EE788: Assignment 1

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All parts of the assignment are for an NMOS type transistor.

From the graph given, the following conditions are used in code for the 3 cases:

Case	L (in μm)	t_{ox} (in nm)	V_{DD} (in V)	V_{th} (in V)
1	1	20	5	0.8
2	0.5	10	3.5	0.55
3	0.35	7	3	0.5

- For fixed mobility calculations, $\mu_n = 200 cm^2/V \cdot s$ is used.
- For all the parts below, based on the V_{th} from the graph, the substrate concentration N_A is obtained via interpolation and used in further calculations.
- Width used is $1 \mu m$ for all calculations. For a width of $W \mu m$, the results obtained below would merely have to be scaled W times.
- For $I_D - V_D$ characteristics, V_G values of 2.5, 3.5 and 4.5 V are used
- For $I_D - V_G$ characteristics, V_D values of 0.5, 2 and 3.5 V are used

For the results of all 3 models,

- As t_{ox} and L decrease, C_{ox} and (W/L) increase, so current increases
- We see that the orders of current in all 3 models are almost identical (Pao-Sah gives a marginally higher value of current. Brews and Piecewise give equal currents)
- In the $I_D - V_G$ characteristics for Case 2 and 3, the curves for $V_D = 2$ and $3.5V$ overlap.

Piecewise Model

Depending on the region of operation, different equations of current are used. Here, $V_{\text{D,sat}} = (V_{GS} - V_{th})/m$

Subthreshold region ($V_{GS} < V_{th}$):

$$I_D = \mu C_{ox}\left(\frac{W}{L}\right)(m-1)\left(\frac{kT}{q}\right)^2 e^{q(V_{GS}-V_{th})/mkT}\left(1-e^{-qV_{DS}/kT}\right)$$

Linear region ($V_{GS} \geq V_{th}$ and $V_{DS} < V_{\text{D,sat}}$):

$$I_D = \mu C_{ox}\left(\frac{W}{L}\right)\left(V_{GS} - V_{th} - \frac{mV_{DS}}{2}\right)V_{DS}$$

Saturation region ($V_{GS} \geq V_{th}$ and $V_{DS} \geq V_{\text{D,sat}}$):

$$I_D = \mu C_{ox}\left(\frac{W}{L}\right)\frac{(V_{GS} - V_{th})^2}{2m}$$

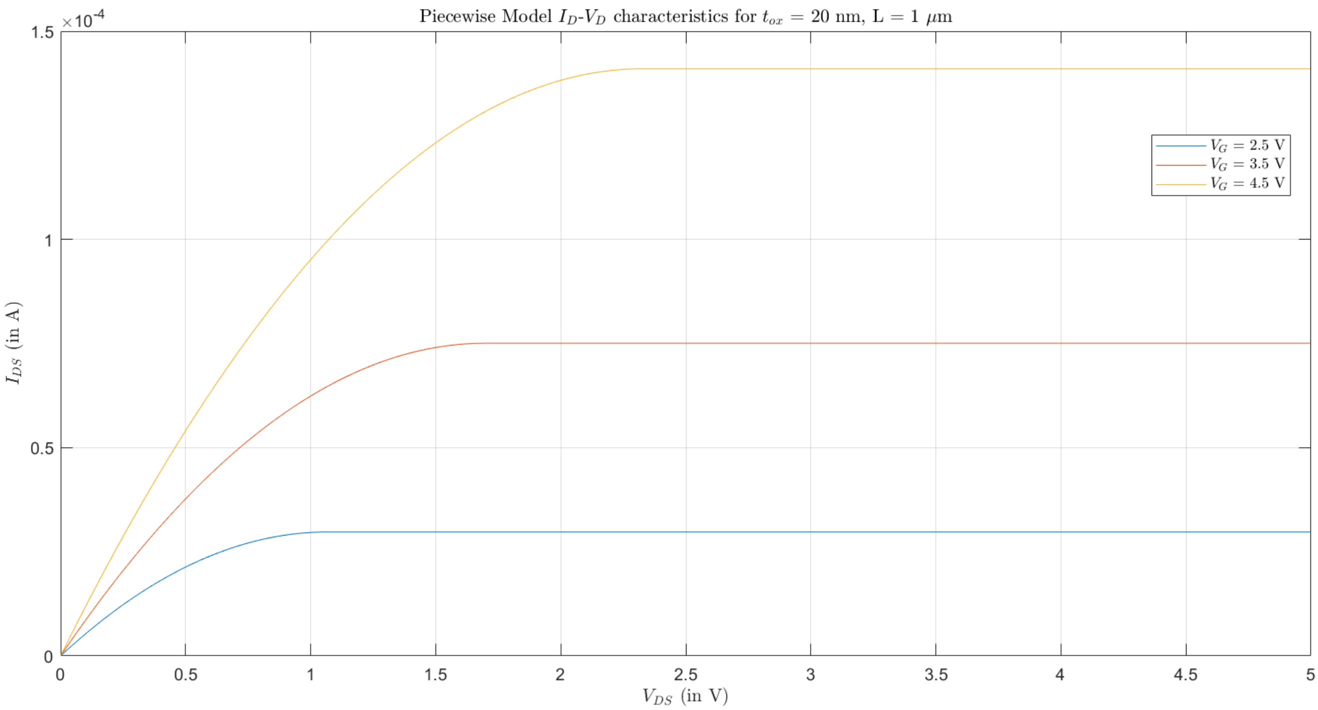

Figure 1: Case 1: $I_D - V_D$ characteristics for Piecewise model

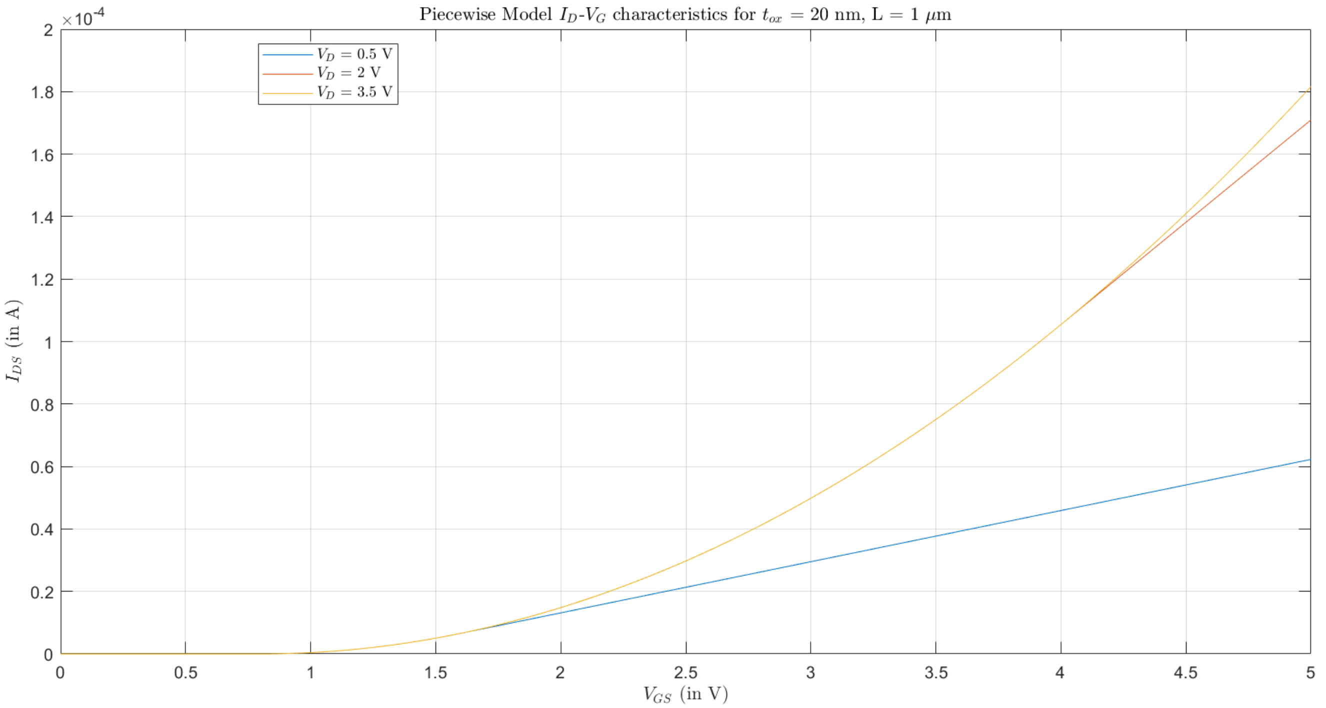

Figure 2: Case 1: $I_D - V_G$ characteristics for Piecewise model

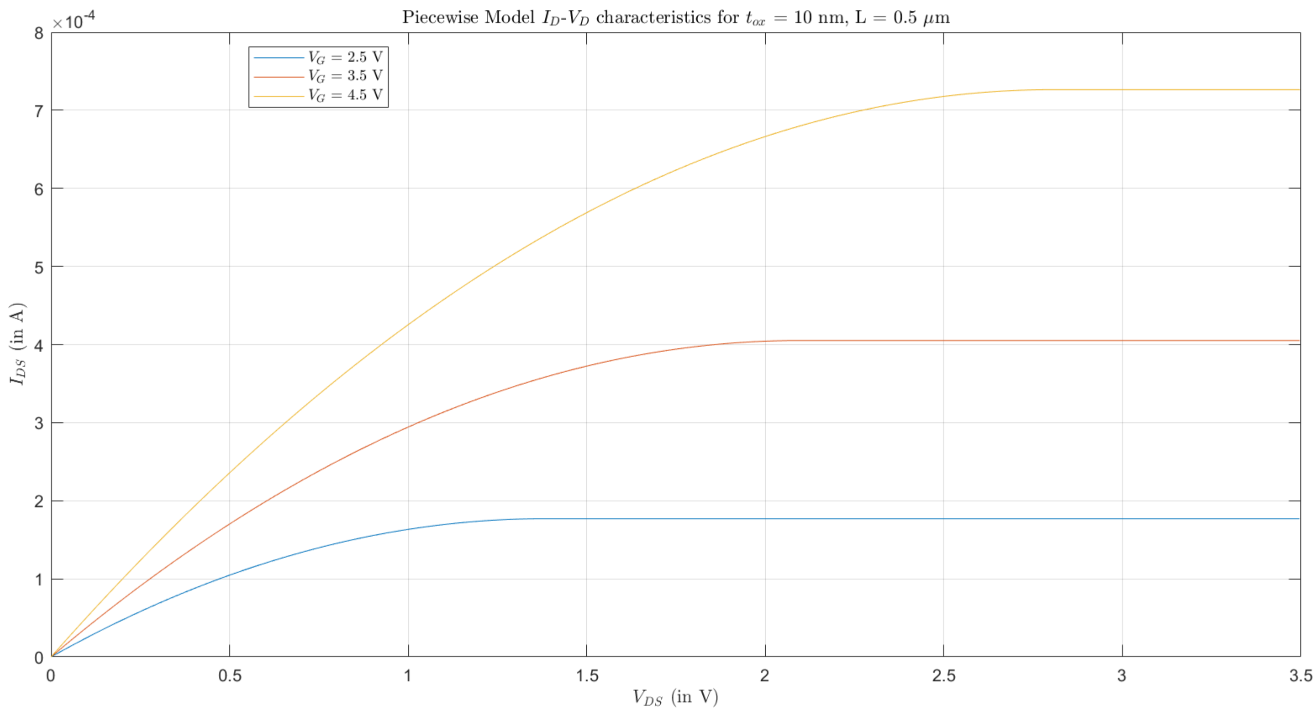

Figure 3: Case 2: $I_D - V_D$ characteristics for Piecewise model

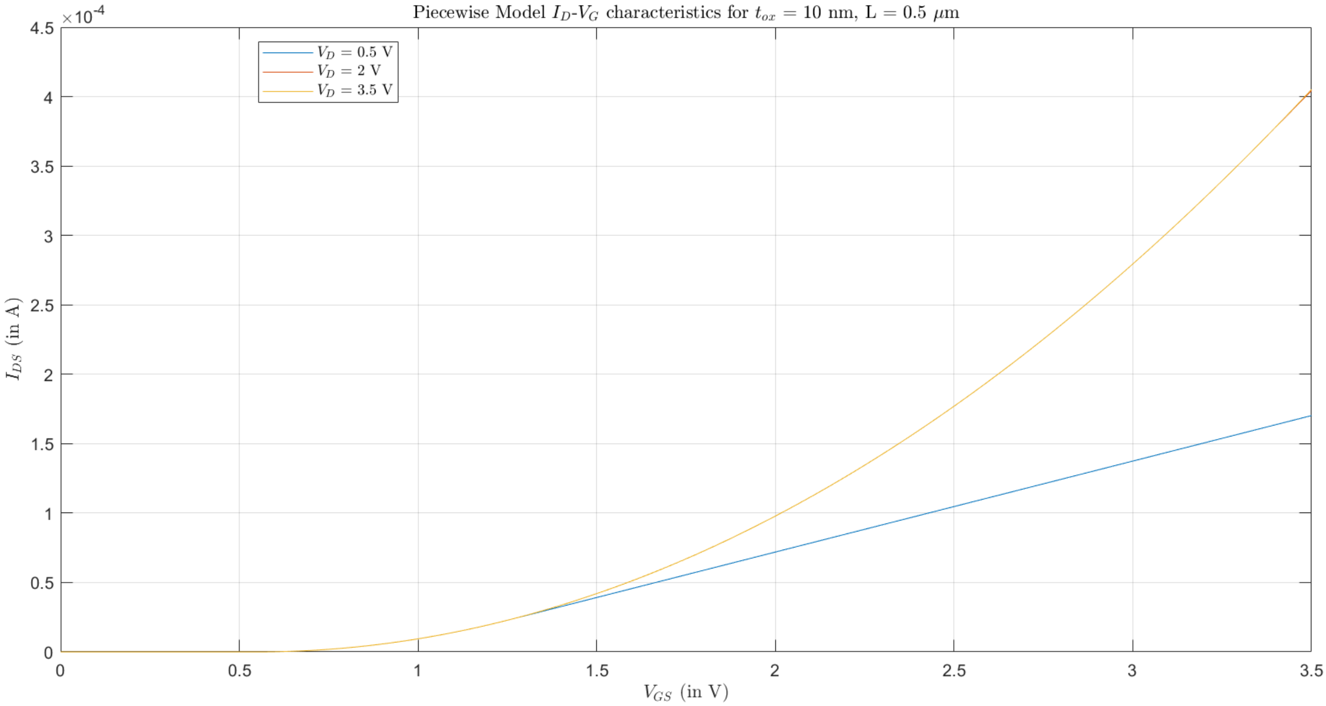

Figure 4: Case 2: $I_D - V_G$ characteristics for Piecewise model

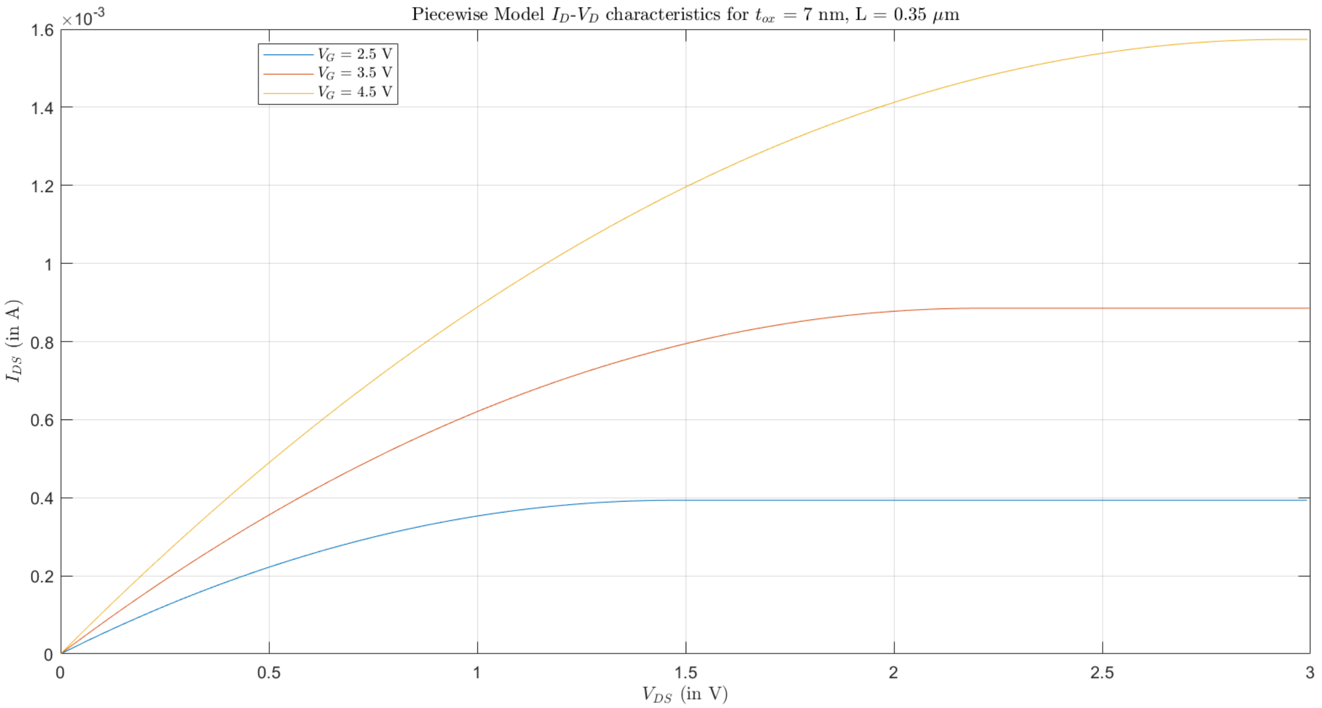

Figure 5: Case 3: $I_D - V_D$ characteristics for Piecewise model

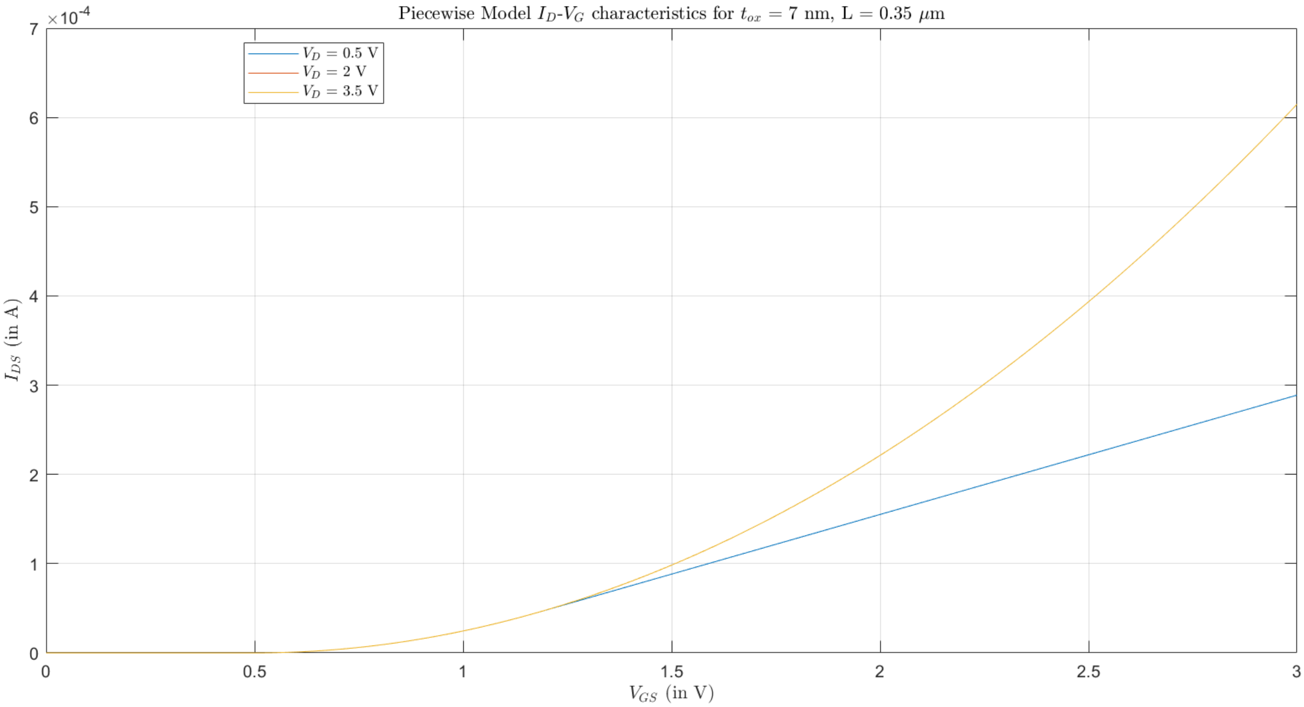

Figure 6: Case 3: $I_D - V_G$ characteristics for Piecewise model

Pao-Sah Model

The following equations are used:

$$I_D = q\mu\left(\frac{W}{L}\right)\int_0^{V_{DS}}\left(\int_\delta^{\Psi_S}\frac{\frac{n_i^2}{N_A}e^{q(\Psi-V)/kT}}{-\frac{d\Psi}{dx}}d\Psi\right)dV \tag{1}$$

$$-\frac{d\Psi}{dx} = \sqrt{\frac{2kTN_A}{\epsilon_{Si}}\left(\frac{q\Psi}{kT}+\frac{n_i^2}{N_A^2}e^{q(\Psi-V)/kT}\right)} \tag{2}$$

$$V_{GS} = V_{FB}+\Psi_S+\frac{2\epsilon_{Si}kTN_A}{C_{ox}}\left(\frac{q\Psi}{kT}+\frac{n_i^2}{N_A^2}e^{q(\Psi_S-V)/kT}\right)^{0.5} \tag{3}$$

For loops are used in the code to evaluate the integral as an approximate sum. From equation 3, the value of Ψ_S is calculated by substituting the other variables and interpolating for the given V_{GS}. Equation 2 is then substituted in equation 1 to evaluate the integral.

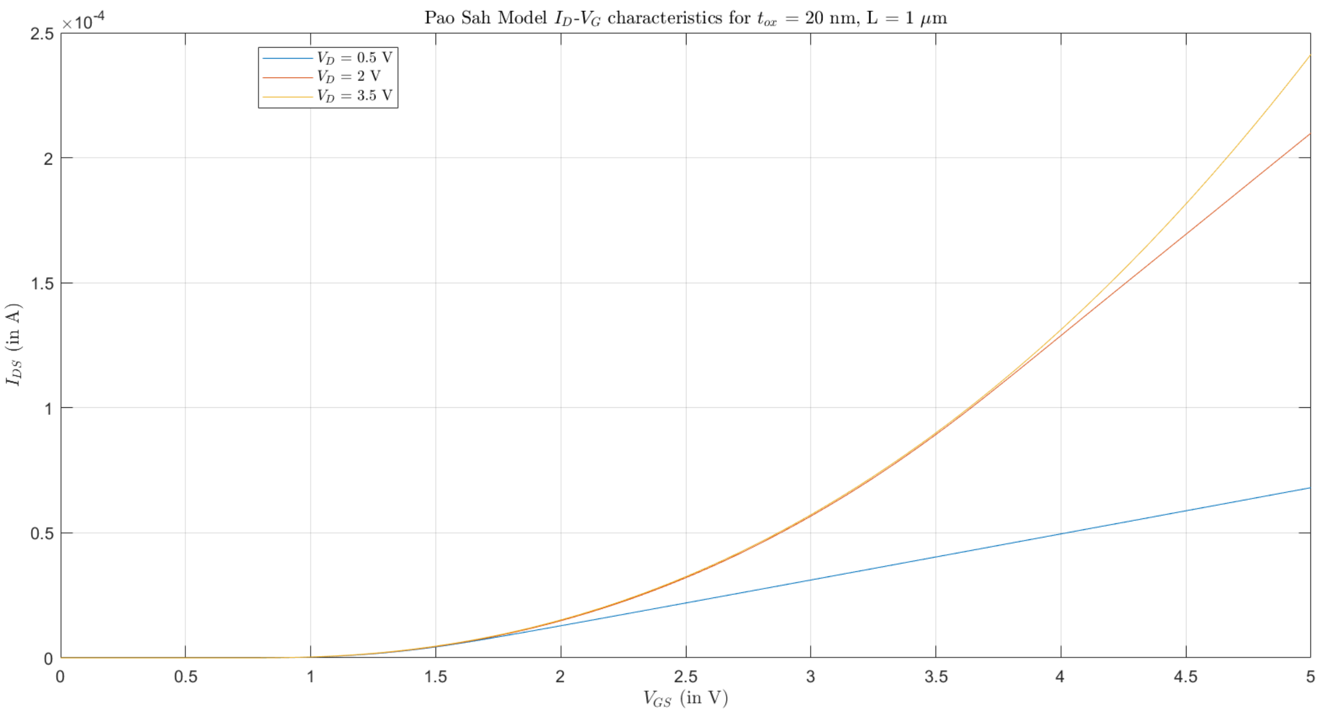

Figure 7: Case 1: $I_D - V_D$ characteristics for Pao-Sah model

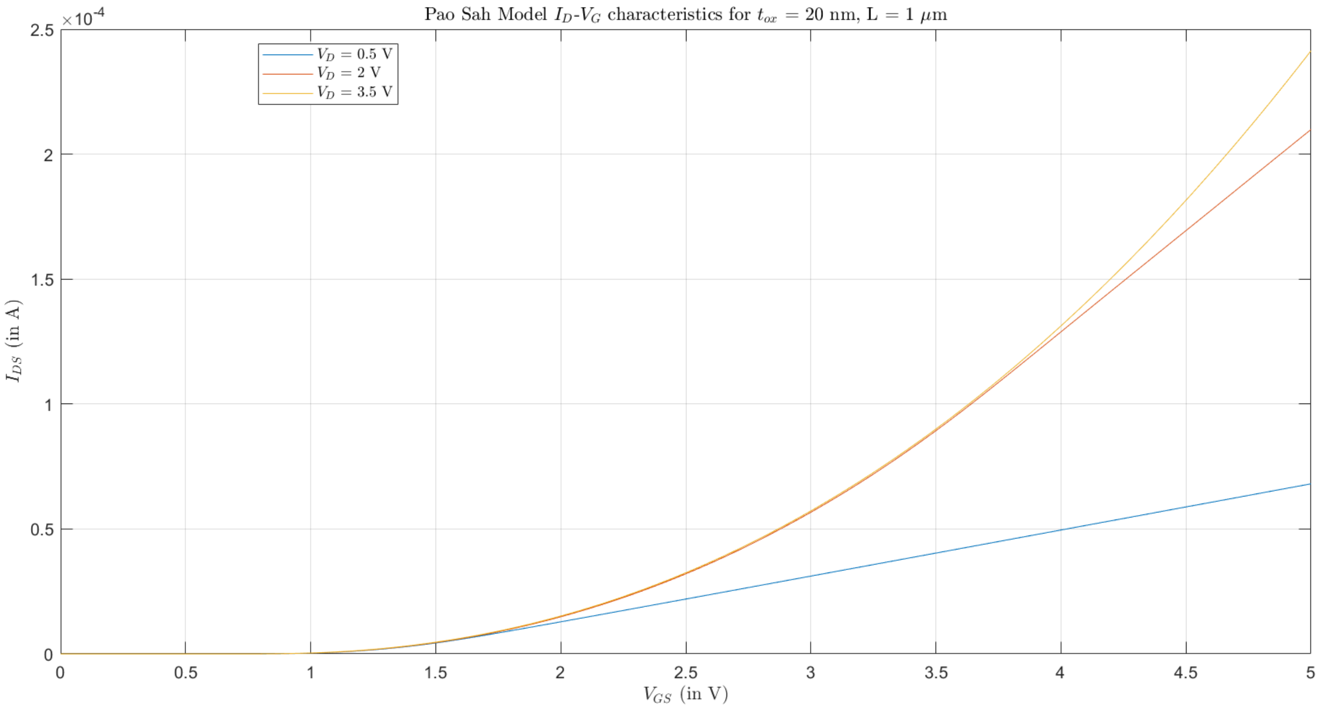

Figure 8: Case 1: $I_D - V_G$ characteristics for Pao-Sah model

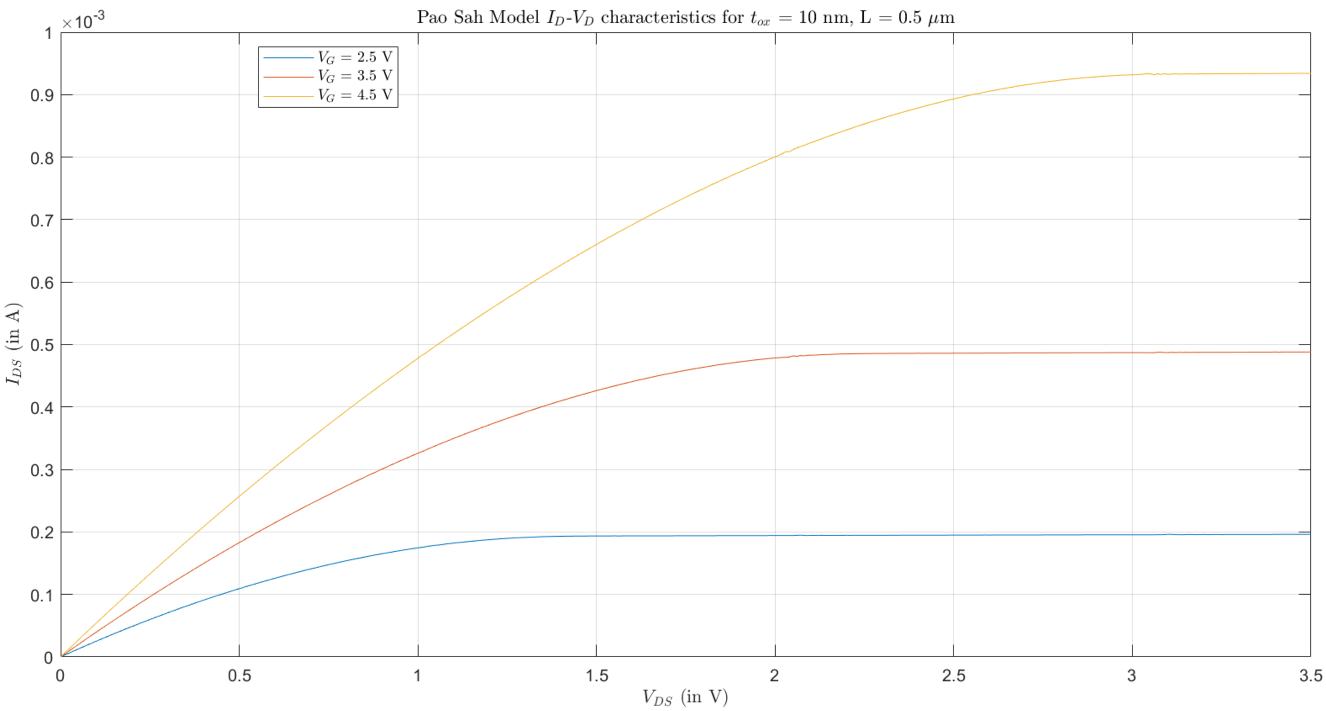

Figure 9: Case 2: $I_D - V_D$ characteristics for Pao-Sah model

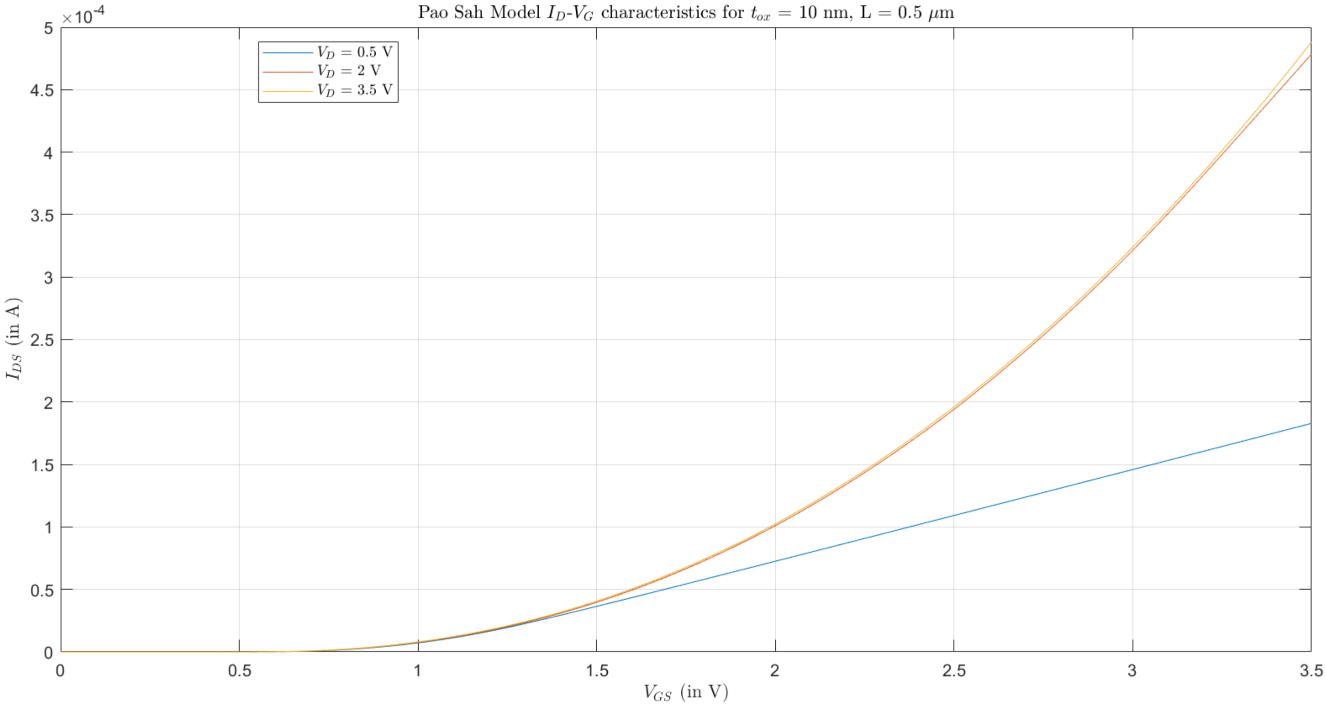

Figure 10: Case 2: $I_D - V_G$ characteristics for Pao-Sah model

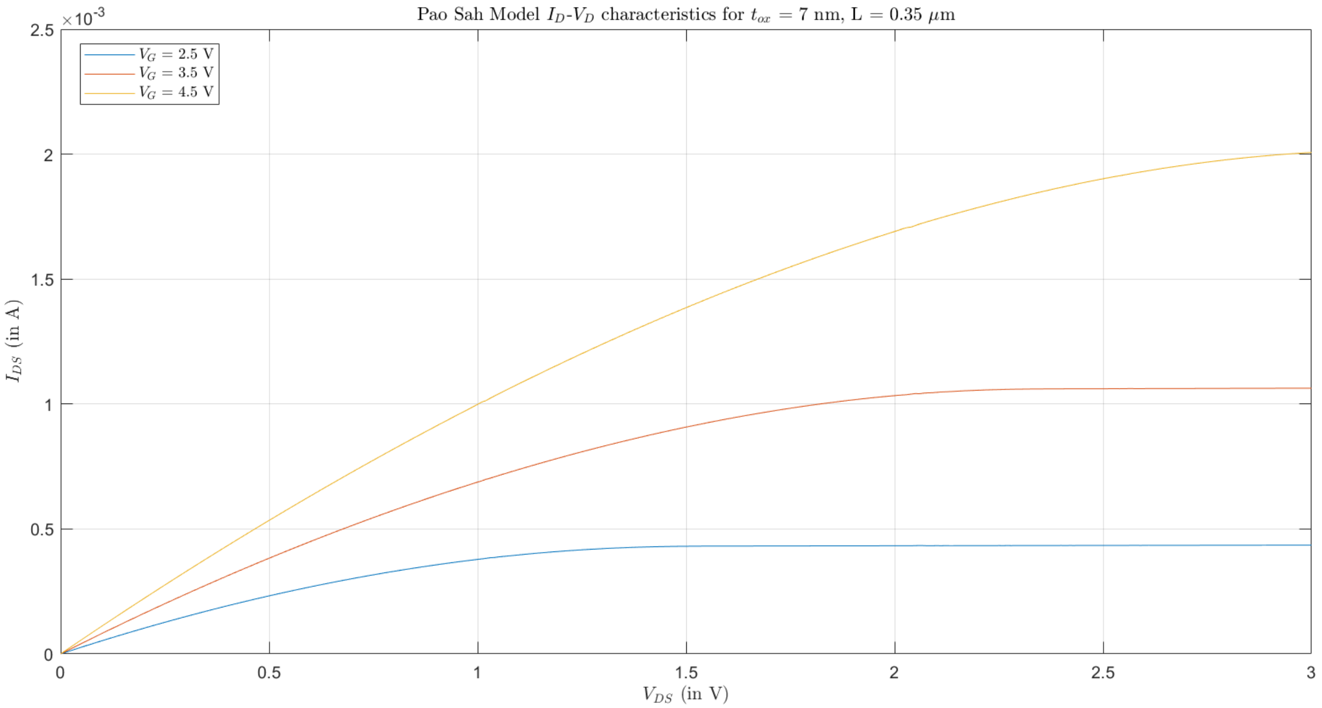

Figure 11: Case 3: $I_D - V_D$ characteristics for Pao-Sah model

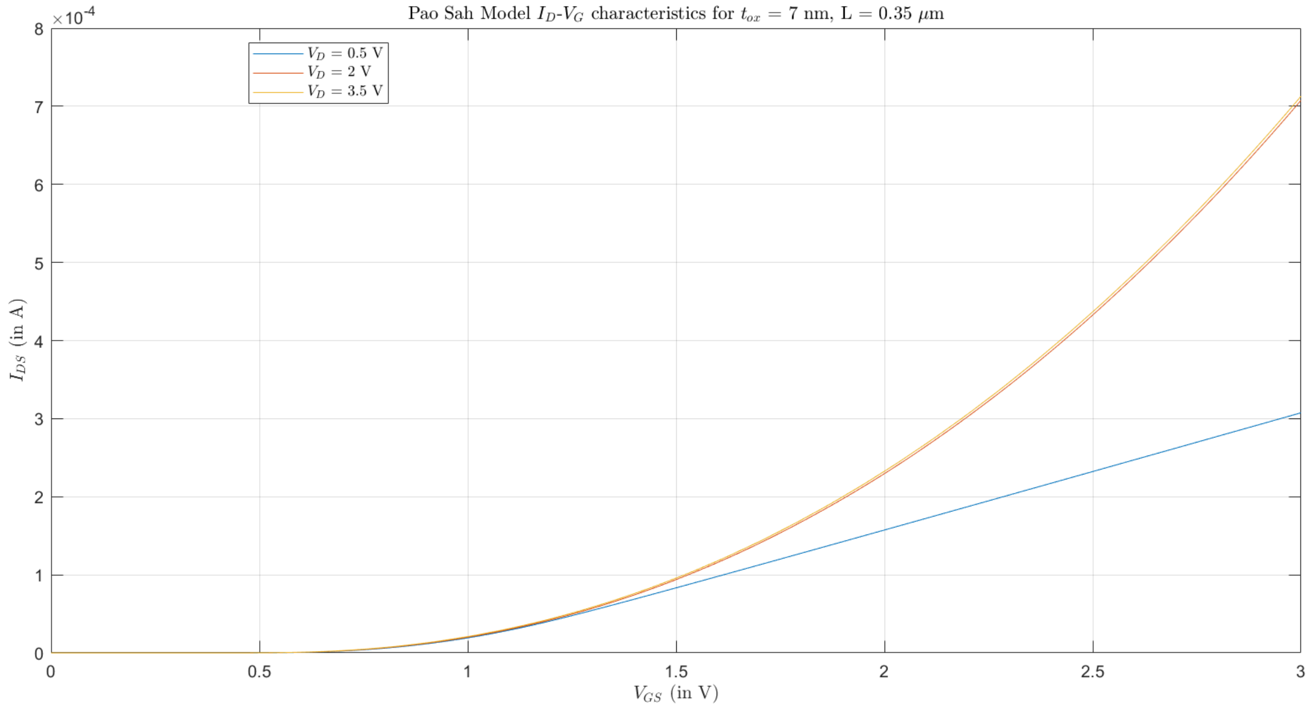

Figure 12: Case 3: $I_D - V_G$ characteristics for Pao-Sah model

Brews Model

Equation 3 from above is used to calculated Ψ_{SS} and Ψ_{SD}, with V as 0 and V_{DS} for the two cases respectively.

$$I_D = \mu\left(\frac{W}{L}\right)\int_{\Psi_{SS}}^{\Psi_{SD}} C_{ox}\left(V_{GS} - V_{FB} - \Psi_S\right) - \sqrt{2\epsilon_{Si} q N_A \Psi_S} + \frac{2kT}{q}\frac{C_{ox}^2\left(V_{GS} - V_{FB} - \Psi_S\right) + \epsilon_{Si} q N_A}{C_{ox}\left(V_{GS} - V_{FB} - \Psi_S\right) + \sqrt{2\epsilon_{Si} q N_A \Psi_S}} d\Psi_S \tag{4}$$

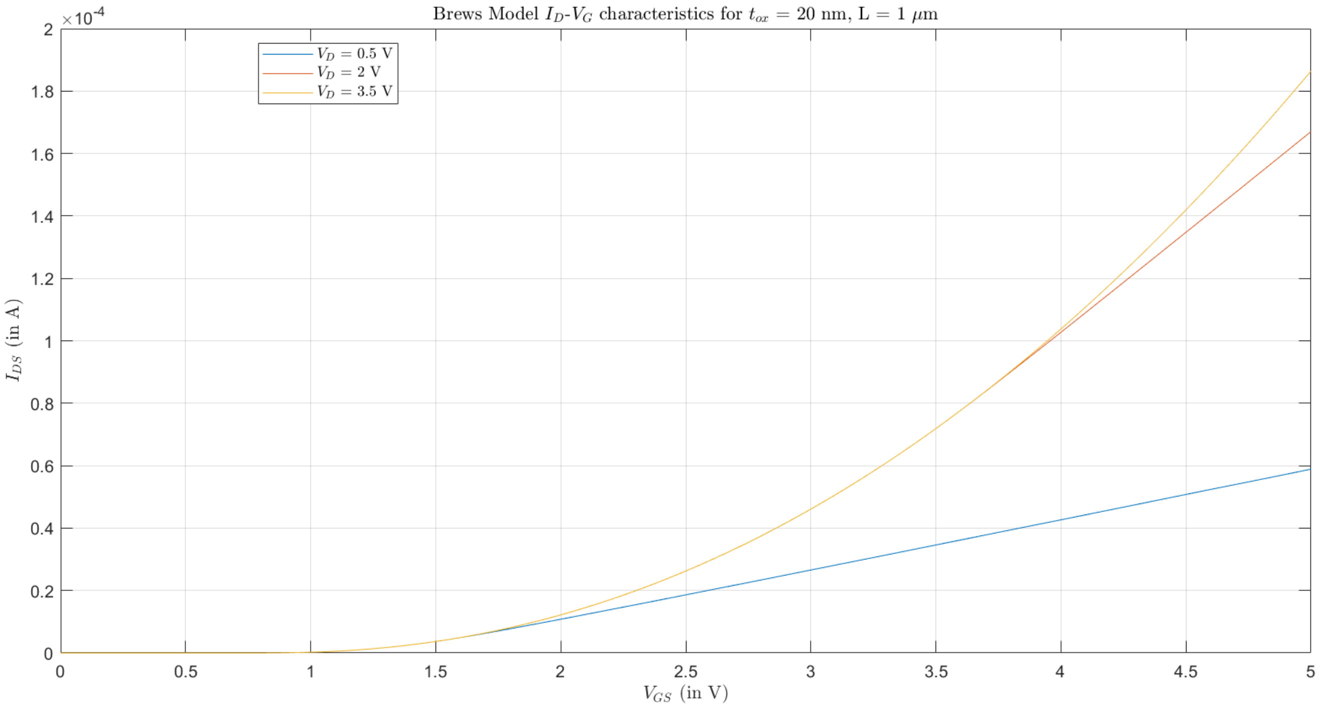

Figure 13: Case 1: $I_D - V_D$ characteristics for Brews model

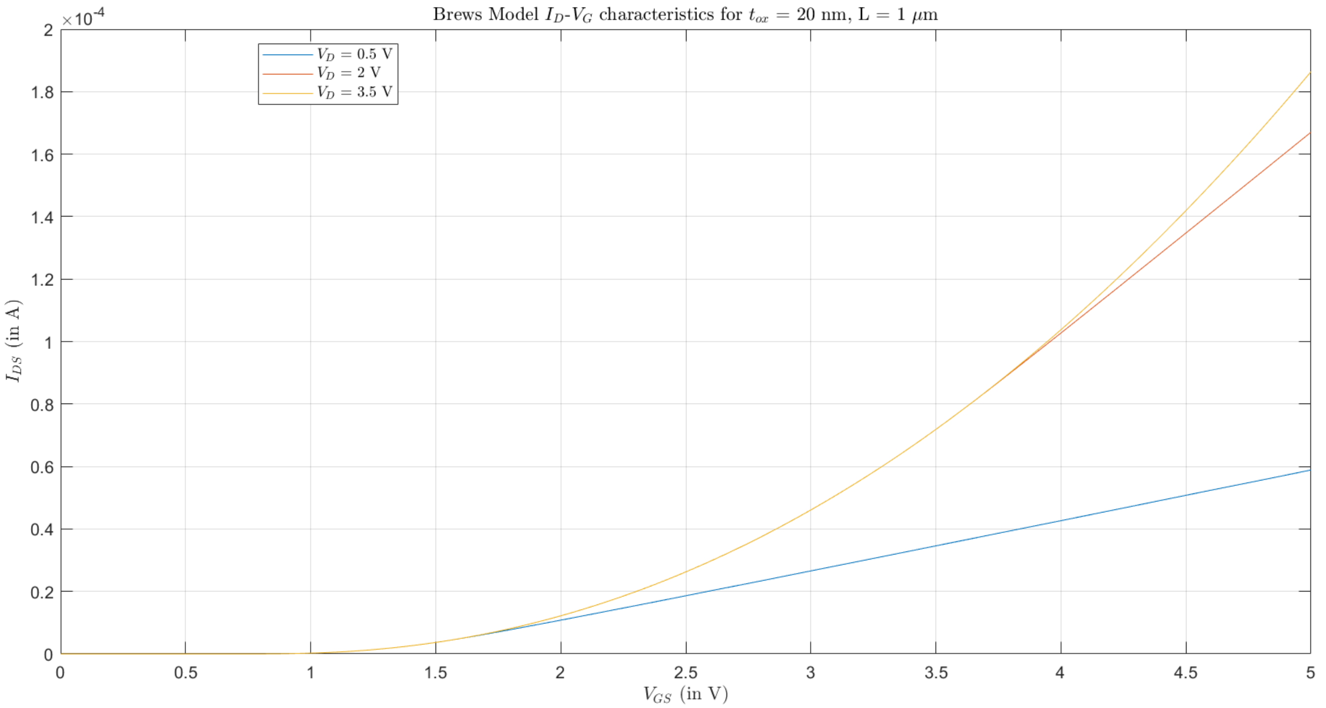

Figure 14: Case 1: $I_D - V_G$ characteristics for Brews model

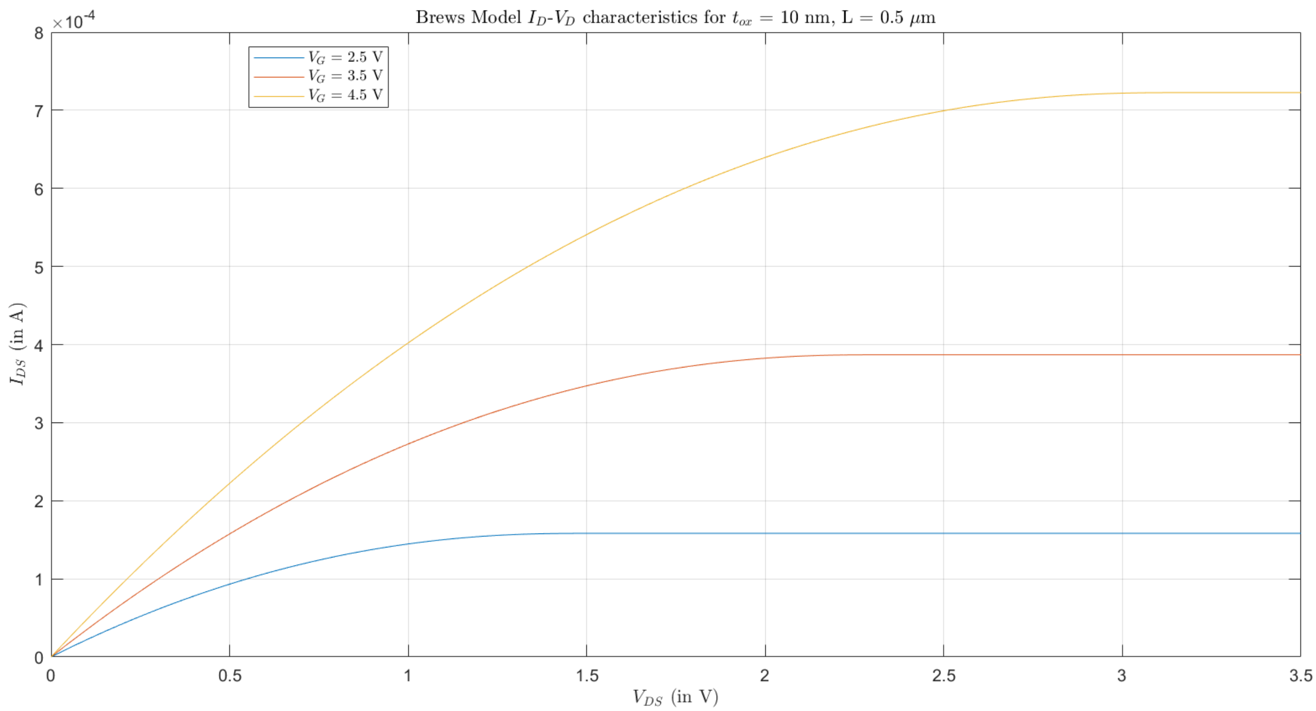

Figure 15: Case 2: $I_D - V_D$ characteristics for Brews model

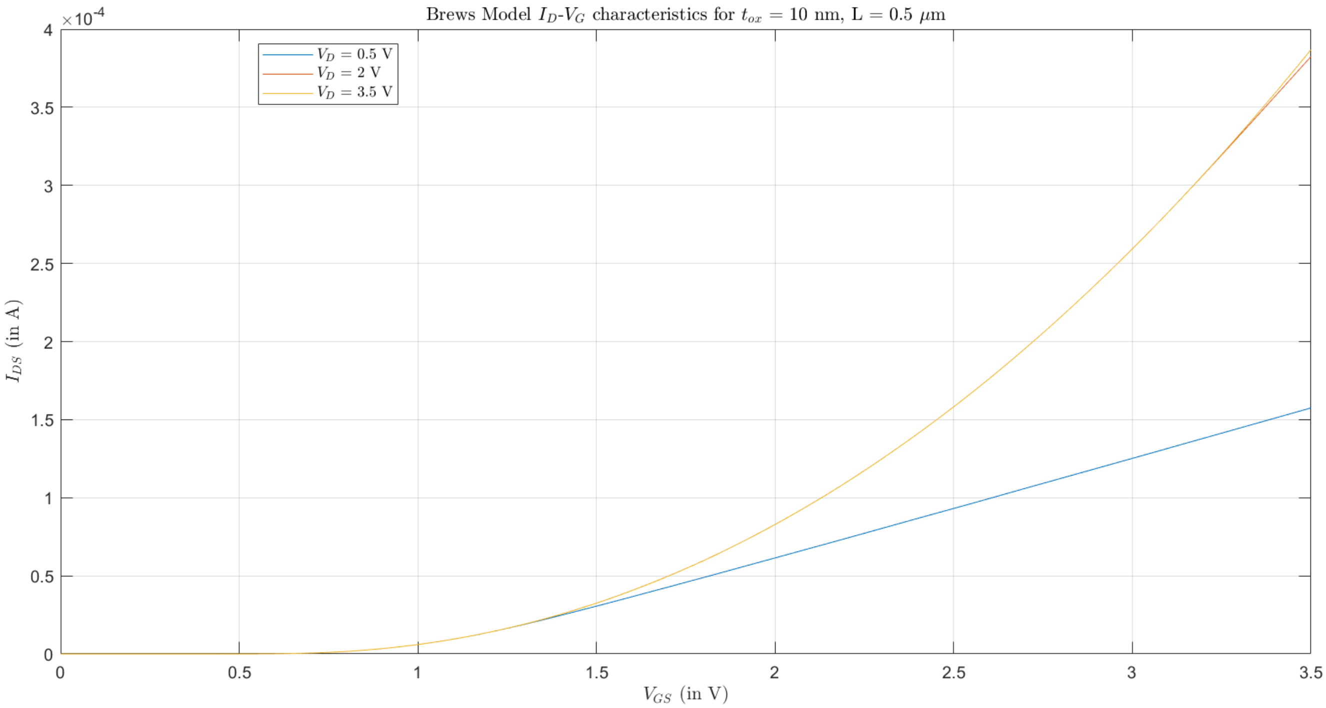

Figure 16: Case 2: $I_D - V_G$ characteristics for Brews model

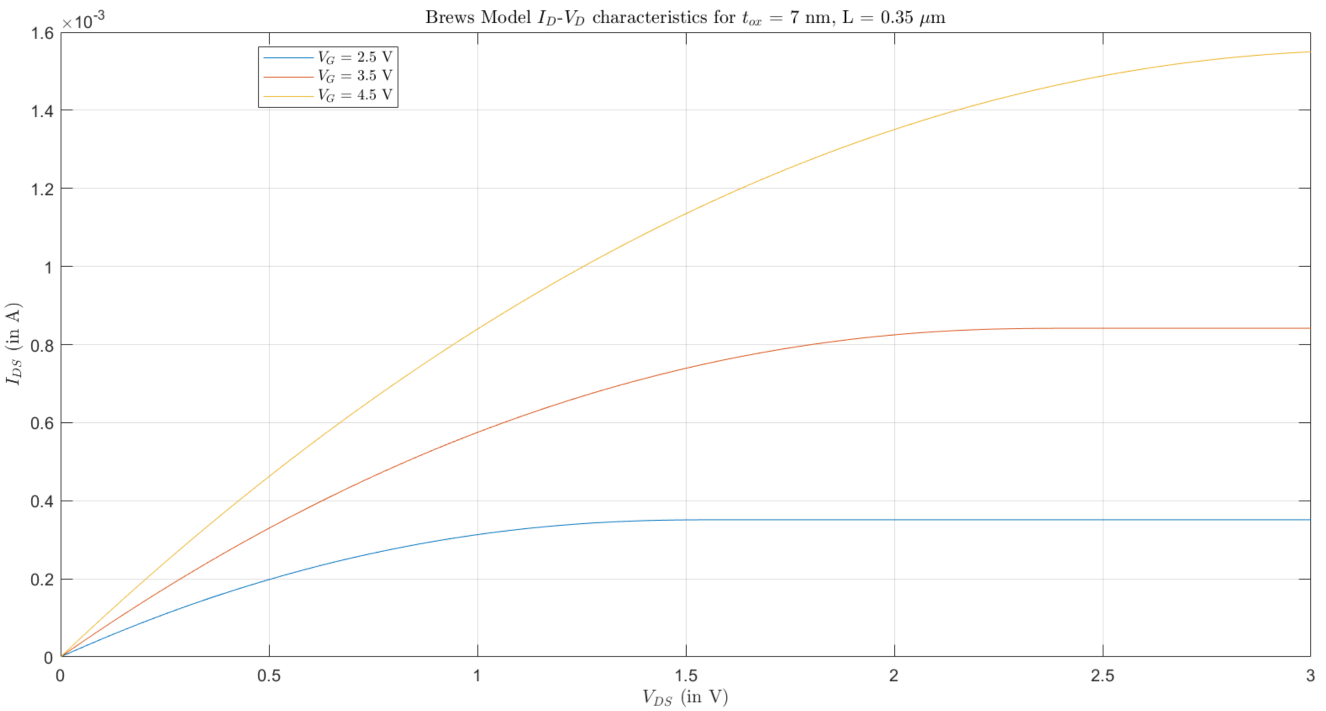

Figure 17: Case 3: $I_D - V_D$ characteristics for Brews model

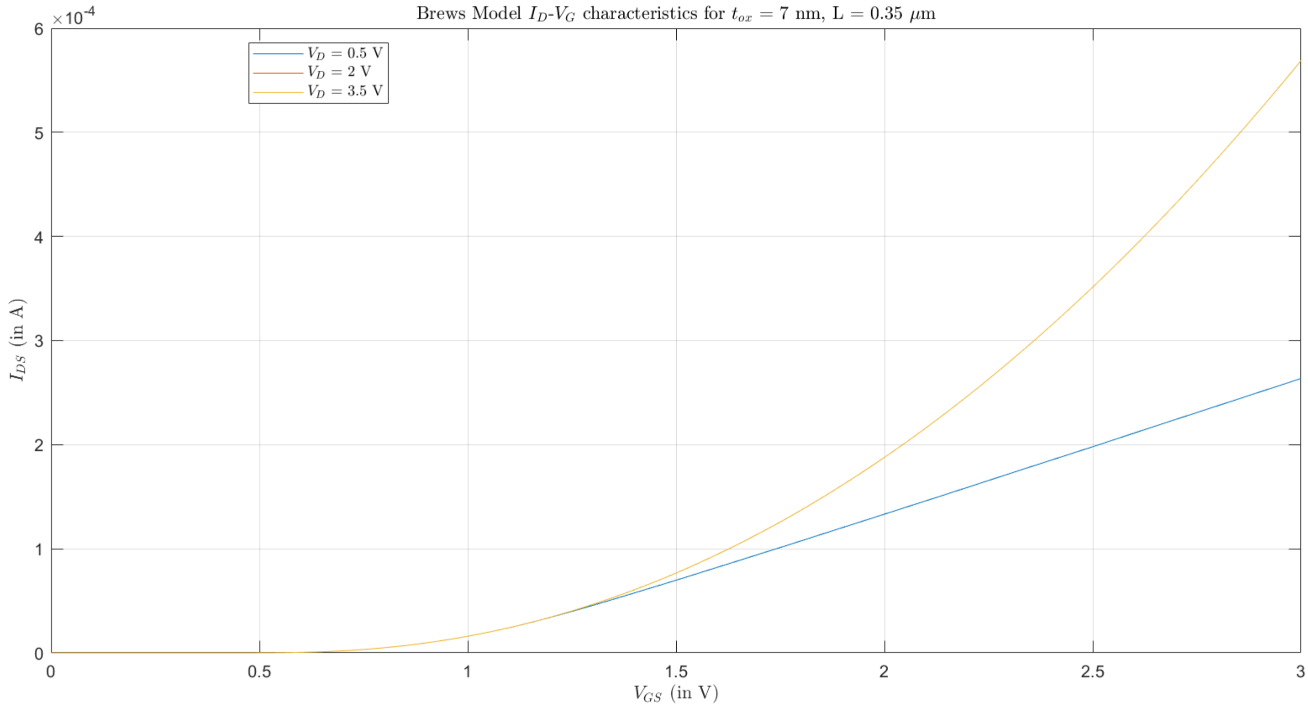

Figure 18: Case 3: $I_D - V_G$ characteristics for Brews model