10.56 An n-channel MOSFET has the following parameters:
$\mu_n = 400\ \text{cm}^2/\text{V-s}$ $t_{ox} = 500\ \text{Å}$ $V_T = +0.75\ \text{V}$ $L = 4\ \mu\text{m}$ $W = 20\ \mu\text{m}$
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 $R_L = 10\ \text{k}\Omega$ is connected to the output, calculate the cutoff frequency.

a) Per (10.96) w/ MKS units,

$$f_T = \frac{\mu_n (V_{GS} - V_T)}{2\pi L^2} = \frac{400\times10^{-4}(4-0.75)}{2\pi(4\times10^{-6})^2} \quad \Rightarrow \underline{f_T = 1.293\ \text{GHz}}.$$

b) From Table B.6, $\varepsilon_r = 3.9$ for SiO_2 at 300 K.

Per (10.35), $C_{ox} = \varepsilon_{ox} / t_{ox} = 3.9\,(8.8541878\times10^{-12}) / 500\times10^{-10}$

$\Rightarrow C_{ox} = 6.906266 \times 10^{-4}\ \text{F/m}^2$

Overlap area = $A = W L_{over} = 20\times10^{-6}\,(0.75\times10^{-6})$ $\Rightarrow A = 1.5\times10^{-11}\ \text{m}^2$

Parasitic capacitances $C_{gdp} = C_{gsp} = C_{ox}\,A = 6.906266\times10^{-4}\,(1.5\times10^{-11})$

$\Rightarrow C_{gdp} = C_{gsp} = 1.03594\times10^{-14}\ \text{F}$

Per page 426 of text, in saturation, $C_{gd} = 0$ and

$C_{gs} = C_{ox}\,W L = 6.906266\times10^{-4}\,(20\times10^{-6})\,4\times10^{-6} \Rightarrow C_{gs} = 5.525013\times10^{-14}\ \text{F}$

The total junction capacitances are then

$C_{gdT} = C_{gd} + C_{gdp} = 0 + 1.03594\times10^{-14}$ $\Rightarrow C_{gdT} = 1.03594\times10^{-14}\ \text{F}$

$C_{gsT} = C_{gs} + C_{gsp} = 5.525013\times10^{-14} + 1.03594\times10^{-14} \Rightarrow C_{gsT} = 6.560953\times10^{-14}\ \text{F}$

Per (10.77),

$$g_{mS} = \frac{W\mu_n C_{ox}}{L}(V_{GS} - V_T) = \frac{20\times10^{-6}(400\times10^{-4})6.906266\times10^{-4}}{4\times10^{-6}}(4-0.75)$$

$\Rightarrow g_{mS} = 8.97815\times10^{-4}\ \text{S}$

Per (10.95),

$$C_M = C_{gdT}(1 + g_{mS}R_L) = 1.03594\times10^{-14}\left[1 + 8.97815\times10^{-4}(10\times10^3)\right]$$

$\Rightarrow C_M = 1.033676\times10^{-13}\ \text{F}$

Per (10.91), $$f_T = \frac{g_{mS}}{2\pi(C_{gsT} + C_M)} = \frac{8.97815\times10^{-4}}{2\pi(6.560953\times10^{-14} + 1.033676\times10^{-13})}$$

$\Rightarrow \underline{f_T = 845.6\ \text{MHz} = 0.8456\ \text{GHz}}.$