

NMOS FET SPICE analysis for BISM3v3 model

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This sheet converts the SPICE BISM3v3 values for an NMOS FET into values that can be used for hand calculations. Not all the SPICE parameters are used, for example the diodes from the Source & Drain to the Bulk are not included. The SPICE parameters are shown in the SPICE notation and I have added units.

The references for this are the manual from the official BSIM webpage <http://www-device.eecs.berkeley.edu/~bsim3/>; the book 'MOSFET Models for SPICE Simulation' by William Liu; and the book 'Design of Integrated Circuits & Systems' by Laker & Sansen.

This sheet uses the default SPICE values highlighted in yellow. Non standards values are in pink. Output is in green.

Please note there are errors in this sheet and I have not compared these results with SPICE simulations.

$$\mu\text{m} := 10^{-6}\text{m} \quad \text{F} := \text{farad} \quad \text{nm} := 10^{-9}\text{m} \quad \text{fF} := 10^{-15}\text{F}$$

$$V_{\text{bs}} := -1 \cdot \text{volt} \quad V_{\text{ds}} := 3 \cdot \text{volt} \quad V_{\text{gs}} := 0.7 \cdot \text{volt}$$

$$W_f := 10\mu\text{m} \quad \text{Width of each finger}$$

$$\epsilon_o := 8.85 \cdot 10^{-14} \frac{\text{F}}{\text{cm}} \quad \epsilon_{\text{ox}} := 4.1 \quad \epsilon_{\text{si}} := 11.9$$

$$L := 0.24\mu\text{m} \quad \text{Gate Length}$$

$$N_f := 10 \quad \text{Number of fingers}$$

$$k := 1.38 \cdot 10^{-23} \frac{\text{joule}}{\text{K}} \quad q := 1.602 \cdot 10^{-19} \text{coul}$$

$$\text{TOX} := 1.5 \cdot 10^{-8} \text{r} \quad \text{TOXM} := 1.5 \cdot 10^{-8} \text{r} \quad \text{TNOM} := 27\text{K}$$

$$\text{NCH} := 1.7 \cdot 10^{17} \frac{1}{\text{cm}^3} \quad \text{NSUB} := 6 \cdot 10^{16} \frac{1}{\text{cm}^3}$$

$$T_{\text{nom}} := \text{TNOM} + 273.15\text{K}$$

Adjust Length & Width

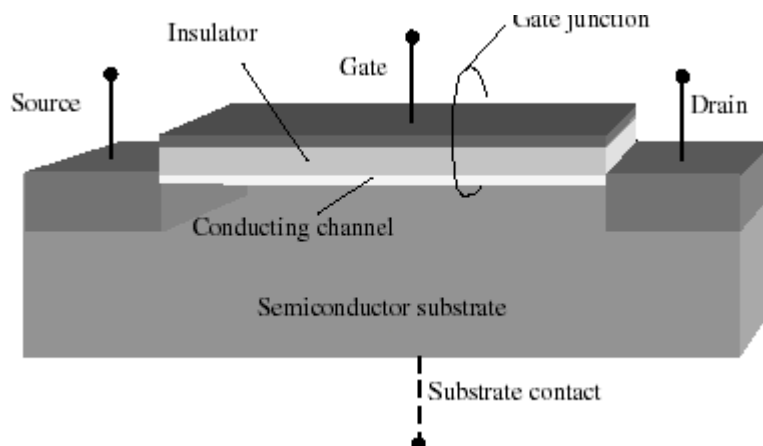
$$\text{LINT} := 3.5 \cdot 10^{-9} \cdot \text{m} \quad \text{WINT} := 4 \cdot 10^{-9} \cdot \text{m}$$

$$L_{\text{eff}} := L - 2 \cdot \text{LINT}$$

$$L_{\text{eff}} = 0.233\mu\text{m}$$

$$W_{\text{eff}} := (W_f - 2 \cdot \text{WINT}) \cdot N_f$$

$$W_{\text{eff}} = 99.92\mu\text{m}$$



Plot of ni intrinsic carrier density

Start by calculating ni which is the intrinsic carrier concentration which is not dependent on the transistor construction. Use the equations from the BISM3v3 manual page A-15, plus Liu A-15. These results look ok to me as Laker & Sansen P6 specify ni as nominally $1.5 \cdot 10^{10} \text{ 1/cm}^3$.

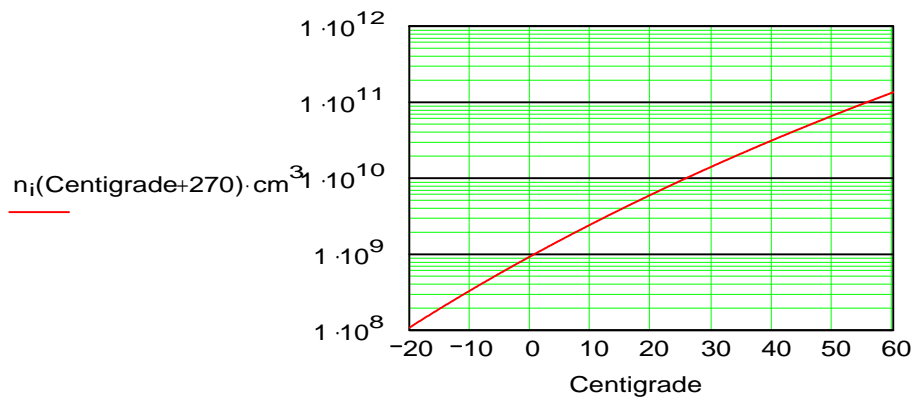
$$V_{tm0}(T_{nom}) := \frac{k \cdot T_{nom}}{q}$$

$$V_{tm0}(T_{nom}) = 0.026 \text{ volt}$$

$$E_{g0}(T_{nom}) := \left[1.16 - \frac{7.02 \cdot 10^{-4} \cdot T_{nom}^2}{(T_{nom} + 1108 \cdot \text{K}) \cdot \text{K}} \right] \text{ volt}$$

$$n_i(T_{nom}) := \left[1.45 \cdot 10^{10} \cdot \left(\frac{T_{nom}}{300.15 \cdot \text{K}} \right)^{1.5} \cdot \exp \left(21.5565981 - \frac{E_{g0}(T_{nom})}{2 \cdot V_{tm0}(T_{nom})} \right) \right] \cdot \frac{1}{\text{cm}^3}$$

$$n_i(300\text{K}) = 1.422 \times 10^{10} \text{ cm}^{-3}$$



Gate and Bulk Capacitance to Channel and n

This part estimates the capacitance from gate-to-channel and from bulk-to-channel according to Laker & Sansen page 6. This allows the ratio n to be calculated, which amongst other things indicates the ratio of gm to gmb.

$$C_{ox} := \frac{\epsilon_o \cdot \epsilon_{ox}}{TOX} \quad C_{gate_channel} := W_{eff} \cdot L_{eff} \cdot C_{ox} \phi_j := \frac{k \cdot T_{nom}}{q} \cdot \ln \left(\frac{NCH \cdot NSUB}{n_i(T_{nom})^2} \right)$$

$$C_{ox} = 2.419 \frac{\text{fF}}{\mu\text{m}^2}$$

$$t_{si}(V_{bc}) := \sqrt{\frac{2 \cdot \epsilon_o \cdot \epsilon_{si} \cdot (\phi_j - V_{bc})}{q \cdot NSUB}} \quad C_j(V_{bc}) := \frac{\epsilon_o \cdot \epsilon_{si}}{t_{si}(V_{bc})}$$

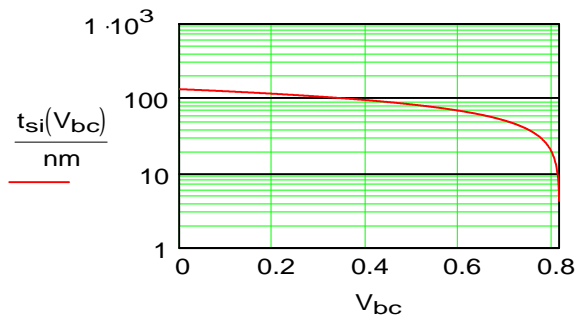
$$C_{gate_channel} = 56 \text{ fF}$$

$$\phi_j = 0.815 \text{ volt}$$

$$C_{bulk_channel}(V_{bc}) := W_{eff} \cdot L_{eff} \cdot C_j(V_{bc})$$

$$t_{si}(0 \cdot \text{volt}) = 134 \text{ nm} \quad t_{si}(1 \cdot \text{volt}) = 64 \text{ nm}$$

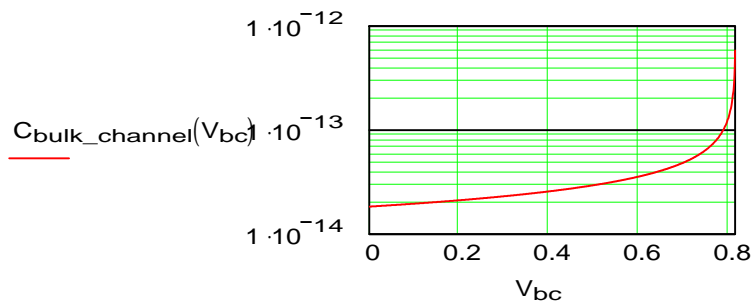
$$C_{bulk_channel}(0 \cdot \text{volt}) = 18.3$$



t_{si} is the thickness of the depletion layer between channel & bulk in nm

$$n := 1 + \frac{C_{\text{bulk_channel}}(0 \cdot \text{volt})}{C_{\text{gate_channel}}}$$

n = 1.326



This value of n is a very important factor in the analysis of the NMOS FET

C_{bulk_channel} is the capacitance from the bulk connection to the channel

Calculate the threshold voltage V_t according to BISM3v3

This is calculated according to Liu, equations 1.6b and A-22 to A-38.

VTH0 := 0.7 · volt K1 := 0.5 · volt^{0.5} K2 := 0.01 K3 := 80 K3B := 0.1 · volt⁻¹

DVT0 := 2.2 DVT1 := 0.53 NLX := 1.74 × 10⁻⁷ · m W0 := 2.5 · 10⁻⁶ m

DSUB := 0.56 ETA0 := 0.08 ETAB := -0.07 · volt⁻¹

$$\phi_f := \frac{k \cdot T_{\text{nom}}}{q} \cdot \ln\left(\frac{N_{\text{CH}}}{n_i(T_{\text{nom}})}\right)$$

Liu 1.6b

2 · φ_f = 0.842 volt

$$V_{bc} := \begin{cases} -3 \cdot \text{volt} & \text{if } 0.9 \cdot \left(2\phi_f - \frac{K1^2}{4 \cdot K2^2}\right) > -3 \cdot \text{volt} \\ -30 \cdot \text{volt} & \text{if } 0.9 \cdot \left(2\phi_f - \frac{K1^2}{4 \cdot K2^2}\right) < -30 \cdot \text{volt} \\ \left[0.9 \cdot \left(2\phi_f - \frac{K1^2}{4 \cdot K2^2}\right)\right] & \text{otherwise} \end{cases}$$

Liu A-23

Liu A-22

V_{bc} = -30 volt

$$V_{bs_eff} := V_{bc} + \frac{(V_{bs} - V_{bc} - 0.001 \cdot \text{volt}) + \sqrt{(V_{bs} - V_{bc} - 0.001 \cdot \text{volt})^2 - 4 \cdot 0.001 \cdot \text{volt} \cdot V_{bc}}}{2}$$

V_{bs} = -1 volt

V_{bs_eff} = -0.9999655 volt

Liu A-25, A-27

$$V_{T_body_effect} := \begin{cases} K1 \cdot \frac{TOX}{TOXM} \cdot \sqrt{2 \cdot \phi_f - V_{bs_eff}} - K1 \cdot \sqrt{2 \cdot \phi_f} - K2 \cdot \frac{TOX}{TOXM} \cdot V_{bs_eff} & \text{if } V_{bs_eff} < 0 \\ K1 \cdot \frac{TOX}{TOXM} \cdot \frac{(\sqrt{2 \cdot \phi_f})^3}{2 \cdot \phi_f - \frac{V_{bs_eff}}{2}} - K1 \cdot \sqrt{2 \cdot \phi_f} - K2 \cdot \frac{TOX}{TOXM} \cdot V_{bs_eff} & \text{if } V_{bs_eff} \geq 0 \end{cases}$$

$$V_{T_body_effect} = 0.23 \text{ v}$$

$$V_{bi} := \frac{k \cdot (TNOM + 273.15 \cdot K)}{q} \cdot \ln \left[\frac{NCH \cdot 10^{20} \text{ cm}^{-3}}{(n_i(TNOM + 273.15 \cdot K))^2} \right] \quad \text{Liu A-33}$$

$$V_{bi} = 1.007 \text{ volt}$$

$$X_{dep} := \sqrt{\frac{2 \cdot \epsilon_o \cdot \epsilon_{si} \cdot 2 \phi_f}{q \cdot NCH}} \quad L_t := \sqrt{\frac{\epsilon_o \cdot \epsilon_{si} \cdot X_{dep}}{\left(\frac{\epsilon_o \cdot \epsilon_{ox}}{TOX}\right)}}$$

As an approximation, all L_t values in Liu equations A-34 to A-36 are taken as this which is A-34.

$$X_{dep} = 80.701 \text{ nm}$$

$$L_t = 59.275 \text{ nm}$$

Liu A-28

$$V_{T_charge_sharing} := DVT0 \cdot \left(\exp\left(-DVT1 \cdot \frac{L_{eff}}{2 \cdot L_t}\right) + 2 \cdot \exp\left(-DVT1 \cdot \frac{L_{eff}}{L_t}\right) \right) \cdot (V_{bi} - 2 \cdot \phi_f) \quad \text{charge_sharing} = 0.218 \text{ v}$$

$$V_{T_reverse_short_channel} := K1 \cdot \frac{TOX}{TOXM} \cdot \left(\sqrt{1 + \frac{NLX}{L_{eff}}} - 1 \right) \cdot \sqrt{2 \cdot \phi_f} \quad \text{A-30}$$

$$V_{T_reverse_short_channel} = 0.1$$

$$V_{T_narrow_width} := (K3 + K3B \cdot V_{bs_eff}) \cdot \frac{TOX}{W_{eff} + W0} \cdot 2 \cdot \phi_f \quad \text{Liu A-31}$$

$$V_{T_narrow_width} = 0.00985 \text{ v}$$

Liu A-29

$$V_{T_DIBL} := \left(\exp\left(-DSUB \cdot \frac{L_{eff}}{2 \cdot L_t}\right) + 2 \cdot \exp\left(-DSUB \cdot \frac{L_{eff}}{L_t}\right) \right) \cdot (ETA0 + ETAB \cdot V_{bs_eff}) \cdot V_{ds} \quad V_{T_DIBL} = 0.249 \text{ volt}$$

Liu A-26

$$V_T := V_{TH0} + V_{T_body_effect} - V_{T_charge_sharing} - V_{T_DIBL} + V_{T_reverse_short_channel} + V_{T_narrow}$$

$$V_T = 0.62 \text{ volt}$$

Calculate μ_{eff} so that we can get $KP = \mu C_{ox}$ and for $MOBMOD = 1$.

$$U0 := 670 \cdot \frac{\text{cm}^2}{\text{volt} \cdot \text{sec}}$$

$$UA := 2.25 \cdot 10^{-9} \cdot \frac{\text{m}}{\text{volt}}$$

$$UB := 5.87 \cdot 10^{-19} \cdot \left(\frac{\text{m}}{\text{volt}} \right)^2$$

$$UC := -4.65 \cdot 10^{-11} \cdot \frac{\text{m}}{\text{volt}^2}$$

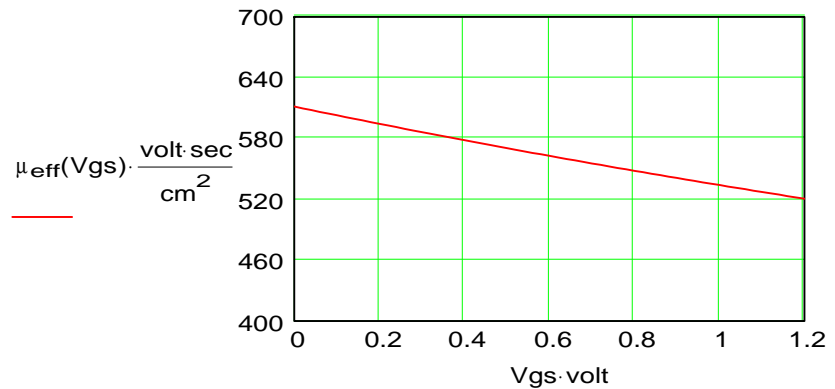
$$\mu_{\text{eff}}(V_{\text{gs}}) := \frac{U_0}{1 + (U_A + U_C \cdot V_{\text{bs_eff}}) \cdot \left[\frac{(V_{\text{gs}} - V_T) + 2 \cdot V_T}{\text{TOX}} \right] + U_B \cdot \left[\frac{(V_{\text{gs}} - V_T) + 2 \cdot V_T}{\text{TOX}} \right]^2}$$

This is calculated according to BISM section B.1.3 for $V_{\text{bs}} = 0$

$$\mu_{\text{eff}}(0.7 \text{ volt}) = 555.291 \frac{\text{cm}^2}{\text{volt} \cdot \text{sec}}$$

$$K_P := U_0 \cdot C_{\text{ox}}$$

$$K_P = 0.162 \frac{\text{mA}}{\text{volt}^2}$$



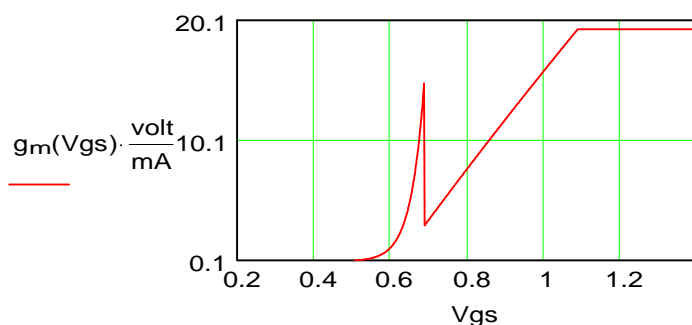
Now calculate gm

The forward transconductance is calculated for the various regions. The result looks ok to me, but I have not carried out a simulation on a SPICE simulator to check. The equations are from Laker & Sansen page 30.

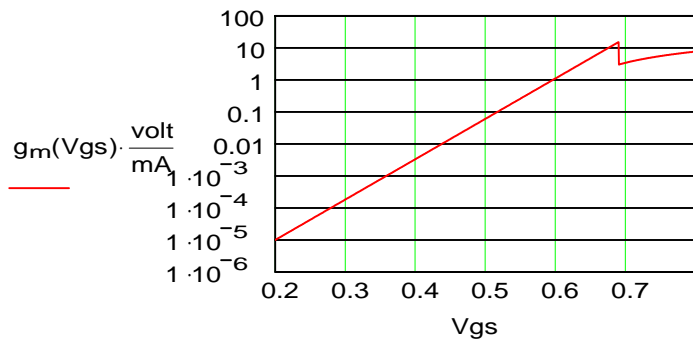
$$V_{\text{SAT}} := 8 \times 10^4 \frac{\text{m}}{\text{sec}} \quad J_S := 1 \cdot 10^{-4} \frac{\text{amp}}{\text{m}^2}$$

$$I_{\text{d_sat}} := L_{\text{eff}} \cdot W_{\text{eff}} \cdot J_S$$

$$g_m(V_{\text{gs}}) := \begin{cases} \frac{I_{\text{d_sat}}}{n \cdot \frac{k \cdot T_{\text{nom}}}{q}} \cdot \frac{W_{\text{eff}}}{L_{\text{eff}}} \cdot \exp\left(\frac{V_{\text{gs}}}{n \cdot \frac{k \cdot T_{\text{nom}}}{q}}\right) & \text{if } V_{\text{gs}} - V_T < 2 \cdot n \cdot \frac{k \cdot T_{\text{nom}}}{q} \\ W_{\text{eff}} \cdot C_{\text{ox}} \cdot V_{\text{SAT}} & \text{if } W_{\text{eff}} \cdot C_{\text{ox}} \cdot V_{\text{SAT}} < \frac{\mu_{\text{eff}}(V_{\text{gs}}) \cdot C_{\text{ox}}}{n} \cdot \frac{W_{\text{eff}}}{L_{\text{eff}}} \cdot (V_{\text{gs}} - V_T) \\ \frac{\mu_{\text{eff}}(V_{\text{gs}}) \cdot C_{\text{ox}}}{n} \cdot \frac{W_{\text{eff}}}{L_{\text{eff}}} \cdot (V_{\text{gs}} - V_T) & \text{otherwise} \end{cases}$$



Note the discontinuity as the gm goes from the w_i to s_i region



$$g_{mb}(V_{gs}) := (n - 1)g_m(V_{gs})$$

$$g_m(0.8 \text{ volt}) = 7.735 \frac{\text{mA}}{\text{volt}}$$

$$g_{mb}(0.8 \text{ volt}) = 2.52 \frac{\text{mA}}{\text{volt}}$$

Early Voltage and Output Impedance

This is calculated from the Early Voltage, refer Page 485 and 236 from Liu. First calculate the bulk-charge coefficient according to A-58. The $V_{ds_{sat}}$ according to A-63. The calculation for the bulk-charge coefficient A_{bulk} is an approximation of the BSIM equation ingoring some second order effects. V_a is calculated for the DIBL region.

$$XJ := 1.5 \cdot 10^{-7} \cdot \text{mA} \quad A0 := 1$$

$$DROUT := 0.308 \quad PDIBLC1 := 0.027 \quad PDIBLC2 := 0.006651 \quad PDIBLCB := 0.1879 \cdot \text{volt}^{-1}$$

$$A_{bulk} := \left(1 + \frac{K1}{2 \cdot \sqrt{2 \cdot \phi_f - V_{bs_eff}}} \right) \cdot \frac{TOX}{TOXM} \cdot \left(\frac{A0 \cdot L_{eff}}{L_{eff} + 2 \cdot \sqrt{XJ \cdot X_{dep}}} \right)$$

Liu A-58. Note this is simplified because the default values for AGA, B0 and B1 are zero

$$A_{bulk} = 0.609$$

$$\epsilon_{sat} := \frac{2 \cdot VSAT}{\mu_{eff}(V_{gs})}$$

Liu A-62

$$V_{ds_sat} := \frac{\epsilon_{sat} \cdot L_{eff} \cdot \left(V_{gs} - V_T + \frac{2 \cdot k \cdot T_{nom}}{q} \right)}{A_{bulk} \cdot \epsilon_{sat} \cdot L_{eff} + \left(V_{gs} - V_T + \frac{2 \cdot k \cdot T_{nom}}{q} \right)}$$

Liu A-63, for $R_{ds} = 0$. Note the V_{gs} smoothing is not included

$$V_{ds_sat} = 0.164 \text{ volt}$$

$$\theta_{rout} := PDIBLC1 \cdot \left(\exp\left(-DROUT \cdot \frac{L_{eff}}{2 \cdot L_t}\right) + 2 \cdot \exp\left(-DROUT \cdot \frac{L_{eff}}{L_t}\right) \right) + PDIBLC2 \quad \text{Liu A-81}$$

$$\theta_{rout} = 0.037$$

$$V_{A_DIBL} := \frac{V_{gs} + \frac{2 \cdot k \cdot T_{nom}}{q}}{\theta_{rout} \cdot (1 + PDIBLCB \cdot V_{bs_eff})} \cdot \left(1 - \frac{A_{bulk} \cdot V_{ds_sat}}{A_{bulk} \cdot V_{ds_sat} + V_{gs} + \frac{2 \cdot k \cdot T_{nom}}{q}} \right) \quad \text{A-82}$$

$$V_{A_DIBL} = 21.8 \text{ volt}$$

The current taken at 1V above V_t in the si operating region can be used to define the output impedance.

$$I_{d_1V_V_{gs}} := \frac{KP}{2 \cdot n} \cdot \frac{W_{eff}}{L_{eff}} \cdot (1 \text{ volt})^2 \quad I_{d_1V_V_{gs}} = 0.026 \text{ amp} \quad \text{Output_impedance} := \frac{V_{A_DIBL} + V_T + 1 \text{ volt}}{I_{d_1V_V_{gs}}}$$

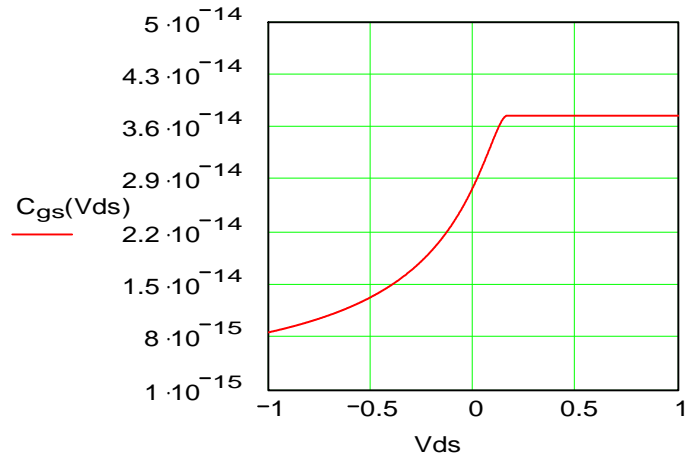
Output_impedance = 893.4 ohm

Capacitance Calculations

The Capacitances are calculated as a function of V_{ds} which corresponds to different values of α from LIU equation 1-33. The capacitance equations are B-7 & B11.

Note these only apply when $V_{gs} > V_t$.

$$\alpha(V_{ds}) := \begin{cases} 1 - \frac{V_{ds}}{V_{ds_sat}} & \text{if } V_{ds} < V_{ds_sat} \\ 0 & \text{if } V_{ds} \geq V_{ds_sat} \end{cases} \quad C_{gs}(V_{ds}) := W_{eff} \cdot L_{eff} \cdot C_{ox} \cdot \left[\frac{2}{3} \cdot \left[\frac{2 \cdot \alpha(V_{ds}) + 1}{(1 + \alpha(V_{ds}))^2} \right] \right]$$



$$\delta := \frac{K1}{2 \cdot \sqrt{2 \cdot \phi_f - V_{bs}}} \quad C_{ds}(V_{ds}) := W_{eff} \cdot L_{eff} \cdot C_{ox} \cdot \left[\frac{4 \cdot (1 + \delta)}{15} \cdot \frac{\alpha(V_{ds})^2 + 3 \cdot \alpha(V_{ds}) + 1}{(1 + \alpha(V_{ds}))^3} \right] \quad \delta = 0.184$$

