

Summary of the Important Relationships of Open-loop Amplifiers.

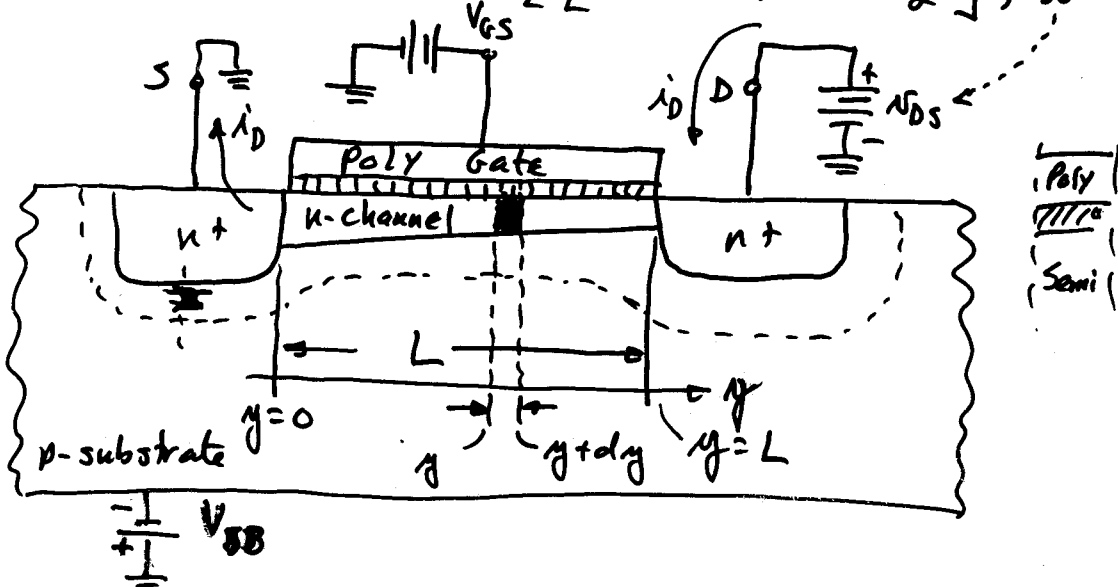
Quantity	Voltage Amplifier	Transconductance Amplifier	Transresistance Amplifier	Current Amplifier
Input-output variable	Voltage-voltage	Voltage-current	Current-voltage	Current-current
Small Signal Model				
Small Signal Amplifier with Source & Load				
Ideal RS	$R_S = 0$ or $R_S \ll R_i$	$R_S = 0$ or $R_S \ll R_i$	$R_S = \infty$ or $R_S \gg R_i$	$R_S = \infty$ or $R_S \gg R_i$
Ideal RL	$R_L = \infty$ or $R_L \gg R_o$	$R_L = 0$ or $R_L \ll R_o$	$R_L = \infty$ or $R_L \gg R_o$	$R_L = 0$ or $R_L \ll R_o$
Overall Forward Gain	$A_v = \frac{R_i R_L A_{vf}}{(R_S + R_i)(R_L + R_o)}$	$G_M = \frac{R_i R_o G_{mf}}{(R_S + R_i)(R_L + R_o)}$	$R_M = \frac{R_S R_L R_{mf}}{(R_S + R_i)(R_L + R_o)}$	$A_I = \frac{R_S R_o A_{if}}{(R_S + R_i)(R_L + R_o)}$

DEVELOPMENT OF LARGE-SIGNAL MODEL FOR MOSFET FOR SAH. EQ. AND FOR DSM TECHNOLOGY

SAH MODEL

$$i_D = \frac{k'}{2} \frac{W}{L} (V_{GS} - V_{TN})^2, \quad N_{DS} \geq N_{GS} - V_T$$

$$* i_D = k' \frac{W}{L} \left[(N_{GS} - V_{TN}) N_{DS} - \frac{N_{DS}^2}{2} \right], \quad N_{DS} < N_{GS} - V_T$$



Note: $V(y) = 0$ for $y = 0$ and $V(y=L) = V_{DS}$

1.) Charge per unit area at point y in the channel is

$$q = C_N \rightarrow Q_n(y) = C_{ox} [V_{GS} - V_T - V(y)]$$

2.) $i_{DS} = Q_n \times v \times W$ where $v =$ carrier velocity

3.) Assume $v = \mu E_y = \mu \frac{dV(y)}{dy}$

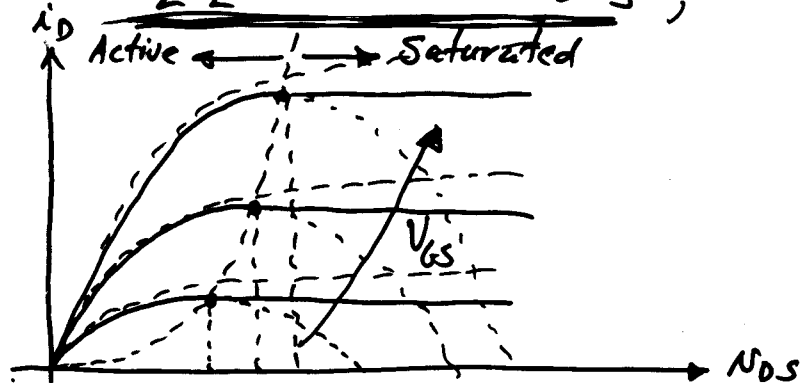
4.) $i_{DS} = i_D = C_{ox} [V_{GS} - V(y) - V_T] \mu E W$

$$\therefore i_D dy = \frac{\mu C_{ox} W}{k'} [V_{GS} - V(y) - V_T] dV(y)$$

$$5.) \int_0^L i_D dy = k'W \int_0^{N_{DS}} [N_{GS} - n(y) - V_T] dn(y)$$

$$i_{DL} = k'W \left[(N_{GS} - V_T) N_{DS} - \frac{N_{DS}^2}{2} \right]$$

$$i_D = \frac{k'W}{L} \left[(N_{GS} - V_T) N_{DS} - \frac{N_{DS}^2}{2} \right], \quad N_{DS} < N_{GS} - V_T$$



$$\frac{di_D}{dN_{DS}} = 0 \rightarrow N_{DS} = N_{GS} - V_T = N_{DS}(\text{sat})$$

6.) Saturation region model ($N_{DS} \geq N_{GS} - V_T$)

$$N_{DS} \leftarrow N_{GS} - V_T \Rightarrow i_D = \frac{k'W}{L} \left[(N_{GS} - V_T)(N_{GS} - V_T) - \frac{(N_{GS} - V_T)^2}{2} \right]$$

$$i_D = \frac{k'W}{2L} (N_{GS} - V_T)^2, \quad N_{DS} \geq N_{GS} - V_T$$

Channel Modulation

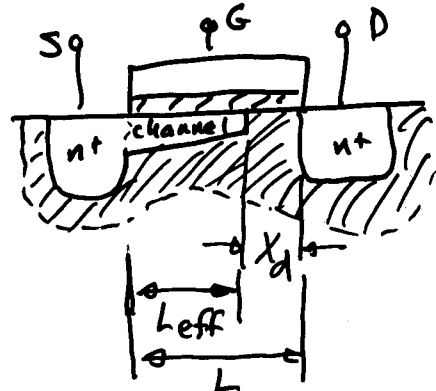
Assume saturation -

$$L_{\text{eff}} = L - X_d$$

$$i_D = \frac{k'W}{2L_{\text{eff}}} (N_{GS} - V_T)^2$$

$$\frac{di_D}{dN_{DS}} = -\frac{k'W}{2L_{\text{eff}}^2} (N_{GS} - V_T)^2 \frac{dL_{\text{eff}}}{dN_{DS}} = -\frac{i_D}{L_{\text{eff}}} \frac{dL_{\text{eff}}}{dN_{DS}} = \frac{i_D}{L_{\text{eff}}} \frac{dX_d}{dN_{DS}}$$

$$\frac{di_D}{dN_{DS}} \equiv \lambda i_D \Rightarrow \lambda = \frac{1}{L_{\text{eff}}} \frac{dX_d}{dN_{DS}}$$



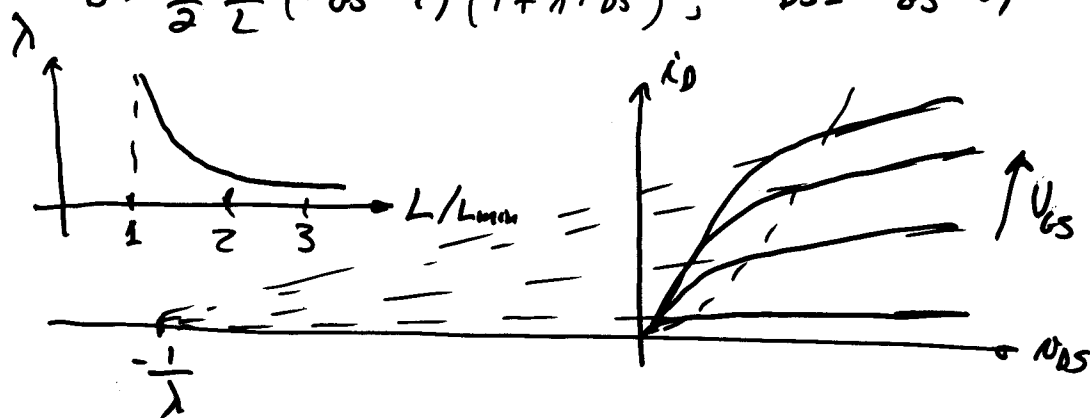
$$\therefore i_D(N_{DS}) = i_D(\lambda=0) + \left(\frac{di_D}{dN_{DS}}\right) N_{DS} = i_D + \lambda i_D N_{DS}$$

$$i_D(N_{DS}) = i_D (1 + \lambda N_{DS})$$

$$i_D = \frac{k'_n W}{L} \left[(N_{GS} - V_T) N_{DS} - \frac{N_{DS}^2}{2} \right] (1 + \lambda N_{DS}), \quad N_{DS} < N_{GS} - V_T$$

or

$$i_D = \frac{k'_n W}{2L} (N_{GS} - V_T)^2 (1 + \lambda N_{DS}), \quad N_{DS} \geq N_{GS} - V_T$$



What about deep submicron technology (DSM)?
DSM effects?

- 1.) Strong vertical field
- 2.) Saturation of drift velocity.

$$v = \mu_e \frac{E_y}{1 + \frac{E_y}{E_c}}, \quad E_y < E_c = \text{critical field}$$

$$v = v_{sat} = \frac{\mu_e E_c}{2}, \quad E_y \geq E_c$$

A redevelopment of previous eqs. gives,
Linear region:

$$i_{DS} = \frac{W}{L} \left(\frac{\mu_e (ox)}{1 + \frac{N_{DS}}{E_c L}} \right) \left(N_{GS} - V_T - \frac{N_{DS}}{2} \right) N_{DS} (1 + \lambda N_{DS})$$

Saturation Region:

$$i_{DS} = i_D = W C_{ox} (N_{GS} - V_T - N_{DS}) N_{sat} = W C_{ox} (N_{GS} - V_T - N_{DS}) \frac{\mu_0 E_c}{2}$$

$$i_{DS} = \frac{W \mu_0 C_{ox} E_c}{2} (N_{GS} - V_T - N_{DS})$$

What is $N_{DS}(\text{sat})$?

Equate the two currents (linear & sat.) and solve for $N_{DS}(\text{sat})$

$$\frac{W}{L} \left(\frac{\mu_0 C_{ox}}{1 + \frac{N_{DS}}{E_c L}} \right) (N_{GS} - V_T - \frac{N_{DS}}{2}) N_{DS} = \frac{W \mu_0 C_{ox} E_c}{2} (N_{GS} - V_T - N_{DS})$$

$$\frac{W \mu_0 C_{ox} E_c}{E_c L + N_{DS}} (N_{GS} - V_T - \frac{N_{DS}}{2}) N_{DS} = \frac{W \mu_0 C_{ox} E_c}{2} (N_{GS} - V_T - N_{DS})$$

$$N_{GS} N_{DS} - V_T N_{DS} - \frac{N_{DS}^2}{2} = \frac{1}{2} (N_{GS} - V_T - N_{DS}) (E_c L + N_{DS})$$



$$N_{DS} [(N_{GS} - V_T) + E_c L] = E_c L (N_{GS} - V_T)$$

$$\therefore N_{DS}(\text{sat}) = \frac{E_c L (N_{GS} - V_T)}{(N_{GS} - V_T) + E_c L}$$

Next write eq. for saturation

$$\begin{aligned} \therefore i_{DS} &= W C_{ox} (N_{GS} - V_T - N_{DS}) N_{sat} = W C_{ox} \left[N_{GS} - V_T - \frac{(N_{GS} - V_T) E_c L}{(N_{GS} - V_T) + E_c L} \right] \\ &= W C_{ox} N_{sat} \left[\frac{(N_{GS} - V_T)^2}{(N_{GS} - V_T) + E_c L} \right] = \frac{W \mu_0 E_c C_{ox}}{2} \left[\frac{(N_{GS} - V_T)^2}{(N_{GS} - V_T) + E_c L} \right] \end{aligned}$$

When $N_{DS} > N_{DS}(\text{sat})$

$$\text{or } i_{DS} = \frac{W \mu_0 C_{ox} E_c}{2} \left[\frac{(N_{GS} - V_T)^2}{(N_{GS} - V_T) + E_c L} \right] (1 + \lambda N_{DS})$$