0}} = 5.26\times10^{5}\text{cm}^{-3}$$

(b) The mobilities are μ_n = 1373.36 and μ_p = 485.6 cm^2/V-sec so that the conductivity is calculated from

$$\sigma = (1.6\times10^{-19})[(5.26\times10^{5})](1373.36) + (4\times10^{14})(485.6)]$$

This gives

$$\sigma = 0.31 \qquad \rho = (1/\sigma) = 32.17[\Omega - cm]$$

(c) The resistance is

$$R = \left(\frac{100\times10^{-4}(32.17)}{1\times10^{-8}}\right) = 32.17\Omega$$

[3.9] (a) Start with

$$\sigma = q\left(\mu_n\frac{n_i^2}{p} + \mu_p p\right)$$

(b) Differentiate:

$$\frac{d\sigma}{dp} = \frac{d}{dp}\left(\mu_n\frac{n_i^2}{p} + \mu_p p\right) = -\mu_n\frac{n_i^2}{p^2} + \mu_p = 0$$

so we require

$$p = \sqrt{\frac{\mu_n}{\mu_p}}n_i > n_i$$

(c) The last equation shows that the highest resistively material is slightly p-type.

[3.10] (a) This is

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{(3.9)(8.854\times10^{-14})}{90\times10^{-8}} = 3.837\times10^{-7}\frac{\text{F}}{\text{cm}^2}$$

(b) $k'_n = \mu_n C_{ox}$ = 214.86 μA/V^2
(c) $\beta_n = k'_n (W/L)$ = 1.719 mA/V^2

[3.11] $\beta_n = k'_n$ (W/L) with

$$k_n' = \mu_n\left(\frac{(3.9)(8.854\times10^{-14})}{10\times10^{-7}}\right) = 172.65\mu\text{A/V}^2$$

(a) $\beta_n = k'_n$ (W/L) = 172.65(10/0.5) = 3.453 x 10^{-7} A/V^2. The resistance is R_n = 111.39 Ω
(b) The resistance is reduced to

$$R_n = \frac{1}{(1.7265\times10^{-6})\left(\frac{22}{0.5}\right)(3.3-0.8)} = 50.63\Omega$$

[3.12] (a) $k'_p = \mu_p C_{ox}$ so we calculate

$$k_p' = (220)\left(\frac{(3.9)(8.854\times10^{-14})}{11.5\times10^{-7}}\right) = 66.06\mu A/V^2$$

The resistance is then given by

$$R_p = \frac{1}{(66.06\times10^{-6})\left(\frac{14}{0.5}\right)(3.3-0.8)} = 216.25\Omega$$

[3.13] Start with

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = 3.63\times10^{-7}\frac{F}{cm^2}$$

(a) $k'_n = \mu_n C_{ox} = 196.28\ \mu A/V^2$ and $k'_p = \mu_p C_{ox} = 79.97\ \mu A/V^2$. With the aspect ratios we have $\beta_n = 6.73\ mA/V^2$ and $\beta_p = 2.74\ mA/V^2$ so that $R_n = 56.1\ \Omega$ and $R_p = 142.48\ \Omega$ using the formulas.
(b) $R_p = 0.8\ R_n$ so

$$\frac{1}{\beta_p(3.3-0.65)} = 44.88\Omega$$

or

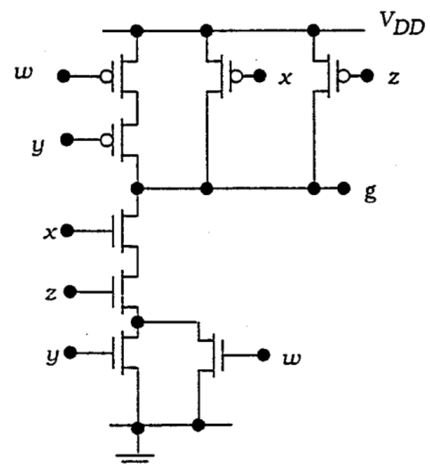
$$\beta_p = 8.408\times10^{-3} = k_p'\left(\frac{W}{0.35}\right)$$

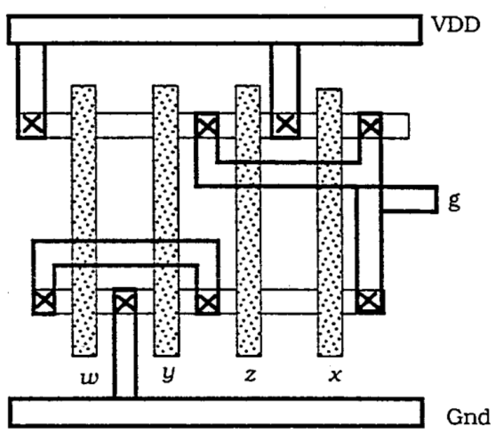
which gives the value of W = 36.8 μm needed for the pFET.

[3.14] The function is

$$Out = \overline{x\cdot z\cdot(y+w)}$$

This leads to the following circuit.



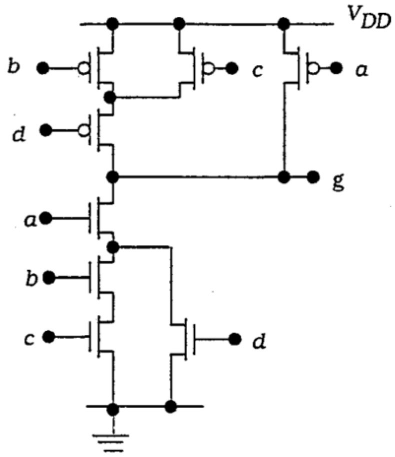


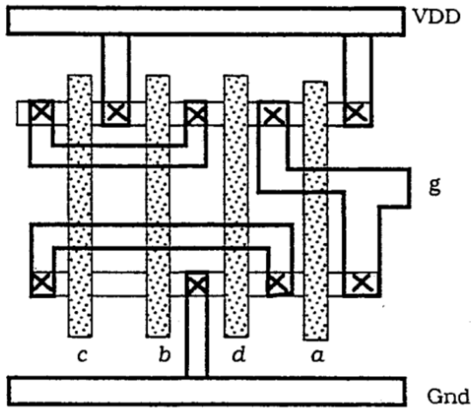
Problem [3.14]

[3.15] The function is

$$F = \overline{a \cdot b \cdot c + a \cdot d} = \overline{a \cdot (b \cdot c + d)}$$

which is shown in the circuit below.



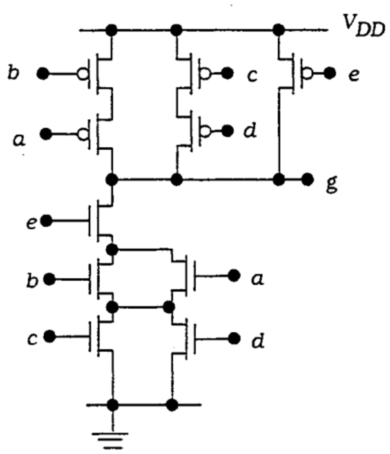


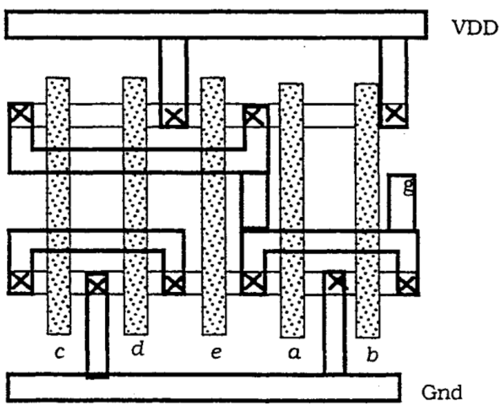
Problem [3.15]

[3.16] The OAI function is

$$g = \overline{(a+b) \cdot (c+d) \cdot e}$$

This is obtained from the CMOS circuit shown below. The placement of the inputs has be chosen to facilitate the layout.



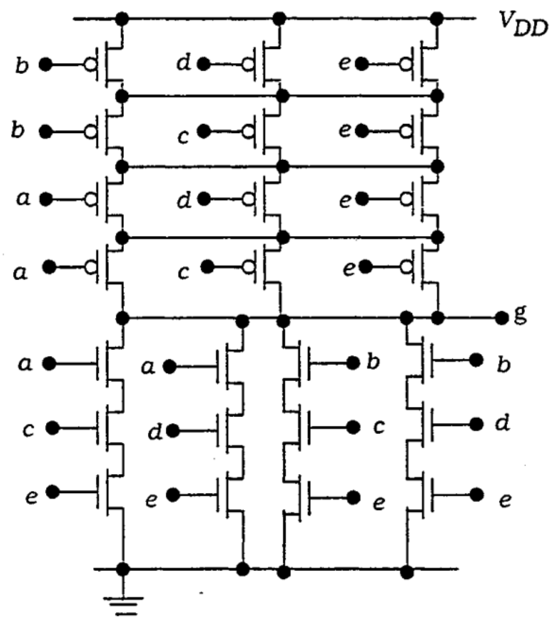


Problem [3.16] Circuit

[3.17] Expanding gives

$$g = \overline{(a+b)\cdot(c+d)\cdot e}$$
$$= \overline{(a\cdot c+a\cdot d+b\cdot c+b\cdot d)\cdot e}$$
$$= \overline{a\cdot c\cdot e+a\cdot d\cdot e+b\cdot c\cdot e+b\cdot d\cdot e}$$

The third line is an expanded AOI form, but uses excess transistors. This can be seen in the circuit below. Although we could do a somewhat messy layout, of the gate as-is, we can see by inspection that the expanded AOI form is not an efficient implementation of the logic function.



Problem [3.17]

[3.18] Yes, this is a functional gate. The function is

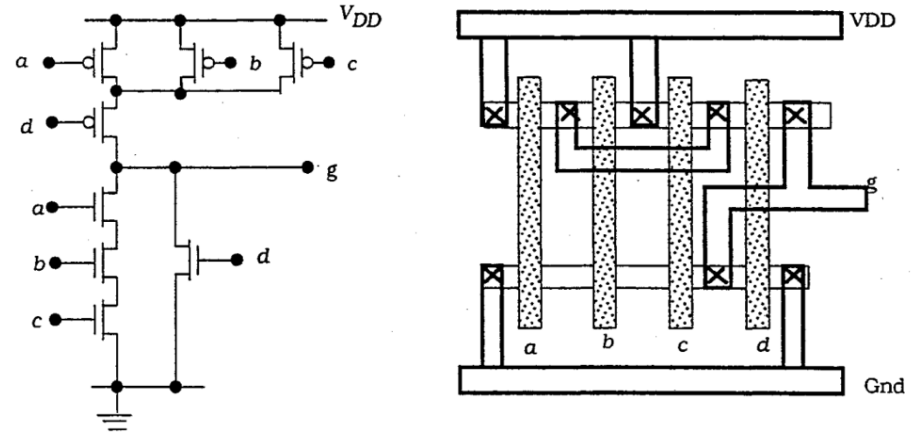
$$f = \overline{a\cdot b+c+d}$$

as can be verified by tracing the circuit.

[3.19] We start with

$$g = \overline{a \cdot b \cdot c + d}$$

The CMOS circuit and layout are drawn below.



Problem [3-19]