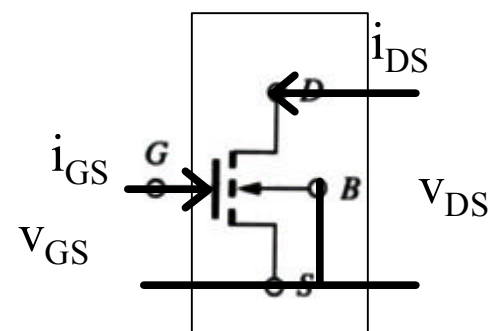
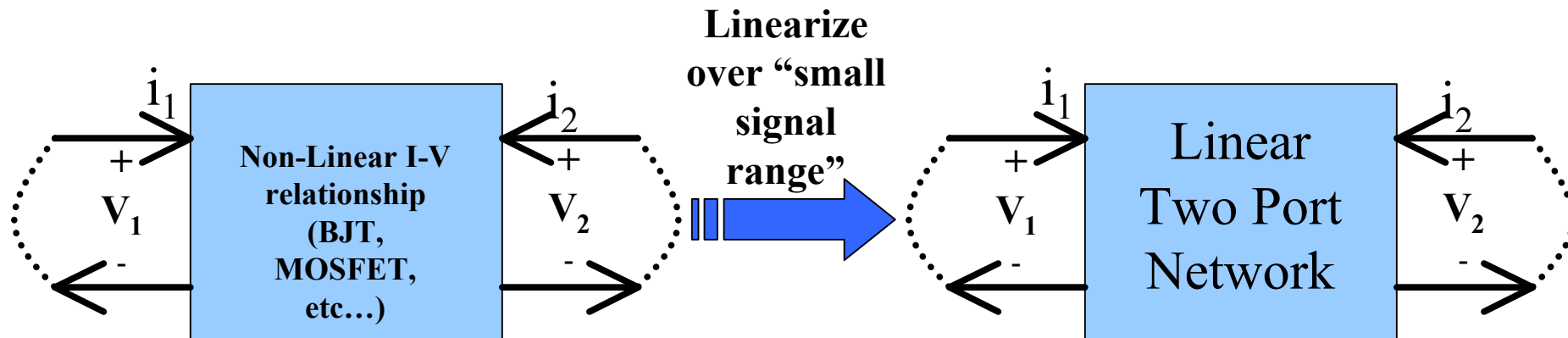


MOSFET Small Signal Model and Analysis

- Just as we did with the BJT, we can consider the MOSFET amplifier analysis in two parts:
- Find the DC operating point
- Then determine the amplifier output parameters for very small input signals.

MOSFET Small Signal Model and Analysis



General “y-parameter” Network MOSFET “y-parameter” Network

$$I_1 = y_{11} V_1 + y_{12} V_2$$

$$I_{GS} = y_{11} V_{GS} + y_{12} V_{DS}$$

$$I_2 = y_{21} V_1 + y_{22} V_2$$

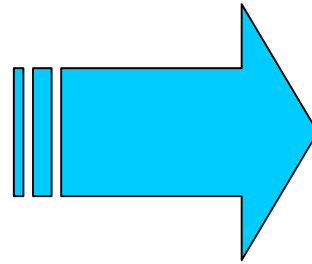
$$I_{DS} = y_{21} V_{GS} + y_{22} V_{DS}$$

MOSFET Small Signal Model and Analysis

$$\begin{bmatrix} I_{GS} \\ I_{DS} \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_{GS} \\ V_{DS} \end{bmatrix}$$

$$I_{GS} = y_{11} V_{GS} + y_{12} V_{DS}$$

$$I_{DS} = y_{21} V_{GS} + y_{22} V_{DS}$$



$$y_{ij} = \left. \frac{\partial I_j}{\partial V_i} \right|_{V_{GS,Q}, V_{DS,Q}}$$

Derivative of current-voltage equation evaluated at the Quiescent Point

MOSFET Amplifiers are biased into Saturation (or Active Mode)

$$I_{DS} = \frac{K_n}{2} [(V_{GS} - V_{TN})^2] (1 + \lambda V_{DS}) \quad \text{for } V_{DS} \geq V_{GS} - V_{TN}$$

1.) Input Conductance

$$I_{GS} = 0 \Rightarrow \frac{\partial I_{GS}}{\partial V_{GS}} = 0 \quad \text{and} \quad \frac{\partial I_{GS}}{\partial V_{DS}} = 0 \Rightarrow y_{11} = 0 \quad \text{and} \quad y_{12} = 0$$

2.) Output Conductance

$$\frac{\partial I_{DS}}{\partial V_{DS}} = y_{22} = \frac{\lambda K_n}{2} (V_{GS} - V_T)^2$$

3.) Transconductance

$$\frac{\partial I_{DS}}{\partial V_{GS}} = y_{21} = K_n (V_{GS} - V_T) (1 + \lambda V_{DS})$$

MOSFET Small Signal Model and Analysis

Compare with BJT Results

There is a large amount of symmetry between the MOSFET and the BJT

MOSFET

BJT

$$y_{22} = g_o = \frac{I}{2} K_n (V_{GS} - V_T)^2 = \frac{I_{DS}}{\frac{1}{I} + V_{DS}}$$

**Each of these
parameters
act in the
same manner**

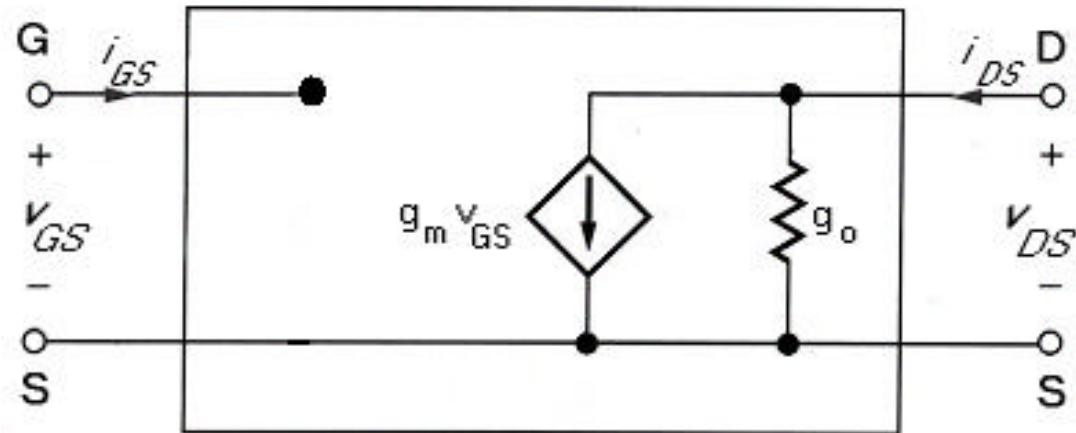
$$y_{22} = \frac{I_C}{V_A + V_{CE}}$$

$$y_{21} = g_m = K_n (V_{GS} - V_T)(1 + I V_{DS}) = \frac{I_{DS}}{\left(\frac{V_{GS} - V_{TN}}{2}\right)}$$

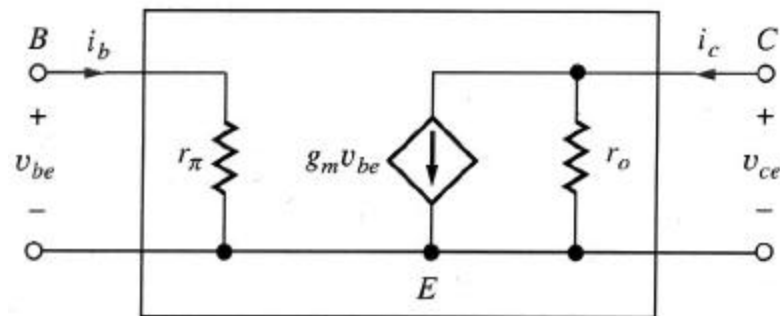
$$y_{21} = \frac{I_C}{V_T}$$

MOSFET Small Signal Model and Analysis

Putting the mathematical model into a small signal equivalent circuit

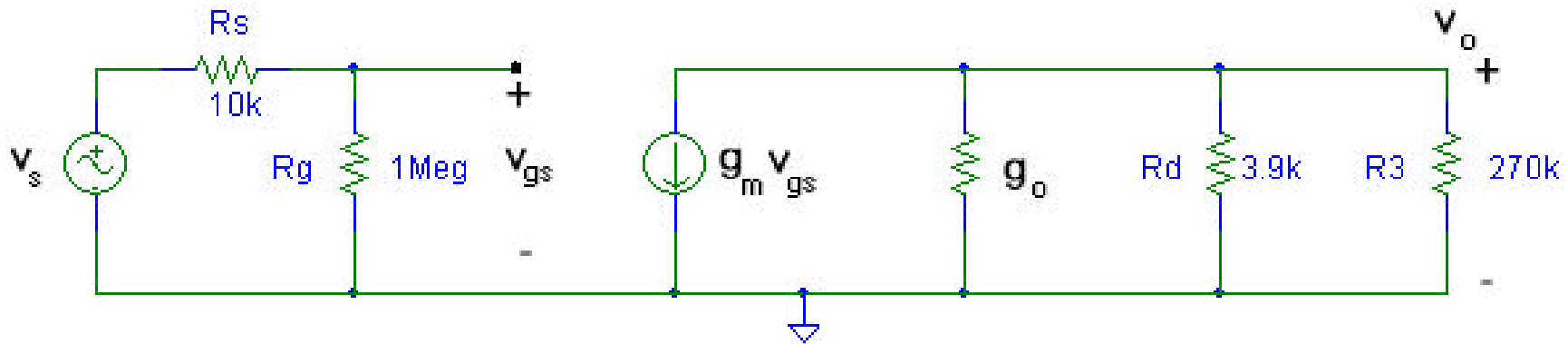


Compare this to the BJT small signal equivalent circuit



MOSFET Small Signal Model and Analysis

Example: Jaeger 13.94



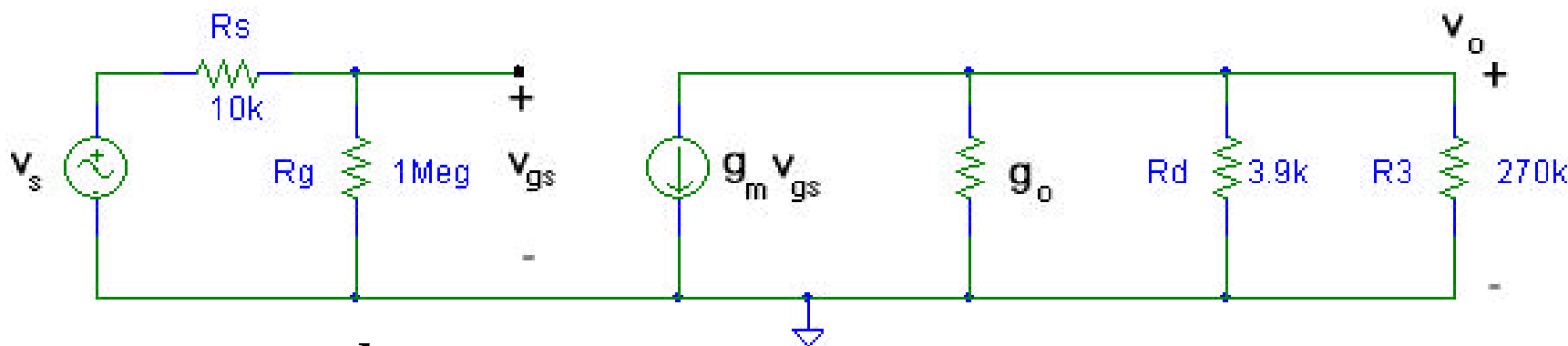
Calculate the voltage gain, $A_v = v_o/v_s$

Given: $K_n = 1 \text{ mA/V}^2$, $\lambda = 0.015 \text{ V}^{-1}$

Bias Point of: $I_{DS} = 2 \text{ mA}$, $V_{DS} = 7.5 \text{ V}$

MOSFET Small Signal Model and Analysis

Example: Jaeger 13.94



$$g_o = \frac{1}{2} K_n (V_{GS} - V_T)^2 \quad g_m = K_n (V_{GS} - V_T) (1 + \lambda V_{DS})$$

Need to find $V_{GS} - V_T$

$$I_{DS} = \frac{K_n}{2} [(V_{GS} - V_{TN})^2] (1 + \lambda V_{DS})$$

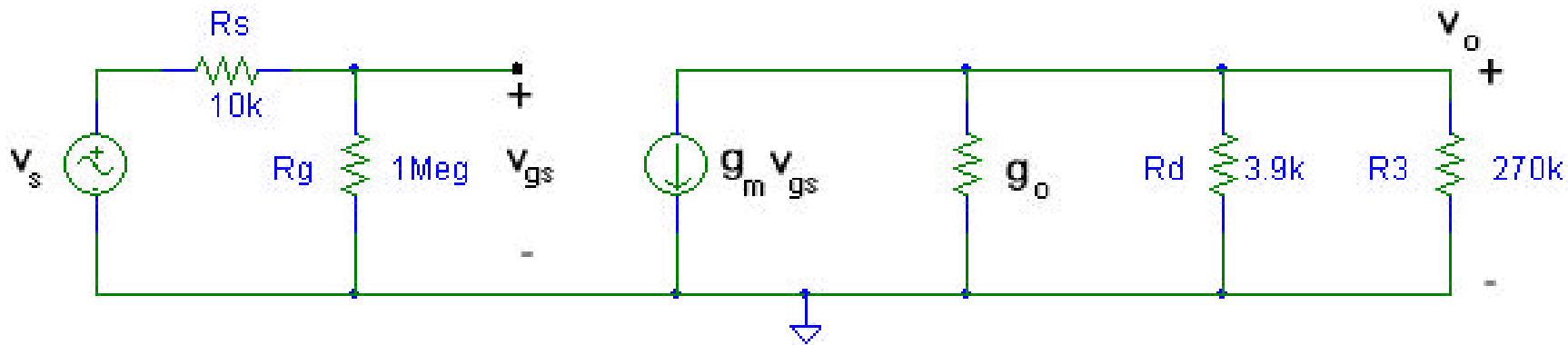
$$2 \text{ mA} = \frac{1 \text{ mA/V}^2}{2} [(V_{GS} - V_{TN})^2] (1 + 0.015 (7.5))$$

$$V_{GS} - V_{TN} = \sqrt{\frac{4}{1.11}} = 1.9 \text{ V}$$

$$\therefore g_m = 2.11 \text{ mS} \quad g_o = 27.1 \text{ mS} \Rightarrow r_o = 36.9 \text{ k}\Omega$$

MOSFET Small Signal Model and Analysis

Example: Jaeger 13.94



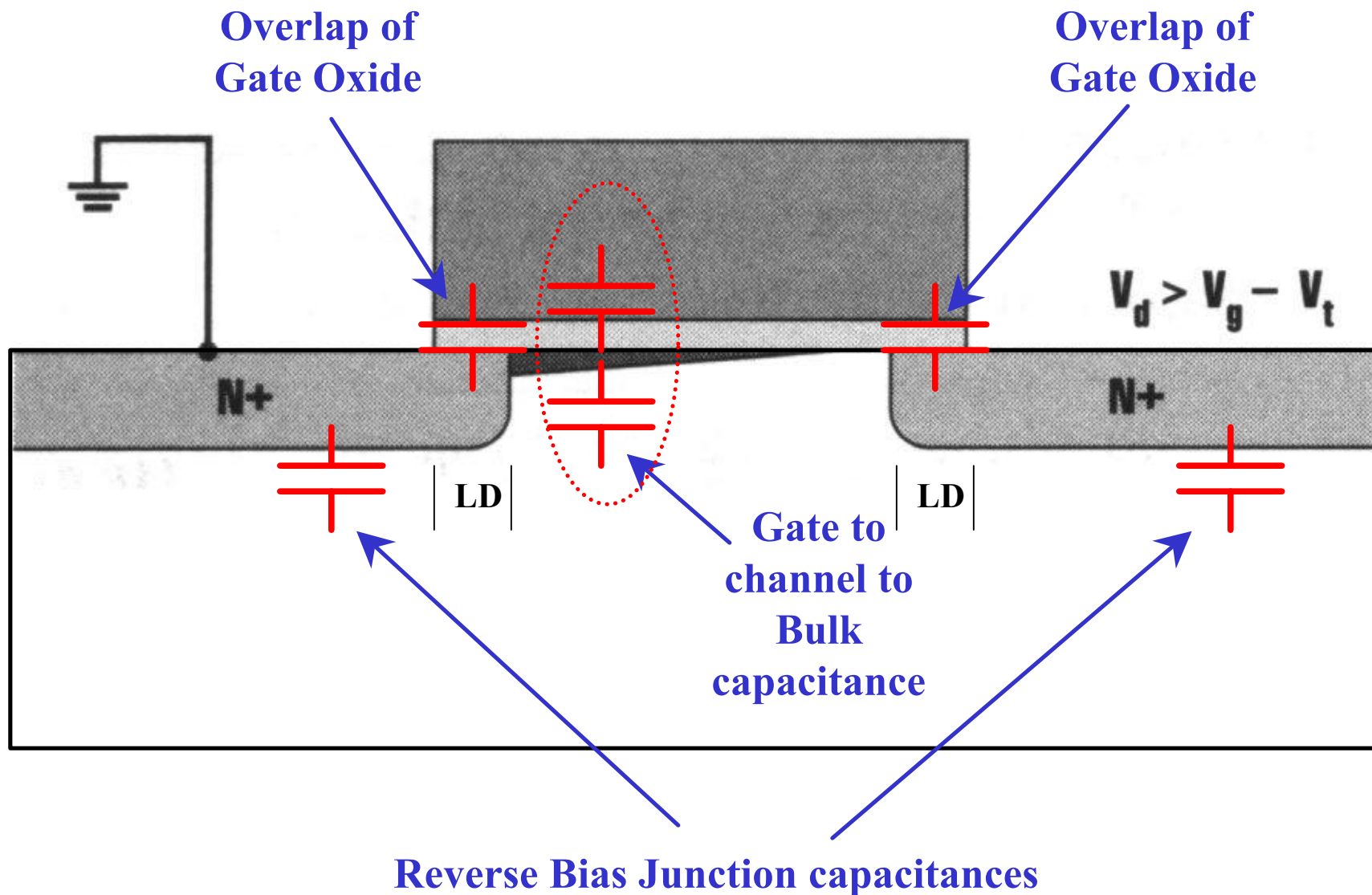
$$A_v = \frac{v_o}{v_s} = \frac{v_{GS}}{v_s} \frac{v_o}{v_{GS}}$$

$$\frac{v_{GS}}{v_s} = \frac{1\text{Meg}}{10k + 1\text{Meg}} = 0.99 \quad \text{and} \quad \frac{v_o}{v_{GS}} = -g_m (r_o \parallel R_d \parallel R_3) = -2.1\text{mS}(3.48k) = -7.35$$

$$\therefore A_v = \frac{v_o}{v_s} = \frac{v_{GS}}{v_s} \frac{v_o}{v_{GS}} = -7.27 \text{ [V/V]}$$

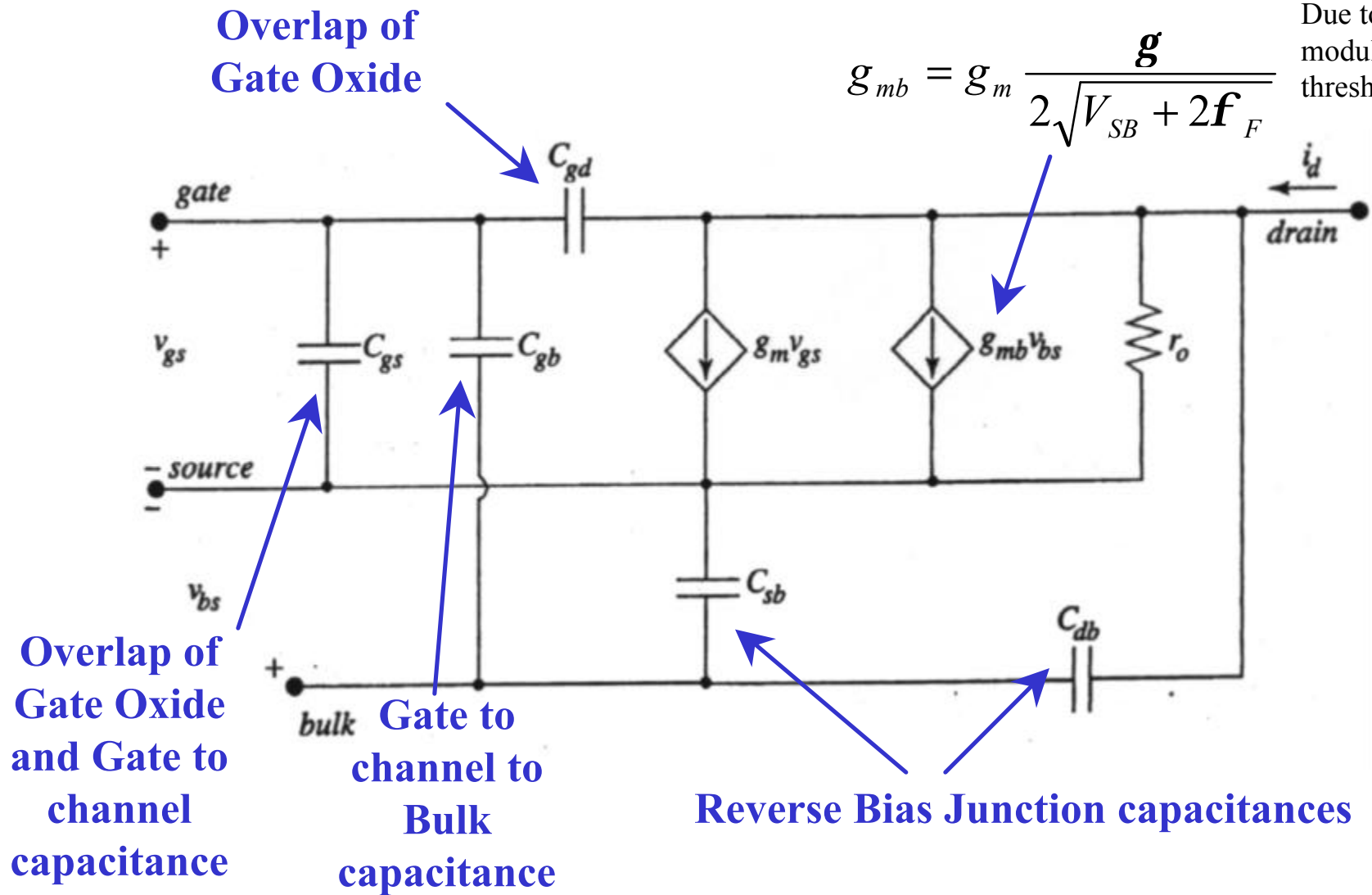
MOSFET Small Signal Model and Analysis

Add in capacitances



MOSFET Small Signal Model and Analysis

Complete Model of a MOSFET



MOSFET Small Signal Model and Analysis

SPICE MOSFET Model

SPICE models the drain current (I_{DS}) of an n-channel MOSFET using the following parameters/equations (SPICE variables are shown in ALL CAPITAL LETTERS)

Cutoff: $I_{DS} = 0$

Linear:

$$I_{DS} = \frac{KP}{2} \left(\frac{W}{L_{EFF}} \right) V_{DS} [2(V_{GS} - V_{TH}) - V_{DS}] (1 + (LAMBDA) V_{DS})$$

Saturation:

$$I_{DS} = \frac{KP}{2} \left(\frac{W}{L_{EFF}} \right) [(V_{GS} - V_{TH})^2] (1 + (LAMBDA) V_{DS})$$

Threshold Voltage:

$$V_{TH} = V_{TO} + GAMMA (\sqrt{2PHI - V_{BS}} - \sqrt{2PHI})$$

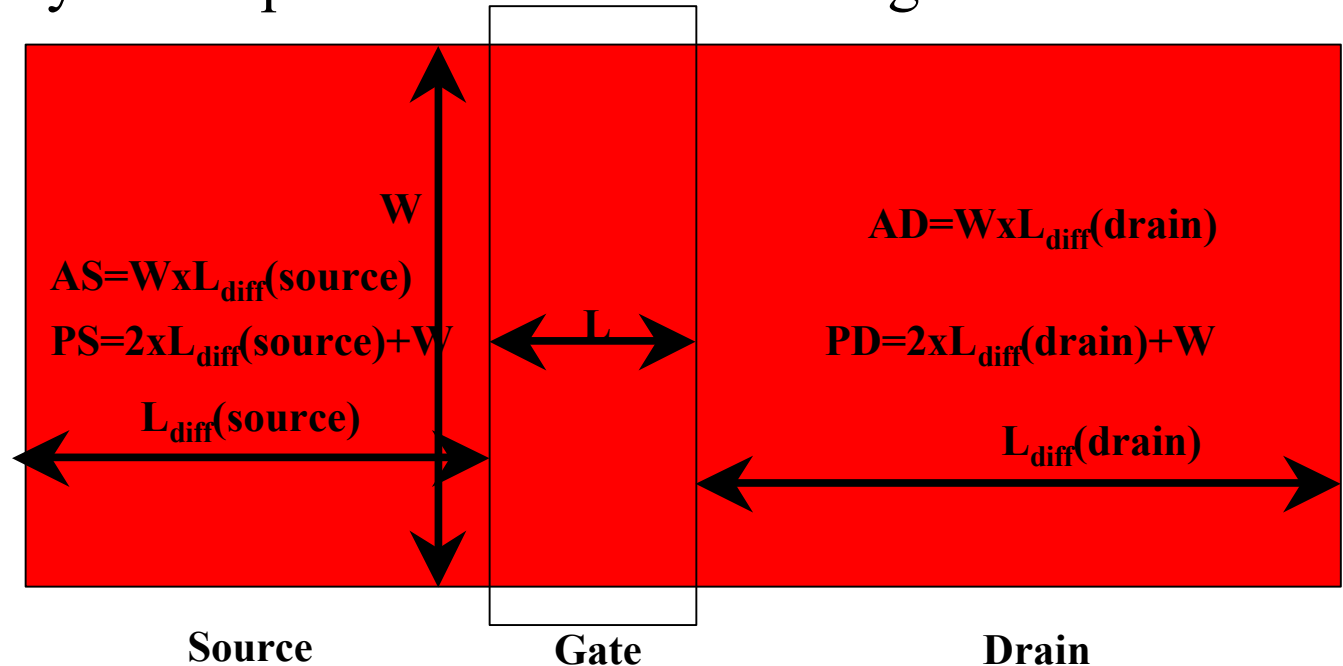
Channel Length

$$L_{EFF} = L - 2LD$$

MOSFET Small Signal Model and Analysis

SPICE MOSFET Model – Additional Parameters

SPICE takes many of its parameters from the integrated circuit layout design:



L = polysilicon gate length

W = polysilicon gate width

AD = drain area

AS = source area

PD = perimeter of drain diffusion (not including edge under gate)

PS = perimeter of source diffusion (not including edge under gate)

NRD = number of “squares” in drain diffusion

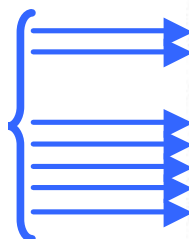
NRS = number of “squares” in source diffusion

} Specified in terms of the
minimum feature size

MOSFET Small Signal Model and Analysis

SPICE MOSFET Model – Additional Parameters

Most
Used



Model Parameters (see .MODEL statement)	Default value	Units
LEVEL	1	
L	DEFL	meter
W	DEFW	meter
LD	0	meter
WD	0	meter
VTO	0	volt
KP	2E - 5	amp/volt ²
GAMMA	0	volt ^{1/2}
PHI	.6	volt
LAMBDA	0	volt ⁻¹
RD	0	ohm
RS	0	ohm
RG	0	ohm
RB	0	ohm
RDS	infinite	ohm
RSH	0	ohm/square
IS	1E - 14	amp
JS	0	amp/meter ²
PB	.8	volt
CBD	0	farad
CBS	0	farad
CJ	0	farad/meter ²
CJSW	0	farad/meter
MJ	.5	
MJSW	.33	
FC	.5	
CGSO	0	farad/meter
CGDO	0	farad/meter
CGBO	0	farad/meter
NSUB	0	1/cm ³
NSS	0	1/cm ²
NFS	0	1/cm ²
TOX	infinite	meter
TPG	+1	
	+1 = opposite of substrate	
	-1 = same as substrate	
	0 = aluminum	
XJ	0	meter
UO	600	cm ² /volt·sec
UCRIT	1E4	volt/cm
UEXP	0	
UTRA	(not used)	mobility degradation transverse field coefficient
VMAX	0	meter/sec
NEFF	1	
XQC	1	
DELTA	0	
THETA	0	volt ⁻¹
ETA	0	
KAPPA	.2	
KF	0	
AF	1	

MOSFET Amplifiers

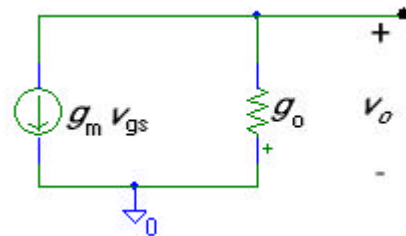
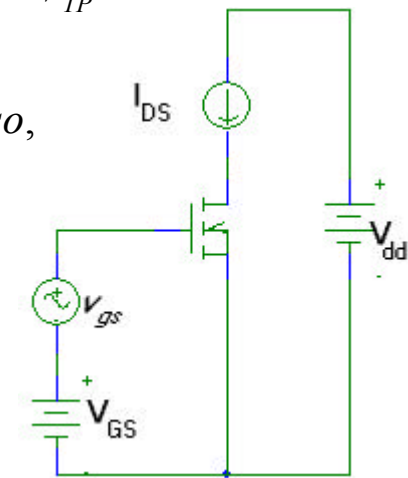
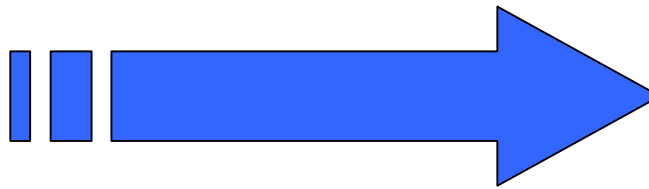
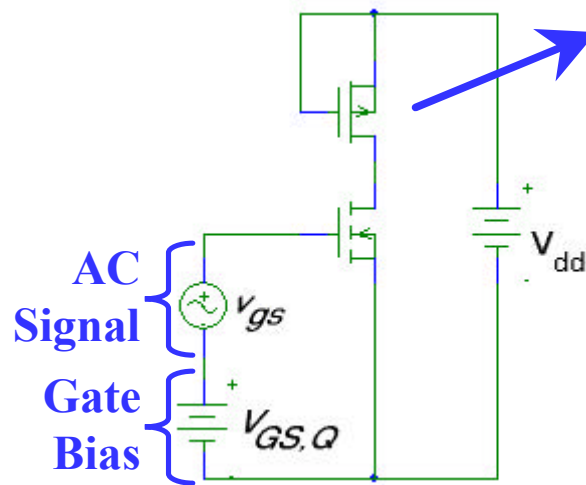
What is the Maximum Gain Possible?

Is it saturated (Constant current)?, $V_{DS} > V_{GS} - V_{TP}$

but $V_{DS} = V_{GS}$

and $V_{TP} \geq 0$ for a depletion mode MOSFET so,

$0 > -V_{TP}$ is always satisfied. \Rightarrow Is Saturated!



g_o is internal to the transistor and can not be avoided. Any additional resistor due to external circuitry will lower the gain. For this reason current sources are often used as the “load” instead of bias resistors in amplifier circuits.

$$A_{v,Max} = -g_m v_o$$

$$A_{v,Max} = -\frac{K_n (V_{GS} - V_T)(1 + I V_{DS})}{I K_n (V_{GS} - V_T)^2}$$

$$A_{v,Max} = -\frac{(1 + I V_{DS})}{I (V_{GS} - V_T)}$$