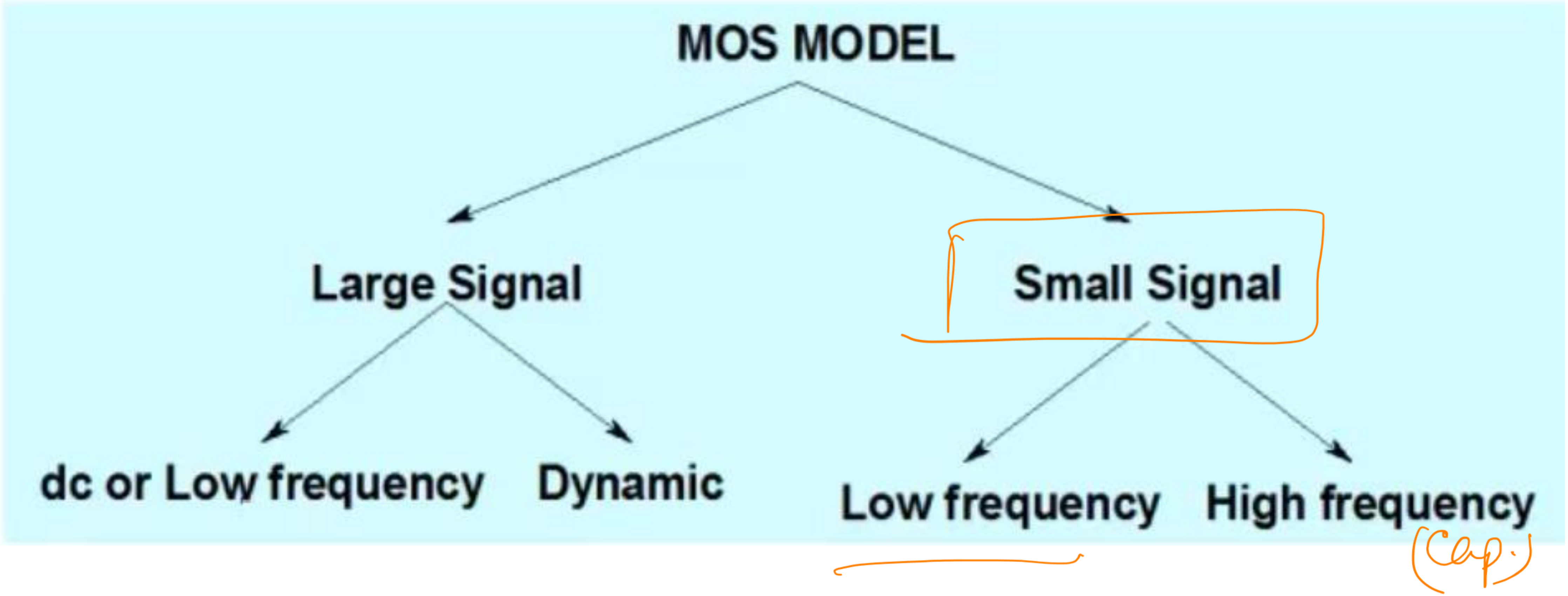
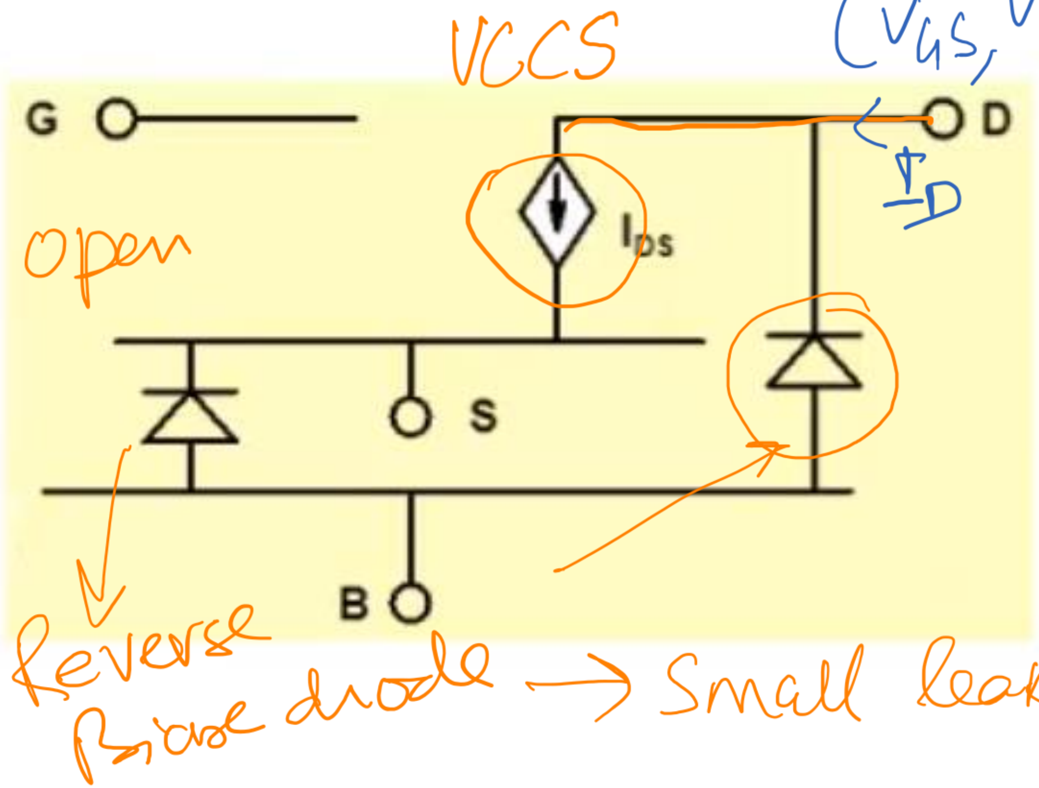
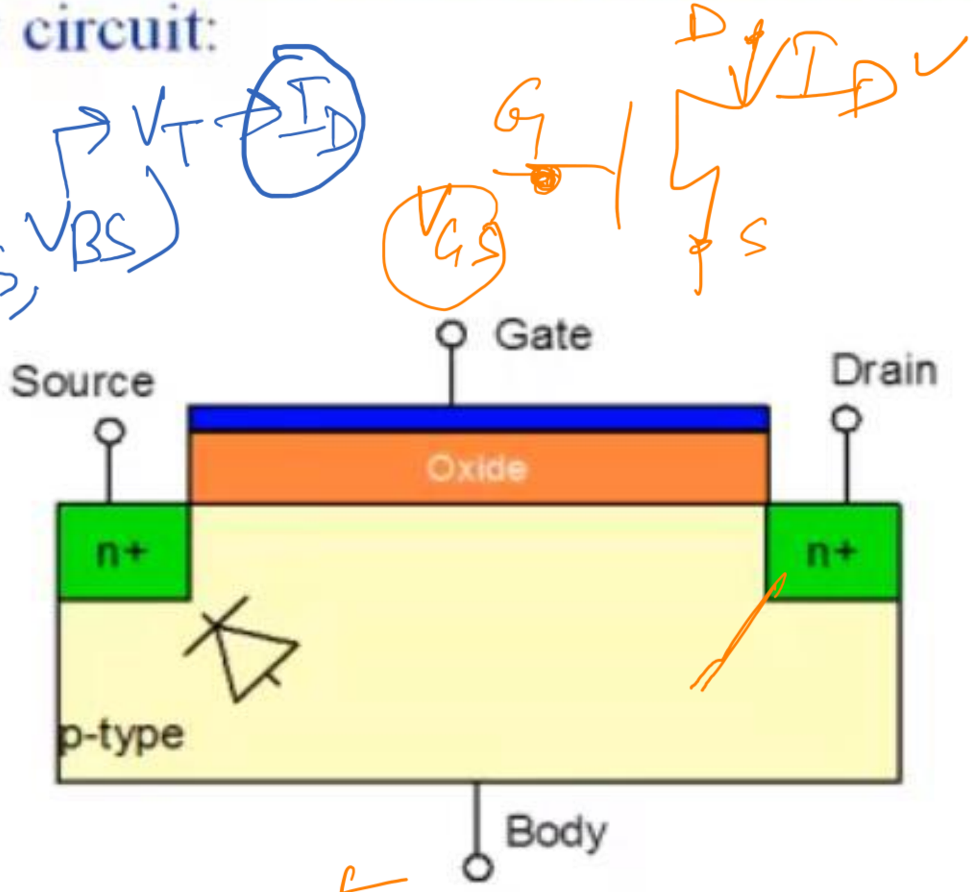
MOS models : The classification of models can be done on the basis of magnitude and frequency of applied voltages



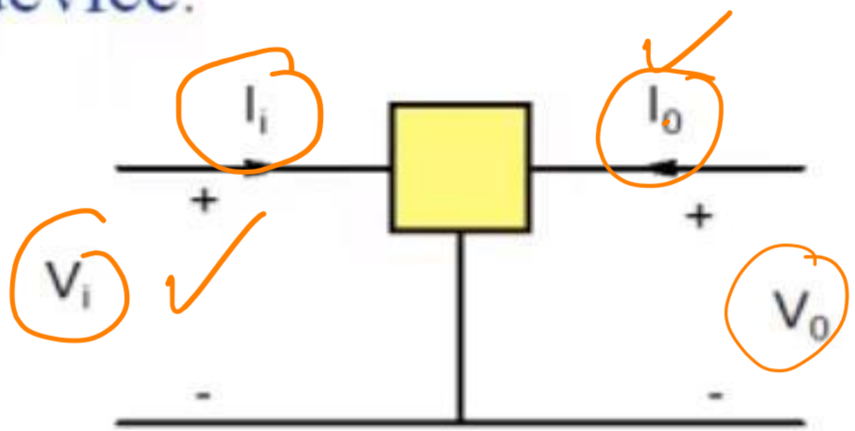
The dc model of the transistor in triode and saturation region can be represented in the form of an equivalent circuit:

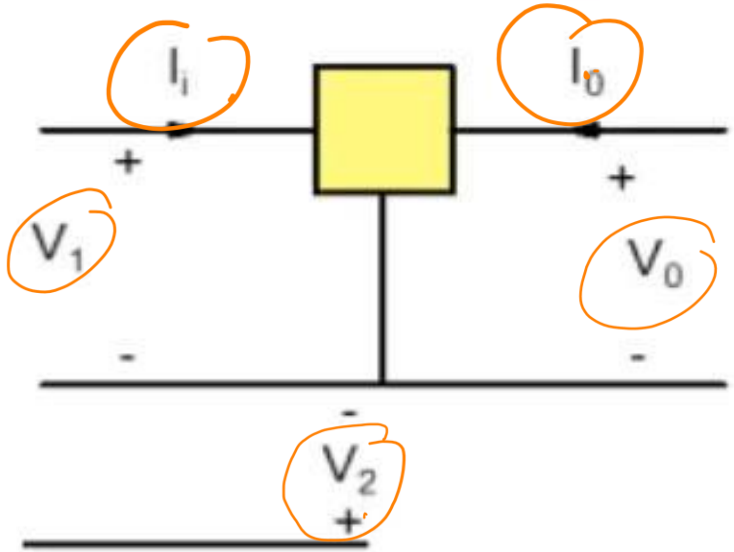


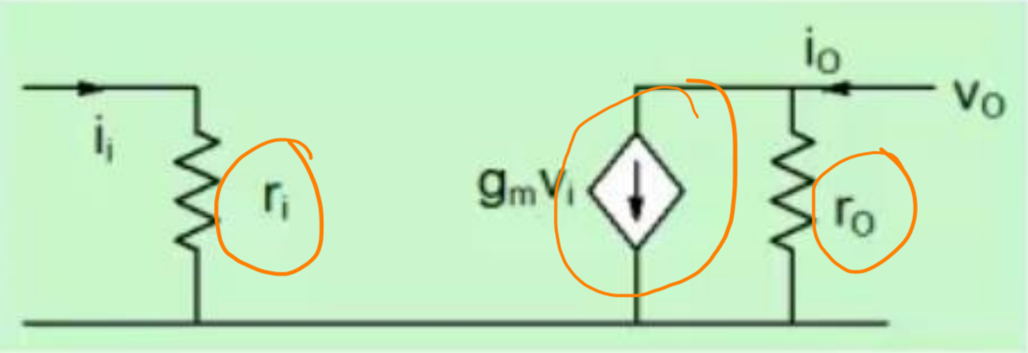


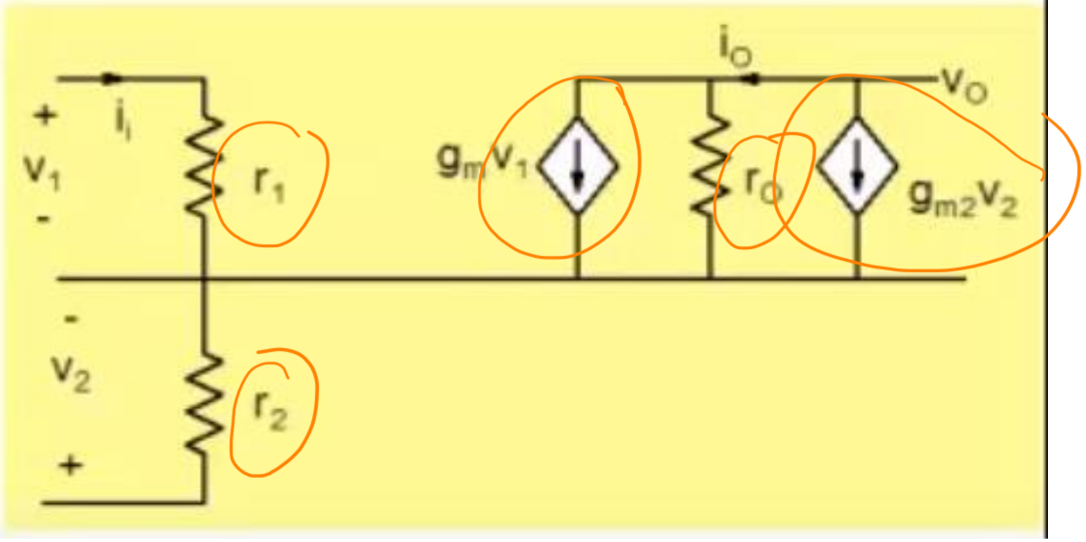
Series resistance associated with gate, source, drain and body terminals is not shown but can play an important role.

Complete small signal model (dc) for a 3-terminal unilateral device.



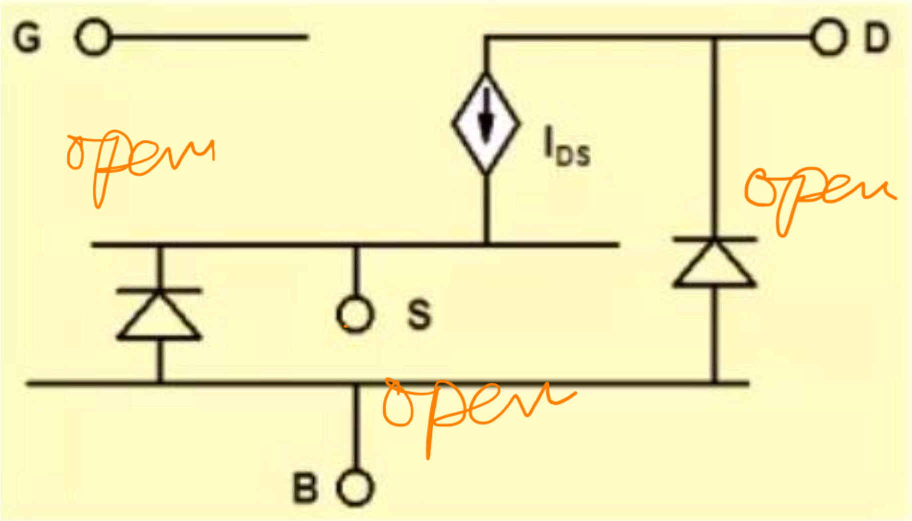






Small Signal Model (dc/low frequency)

Saturation



$$I_{ds} = \frac{\beta_N}{2}\left(V_{gs} - V_{THN}\right)^2 (1 + \lambda_n V_{ds})$$

Small signal (dc)

Bias

$$V_{gs} = \underbrace{V_{GSQ}}_{\text{Bias}} + \underbrace{v_{gs}}_{\text{Small signal}}$$

Bias Small

$$V_{ds} = V_{DSQ} + v_{ds}$$

$$V_{sb} = V_{SBQ} + v_{sb}$$

$$I_{ds} = I_{DSQ} + i_{ds}$$

$$I_{DSQ} + i_{ds} = \frac{\beta_N}{2}\left[V_{GSQ} + v_{gs} - V_{THN}\left(V_{BSQ} + v_{bs}\right)\right]^2\left(1 + \lambda_n V_{DSQ} + \lambda_n v_{ds}\right)$$

not really multiplication, but function

$V = IR$

$I = \frac{V}{R}$

$$i_{ds} \cong I_{DSQ}\left\{\left(\lambda_n v_{ds} + \frac{2v_{gs}}{V_{GSQ} - V_{THN}} + \frac{\gamma \times v_{bs}}{(V_{GSQ} - V_{THN}) \times \sqrt{2\varphi_F - V_{BSQ}}}\right)\right\}$$

$I_{DSQ} = \beta(V_{GS} - V_T)^2$

$V_{GS} - V_T = \sqrt{\frac{I_{DSQ}}{\beta}}$

$$i_{ds} = \frac{v_{ds}}{r_o} + g_m v_{gs} + g_{mb} v_{bs}$$

$i_{ds} = I_{DSQ} \cdot \lambda_n v_{ds}$

$r_o = \frac{1}{\lambda_n I_{DSQ}}$

$$r_o = \frac{1}{\lambda_n I_{DSQ}}$$

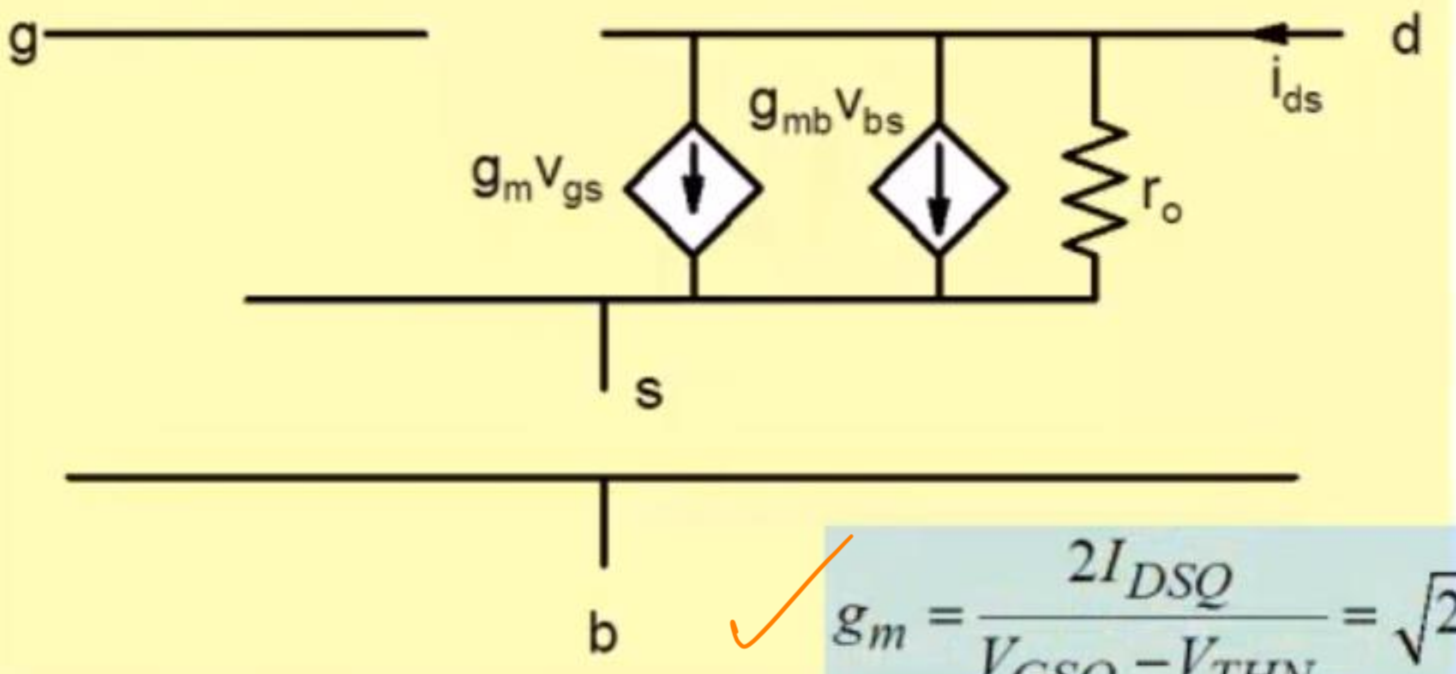
$$g_m = \frac{2I_{DSQ}}{V_{GSQ} - V_{THN}} = \boxed{\sqrt{2I_{DSQ}\beta}}$$

$$g_{mb} = g_m . \eta$$

$$\eta = \frac{\gamma}{2\sqrt{2\Phi_F + V_{SBQ}}}$$

Low frequency Small Signal model

$$i_{ds} = g_m v_{gs} + g_{mb} v_{bs} + \frac{v_{ds}}{r_o}$$



$$g_m = \frac{2I_{DSQ}}{V_{GSQ} - V_{THN}} = \sqrt{2I_{DSQ}\beta}$$

$$r_o = \frac{1}{\lambda_n I_{DSQ}}$$

$$g_{mb} = g_m . \eta$$

$$\eta = \frac{\gamma}{2\sqrt{2\Phi_F + V_{SBQ}}}$$

The small signal approximation $i_{ds} = g_m v_{gs}$ is accurate when

$v_{gs} << 2(V_{GS} - V_{THN})$

In BJT:

$v_{be} < V_T = \frac{KT}{q}$

$= 26mV$

In MOS

$\frac{v_{gs}}{V_{GS} - V_{THN}} << 2$

5%

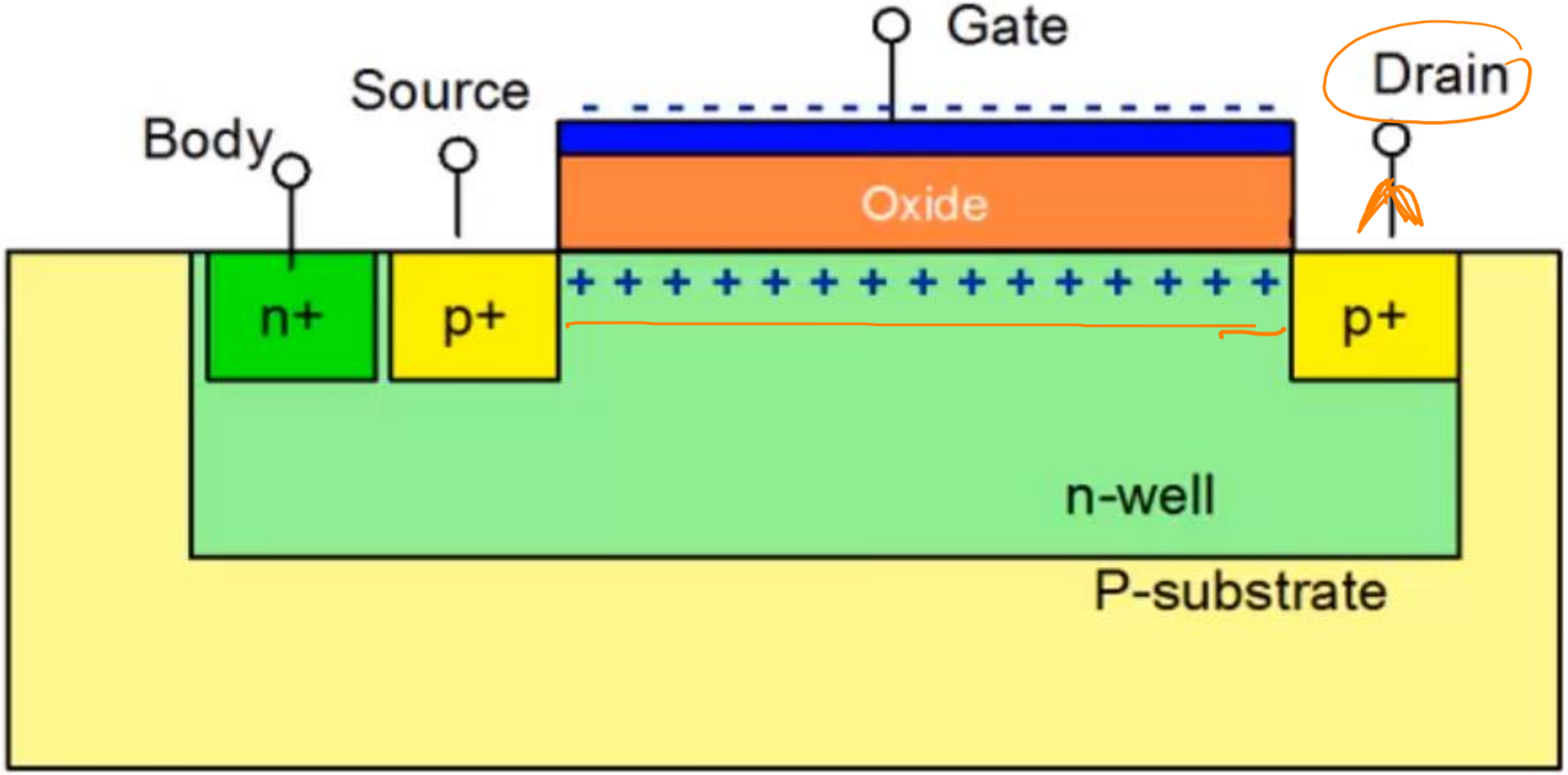
10%

$v_{gs} \approx 0.2(V_{GS} - V_T)$

$0.2 \approx 200mV$

$\frac{v_{gs}}{V_{GS} - V_T}$	+0.1	−0.1	+0.2	−0.2	—	—	—
Err%	−4.7	5.26	−9.1	11.11	—	—	—

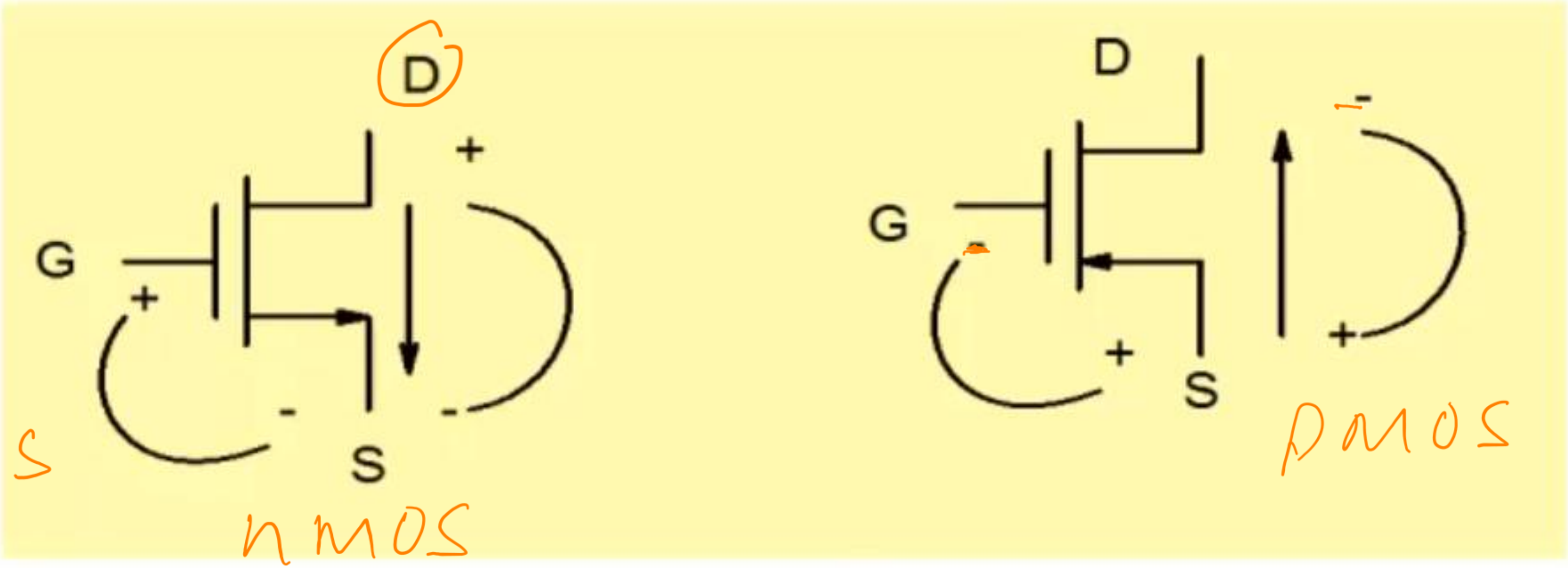
PMOS



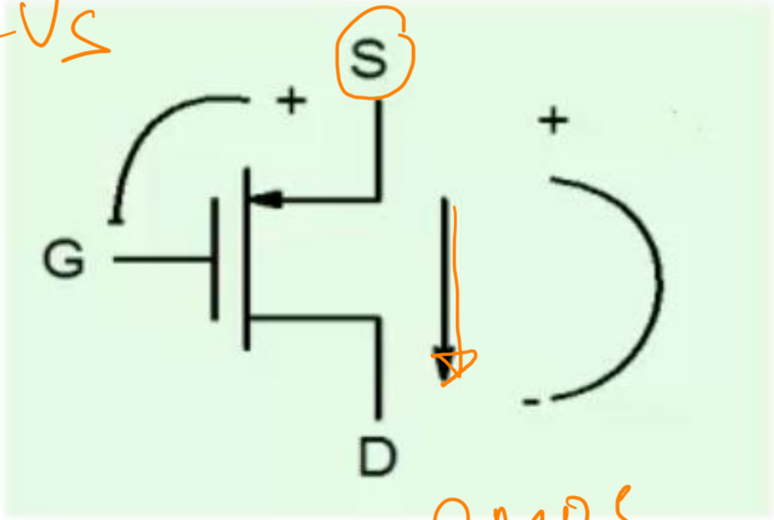
V_{GS} is negative ; Threshold voltage V_{TP} is negative

V_{DS} is negative ; I_{DS} is negative

Vgs



Vgs = Vg - Vs



$$V_{GSN} \rightarrow V_{SGP}$$

$$I_{DSN} \rightarrow I_{SDP}$$

$$V_{DSN} \rightarrow V_{SDP}$$

Transformations

$$V_{GSN} \to V_{SGP} \qquad V_{DSN} \to V_{SDP} \qquad V_{BSN} \to V_{SBP}$$

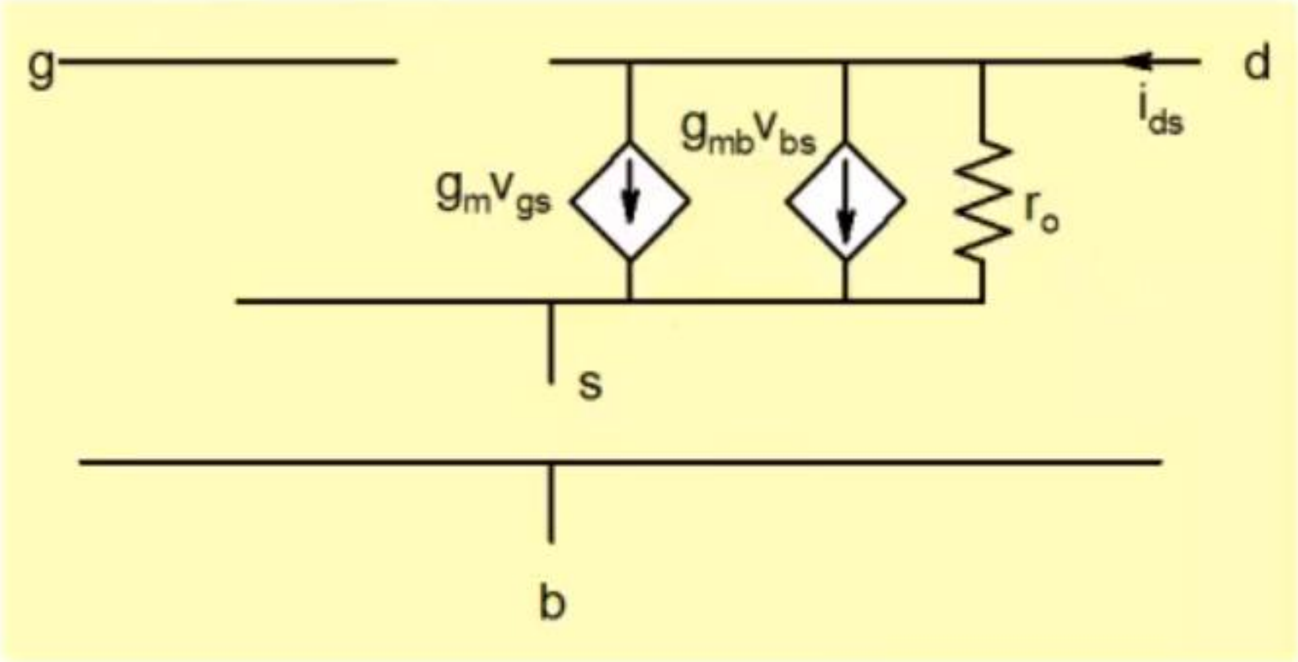
$$V_{THN} \to -V_{THP} \qquad I_{DSN} \to I_{SDP}$$

$$I_{DS} = \frac{\beta_N}{2}(V_{GS} - V_{THN})^2[1 + \lambda_n V_{DS}] \to$$

$$I_{SD} = \frac{\beta_P}{2}(V_{SG} + V_{THP})^2[1 + \lambda_p V_{SD}]$$

$$i_{sd} = g_m v_{sg} + g_{mb} v_{sb} + \frac{v_{sd}}{r_o} \qquad i_{ds} = g_m v_{gs} + g_{mb} v_{bs} + \frac{v_{ds}}{r_o}$$ same as NMOS

Small Signal Model

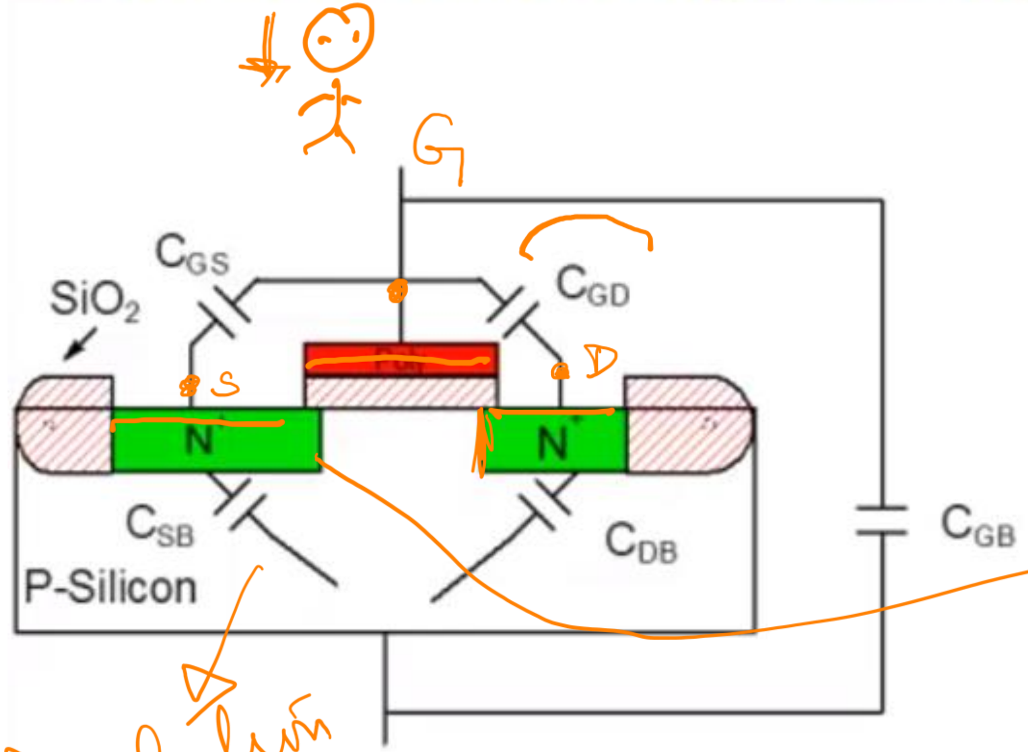


$$g_m = \frac{2I_{SDQ}}{V_{SGQ} + V_{THP}}$$

$$r_o = \frac{1}{\lambda_p I_{SDQ}}$$

Capacitance Model   Saturation

- . There are five distinct components of capacitance as illustrated below

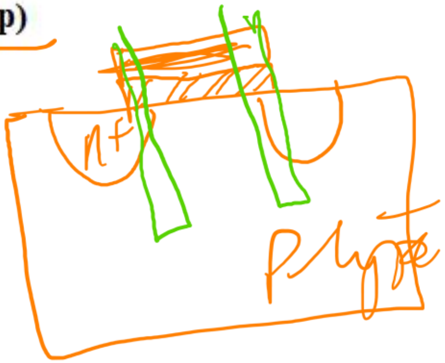


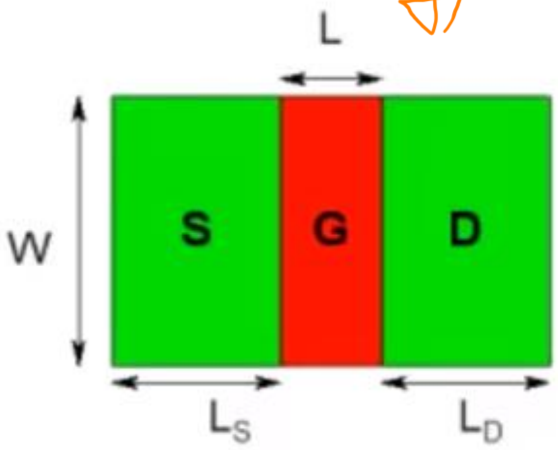
Depletion cap (PN jn)

$$C_{gs} \cong \frac{2}{3} C_{ox}'.W.L + C_{gso}.W$$

(Channel)   (overlap)

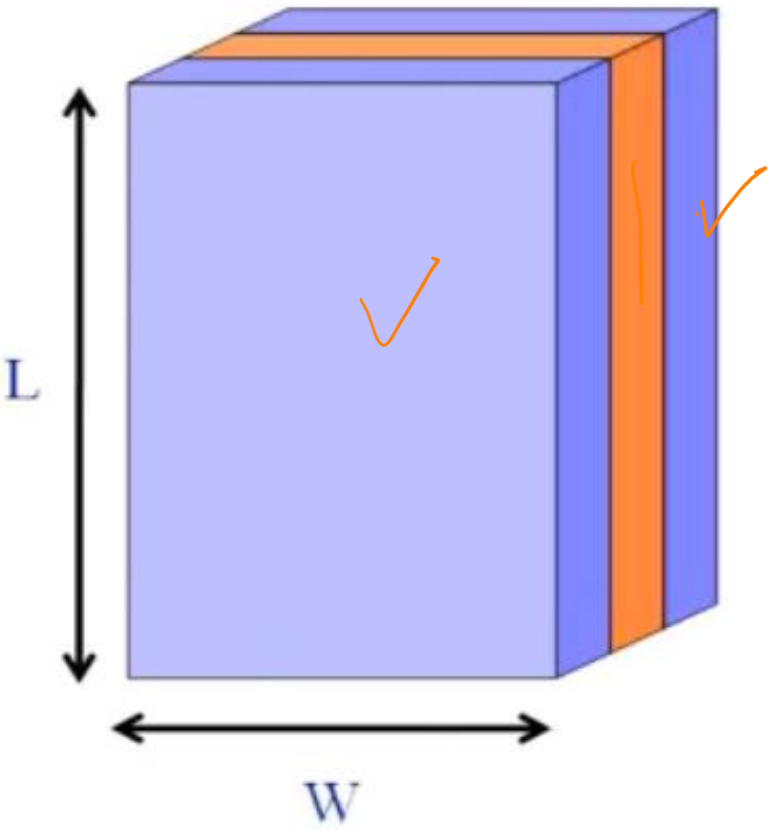
$$C_{gd} = C_{GDO}.W$$

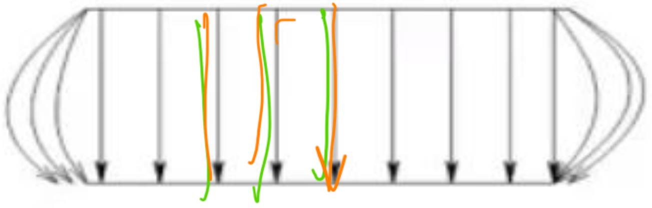




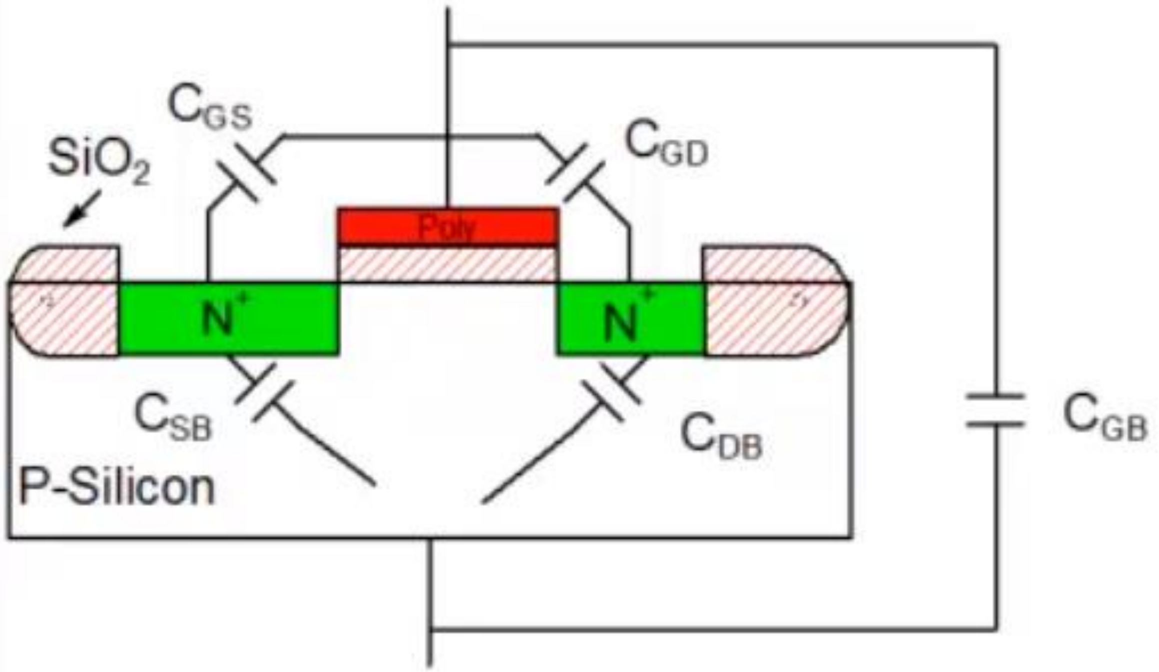
Capacitances: Area and Perimeter Components

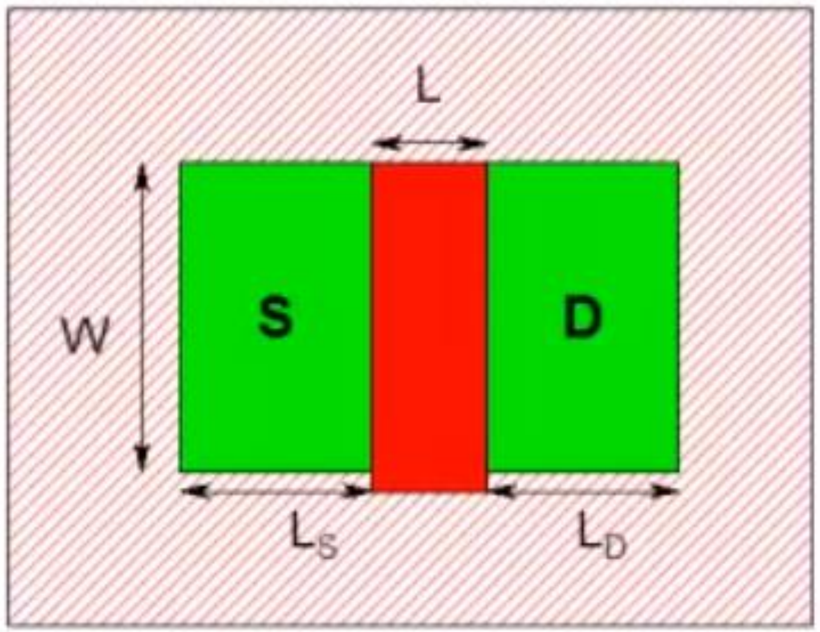
Fringe





$$C = \frac{\varepsilon}{d} \times W \times L + \boxed{C_p \times (2L + 2W)}$$



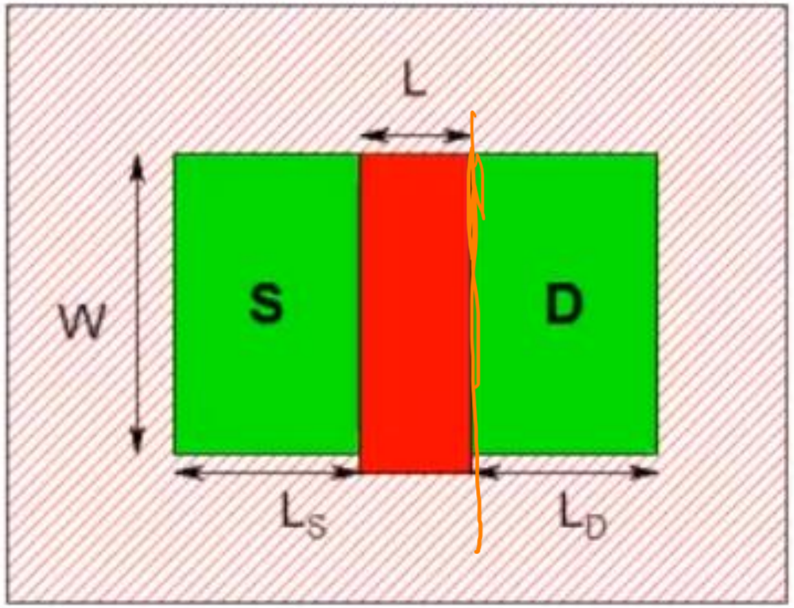


$$\uparrow C_{sb} = \frac{C_j . A_s}{\left(1 + \frac{V_{SB}}{P_B}\right)^{M_j}} + \frac{C_{jsw} . P_S}{\left(1 + \frac{V_{SB}}{P_{BSW}}\right)^{M_{jsw}}}, \quad P_S = 2L_S + \overset{\cancel{2W}}{W}, \quad A_s = W . L_S$$

already taken in overlap part

$$C_{db} = \frac{C_{jsw}.P_D}{\left(1+\frac{V_{DB}}{P_{BSW}}\right)^{M_{jsw}}} + \frac{C_j.A_D}{\left(1+\frac{V_{DB}}{P_B}\right)^{M_j}} \quad P_D = 2L_D + W$$

$C_{gb} = C_{GBO}.L \sim$ often negligible



V_DS

Triode/Linear Region

$$C_{gs} = \frac{1}{2} C_{ox'} . W . L + C_{GSO} . W$$

$$C_{gd} = \frac{1}{2} C_{ox'} . W . L + C_{GDO} . W$$

$$C_{sb} = same\ as\ before$$

$$C_{db} = same\ as\ before$$

$$C_{gb} = same\ as\ before$$

Assuming V_{DS} ~0

Cutoff Region

$$\boxed{C_{gs} = C_{GSO} . W}$$

$$C_{gd} = C_{GDO} . W$$

$$C_{sb} = same\ as\ before$$

$$C_{db} = same\ as\ before$$

$$C_{gb} = C_{GBO} . L + C_{ox'} . W . L$$

Assuming Tr. is in accumulation

Summary

$$C_{gs} \cong \frac{2}{3} C_{ox}' W.L + C_{gso}.W \qquad C_{gd} = C_{GDO}.W$$

[Um]

$$C_{sb} = \frac{C_j.A_s}{\left(1 + \frac{V_{SB}}{P_B}\right)^{M_j}} + \frac{C_{jsw}.P_S}{\left(1 + \frac{V_{SB}}{P_{BSW}}\right)^{M_{jsw}}}, \quad P_S = 2L_S + W \quad , \quad A_s = W.L_S$$

$$C_{db} = \frac{C_{jsw}.P_D}{\left(1 + \frac{V_{DB}}{P_{BSW}}\right)^{M_{jsw}}} + \frac{C_j.A_D}{\left(1 + \frac{V_{DB}}{P_B}\right)^{M_j}} \quad P_D = 2L_D + W$$

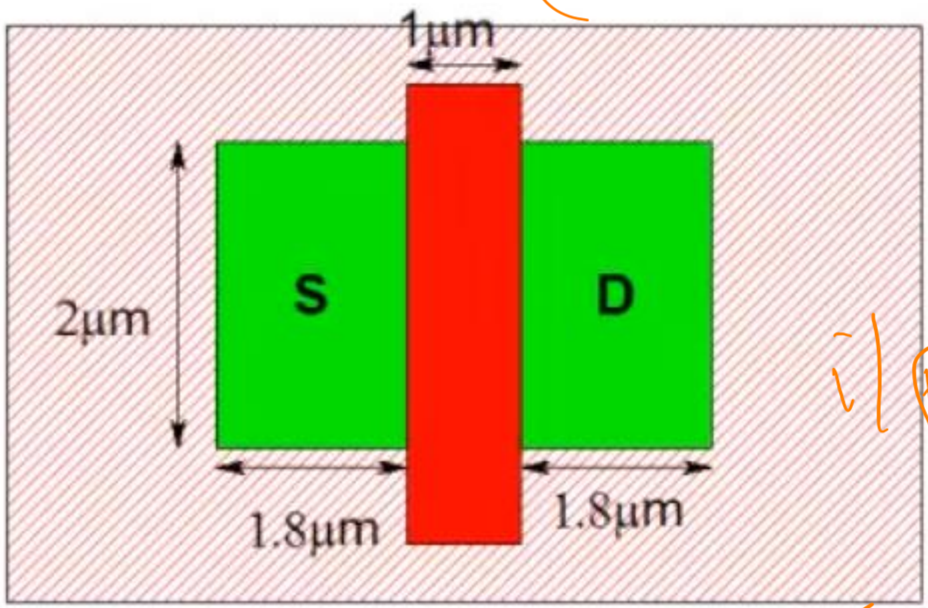
The capacitance model presented herein requires 10 parameters:

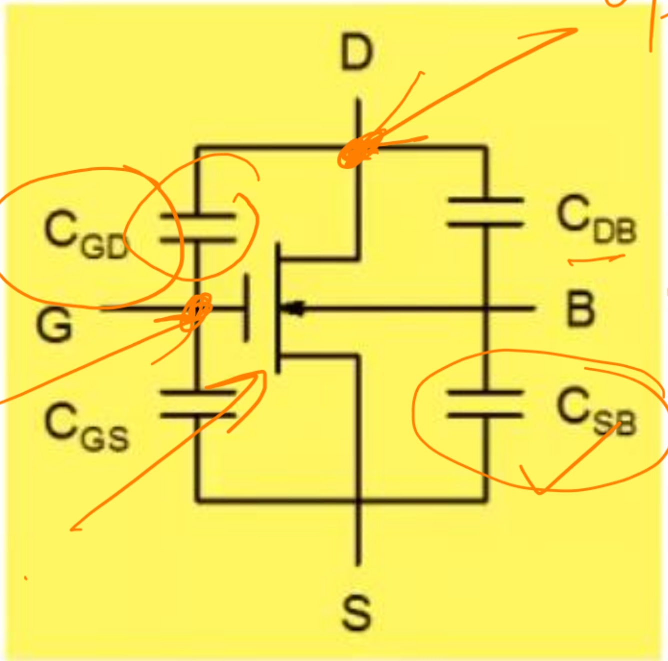
$$C_{GSO}, C_{GDO}, C_{GBO}, C'_{OX}, C_J, PB, M_J, C_{JSW}, P_{BSW}, M_{JSW}$$

→ Miller effect (?)

Typical Values of Capacitances

(in given tech.)





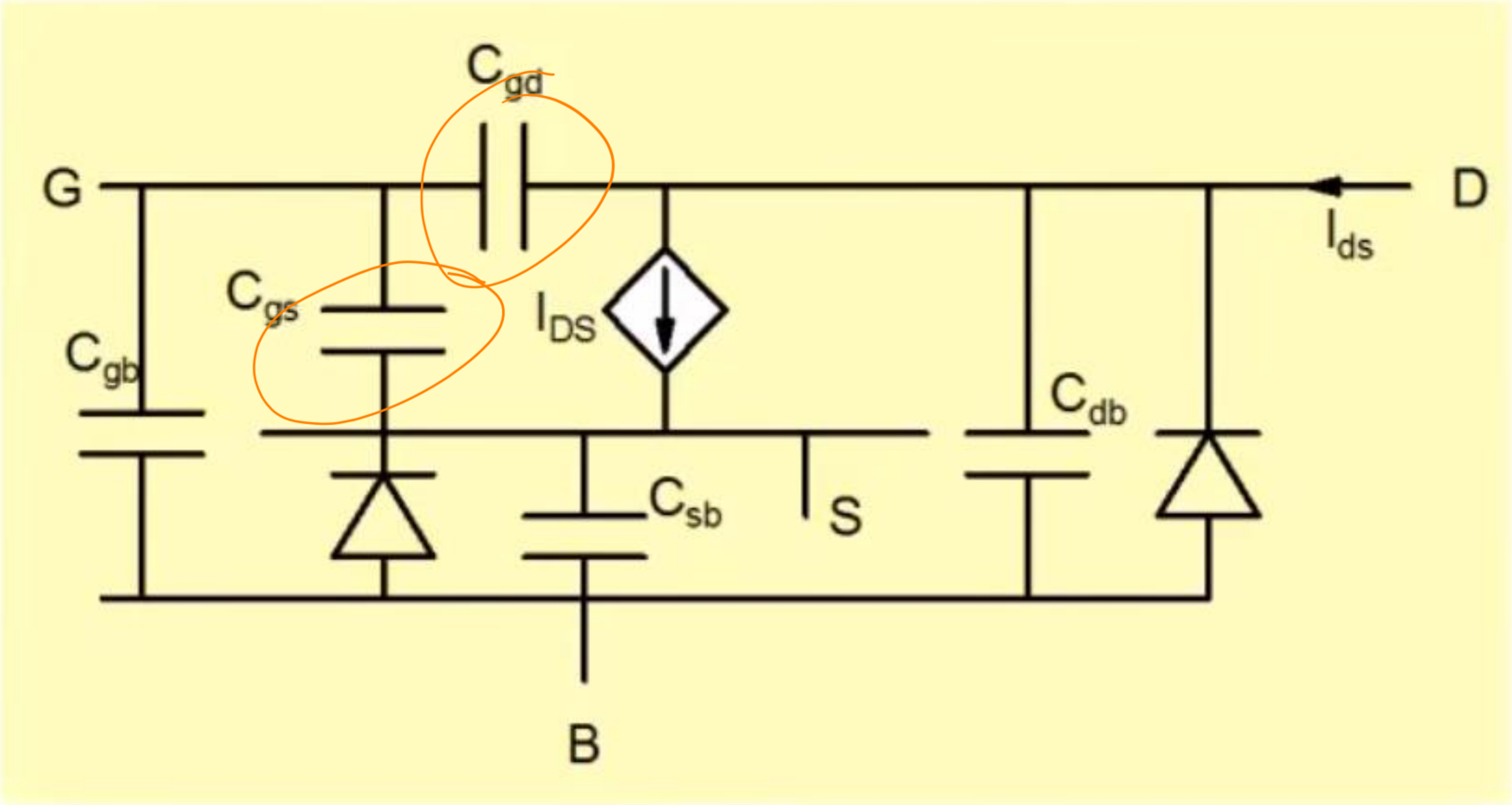
$C_{gs} = 4.1\,fF$; $C_{gd} = 0.43\,fF$ ← (may look smaller)

$C_{sb} = 4.47\,fF$

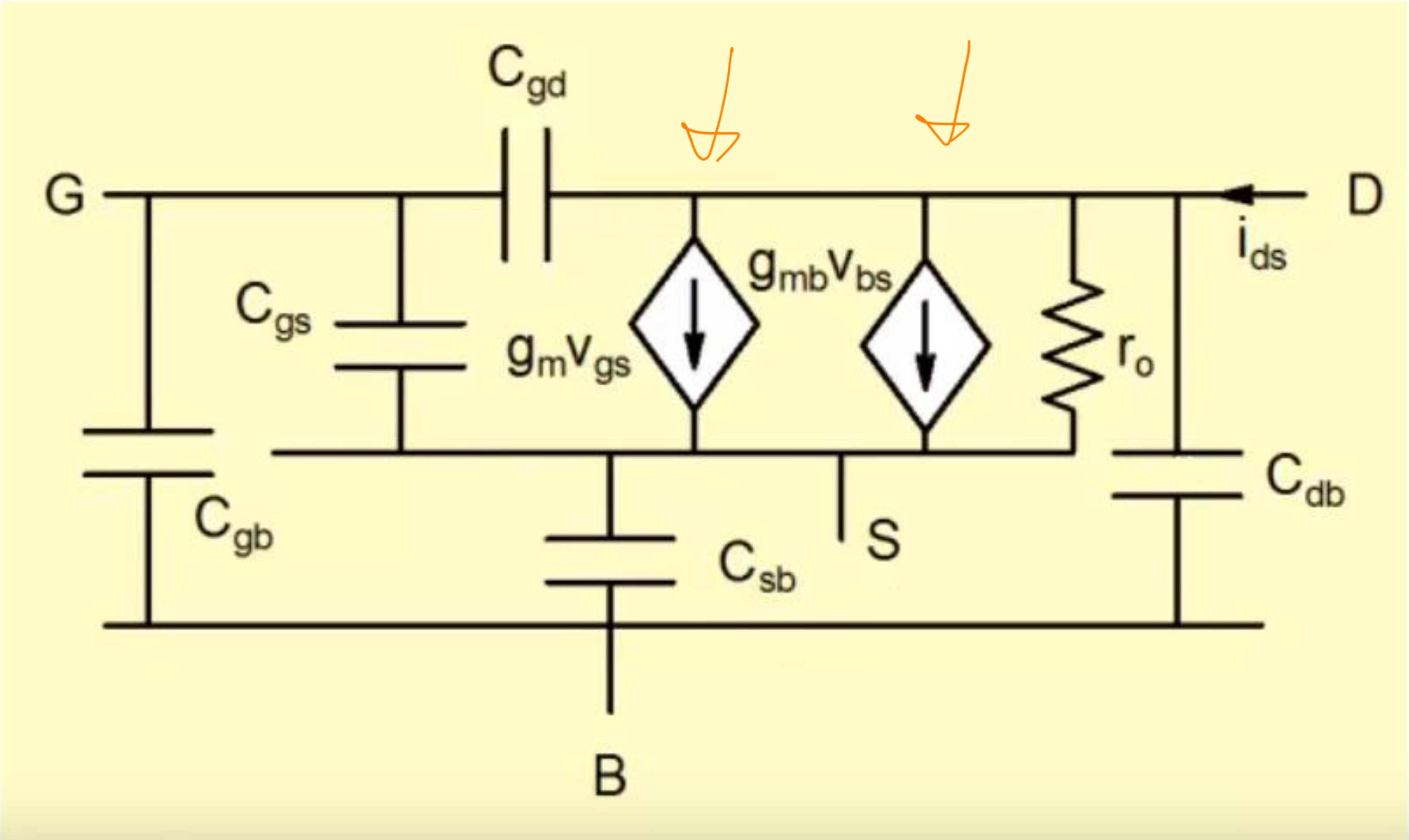
$C_{db} = 2.75\,fF$

$V_{SB} = 0$; $V_{DS} = 2V$

Complete Large Signal Model



High Frequency Small Signal Model



- We have so far discussed simple MOS models which are suitable for 'hand-analysis' of circuits. For more accurate prediction of circuit characteristics using circuit simulation more accurate MOS models are required.

- SPICE and its various variants are the most popular circuit simulation tool. In SPICE, there are a number of MOS models that are available including Level-1, level-2, Level-3, BSIM1, BSIM2, BSIM3, BSIM4 etc.

- Level-1 model is the simplest and is basically similar to the large signal model that we have described earlier. A popular model for submicron devices is BSIM3 model.

*** SPICE- Simulation Program with Integrated Circuit Emphasis**

*** BSIM- Berkeley Short-channel IGFET Model**

BSIM3 : Berkeley Short Channel IGFET (Insulated gate Field Effect) Model

$$I_{ds} = \frac{I_{dso(Vdseff)}}{1 + \frac{R_{ds} I_{dso(Vdseff)}}{V_{dseff}}} \left(1 + \frac{V_{ds} - V_{dseff}}{V_A}\right)\left(1 + \frac{V_{ds} - V_{dseff}}{V_{ASCBE}}\right)$$

$$I_{dso} = \frac{W_{eff} \mu_{eff} C_{ox} V_{gsteff} \left(1 - A_{bulk} \frac{V_{dseff}}{2(V_{gsteff} + 2v_t)}\right) V_{dseff}}{L_{eff}[1 + V_{dseff} / (E_{sat} L_{eff})]}$$

$$V_A = V_{Asat} + \left(1 + \frac{P_{vag} V_{gsteff}}{E_{sat} L_{eff}}\right)\left(\frac{1}{V_{ACLM}} + \frac{1}{V_{ADIBLC}}\right)^{-1}$$

$$V_{ACLM} = \frac{A_{bulk} E_{sat} L_{eff} + V_{gsteff}}{P_{CLM} A_{bulk} E_{sat}\, litl} (V_{ds} - V_{dseff})$$

Predictive Technology Model

- Introduction
- Latest Models
- Nano-CMOS
- Post-Silicon
- Interconnect
- Reliability
- Contact

LATEST MODELS

PTM

Typical SPICE model files for each future generation are available here.

Attention: By using a **PTM** file, you agree to acknowledge both the URL of **PTM**: http://ptm.asu.edu/ **and the related publications** in all documents and publications involving its usage.

New!

June 01, 2012:

PTM releases a new set of models for multi-gate transistors (**PTM-MG**), for both HP and LSTP applications. It is based on BSIM-CMG, a dedicated model for multi-gate devices.

Acknowledgement: PTM-MG is developed in collaboration with ARM.

Please start from models and param.inc.

- 7nm PTM-MG HP NMOS, HP PMOS, LSTP NMOS, LSTP PMOS
- 10nm PTM-MG HP NMOS, HP PMOS, LSTP NMOS, LSTP PMOS
- 14nm PTM-MG HP NMOS, HP PMOS, LSTP NMOS, LSTP PMOS
- 16nm PTM-MG HP NMOS, HP PMOS, LSTP NMOS, LSTP PMOS
- 20nm PTM-MG HP NMOS, HP PMOS, LSTP NMOS, LSTP PMOS

FinFET

The entire package is also available here: PTM-MG

November 15, 2008:

PTM releases a new set of models for low-power applications (PTM LP), incorporating high-k/metal gate and stress effect.

- 16nm PTM LP model: V2.1
- 22nm PTM LP model: V2.1
- 32nm PTM LP model: V2.1
- 45nm PTM LP model: V2.1

September 30, 2008:

PTM releases a new set of models for high-performance applications (PTM HP), incorporating high-k/metal gate and stress effect.

- 16nm PTM HP model: V2.1
- 22nm PTM HP model: V2.1

https://bsim.berkeley.edu/models/bsim4/

BSIM Group — About | News | Models | Publications | Members | Links

- BSIM-CMG
- BSIM-IMG
- BSIM-SOI
- BSIM-BULK
- BSIM4

→ Silicon on Insulator

el

BSIM4, as the extension of BSIM3 model, ysical effects into sub-100nm regime. It is a physics-based, accurate, scalable, robust SPICE model for circuit simulation and CMOS technology development. It is developed by the BSIM Research Group in the Department of Electrical Engineering and Computer Sciences (EECS) at the University of California, Berkeley. All suggestions for model improvements are charted by the Compact Model Coalition (CMC).

BSIM4 has been used for the 0.13 um, 90 nm, 65 nm, 45/40 nm, 23/28 nm, and 22/20nm technology nodes.

See BSIM3, a predecessor of BSIM4, here.

Latest Release

BSIM4 4.8.1 was released on Feb. 15, 2017.

We would like to thank CMC members for testing beta models and providing valuable feedbacks during model development.

Download BSIM4 4.8.1 model package, including

- Model code in C

PTM

```
* PTM Low Power 16nm Metal Gate / High-K / Strained-Si
* nominal Vdd = 0.9V

.model  nmos  nmos  level = 54

+version = 4.0        binunit = 1           paramchk= 1           mobmod  = 0
+capmod  = 2          igcmod  = 1           igbmod  = 1           geomod  = 1
+diomod  = 1          rdsmod  = 0           rbodymod= 1           rgatemod= 1
+permod  = 1          acnqsmod= 0           trnqsmod= 0

+tnom    = 27         toxe    = 1.2e-009    toxp    = 9e-010      toxm    = 1.2e-009
+dtox    = 3e-010     epsrox  = 3.9         wint    = 5e-009      lint    = 0
+ll      = 0          wl      = 0           lln     = 1           wln     = 1
+lw      = 0          ww      = 0           lwn     = 1           wwn     = 1
+lwl     = 0          wwl     = 0           xpart   = 0           toxref  = 1.2e-009

+vth0    = 0.68191    k1      = 0.4         k2      = 0           k3      = 0
+k3b     = 0          w0      = 2.5e-006    dvt0    = 1           dvt1    = 2
+dvt2    = 0          dvt0w   = 0           dvt1w   = 0           dvt2w   = 0
+dsub    = 0.1        minv    = 0.05        voffl   = 0           dvtp0   = 1e-011
+dvtp1   = 0.1        lpe0    = 0           lpeb    = 0           xj      = 5e-009
+ngate   = 1e+023     ndep    = 7e+018      nsd     = 2e+020      phin    = 0
+cdsc    = 0          cdscb   = 0           cdscd   = 0           cit     = 0
+voff    = -0.1014    nfactor = 1.6         eta0    = 0.0095      etab    = 0
+vfb     = -0.55      u0      = 0.028       ua      = 6e-010      ub      = 1.2e-018
+uc      = 0          vsat    = 200000      a0      = 1           ags     = 0
+a1      = 0          a2      = 1           b0      = 0           b1      = 0
+keta    = 0.04       dwg     = 0           dwb     = 0           pclm    = 0.02
+pdiblc1 = 0.001      pdiblc2 = 0.001       pdiblcb = -0.005      drout   = 0.5
+pvag    = 1e-020     delta   = 0.01        pscbe1  = 8.14e+008   pscbe2  = 1e-007
+fprout  = 0.2        pdits   = 0.01        pditsd  = 0.23        pditsl  = 2300000
+rsh     = 5          rdsw    = 170         rsw     = 75          rdw     = 75
+rdswmin = 0          rdwmin  = 0           rswmin  = 0           prwg    = 0
+prwb    = 0          wr      = 1           alpha0  = 0.074       alpha1  = 0.005
+beta0   = 30         agidl   = 0.0002      bgidl   = 2.1e+009    cgidl   = 0.0002
+egidl   = 0.8        aigbacc = 0.012       bigbacc = 0.0028      cigbacc = 0.002
```