**Example-** An n-channel silicon MOSFET has a channel length of 0.72 μm, width of 3.1 μm, an electron mobility of 1000 $cm^2$/V-s, saturation velocity of $8 \times 10^6$ cm/s, and a threshold voltage of 1.4 V at 300 K. The gate oxide overlaps the drain and source contacts by 60 nm. It has an oxide ($SiO_2$) layer thickness of 16 nm. If the MOSFET is in saturation with $V_{GS} = 5$ V and has a 6 kΩ load, find the transit time cutoff frequency, cutoff frequency, and ideal cutoff frequency.

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

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

$$\tau_t = L/v_{sat} = 0.72\times10^{-6}\,m/\,8\times10^{4}\,m/s \;\Rightarrow\; \underline{\tau_t = 9\times10^{-12}\,s = 9\,ps}.$$

This leads to transit time cutoff frequency of

$$f_{limit} \cong 1/\tau_t = 1/9\times10^{-12} \;\Rightarrow\; \underline{f_{limit} = 111.1\,GHz}\ \textbf{(not an issue).}$$

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

$$C_{ox} = \varepsilon_{ox}/t_{ox} = 3.9(8.8541878\times10^{-12}\,F/m)/16\times10^{-9}\,m$$

$$\Rightarrow\; \underline{C_{ox} = 2.15821\times10^{-3}\,F/m^2 = 2.15821\times10^{-7}\,F/cm^2}.$$

The gate-drain & gate-source overlap areas are

$$A_{overlap} = \text{overlap(W)} = 60\times10^{-9}\,(3.1\times10^{-6}) \;\Rightarrow\; \underline{A_{overlap} = 1.86\times10^{-13}\,m^2}.$$

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

$$C_{gdp} = C_{gsp} = C_{ox}\,(A_{overlap}) = 2.15821\times10^{-3}\,(1.86\times10^{-13})$$

$$\Rightarrow\; \underline{C_{gdp} = C_{gsp} = 4.01427\times10^{-16}\,F}.$$

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

$$C_{gs} = C_{ox}\,W\,L = 2.15821\times10^{-3}\,(3.1\times10^{-6})\,0.72\times10^{-6} \Rightarrow \underline{C_{gs} = 4.81712\times10^{-15}\,F}.$$

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

$C_{gdT} = C_{gd} + C_{gdp} = 0 + 4.01427\times10^{-16}$ $\Rightarrow$ **$C_{gdT} = 4.01427\times10^{-16}$ F**, and

$C_{gsT} = C_{gs} + C_{gsp} = 4.81712\times10^{-15} + 4.01427\times10^{-16}$ $\Rightarrow$ **$C_{gsT} = 5.21855\times10^{-15}$ 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)

$$g_{ms} = \frac{W\mu_n C_{ox}}{L}(V_{GS} - V_T) = \frac{3.1\bullet10^{-6}(1000)2.15821\bullet10^{-7}}{0.72\bullet10^{-6}}(5-1.4)$$

$\Rightarrow$ **$g_{ms} = 3.345223\times10^{-3}$ S.**

Per (10.91), the Miller capacitance is

$$C_M = C_{gdT}(1 + g_{ms}R_L) = 4.01427\times10^{-16}[1 + (3.345223\times10^{-3})6\times10^{3}]$$

$\Rightarrow$ **$C_M = 8.4586\times10^{-15}$ F.**

Per (10.95), the cutoff frequency is-

$$f_T = \frac{g_{ms}}{2\pi(C_{gsT} + C_M)} = \frac{3.345223\bullet10^{-3}}{2\pi(5.21855\bullet10^{-15} + 8.4586\bullet10^{-15})}$$

$\Rightarrow$ **$f_T = 3.89269\times10^{10}$ Hz = 38.93 GHz.**

Per (10.96), the ideal cutoff frequency is-

$$f_{T,\text{ideal}} = \frac{\mu_n(V_{GS} - V_T)}{2\pi L^2} = \frac{1000\,(10^{-4})(5-1.4)}{2\pi\,(0.72\bullet10^{-6})^2}$$

$\Rightarrow$ **$f_{T,\text{ideal}} = 1.10524\times10^{11}$ Hz = 110.52 GHz.**