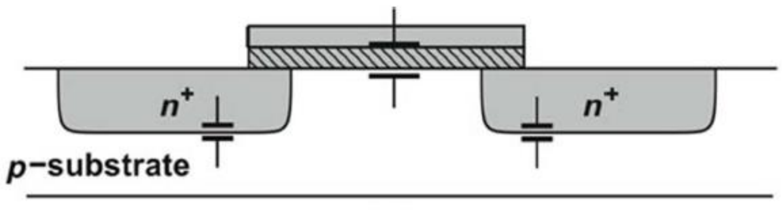
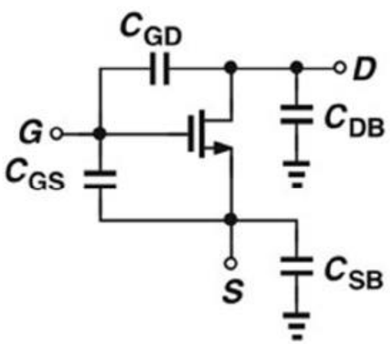
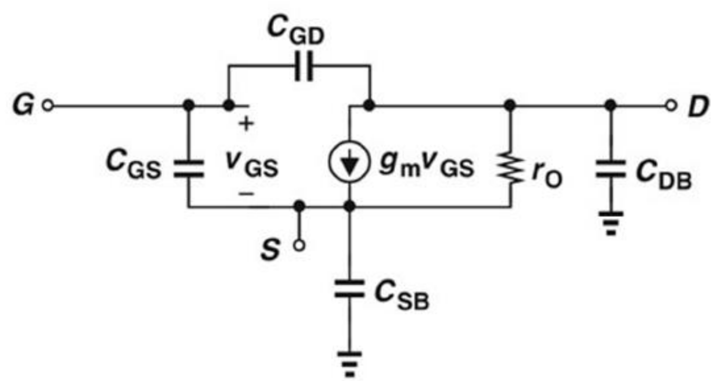
# Lect. 11: High-Frequency Response of MOS Transistors

(Razavi 11.2)

- MOSFET has many capacitive elements



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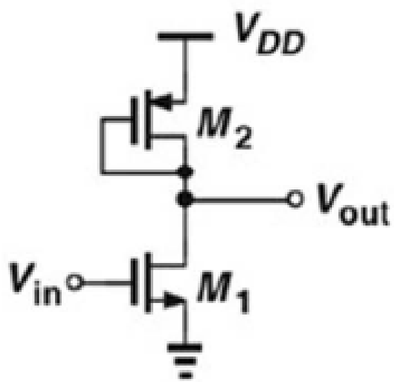
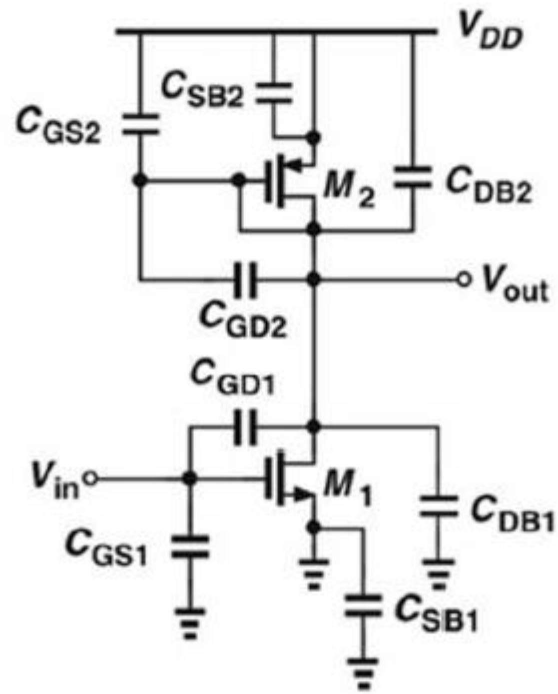
- Circuit with capacitors




- Can be simplified somewhat but still requires very complex analysis

➔ Simulation

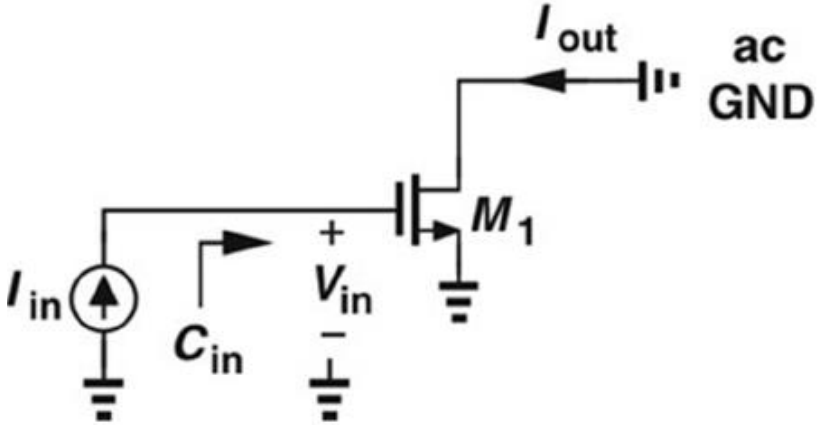
# Lect. 11: High-Frequency Response of MOS Transistors

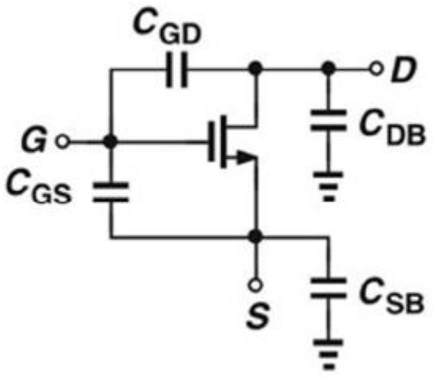
- How fast can a MOSFET transistor operate?

- What determines this?

Unit-Gain Frequency ($f_t$):

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



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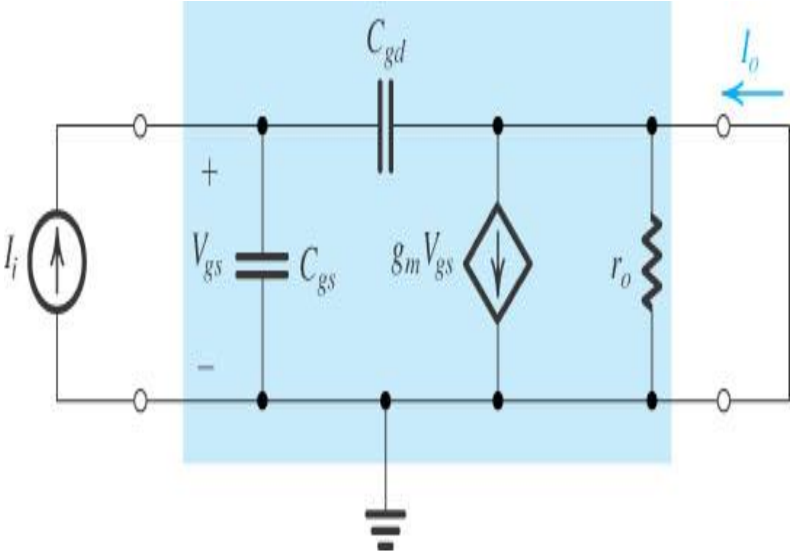


$\frac{I_0}{I_i}$ in frequency ($\omega$) domain?

$$I_0 = g_m V_{gs} - \frac{V_{gs}}{1/j\omega C_{gd}} = g_m V_{gs} - j\omega C_{gd} V_{gs}$$

$$\sim g_m V_{gs} \quad \text{(assuming } g_m >> \omega C_{gd}\text{)}$$

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

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



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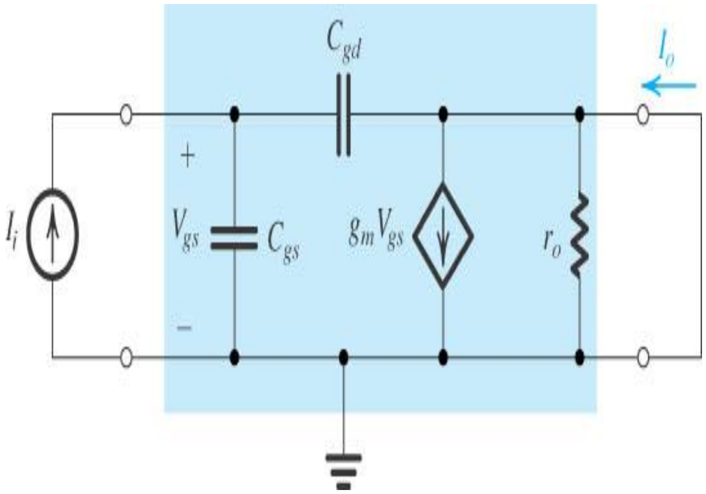
Unit-Gain Frequency ($f_t$):

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




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

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

$$f_T = \frac{g_m}{2\pi(C_{gd} + C_{gs})}$$

How to make MOSFET faster?

Which is faster, NMOS or PMOS?

$$g_m = \sqrt{2\mu C_{ox} \cdot \frac{W}{L} \cdot I_D}$$

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$$f_T = \frac{g_m}{2\pi * (C_{gd} + C_{gs})}$$

Confirm above with our PSPICE model

(L=0.25㎛ , W=10 ㎛ , $V_{DS}$=2V, $V_{GS}$=1.5V)

$$C_{gs} = 1.51*10^{-14}[F]$$

$$C_{gd} = 4.59*10^{-15}[F]$$

$$g_m = 0.00304\,[A/V]$$

$$f_T = \frac{0.00304}{2\pi * (1.968*10^{-14})} = 24.5GHz$$

```
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   )
```

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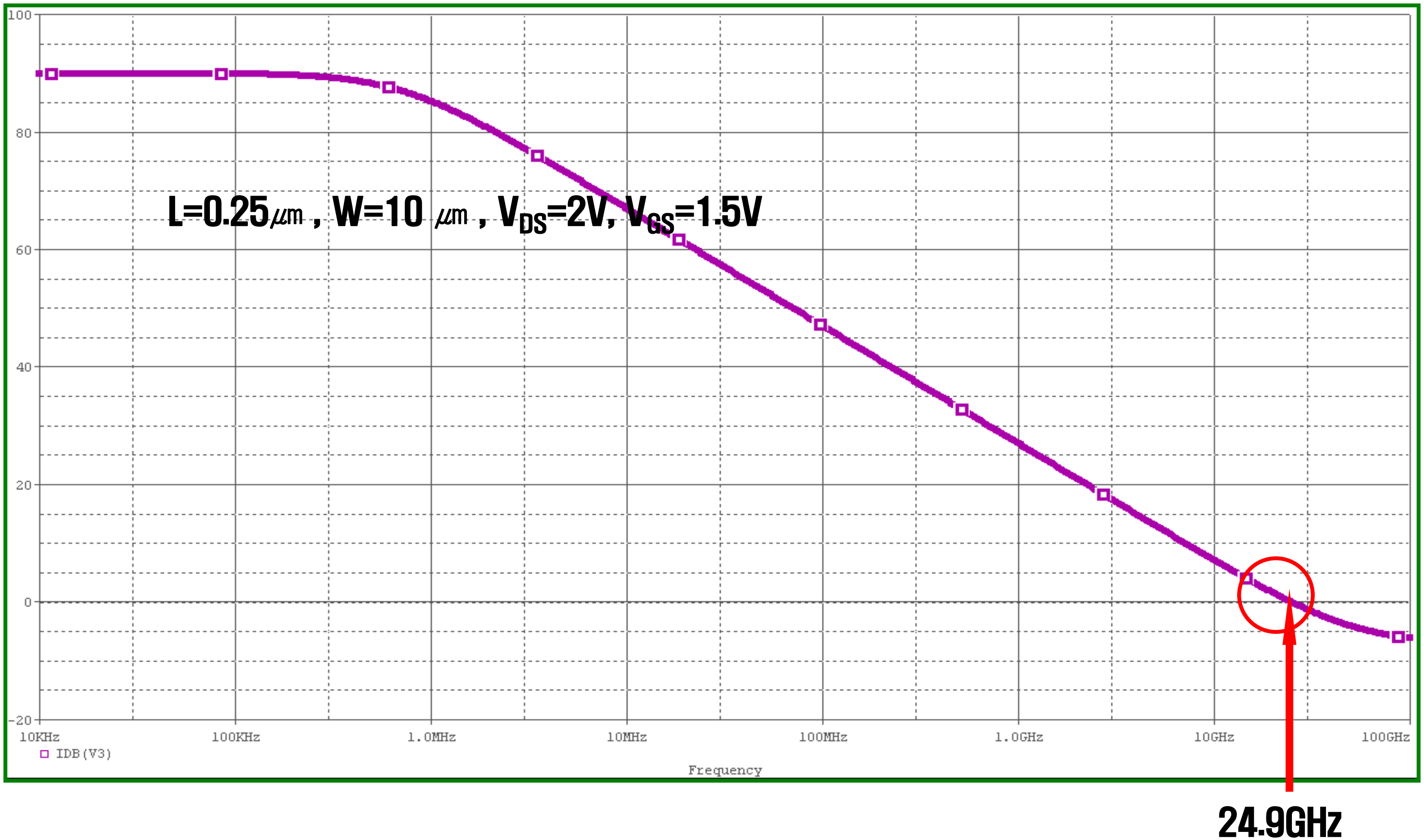

Homework

-Determine by simulation how $f_T$ changes as a function of $V_{GS}$(from 1V to 2V) and $V_{DS}$(from 1V to 2V) for our NMOS transistor with L=0.25$\mu m$, W=10$\mu m$.