Lecture 22
EE 2303/001-Electronics I
April 13, 2009

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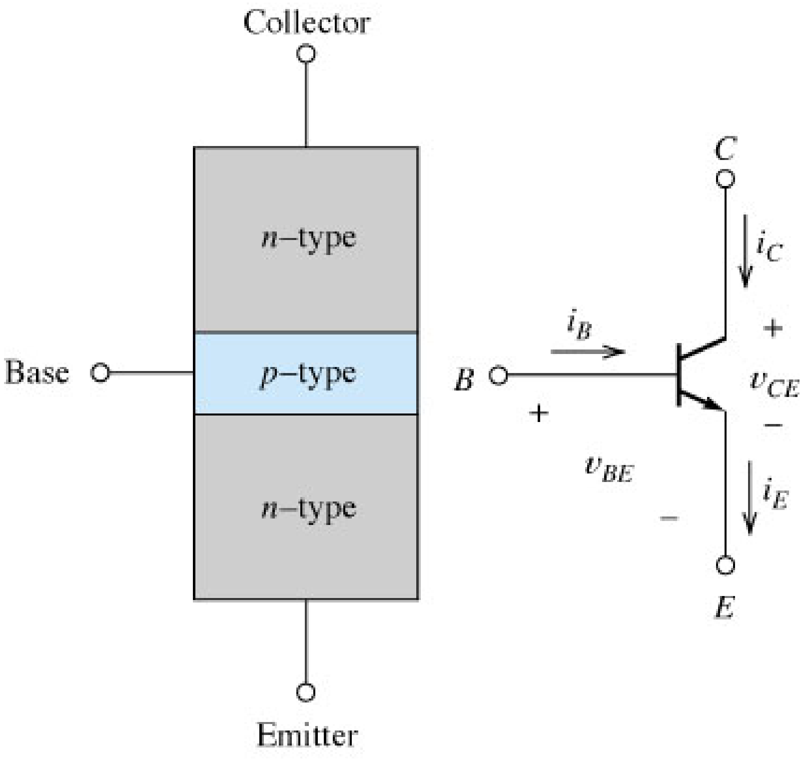
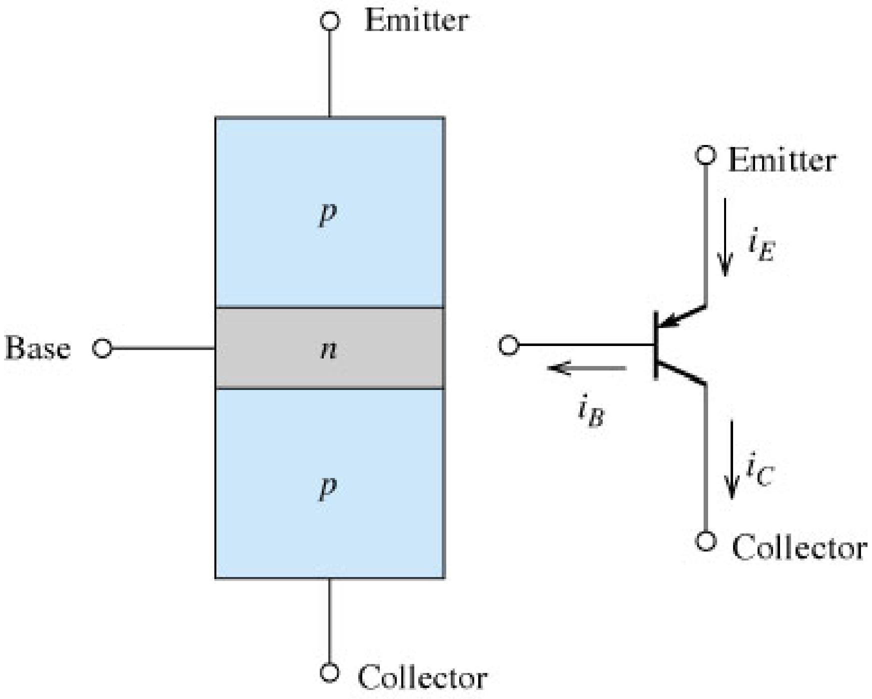


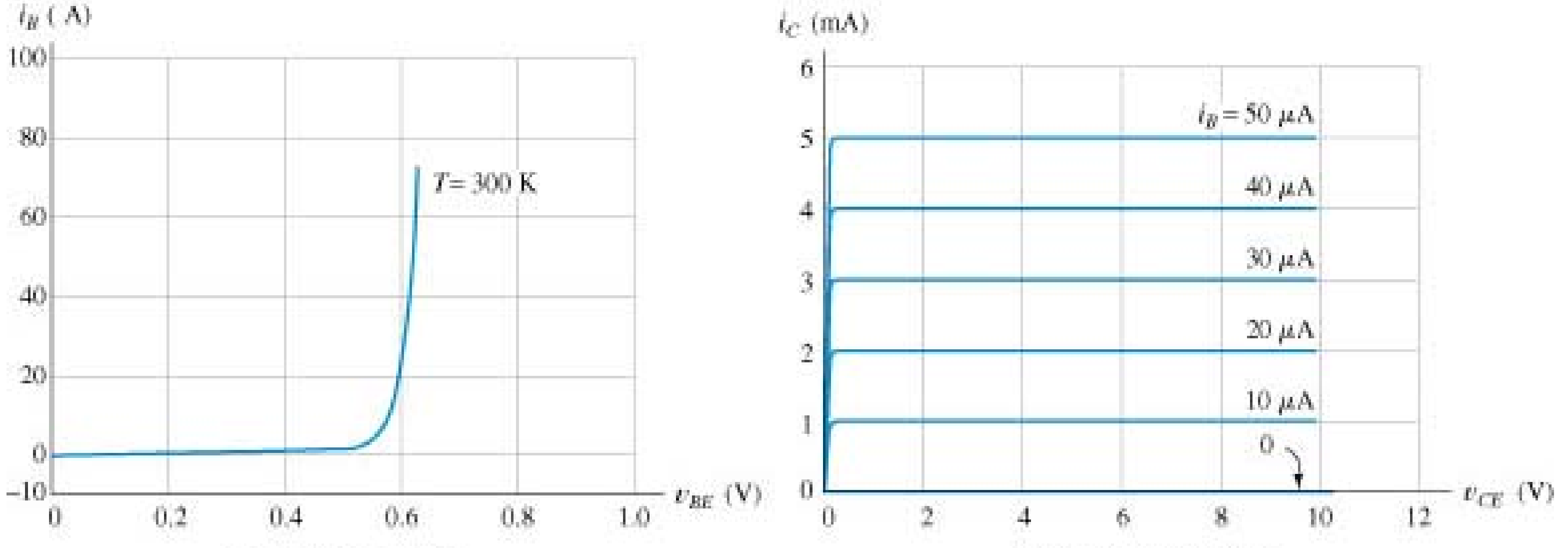
(a) Simplified physical structure

Figure 4.1 The *npn* BJT.



(a) Physical structure

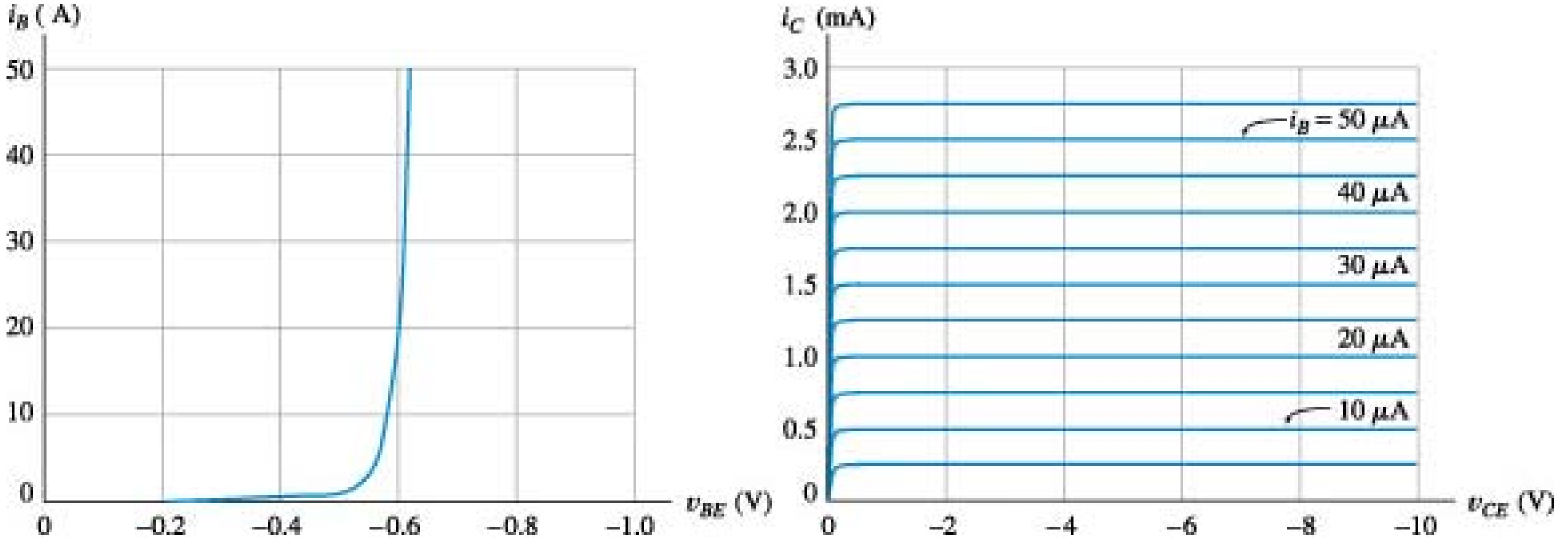
Figure 4.16 The *pnp* BJT.



(a) Input characteristic

(b) Output characteristics

Figure 4.4 Common-emitter characteristics of a typical *npn* BJT.



(a) Input

(b) Output

Figure 4.17 Common-emitter characteristics for a *pnp* BJT.

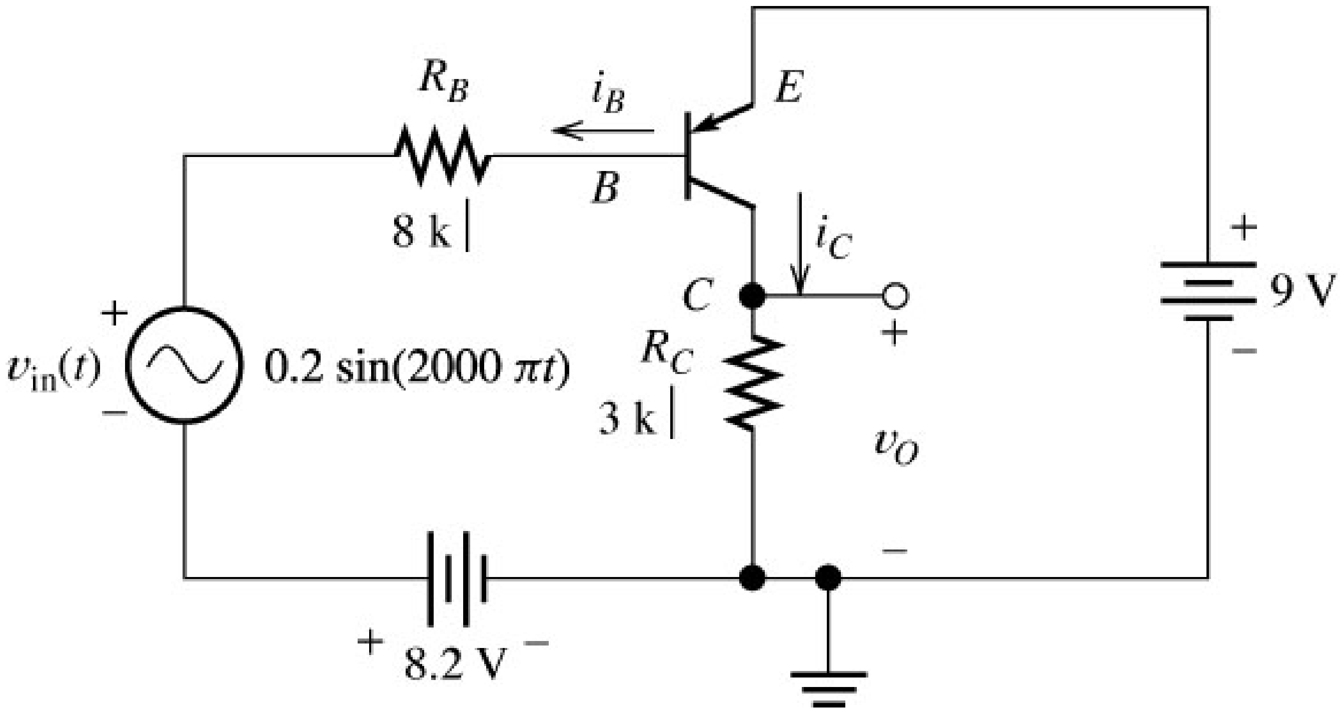


Figure 4.18 Common-emitter amplifier for Exercise 4.8.

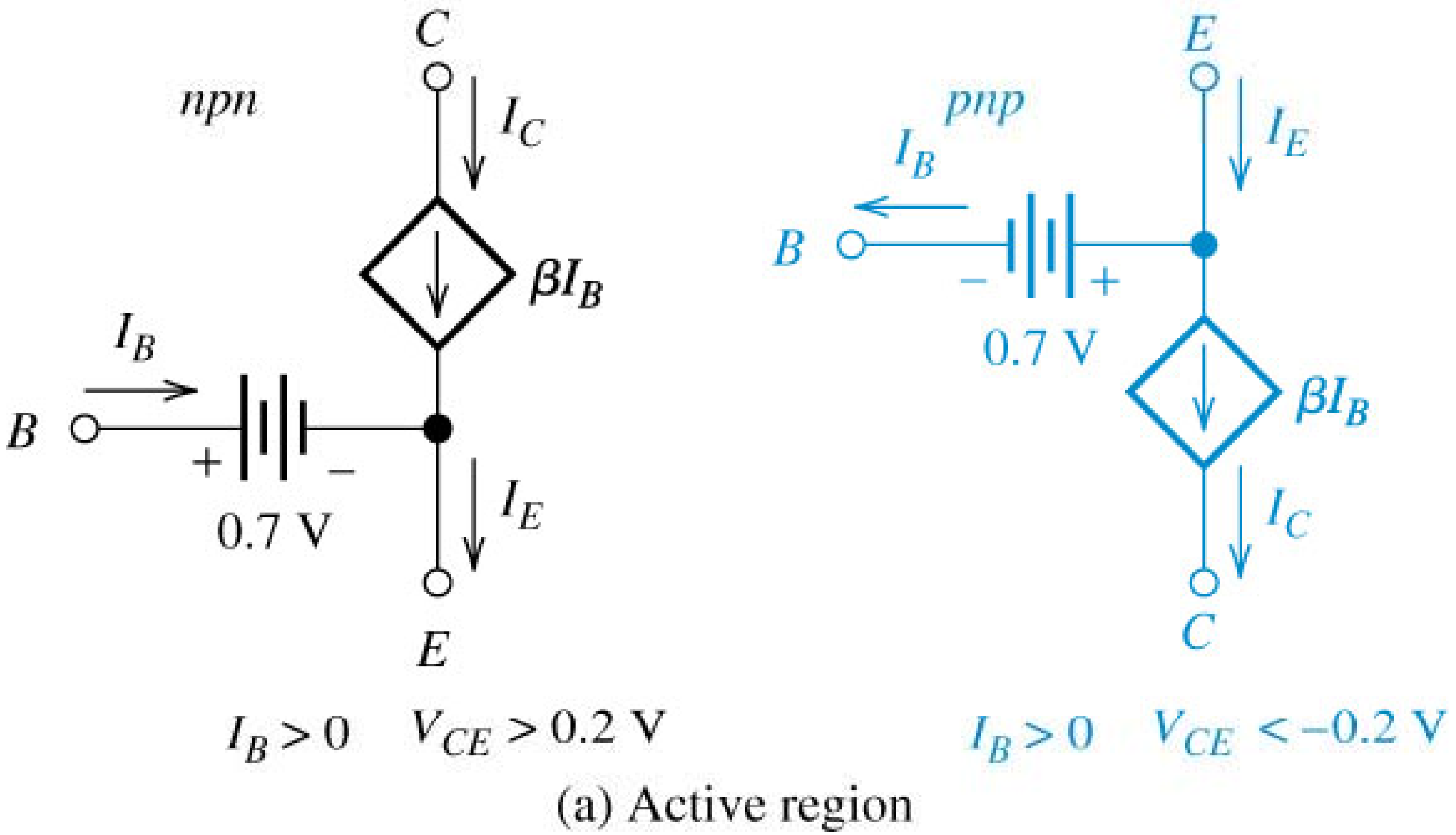
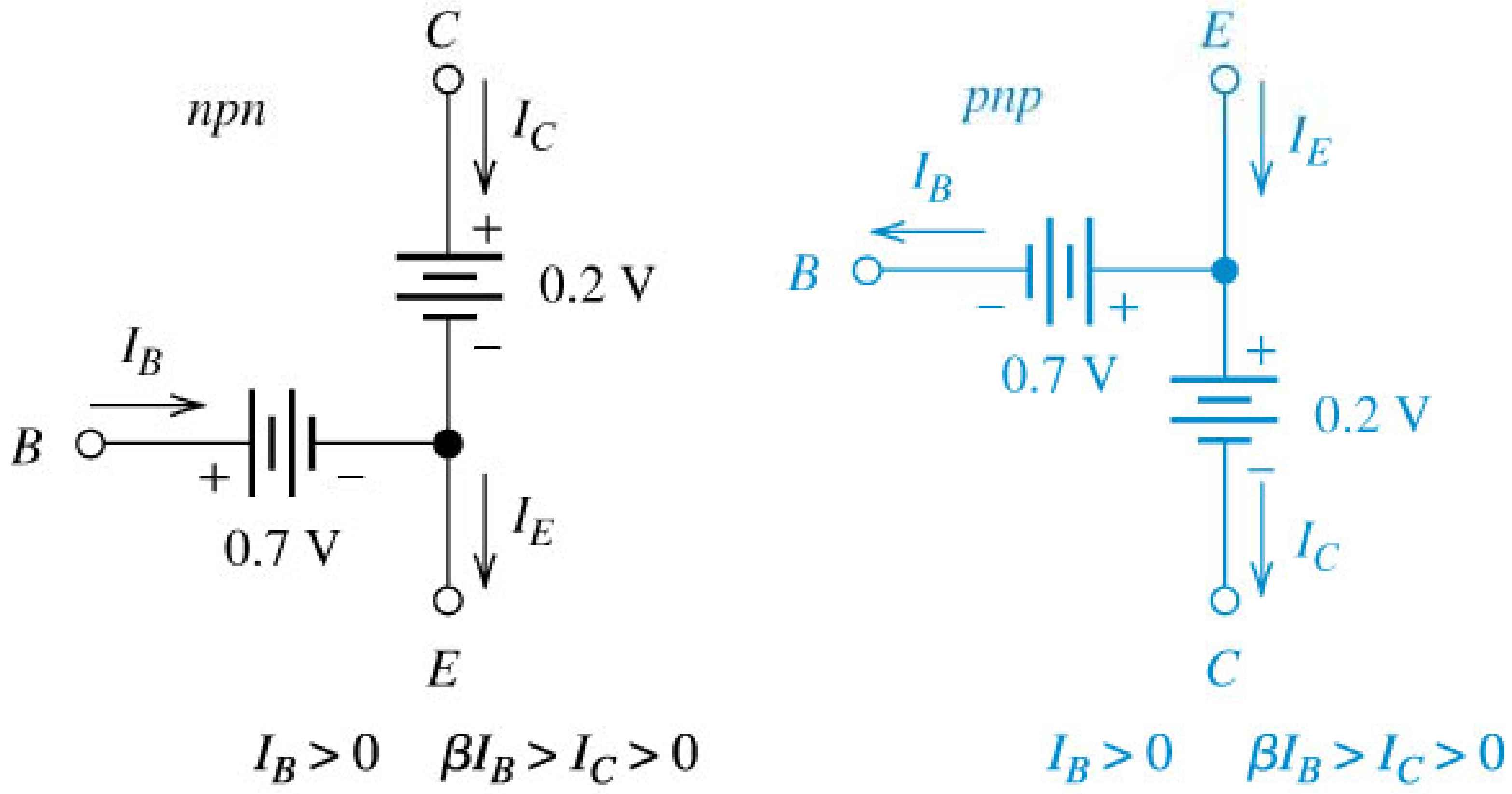
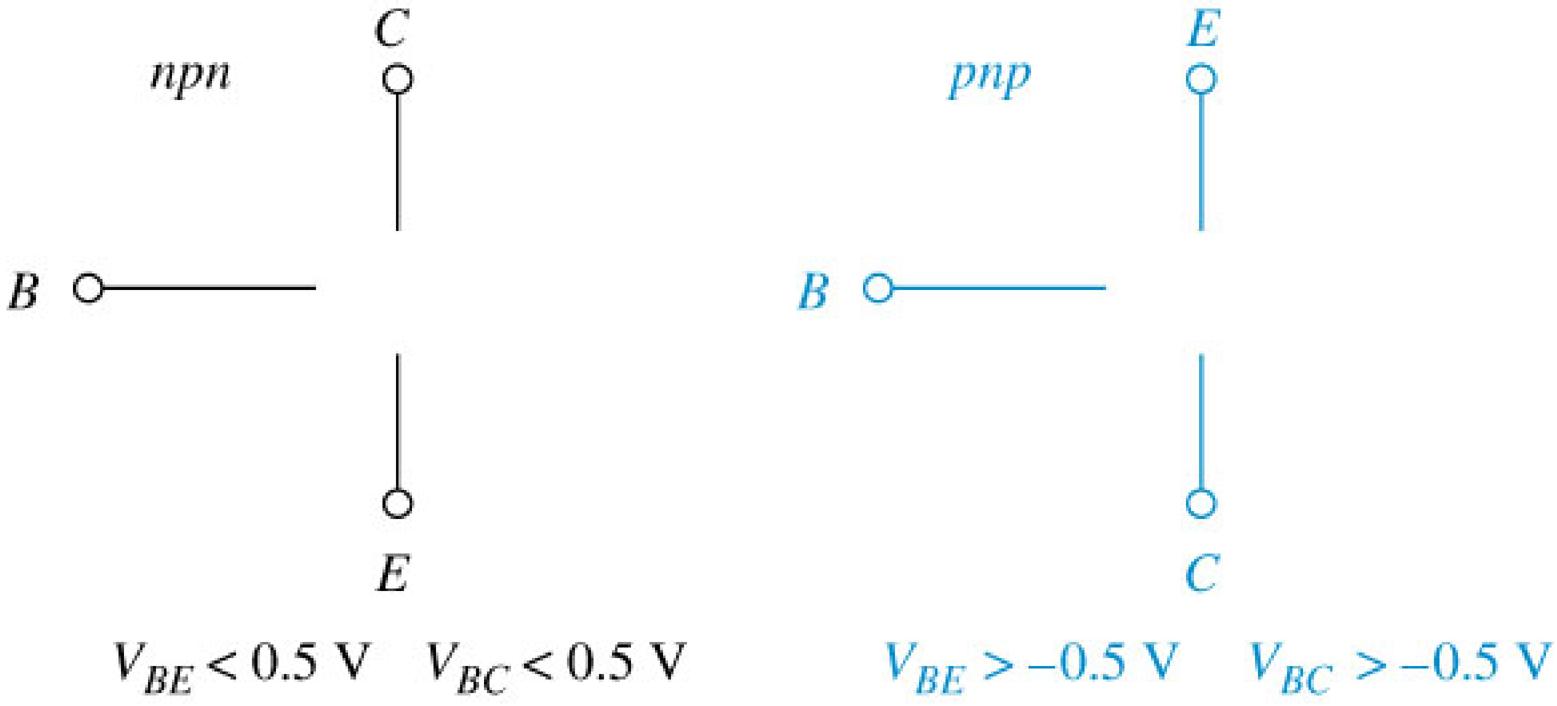


Figure 4.19a BJT large-signal models. (*Note:* Values shown are appropriate for typical small-signal silicon devices at a temperature of 300K.



(b) Saturation region

Figure 4.19b BJT large-signal models. (*Note:* Values shown are appropriate for typical small-signal silicon devices at a temperature of 300K.



(c) Cutoff region

Figure 4.19c BJT large-signal models. (*Note:* Values shown are appropriate for typical small-signal silicon devices at a temperature of 300K.

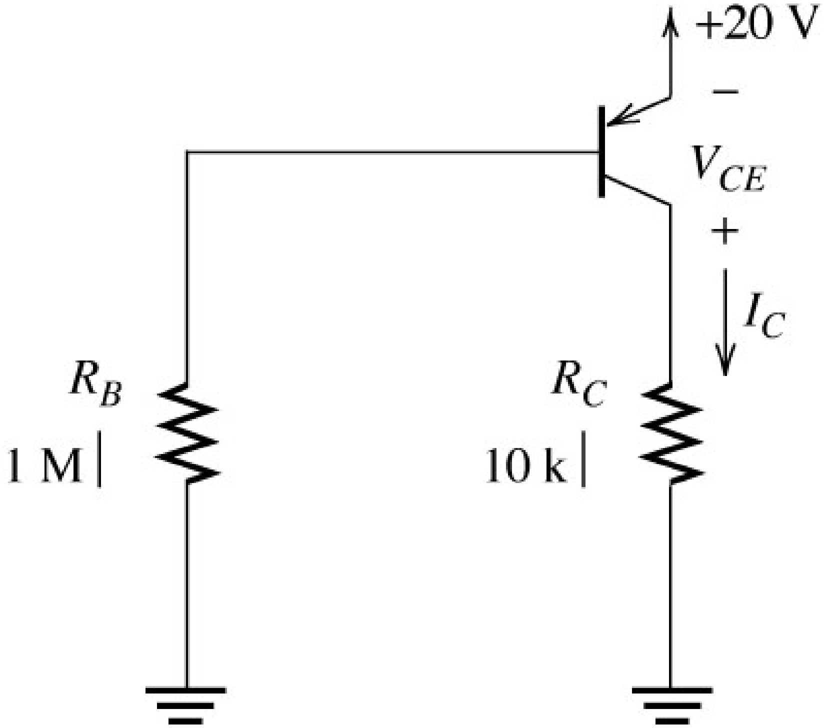


Figure 4.26 Circuit for Exercise 4.12.

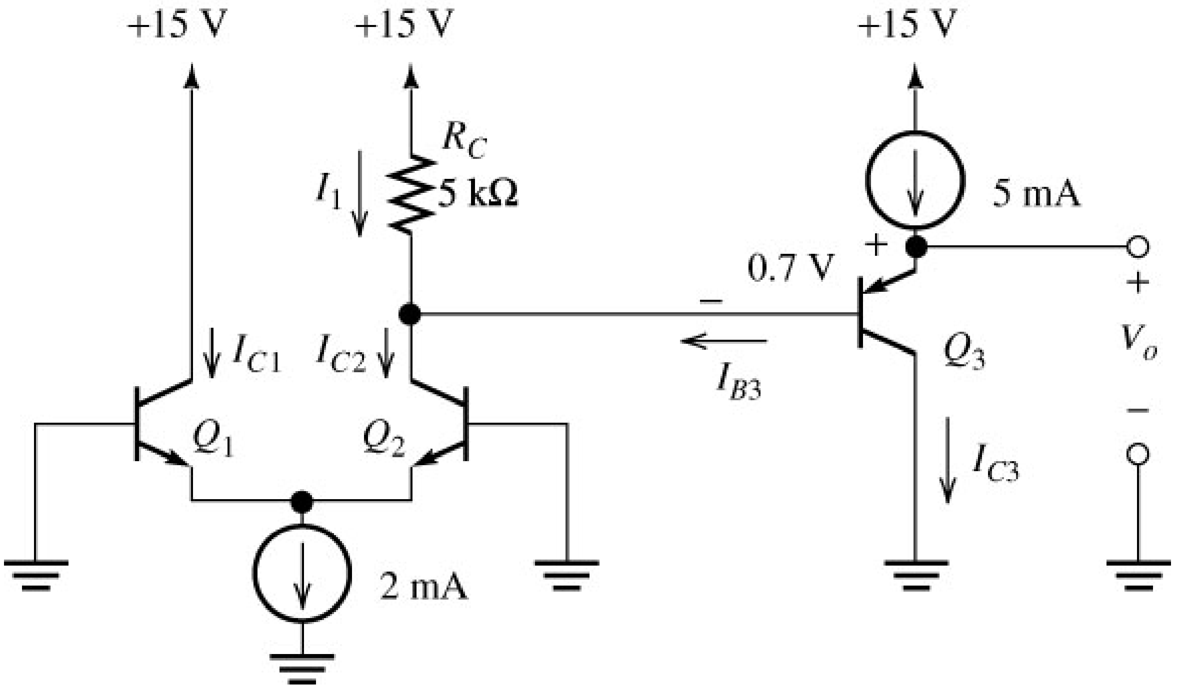


Figure 4.30 Current sources are useful in biasing IC amplifiers.

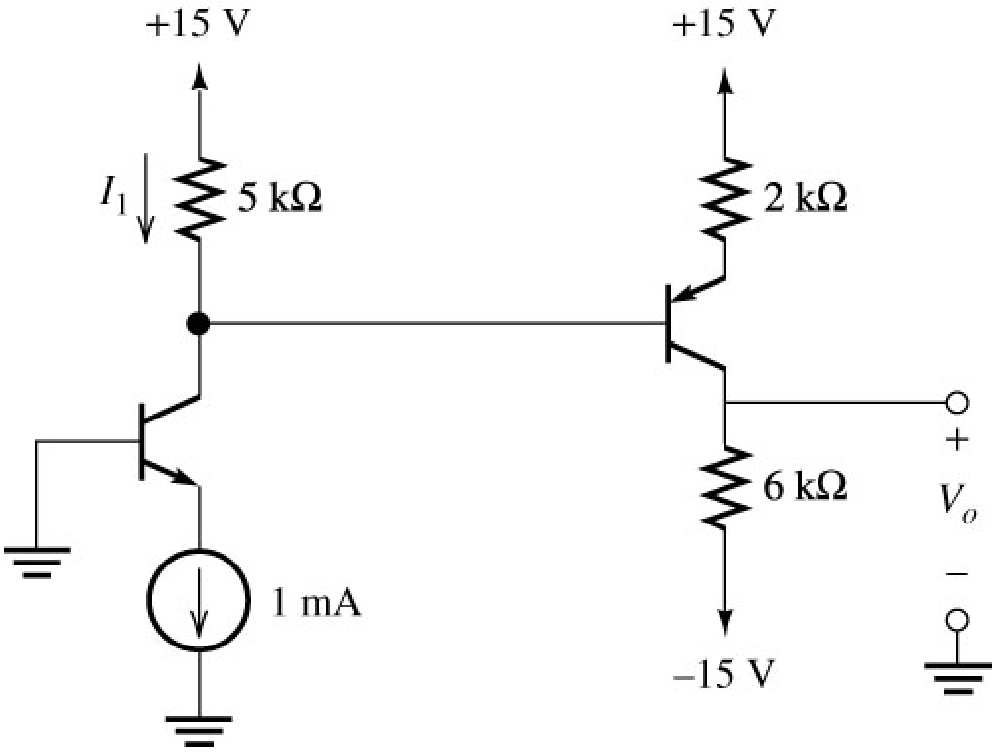


Figure 4.31 Circuit for Exercise 4.18.

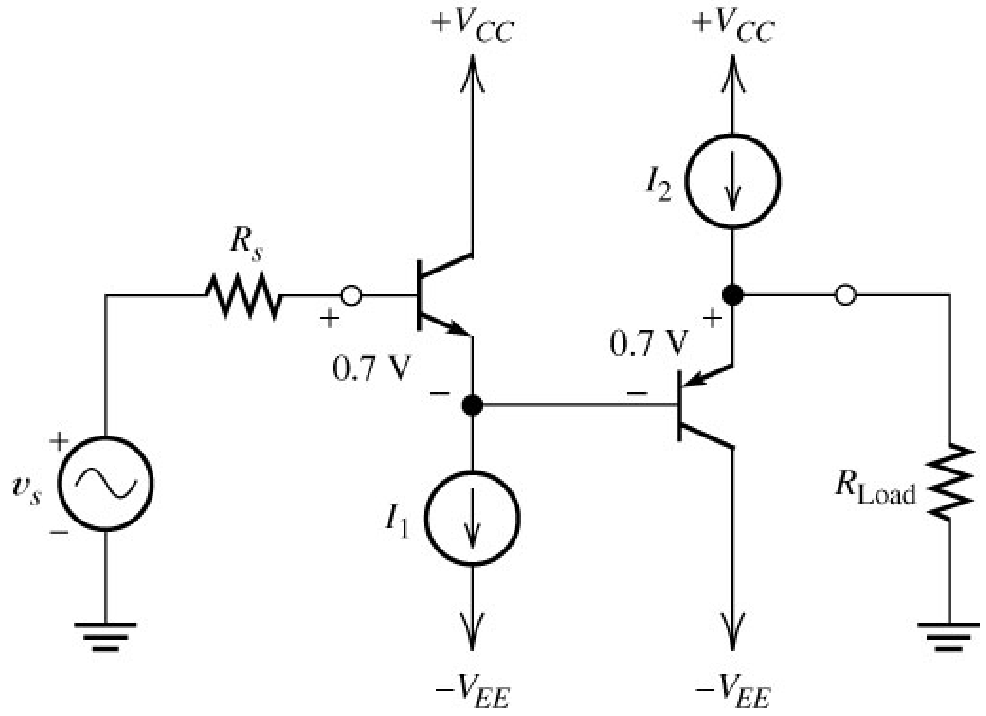


Figure 7.3 The offset voltage can be reduced by cascading a complementary (*pnp*) emitter follower.

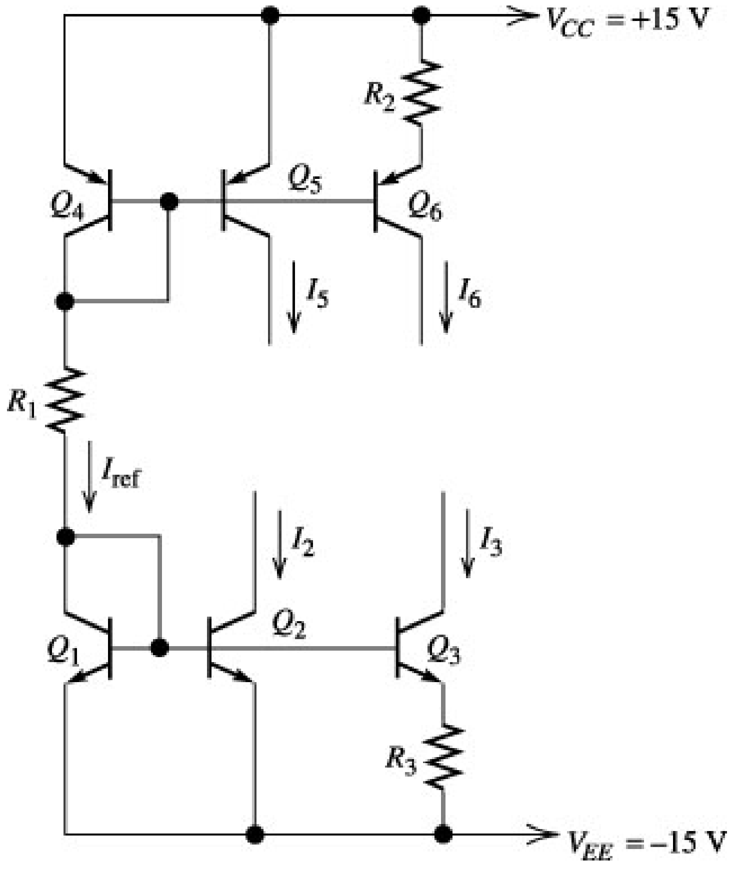
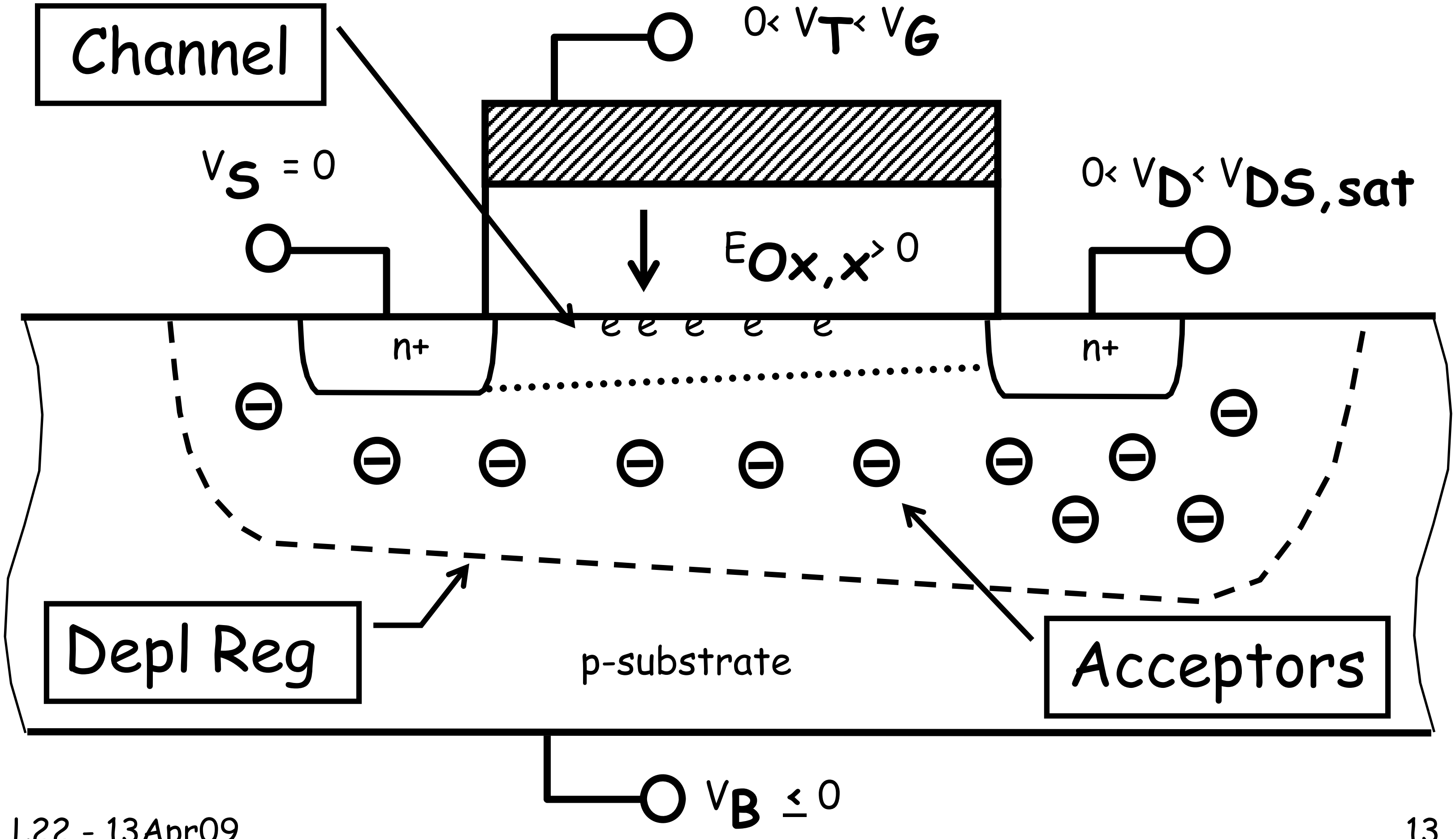


Figure 7.12 Typical biasing circuit for a bipolar IC.

n-channel enhancement MOSFET in ohmic region



Conductance of inverted channel

- $Q'_n = - C'_{Ox}(V_{GC}-V_T)$
- $n'_s = C'_{Ox}(V_{GC}-V_T)/q$, (# inv elect/cm^2)
- The conductivity $\sigma_n = (n'_s/t)\, q\, \mu_n$
- $G = \sigma_n(Wt/L) = n'_s\, q\, \mu_n\, (W/L) = 1/R$, so
- $I = V/R = dV/dR$, $dR = dL/(n'_s q \mu_n W)$

$$I\int_0^L dL = \int_{V_S}^{V_D} C'_{Ox}\left(\left(V_G - V_C\right) - V_T\right)\mu_n W dV$$

Basic I-V relation for MOS channel

$$I_D = \frac{W\mu_n C_{Ox}}{2L}\left(2(V_G - V_T)V_{DS} - V_{DS}^2\right),\ V_{DS} < V_G - V_T$$

At $V_{DS} = V_{DS,sat} = V_G - V_T,\ Q'_n(y = L) = 0 \Rightarrow$ Sat.

so let I_D be given by $I_D(V_{DS,sat})$,

for $V_{DS} > V_{DS,sat} = V_G - V_T$ so

$$I_D = I_{D,sat} = \frac{W\mu_n C_{Ox}}{2L}(V_G - V_T)^2$$

I-V relation for n-MOS (ohmic reg)

$I_D = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\left(2(V_G - V_T)V_{DS} - V_{DS}^2\right)$. Note for

$V_{DS} \geq V_G - V_T = V_{DS,sat}$,

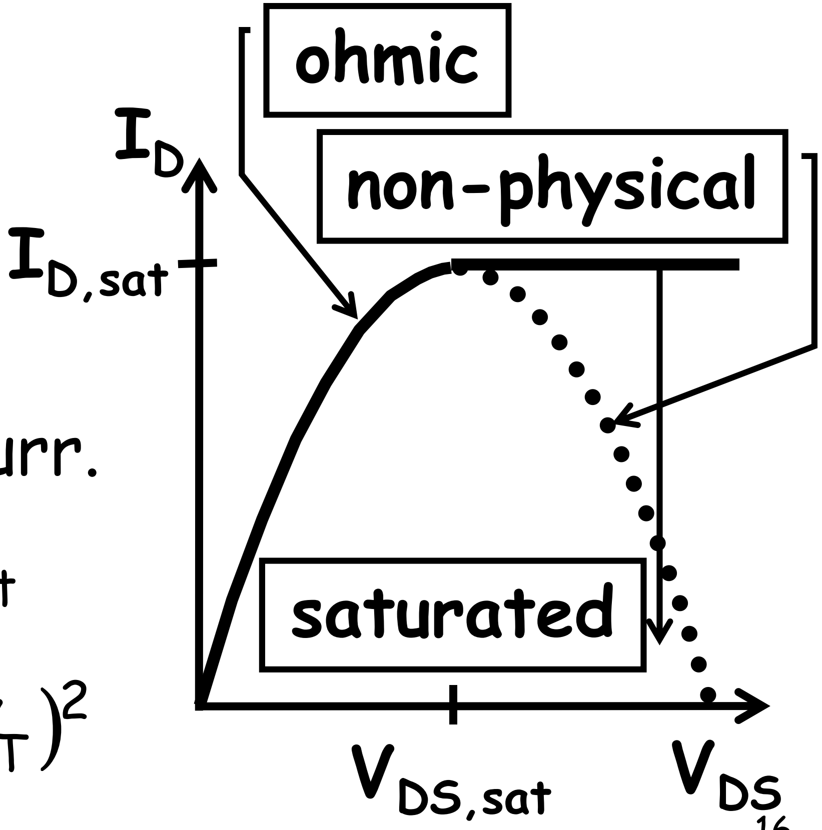
result is non-physical.

At $V_{DS,sat}$, $n'_{s,y=L} = 0$

assume that channel curr.

is const for $V_{DS} \geq V_{DS,sat}$

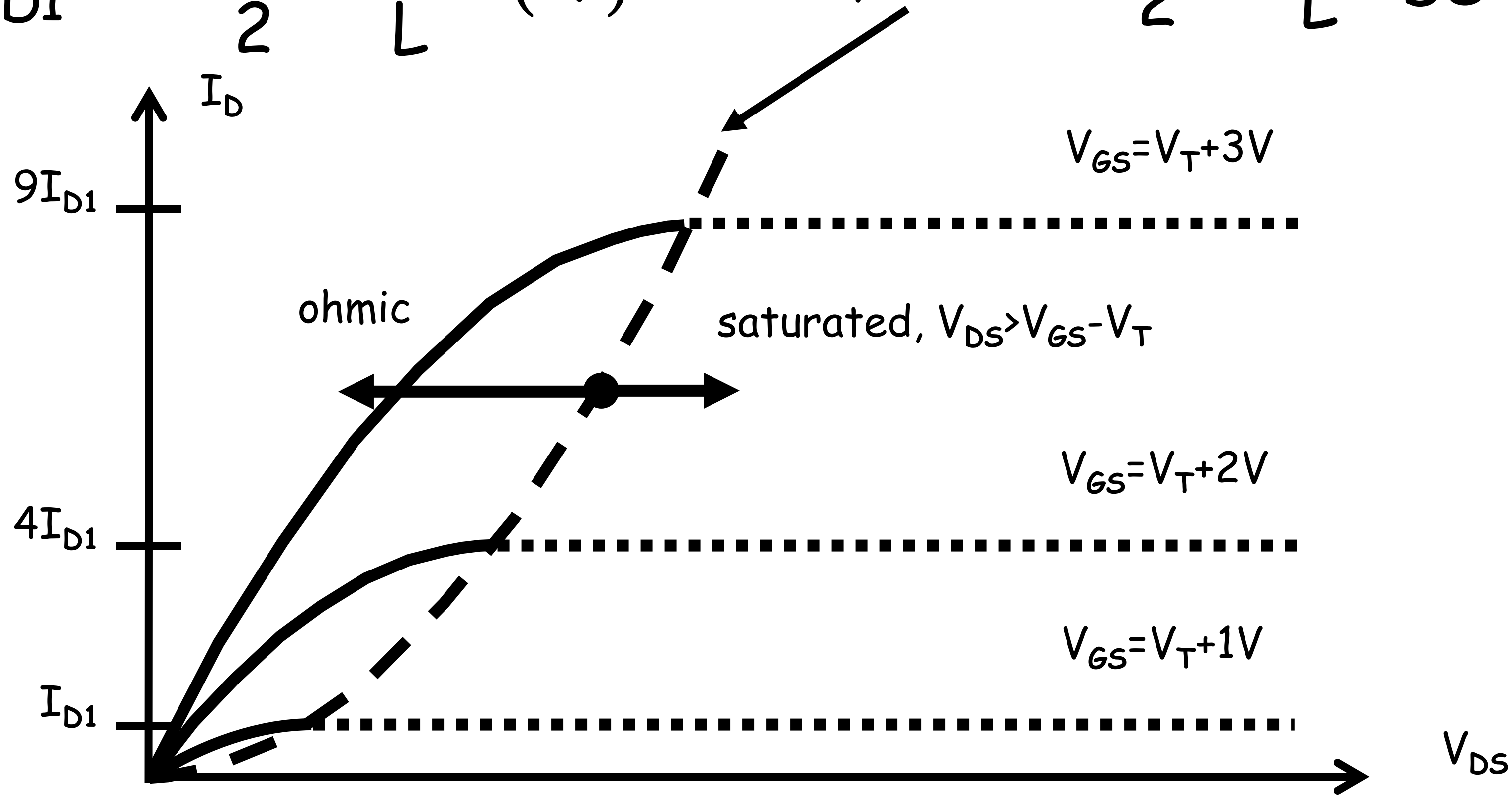
$$I_{D,sat} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\left(V_{GS} - V_T\right)^2$$



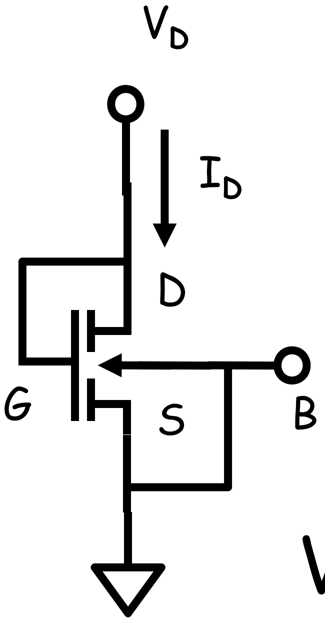
Universal drain characteristic

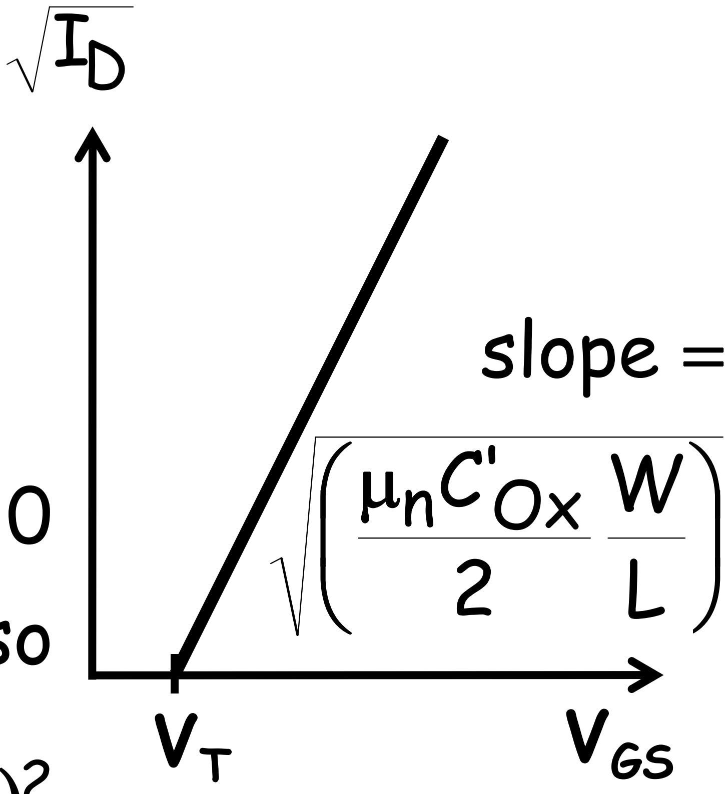
$$I_{D1} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\times(1V)^2$$

$$I_{D,sat} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}V_{DS}^2$$



Characterizing the n-ch MOSFET





slope = $\sqrt{\left(\frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\right)}$

$$V_{DS} = V_{GS}\ ,\ V_T \geq 0$$

$$V_{DS} \geq V_{GS} - V_T\ ,\ \text{so}$$

$$I_{D,sat} = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2$$

Low field ohmic characteristics

$$I_D = \frac{\mu_n C'_{Ox}}{2}\frac{W}{L}\left(2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right),$$

for ohmic region. Furthermore, let

$V_{DS} << V_G - V_T$, so that

$$I_D \approx \mu_n C'_{Ox}\frac{W}{L}(V_{GS} - V_T)V_{DS}$$

$$= KP\frac{W}{L}(V_{GS} - V_T)V_{DS}\text{ , } KP = \mu_n C'_{Ox}$$

$$\left[\frac{dI_D}{dV_{GS}}\right]_{V_{DS}<<V_G-V_T} \approx KP\frac{W}{L}V_{DS}$$

MOSFET circuit parameters

$$\text{Transconductance}$$

$$g_m \equiv \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS}}$$

$$g_{ms} = \frac{W\mu_n C'_{Ox}}{L} V_{DS},\ \text{saturation}$$

$$g_{mL} = \frac{W\mu_n C'_{Ox}}{L} \left(V_{GS} - V_T\right),\ \text{ohmic region}$$

MOSFET circuit parameters (cont)

Output or drain conductance

$$g_d \equiv \left.\frac{\partial I_D}{\partial V_{DS}}\right|_{V_{GS}}$$

$$g_{ds} = 0, \text{ saturation}$$

$$g_{dL} = \frac{W\mu_n C'_{Ox}}{L}\left(V_{GS} - V_T - V_{DS}\right), \text{ ohmic}$$

Substrate bias effect on V_T (body-effect)

Letting V_T calculation be relative to Source

$$V_T - V_S = V_{FB} - 2\left|\phi_p\right| - \frac{-qN_a x_{d,max}}{C'_{Ox}}, \text{ where}$$

$$x_{d,max} = \sqrt{\frac{2\varepsilon\left(2\left|\phi_p\right| + V_{SB}\right)}{qN_a}}, \text{ so } \Delta V_T = V_T\left(V_{SB}\right) -$$

$$V_T\left(V_{SB} = 0\right) = \frac{\sqrt{2\varepsilon_{Si} qN_a}}{C'_{Ox}}\left(\sqrt{2\left|\phi_p\right| + V_{SB}} - \sqrt{2\left|\phi_p\right|}\right)$$

Body effect data

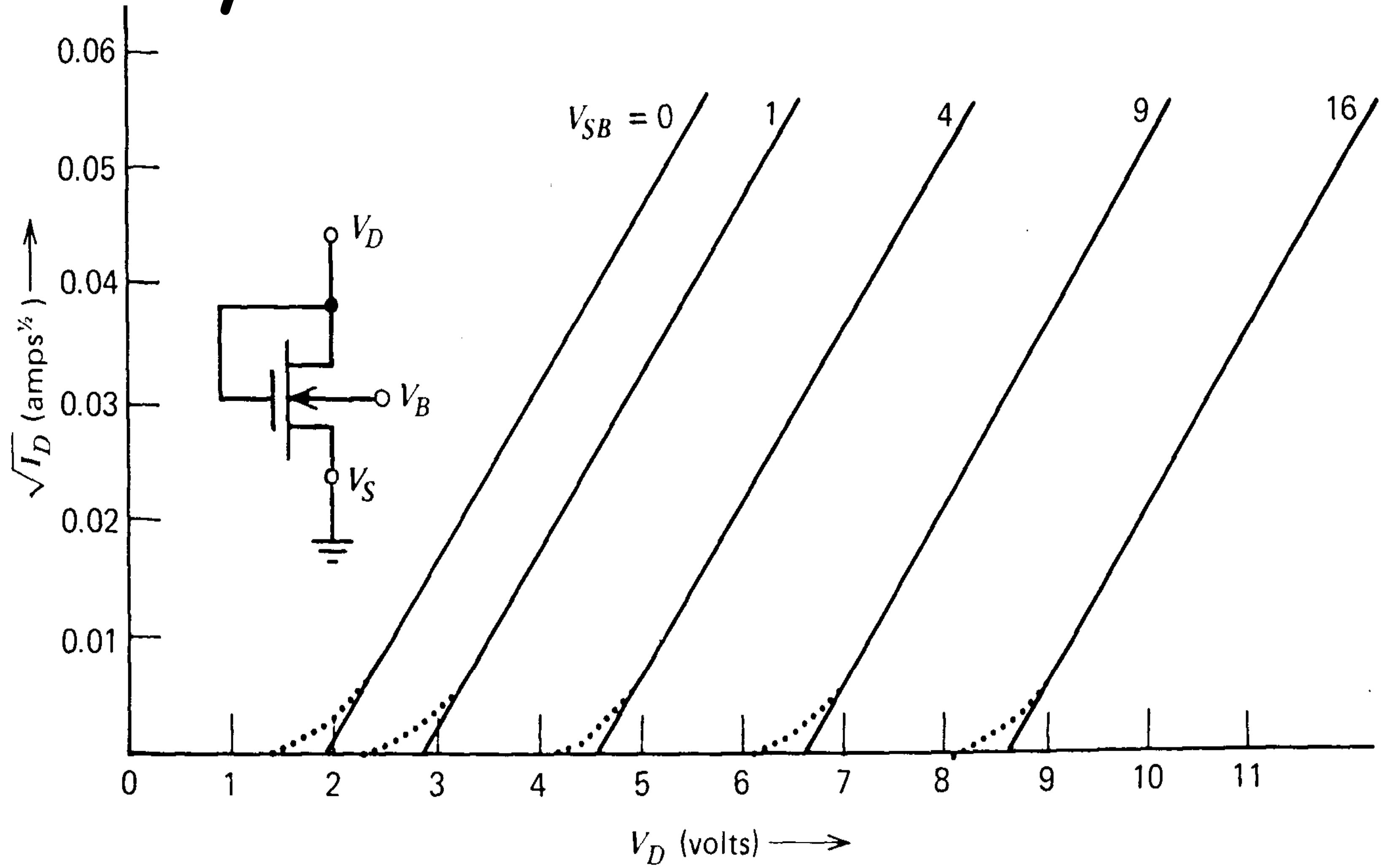


Fig 9.9, *Device Electronics for Integrated Circuits*, 2nd ed., by Richard S. Muller and Theodore I. Kamins, Wiley, NY, 1986

References and Endnotes

- Where not otherwise noted, figures with a figure number (e.g., Fig 3.2) are taken from:
  - Electronics, 2nd edition, by Allan R. Hambley, Prentice Hall, Upper Saddle River, NJ, © 2000.