10.57 Repeat Problem 10.56 for the case when the electrons are traveling at a saturation velocity of $v_{sat} = 4 \times 10^6$ cm/s.

10.56 An n-channel MOSFET has the following parameters:

$\mu_n = 400$ cm²/V-s $t_{ox} = 500$ Å
$L = 2\ \mu$m $W = 20\ \mu$m
$V_T = +0.75$ V

Assume the transistor is biased in the saturation region at $V_{GS} = 4$ V. (*a*) Calculate the ideal cutoff frequency. (*b*) Assume that the gate oxide overlaps both the source and drain contacts by 0.75 μm. If a load resistance of $R_L = 10$ kΩ is connected to the output, calculate the cutoff frequency.

- For part a), find the transit time frequency limit as well. For part b) change the overlap to 0.5 μm.

From Table B.4 and Table B.6, silicon has $n_i = 1.5 \times 10^{10}$ cm^{-3}, $\varepsilon_{s,\mathrm{Si}} = 11.7\varepsilon_0$, and $\varepsilon_{s,\mathrm{SiO2}} = 3.9\varepsilon_0$ at 300 K.

a) From section 10.4.2 of the text, the channel transit time is

$$\tau_t = L/v_{sat} = 2\times10^{-6}\text{ m}/ 4\times10^4\text{ m/s} \Rightarrow \tau_t = 5\times10^{-11}\text{ s} = 50\text{ ps}.$$

This leads to transit time cutoff frequency of

$$f_{\text{limit}} \cong 1/\tau_t = 1/50\times10^{-12} \quad \Rightarrow \underline{f_{\text{limit}} = 20\text{ GHz}}.$$

Per (10.96), the ideal cutoff frequency is-

$$f_{T,\text{ideal}} = \frac{\mu_n(V_{GS}-V_T)}{2\pi L^2} = \frac{400(10^{-4})(4-0.75)}{2\pi(2\bullet10^{-6})^2}$$

$$\Rightarrow \underline{f_{T,\text{ideal}} = 5.1725\times10^9\text{ Hz} = 5.17\text{ GHz}}.$$

b) Using (10.35), the oxide capacitance per unit area is

$$C_{ox} = \varepsilon_{ox}/t_{ox} = 3.9(8.8541878\times10^{-12}\text{ F/m})/500\times10^{-10}\text{ m}$$

$$\Rightarrow C_{ox} = 6.9062665\times10^{-4}\text{ F/m}^2 = 6.9062665\times10^{-8}\text{ F/cm}^2.$$

The gate-drain & gate-source overlap areas are

$$A_{\text{overlap}} = \text{overlap(W)} = 0.5\times10^{-6}(20\times10^{-6}) \Rightarrow A_{\text{overlap}} = 1\times10^{-11}\text{ m}^2.$$

The gate-drain & gate-source parasitic capacitances are-

$$C_{gdp} = C_{gsp} = C_{ox}\,(A_{\text{overlap}}) = 6.9062665 \times 10^{-4}\,(10^{-11})$$

$$\Rightarrow C_{gdp} = C_{gsp} = 6.9062665 \times 10^{-15}\ \text{F}.$$

Per p. 427 of text, with the MOSFET in saturation, $C_{gd} \to 0$ and

$$C_{gs} = C_{ox}\,W\,L = 6.9062665 \times 10^{-4}\,(20{\times}10^{-6})\,2{\times}10^{-6} \Rightarrow C_{gs} = 2.76251 \times 10^{-14}\ \text{F}.$$

Now, the total gate-drain & gate-source capacitances are

$$C_{gdT} = C_{gd} + C_{gdp} = 0 + 6.9062665 \times 10^{-15} \quad \Rightarrow C_{gdT} = 6.9062665 \times 10^{-15}\ \text{F, and}$$

$$C_{gsT} = C_{gs} + C_{gsp} = 2.76251{\times}10^{-14} + 6.9062665{\times}10^{-15}$$

$$\Rightarrow C_{gsT} = 3.45313 \times 10^{-14}\ \text{F}.$$

To find the Miller capacitance C_M, we will need the transconductance g_m of the MOSFET. In saturation, the transconductance is (10.77)

$$g_{ms} = \frac{W\mu_n C_{ox}}{L}(V_{GS} - V_T) = \frac{20{\bullet}10^{-6}\left(400{\bullet}10^{-4}\right)6.9062665{\bullet}10^{-4}}{2{\bullet}10^{-6}}(4 - 0.75)$$

$$\Rightarrow g_{ms} = 8.978146 \times 10^{-4}\ \text{S}.$$

Per (10.91), the Miller capacitance is

$$C_M = C_{gdT}\,(1 + g_{ms}\,R_L) = 6.9062665 \times 10^{-15}\,[1 + (8.978146 \times 10^{-4})\,10 \times 10^{3}]$$

$$\Rightarrow C_M = 6.89117 \times 10^{-14}\ \text{F}.$$

Per (10.95), the cutoff frequency is

$$f_T = \frac{g_{ms}}{2\pi(C_{gsT} + C_M)} = \frac{8.978146{\bullet}10^{-4}}{2\pi(3.45313{\bullet}10^{-14} + 6.89117{\bullet}10^{-14})}$$

$\Rightarrow$ **$f_T = 1.38136 \times 10^{9}$ Hz = 1.38 GHz.**