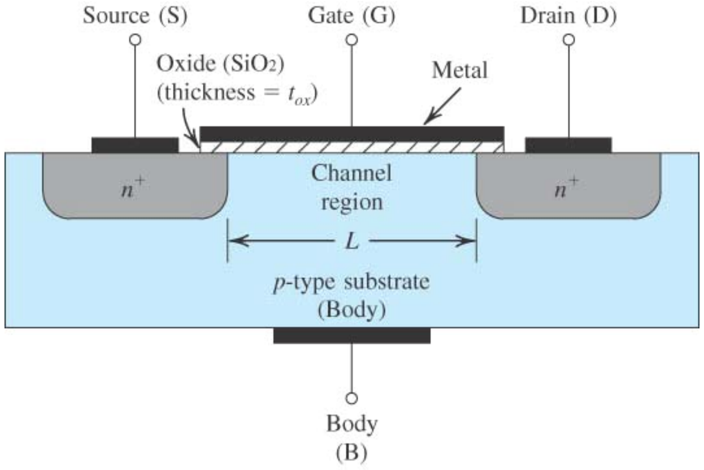
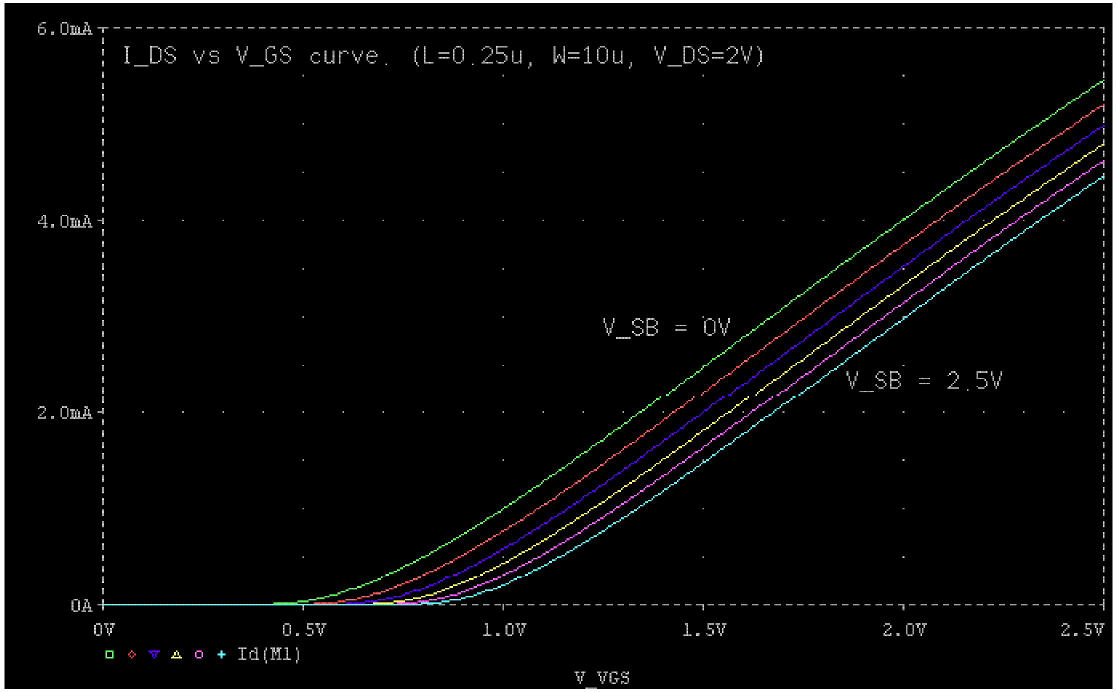
Lect. 22: MOSFET Small-Signal Model (2)

Body effect: Voltage applied to B causes a change in threshold voltage



(b)

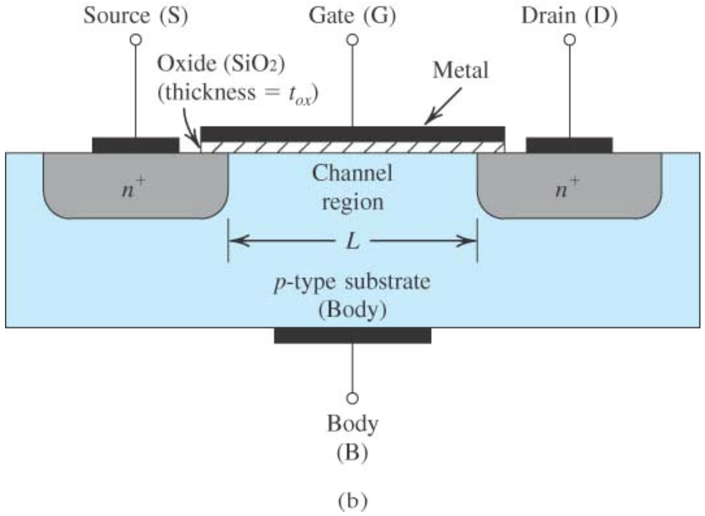


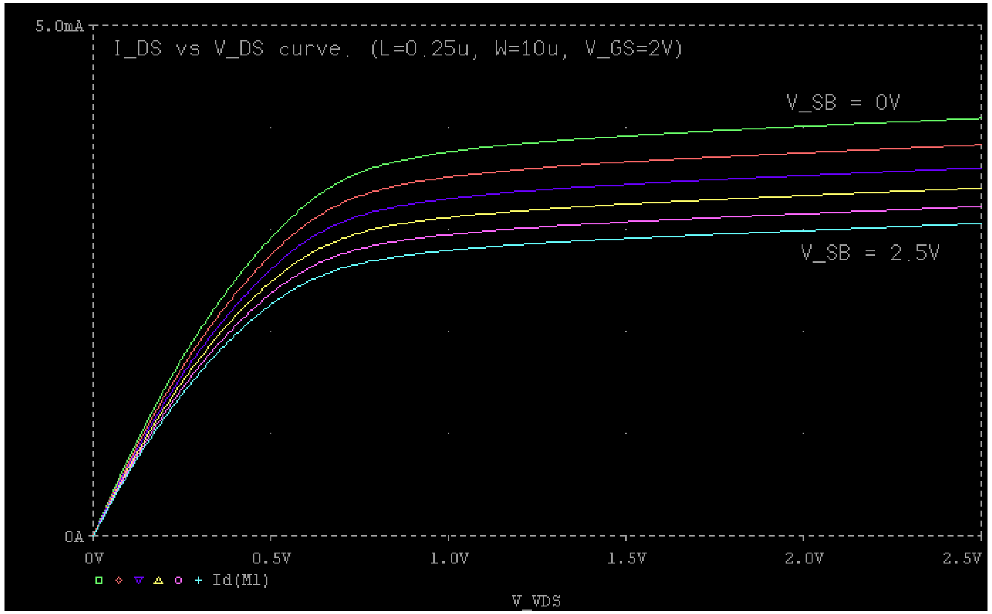
➔V_t increases as V_{SB} increases

Decreased V_B requires higher V_G for threshold

Lect. 22: MOSFET Small-Signal Model (2)

Body effect: Voltage applied to B causes a change in threshold voltage

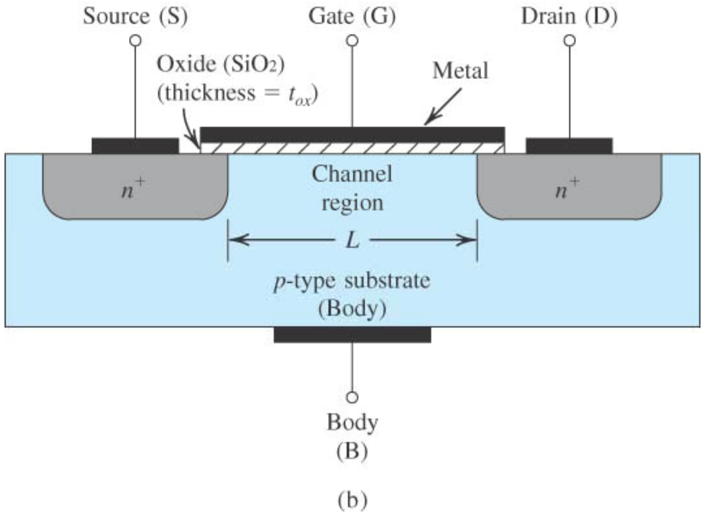




➔ Smaller I_D with higher V_{SB}

➔ Larger I_D with higher V_{BS}

Lect. 22: MOSFET Small-Signal Model (2)



Body effect:

$$V_t = V_{tO} + \gamma[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\,]$$

$$V_t = V_{tO} \text{ when } V_{SB} = 0$$

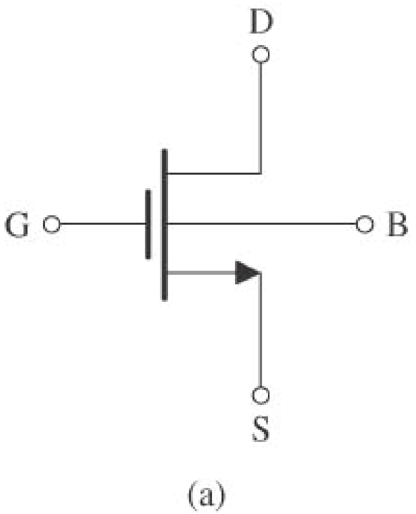
ϕ_f **and** γ **process-dependent parameters**

If S and B can be tied, no body effect.

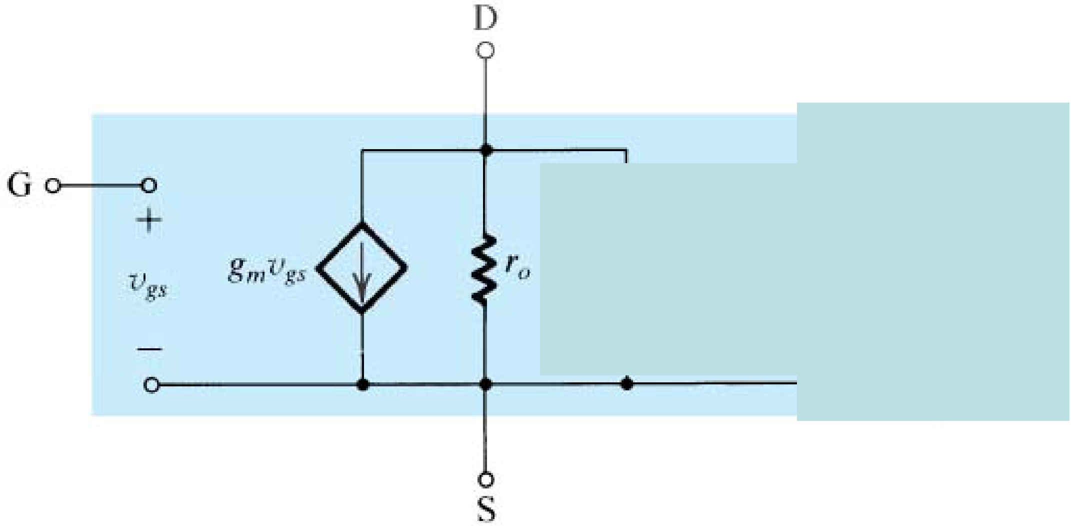
In ICs, B is connected to
- the most negative supply voltage (NMOS)
- the most positive supply voltage (PMOS)

Lect. 22: MOSFET Small-Signal Model (2)

Small-signal model including Body effect



(a)



Practically, Body Effect
Is not easy to model analytically.

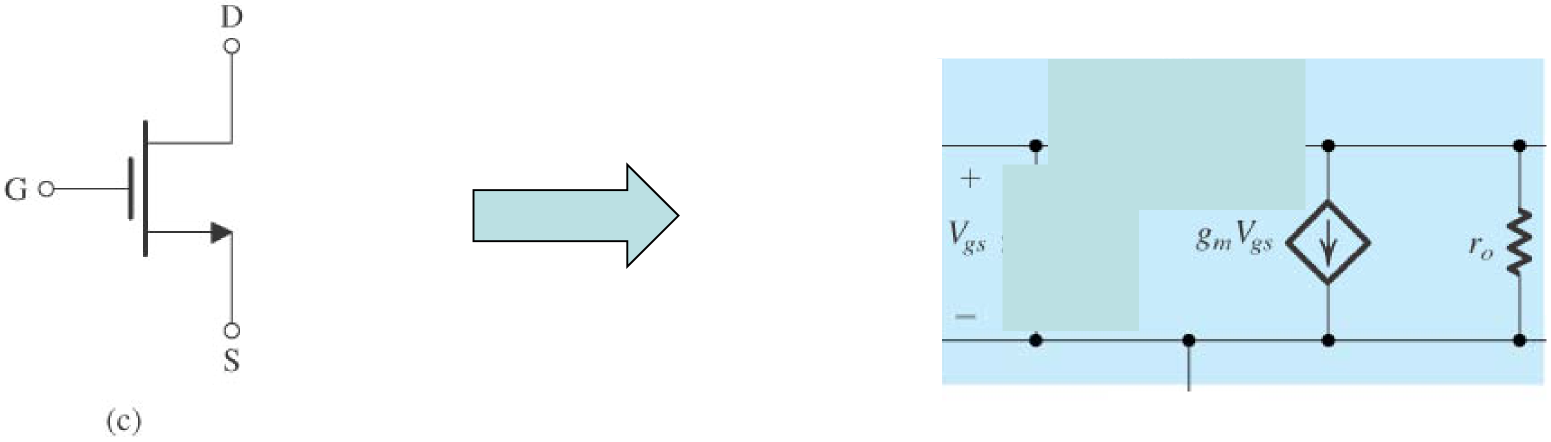
➔ Simulation

$$g_{mb} \equiv \left.\frac{\partial i_D}{\partial \upsilon_{BS}}\right|_{\substack{\upsilon_{GS} = \text{constant} \\ \upsilon_{DS} = \text{constant}}}$$

$$g_{mb} \equiv \chi g_m \qquad (\chi : 0.1 - 0.3)$$

Lect. 22: MOSFET Small-Signal Model (2)

High-Frequency Model for MOSFET



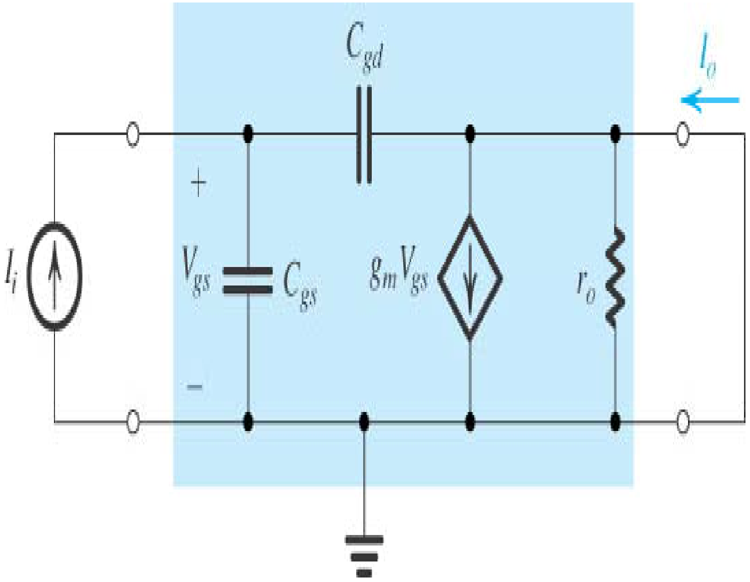
Unit-Gain Frequency (f_t):

Frequency at which magnitude of the short-circuit current gain of CS configuration becomes 1

Or Mag($I_o(\omega)/I_i(\omega)$) = 1

Lect. 22: MOSFET Small-Signal Model (2)

How fast can a MOSFET transistor operate? f_t



$$I_0 = g_m V_{gs} - \frac{V_{gs}}{1/j\omega C_{gd}} = g_m V_{gs} - j\omega C_{gd} V_{gs} = g_m V_{gs} \quad (\because g_m >> \omega C_{g}$$

$$V_{gs} = I_i \cdot \left(\frac{1}{j\omega C_{gd}} \| \frac{1}{j\omega C_{gS}} \right) = I_i \cdot \frac{1}{j\omega (C_{gd} + C_{gs})}$$

$$\therefore \frac{I_0}{I_i} = \frac{g_m}{j\omega (C_{gd} + C_{gs})}$$

$$\text{For } \left| \frac{I_0}{I_i} \right| = 1, \ \omega = \frac{g_m}{C_{gd} + C_{gs}}$$

$$\text{Or } f_T = \frac{g_m}{2\pi (C_{gd} + C_{gs})} \quad \text{(Unit-gain Frequency)}$$

How to make MOSFET faster?
Which is faster NMOS or PMOS?
Current state-of-the-art NMOS has f_T approaching 100 GHz.

Lect. 22: MOSFET Small-Signal Model (2)

- Modern transistors are very complicated in their structure.

- Many parameters are needed to model their characteristics accurately in SPICE

- SPICE parameters for 0.25μm NMOS are shown

- For detailed explanations, See *MOSFET Users' Manual* at *www-device.eecs.berkeley.edu/~bsim3/get.html*

```
MODEL orbit2L2N NMOS (                    LEVEL   = 7
+TNOM    = 27            TOX     = 5.6E-9
+XJ      = 1E-7          NCH     = 2.3549E17      VTH0    = 0.3654765
+K1      = 0.4732214     K2      = 7.994532E-4    K3      = 1E-3
+K3B     = 3.0713494     W0      = 1E-7           NLX     = 1.617898E-7
+DVT0W   = 0             DVT1W   = 0              DVT2W   = 0
+DVT0    = 0.455178      DVT1    = 0.6258687      DVT2    = -0.5
+U0      = 280.4589023   UA      = -1.607126E-9   UB      = 2.806549E-18
+UC      = 3.290051E-11  VSAT    = 1.07496E5      A0      = 1.8770435
+AGS     = 0.3310181     B0      = -3.173524E-8   B1      = -1E-7
+KETA    = -8.69841E-3   A1      = 8.317145E-5    A2      = 0.6592347
+RDSW    = 200           PRWG    = 0.4477477      PRWB    = 0.0208175
+WR      = 1             WINT    = 0              LINT    = 1.392558E-10
+DWG     = -2.28419E-8
+DWB     = -6.95781E-10  VOFF    = -0.0910963     NFACTOR = 1.202941
+CIT     = 0             CDSC    = 2.4E-4         CDSCD   = 0
+CDSCB   = 0             ETA0    = 5.0732E-3      ETAB    = 6.262008E-5
+DSUB    = 0.0310034     PCLM    = 1.5101091      PDIBLC1 = 0.897659
+PDIBLC2 = 2.924029E-3   PDIBLCB = 0.0651312      DROUT   = 1
+PSCBE1  = 7.017738E8    PSCBE2  = 2.271109E-4    PVAG    = 8.531511E-3
+DELTA   = 0.01          RSH     = 4.6            MOBMOD  = 1
+PRT     = 0             UTE     = -1.5           KT1     = -0.11
+KT1L    = 0             KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18     UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0             WLN     = 1              WW      = 0
+WWN     = 1             WWL     = 0              LL      = 0
+LLN     = 1             LW      = 0              LWN     = 1
+LWL     = 0             CAPMOD  = 2              XPART   = 0.5
+CGDO    = 4.59E-10      CGSO    = 4.59E-10       CGBO    = 5E-10
+CJ      = 1.78338E-3    PB      = 0.99           MJ      = 0.4661295
+CJSW    = 4.154041E-10  PBSW    = 0.9563049      MJSW    = 0.3162462
+CF      = 0             PVTH0   = -9.648921E-3   PRDSW   = -10
+PK2     = 3.534961E-3   WKETA   = 0.0120981      LKETA   = -3.31688E-3    )
```

Lect. 22: MOSFET Small-Signal Model (2)

How to do PSPICE simulation?

➔ Instructions will be given during next tutorial (11/9)

Bring your own notebook computer if you can