Single-Stage Integrated-Circuit Amplifiers

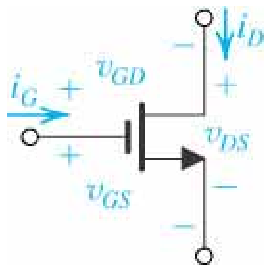
Outline

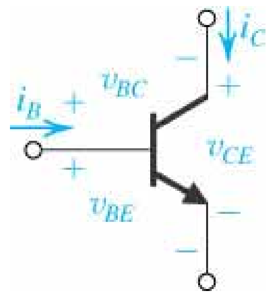
- Comparison between the MOS and the BJT
- From **discrete** circuit to **integrated** circuit

  \- Philosophy, Biasing, …etc.
- Frequency response
- The **C**ommon**-S**ource and **C**ommon**-E**mitter amplifier with active loads
- The **C**ommon**-G**ate and **C**ommon**-B**ase amplifier with active load
- The **S**ource and **E**mitter **F**ollower
- The CS and CE amplifier with **source degeneration**
- Current mirrors with improved performance
- **Cascode** amplifier and **transistor pairings**

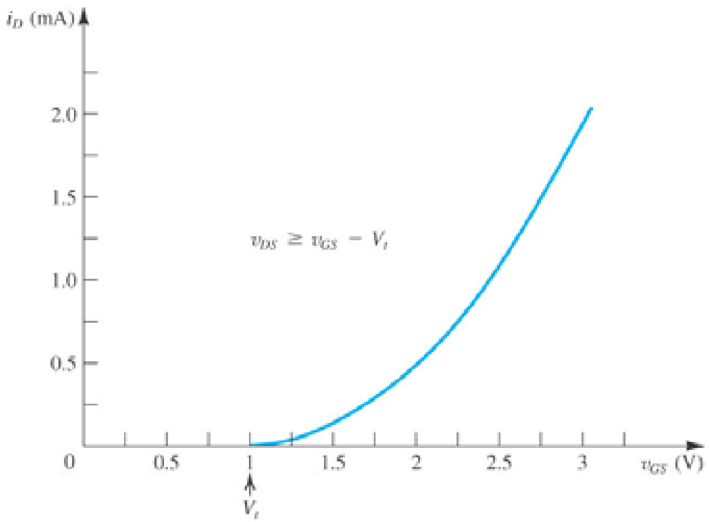
6-1 Comparison between the MOS and the BJT

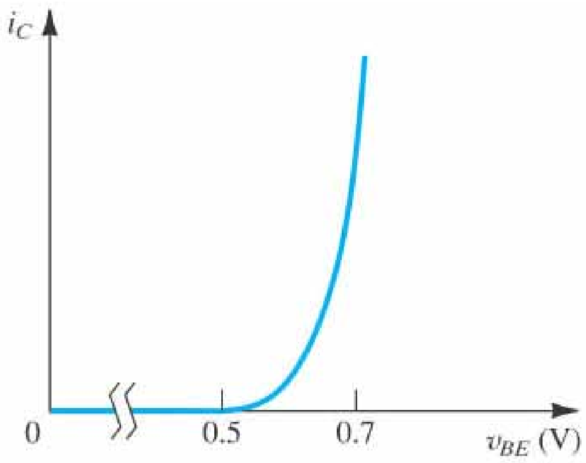
DC characteristics

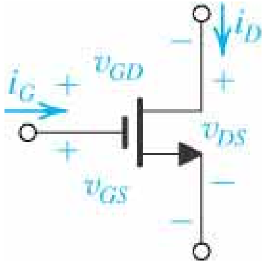


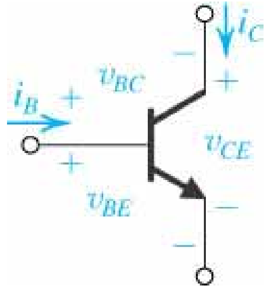


- **Transconductor (i_D - v_{GS} v.s. i_C - v_{BE})**

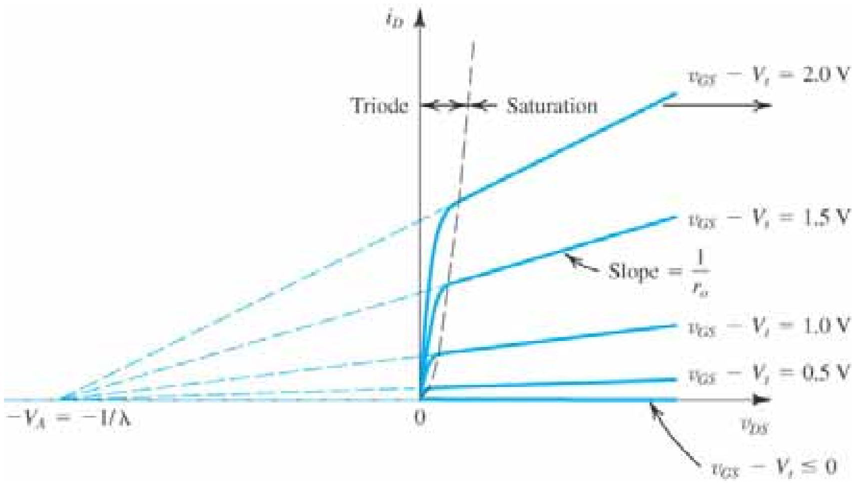


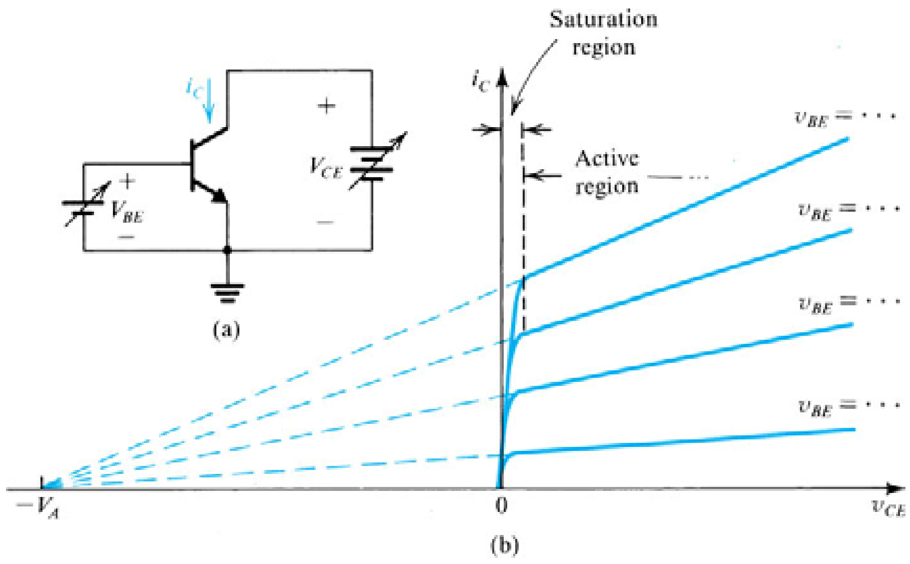




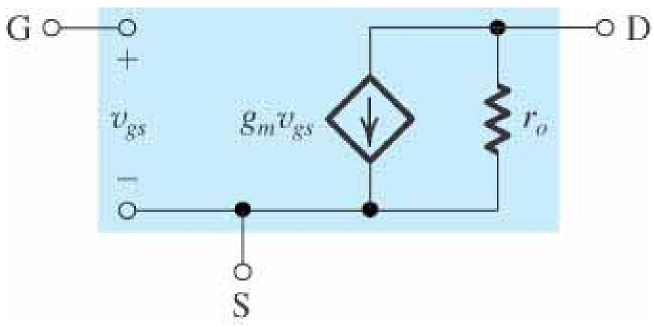


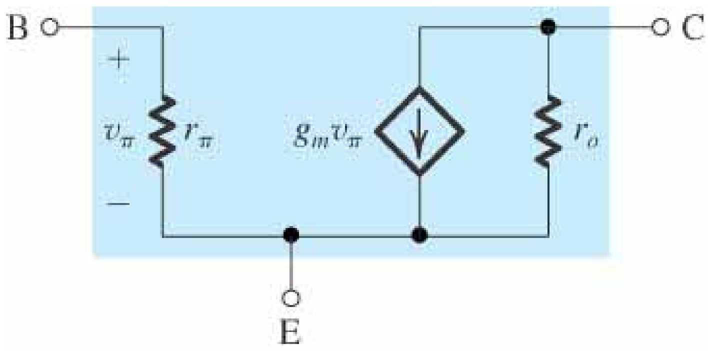
- **Channel-length modulation (i_D - v_{DS}) v.s. Early effect ($i_C – v_{CE}$)**





Low-frequency operation





- **Input resistance**

- **Transconductance**

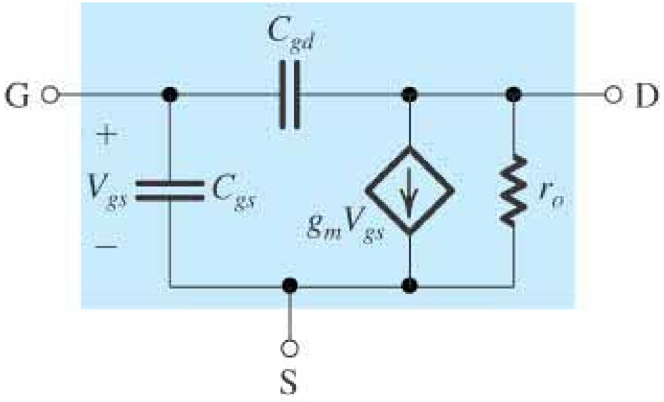
$$g_m = \sqrt{2(\mu_n C_{ox})\left(\frac{W}{L}\right)I_D}$$

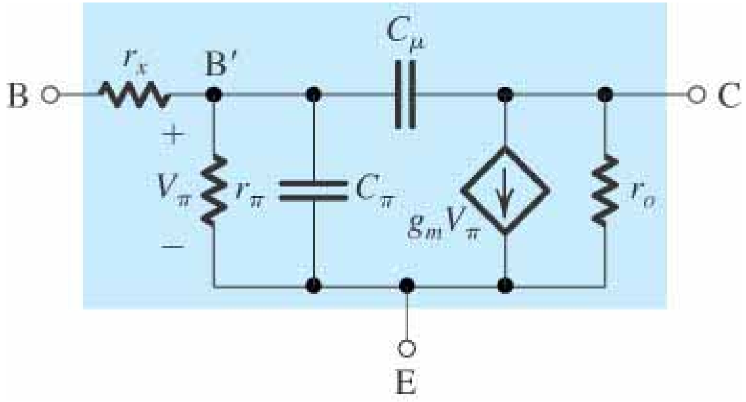
$$g_m = \frac{I_C}{V_T}$$

- **Output resistance**

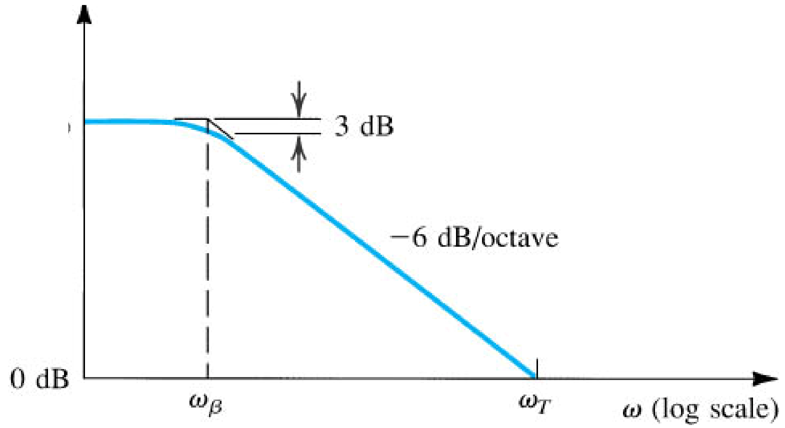
- **Intrinsic gain**

High-frequency operation





- **Cutoff frequency**



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

For $C_{gs} >> C_{gd}$ and $C_{gs} \cong \frac{2}{3} WLC_{ox}$

$$f_T \cong \frac{1.5\mu V_{OV}}{2\pi L^2}$$

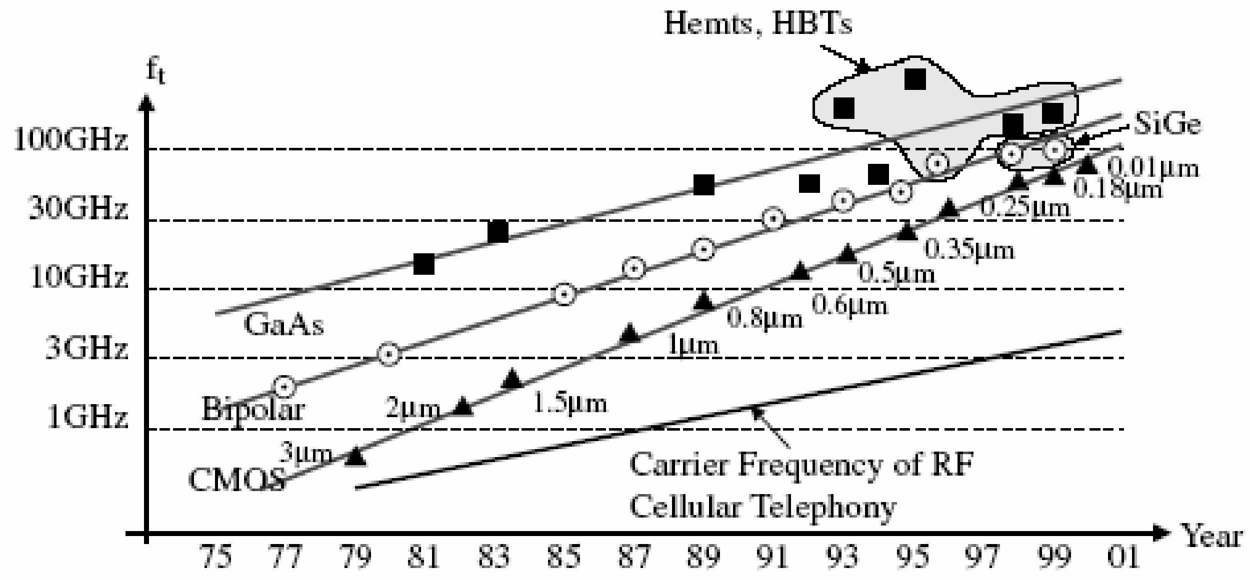
$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$

For $C_\pi >> C_\mu$ and $C_\pi \cong C_{de}$

$$f_T \cong \frac{2\mu V_T}{2\pi W^2}$$

Trends in IC technology

• **Technology speed figure of merit v.s. Time:**



• **Estimated frequency performance based on scaling**

Technology	f_t	f_{max}
0.35 micron	25GHz	40GHz
0.25 micron	40GHz	≈60-70GHz
0.18 micron	60GHz	≈90-100GHz

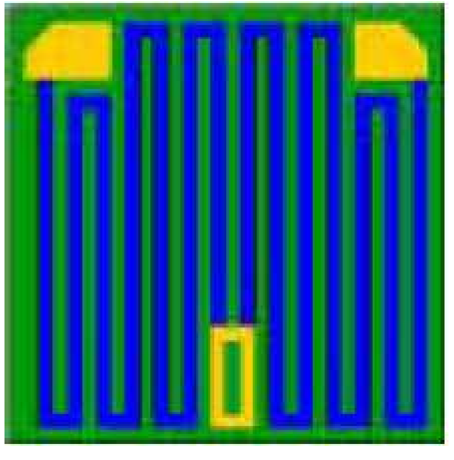
Comparison

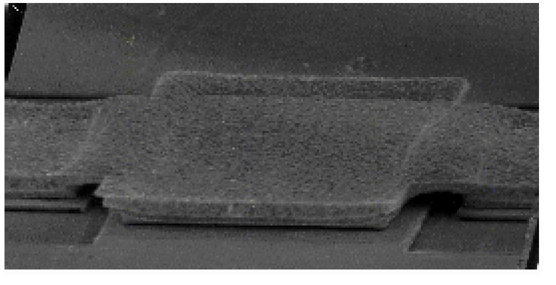
From analogue or digital point of view?

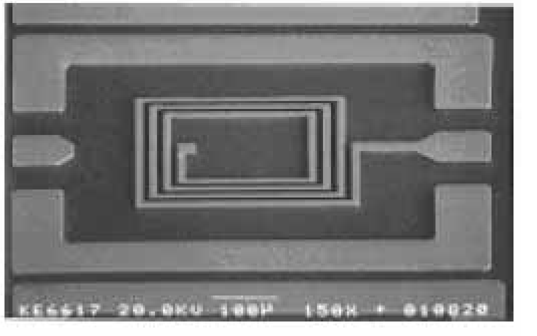
	BJT	**MOS**
DC range of operation	>5 decades of $I_C \propto e^{V_{BE}}$	2-3 decades of $I_D \propto (V_{GS} - V_T)^2$
Small-signal output resistance (r_o)	Slightly larger	Smaller for short channel
Cutoff frequency (f_T)	100GHz	50GHz
Switch implementation	Poor	Good
Noise (thermal about the same)	Less 1/f	More 1/f
Capacitor implementation	Voltage dependent	Reasonably good

6-2 From Discrete- to Integrated- circuit

Components

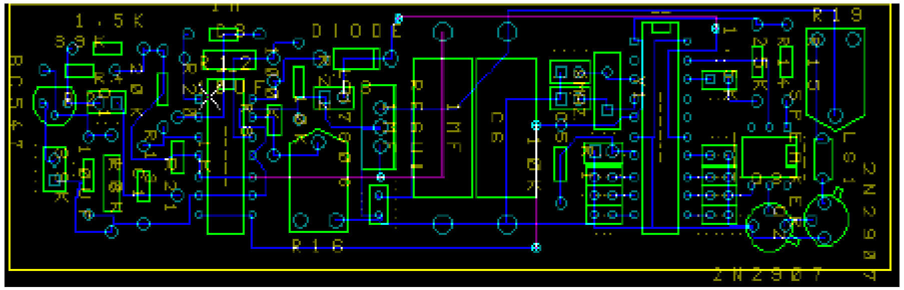


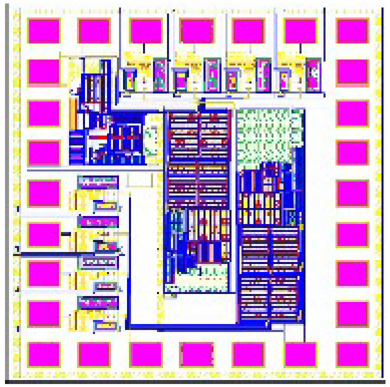


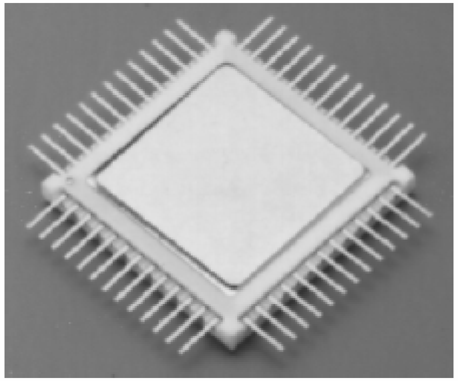


(The pictures are copied from http://140.114.23.141/htdocs/course/922_EE226002/Introduction.pdf , S.H. Hsu)

Hardware products

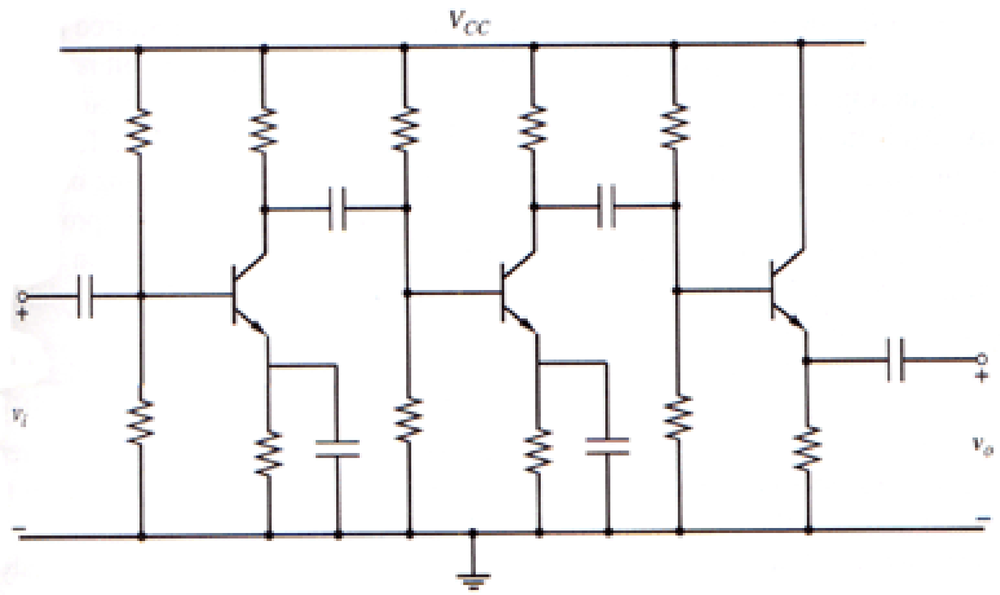


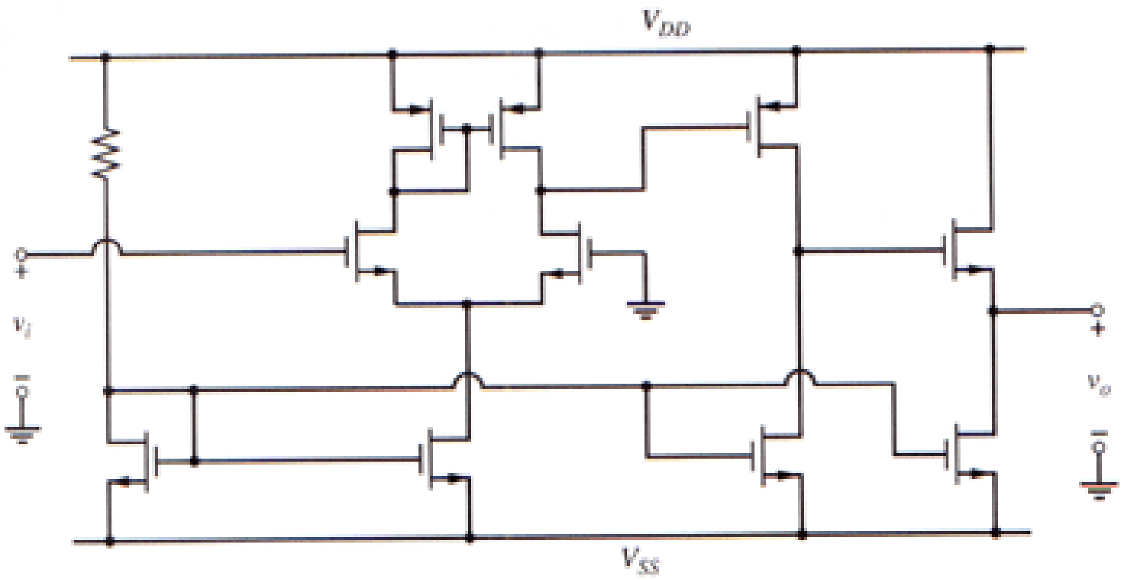




(The pictures are copied from http://140.114.23.141/htdocs/course/922_EE226002/Introduction.pdf , S.H. Hsu)

Design topologies





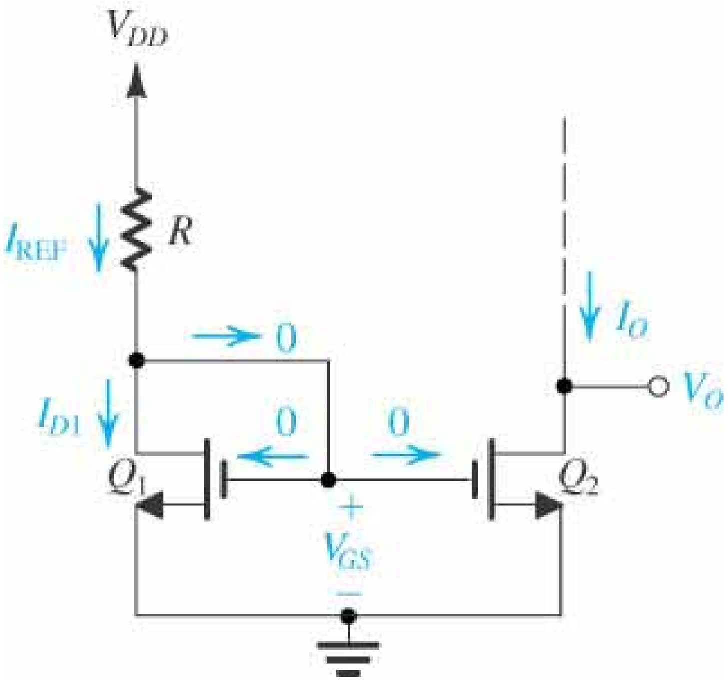
- Active load to replace R

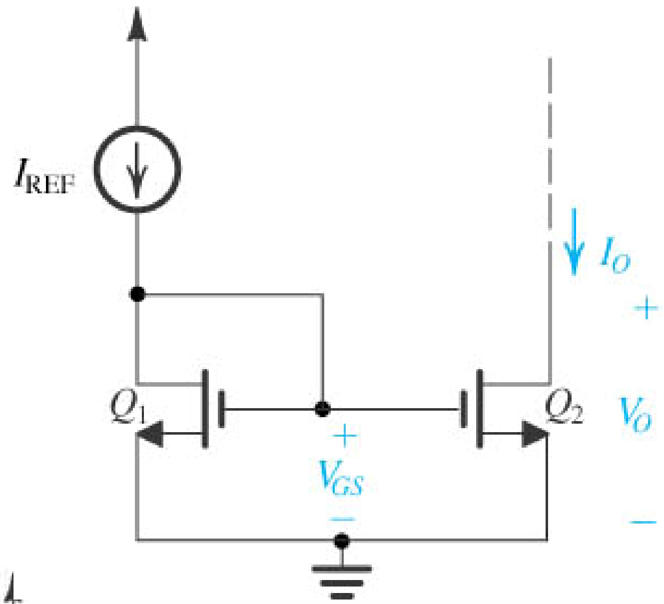
  R=?

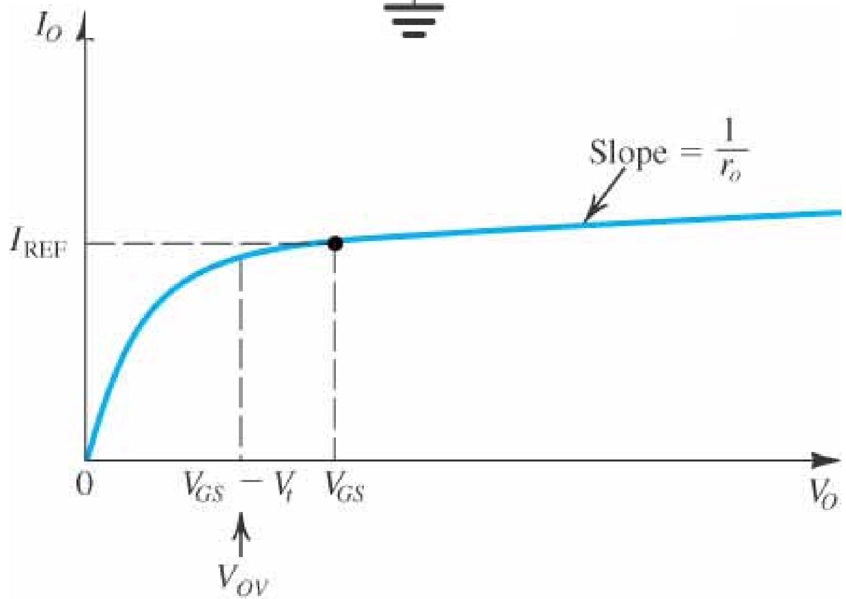
- Current biasing
- Direct-coupled

→Differential architecture to decouple DC signals (Ch7)

IC Biasing – current mirror (amplifier)

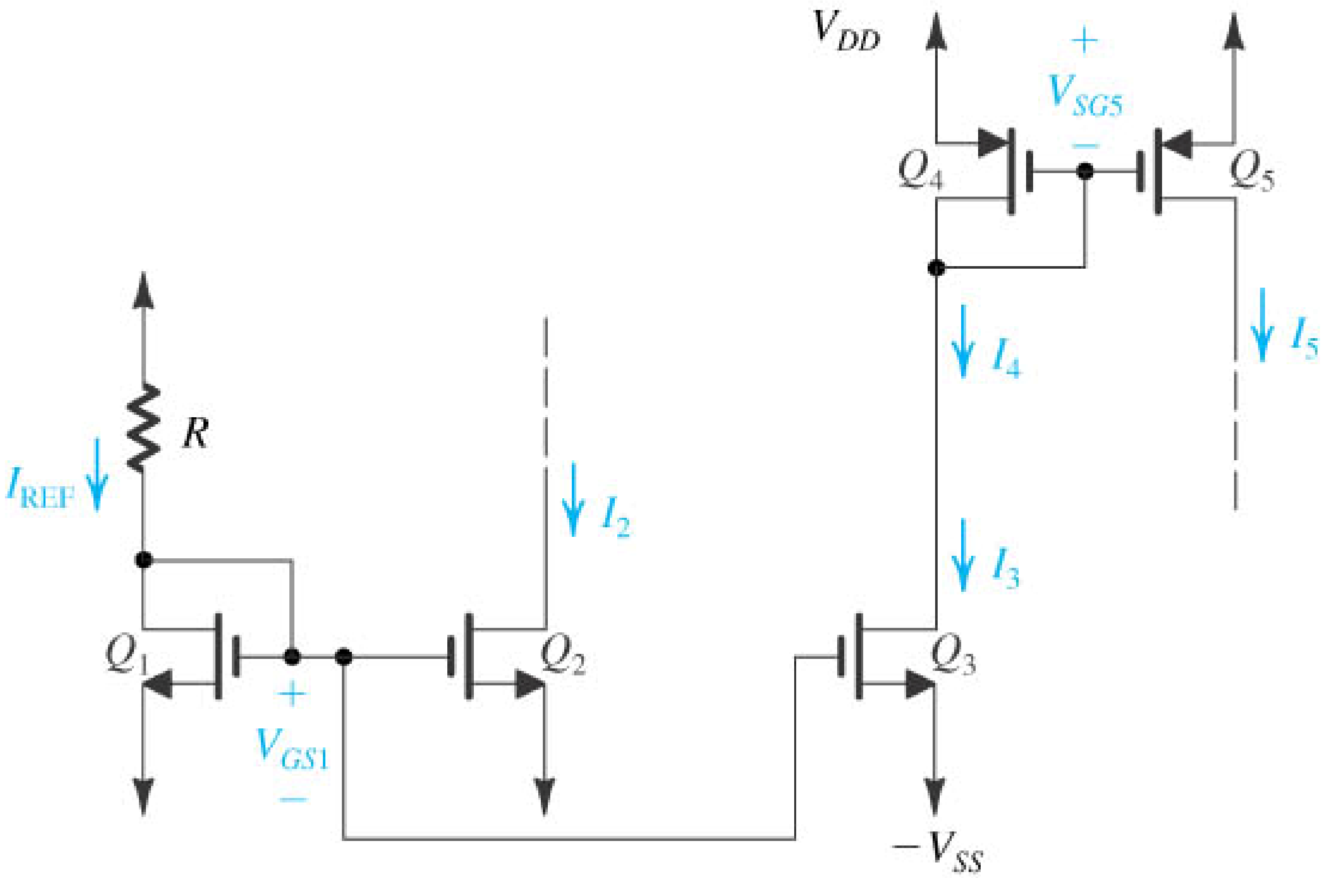




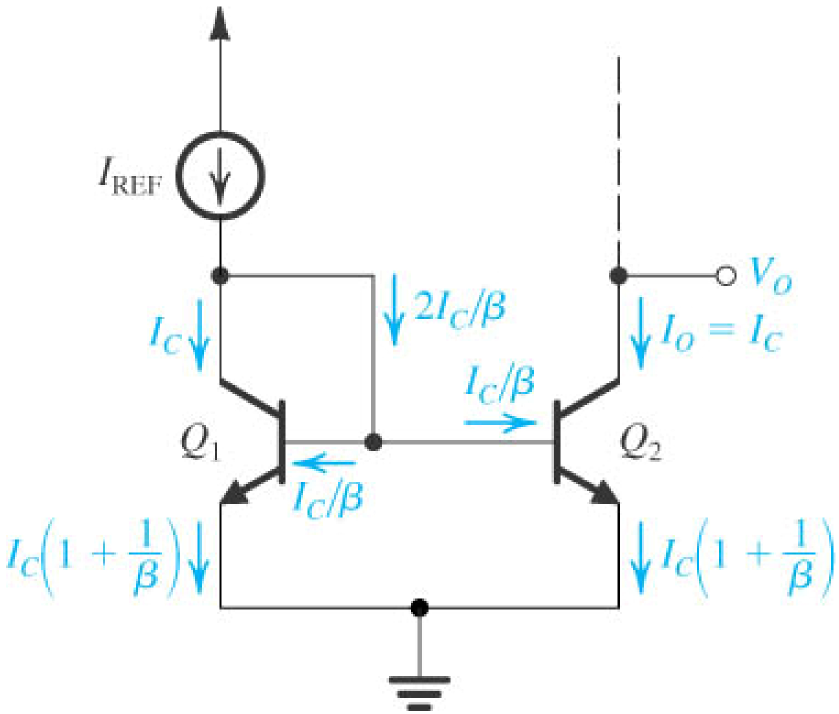


- I_o / I_{REF} =
- Minimum V_o =
- Effect of r_o :

Current steering



BJT current mirror

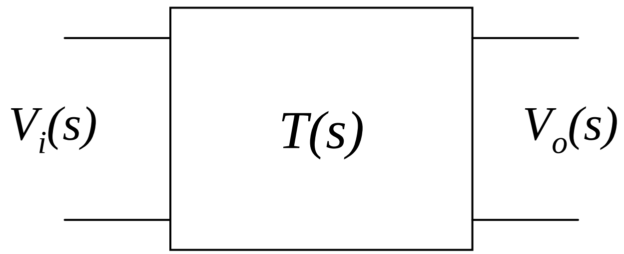


- $I_o / I_{REF} =$
- Minimum $V_o =$
- Effect of r_o :

$$\frac{I_O}{I_{REF}} = \frac{m}{1+\dfrac{m+1}{\beta}}$$

6-3 Frequency response

- In analysing the frequency response of circuits,
  capacitors → 1/sC
  inductors → sL



$$T(s) = \frac{a_m s^m + a_{m-1} s^{m-1} + \cdots + a_0}{s^n + b_{n-1} s^{n-1} + \cdots + b_0}$$

Substituting $s=jw$ into T(s) → The gain and phase response v.s. w

$$T(s) = a_m \frac{(s-Z_1)(s-Z_2)\cdots(s-Z_m)}{(s-P_1)(s-P_2)\cdots(s-P_n)}$$

Zeros :
Poles :

Bode plot

$|T(s)|$ $\angle T(s)$

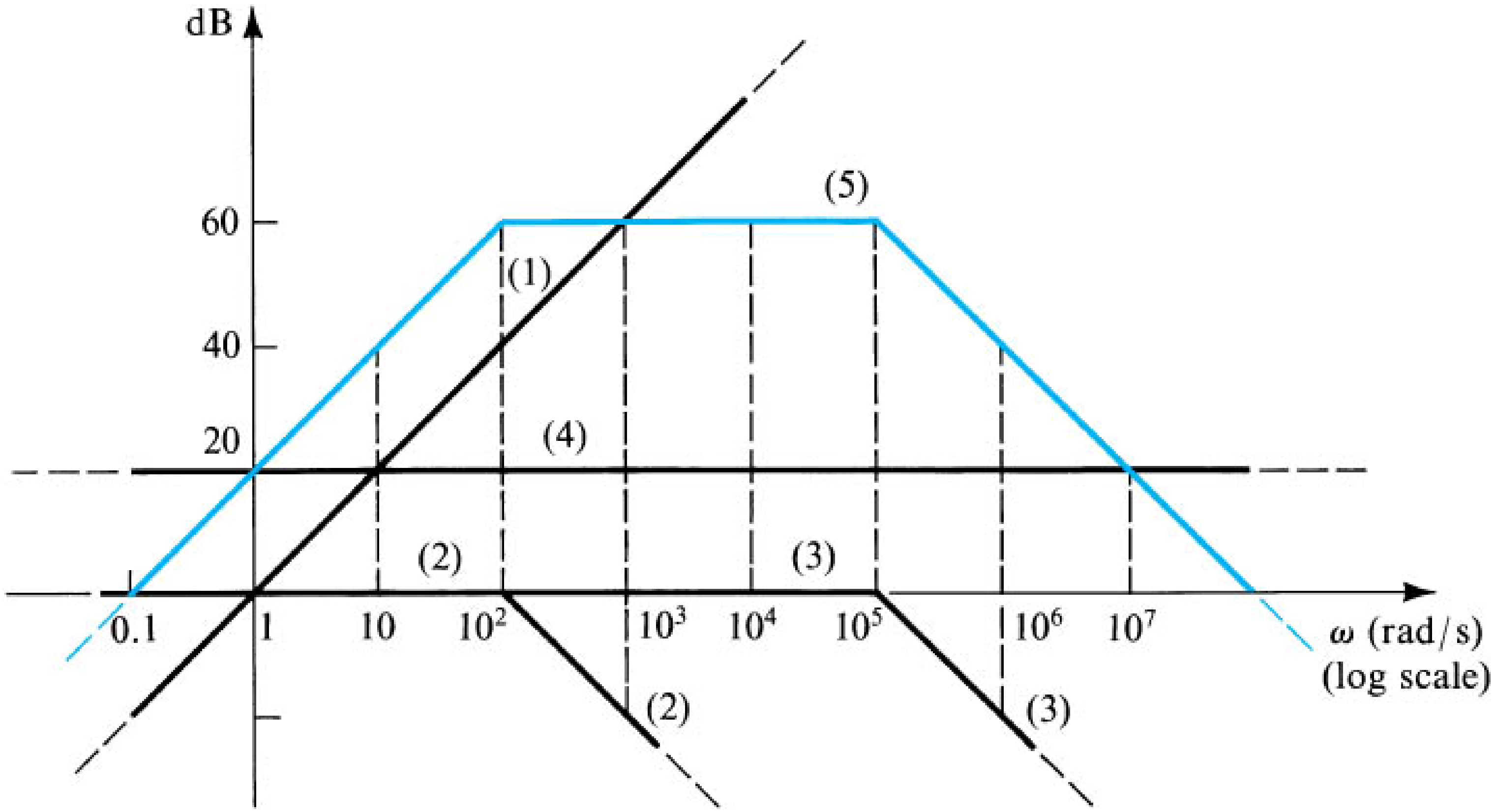
a pole $T(s) = \dfrac{1}{s + p_0}$

a zero $T(s) = s + z_0$

How about positive-valued poles/zeros?

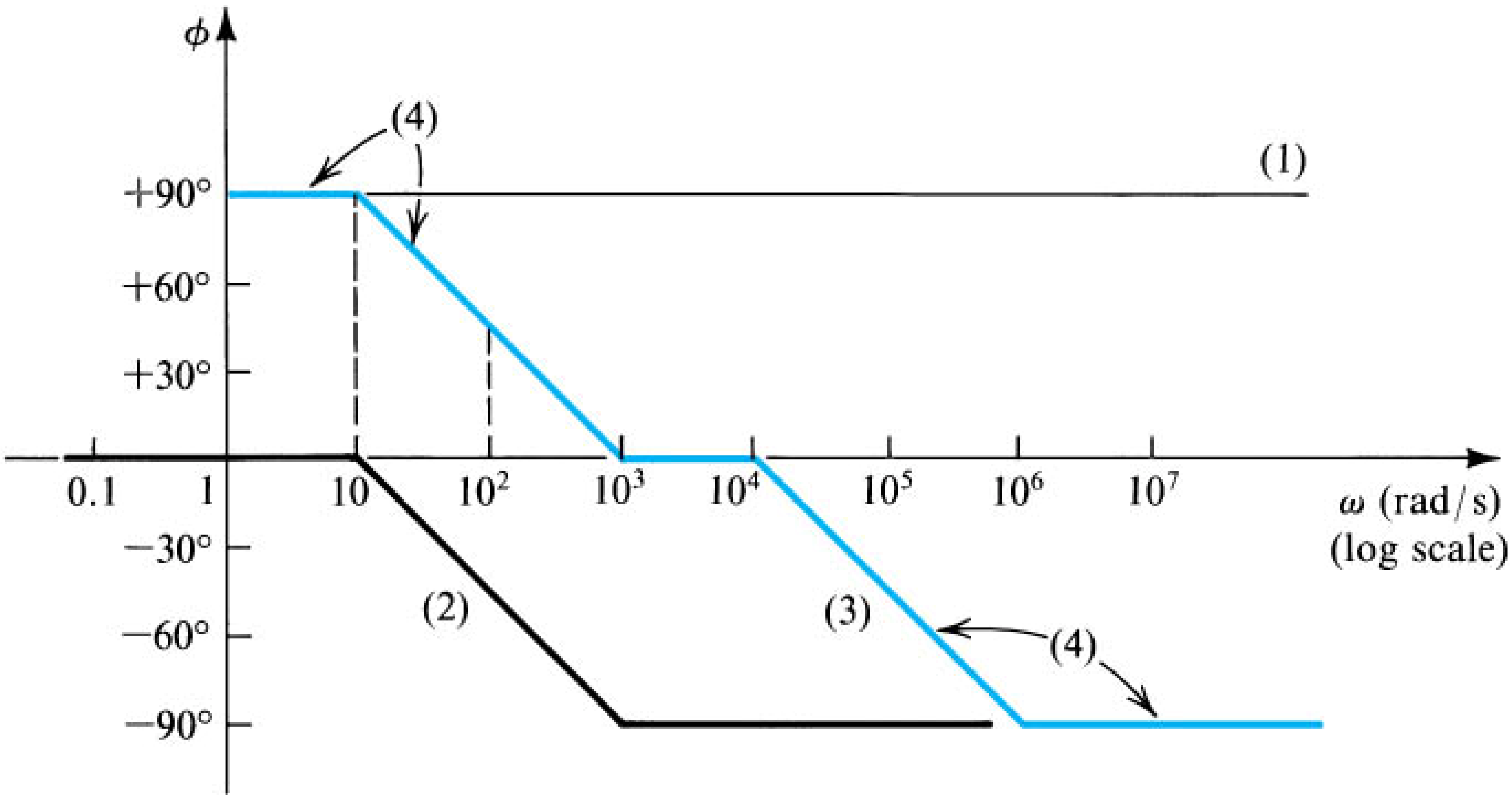
Example

$$T(s) = \frac{10s}{(1+s/10^2)(1+s/10^5)}$$



Example- continued

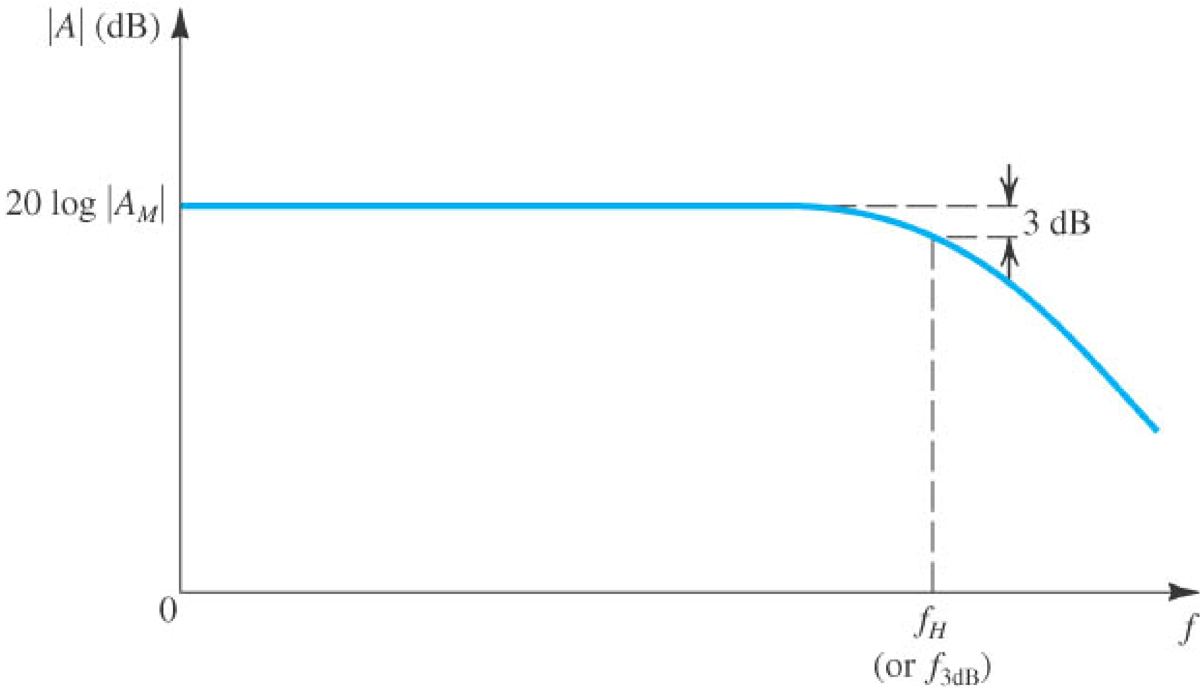
$$T(s)=\frac{10s}{(1+s/10^2)(1+s/10^5)}$$



High-frequency response

• Frequency response of a direct-coupled amplifier

$$F_H(s) = \frac{(1+s/z_1)(1+s/z_2)\cdots(1+s/z_n)}{(1+s/p_1)(1+s/p_2)\cdots(1+s/p_n)}$$



We are mostly interested in **3-dB frequency, f_H (or f_{3dB})**

Methods to derive f_H

- If a dominant pole exists

$$F_H(s) \cong \frac{1}{1 + s / w_{P1}}$$

- If not, use the cond. $|F(w_H)| = ½$ to derive

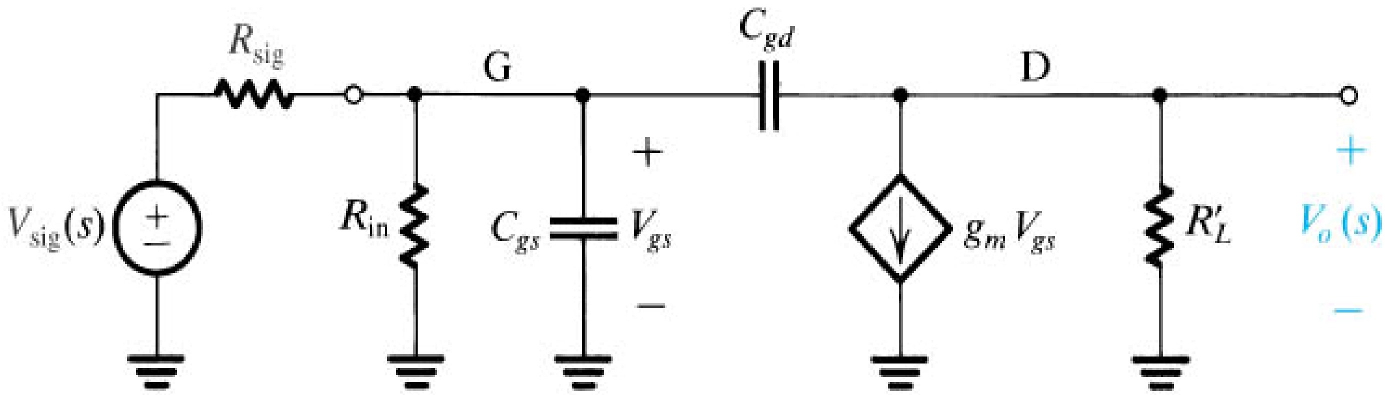
$$w_H \cong 1 \Bigg/ \sqrt{\left(\frac{1}{w_{P1}^2} + \frac{1}{w_{P2}^2} + \cdots + \frac{1}{w_{Pn}^2}\right) - \left(\frac{1}{w_{Z1}^2} + \frac{1}{w_{Z2}^2} + \cdots + \frac{1}{w_{Zn}^2}\right)}$$

- Open-circuit time constants

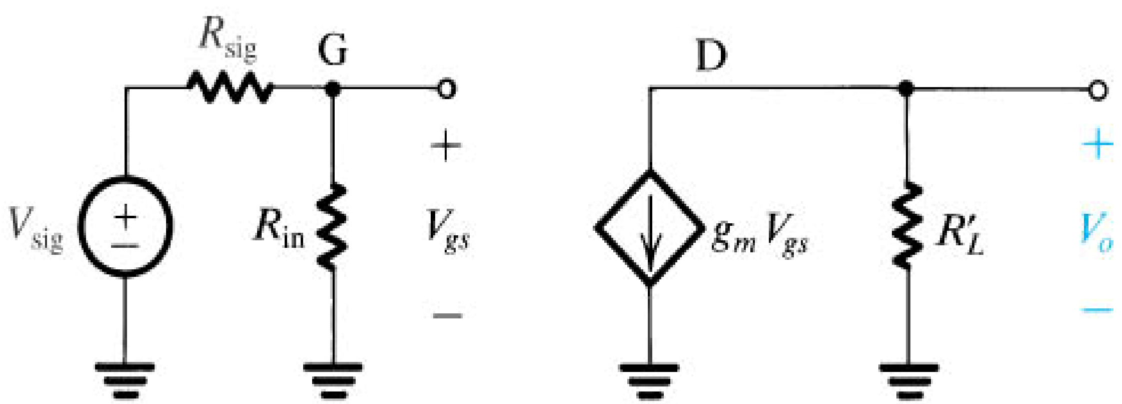
$$w_H \cong \frac{1}{\sum_i C_i R_{io}}$$

R_{io} : resistance seen by C_i when all other Cs are open-circuit and all sources equal zeros

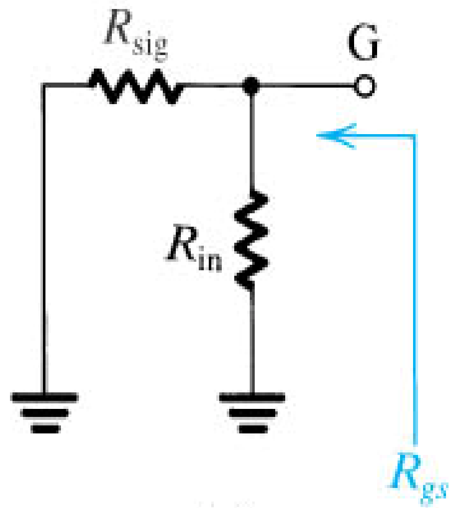
Example 6.6



(a)

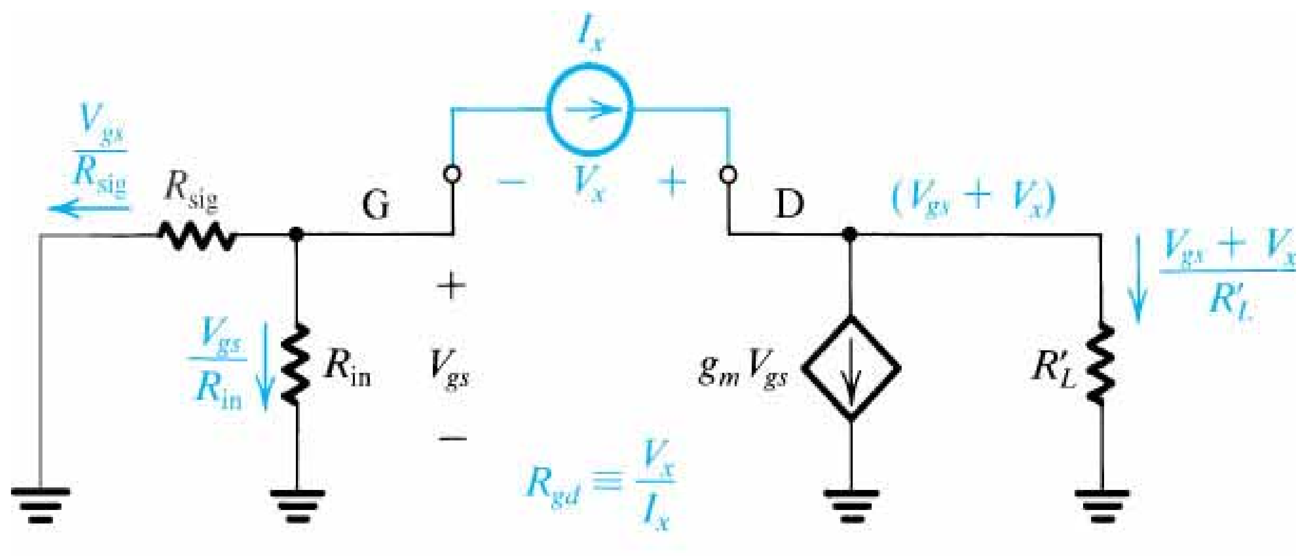


(b)



R_{sig}
G
R_{in}
R_{gs}

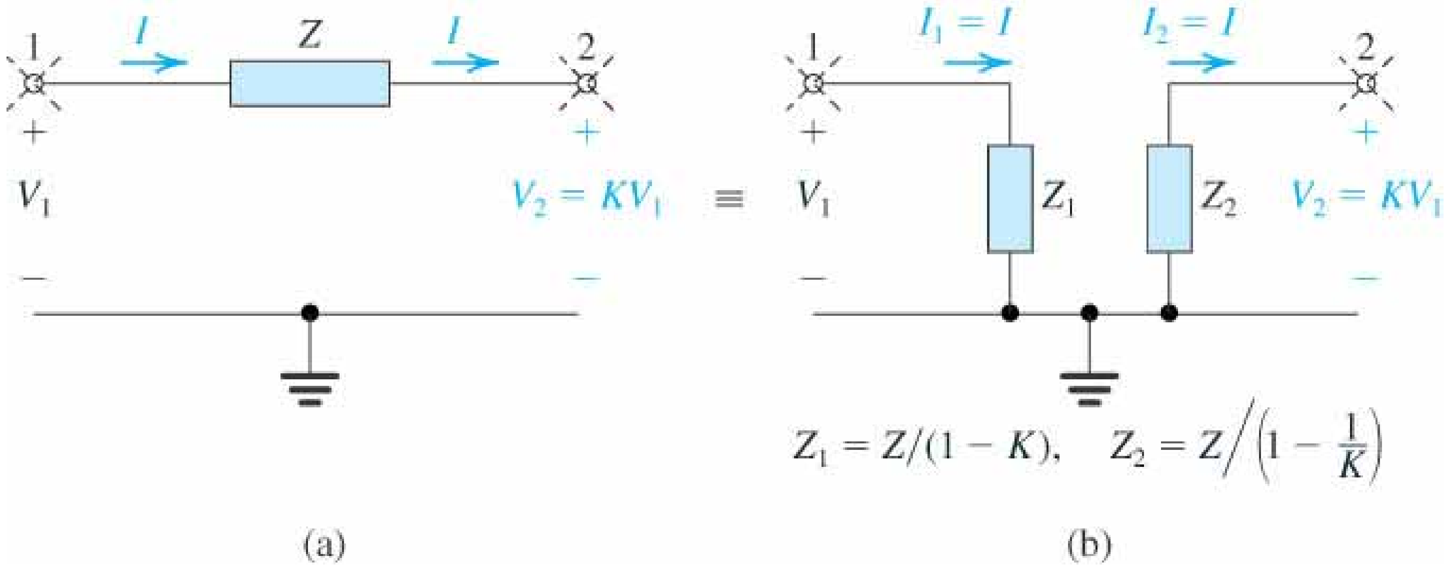
(c)



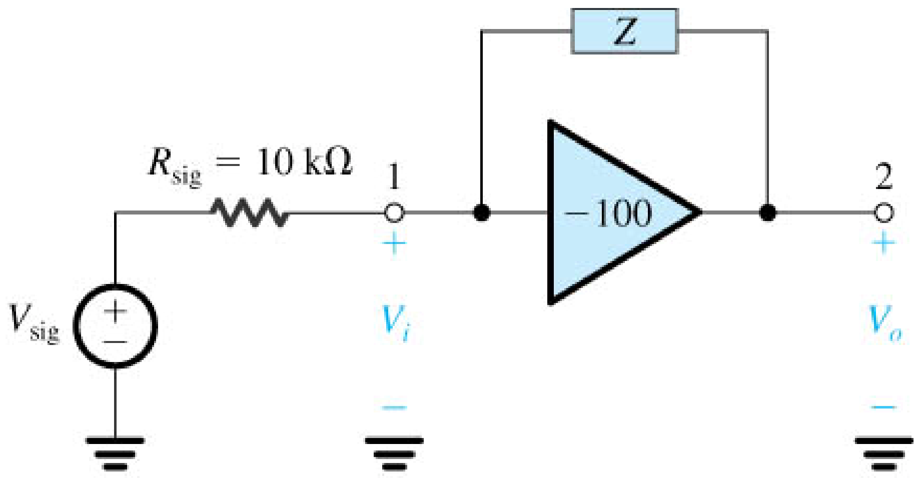
I_x
$\frac{V_{gs}}{R_{sig}}$
R_{sig}
G
$-$ V_x $+$
D
$(V_{gs}+V_x)$
$\frac{V_{gs}+V_x}{R'_L}$
$\frac{V_{gs}}{R_{in}}$
R_{in}
$+$
V_{gs}
$-$
$g_m V_{gs}$
R'_L
$R_{gd} \equiv \frac{V_x}{I_x}$

(d)

Miller's theorem – one useful technique for analysing freq response



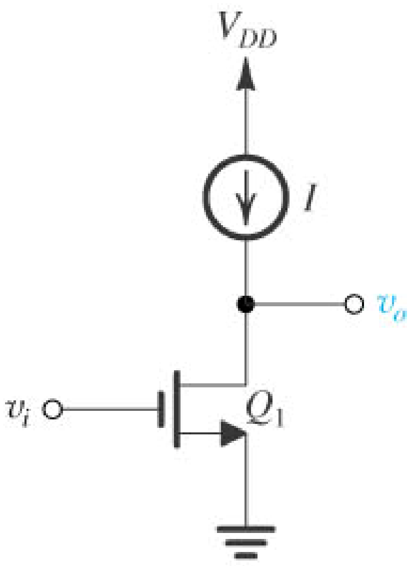
Example 6.7



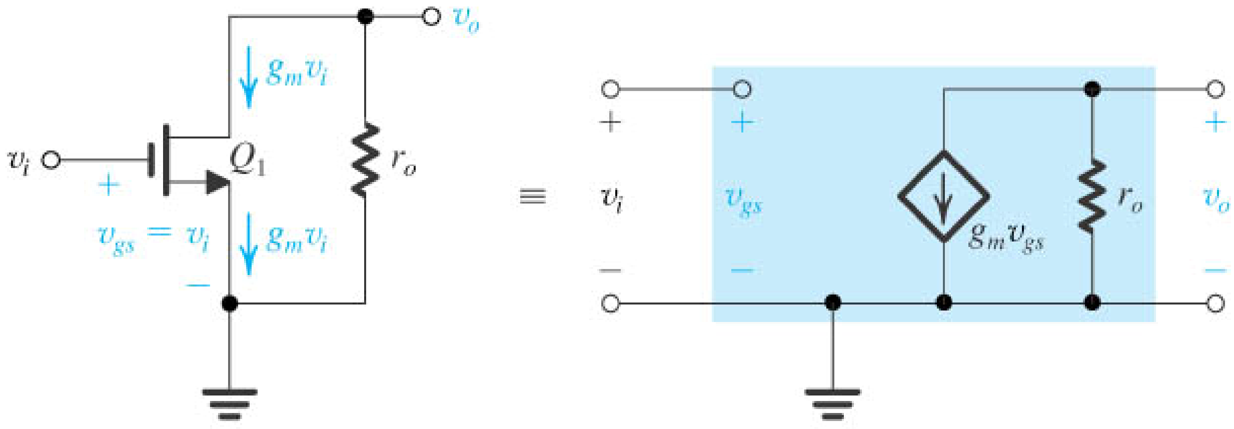
(a)

6-4 Common-Source and Common-Emitter amplifers with acitive loads

Common-source amplifier



(a)



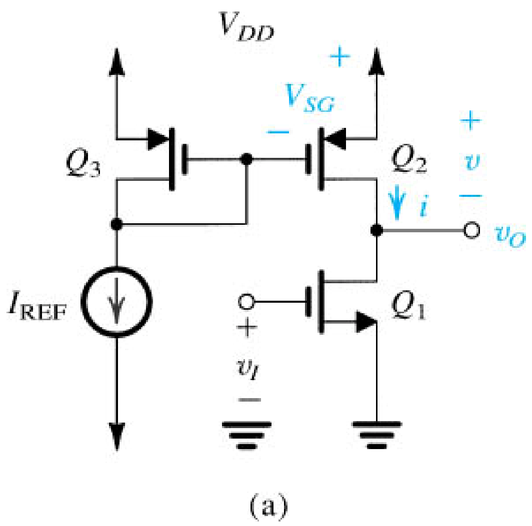
(b)

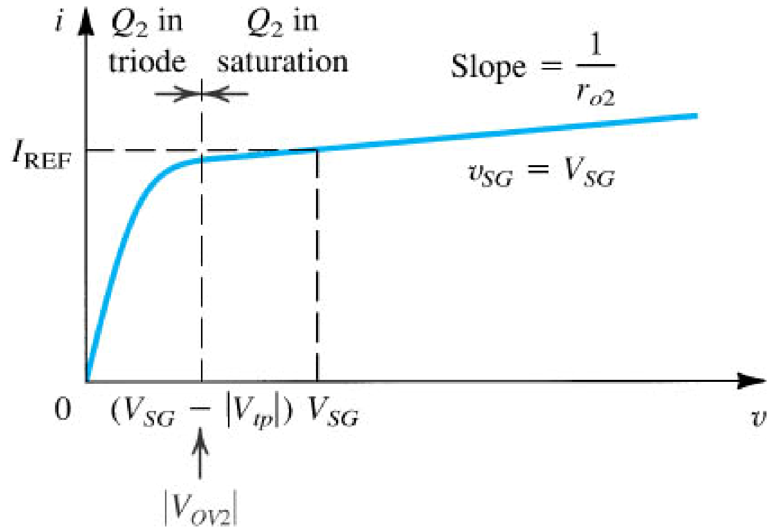
$$R_i =$$

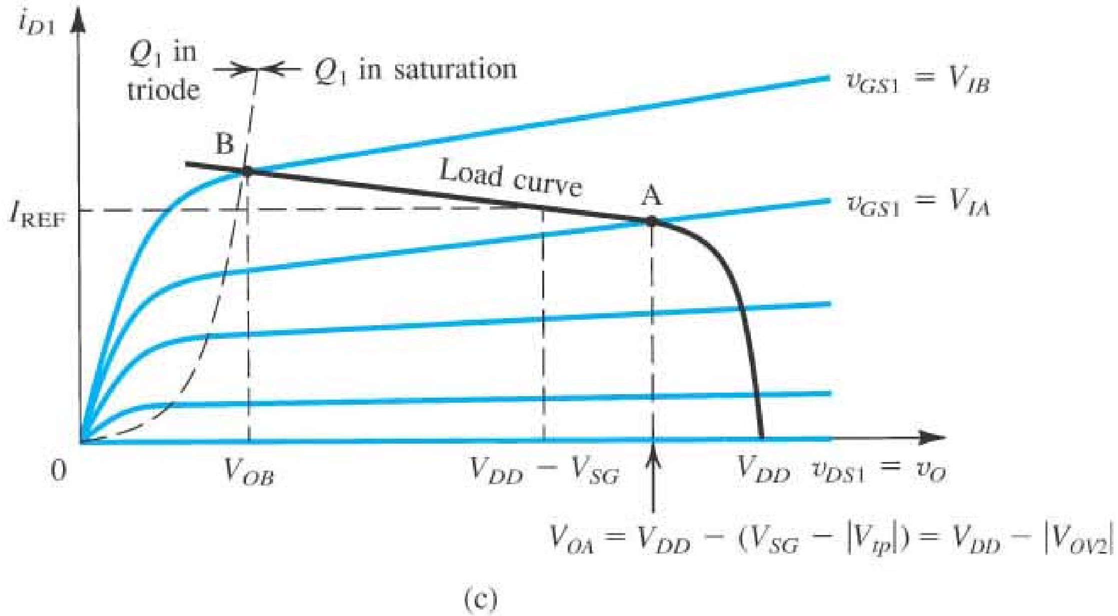
$$A_{vo} =$$

$$R_o =$$

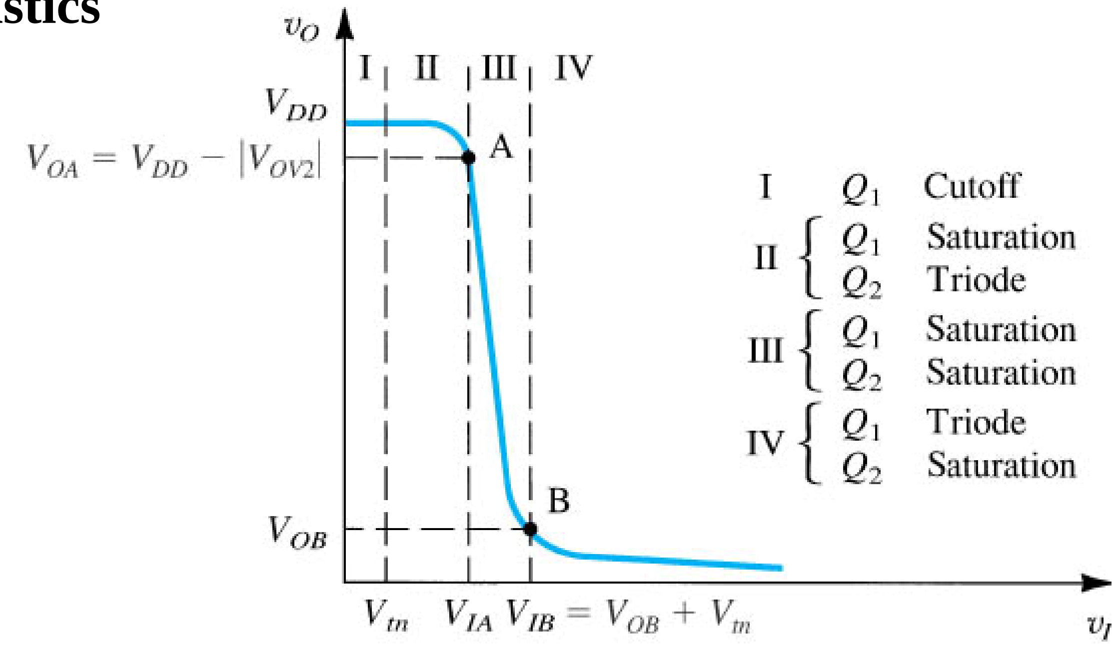
Common-source amplifier with active load







- **Large-signal characteristics**



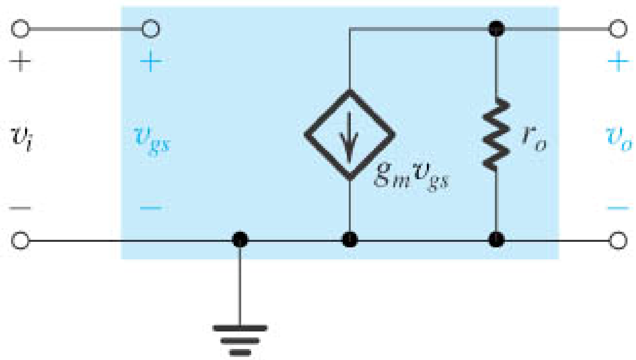
(d)

- **Small-signal characteristics (in region III)**

$R_{in} =$

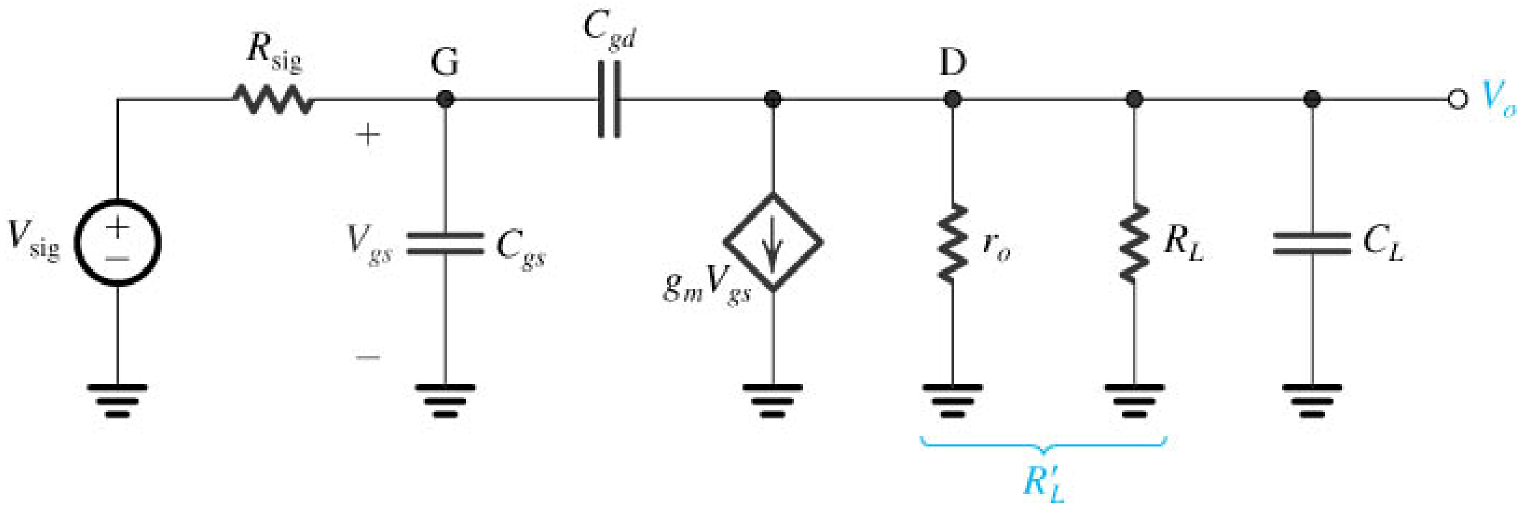
$A_v =$

$R_{out} =$

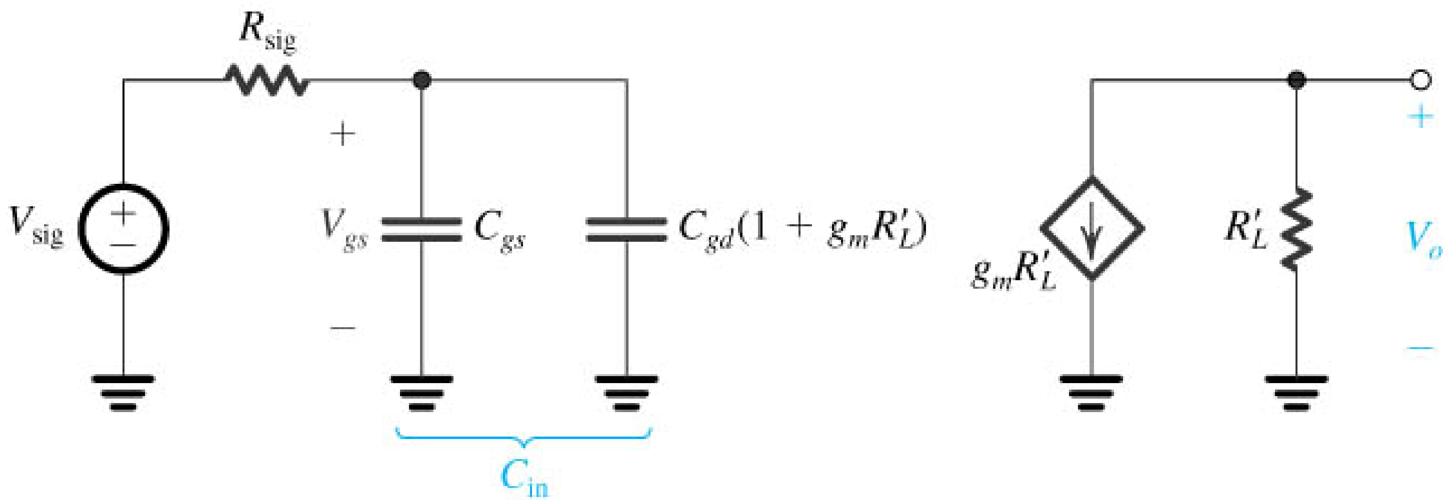


(b)

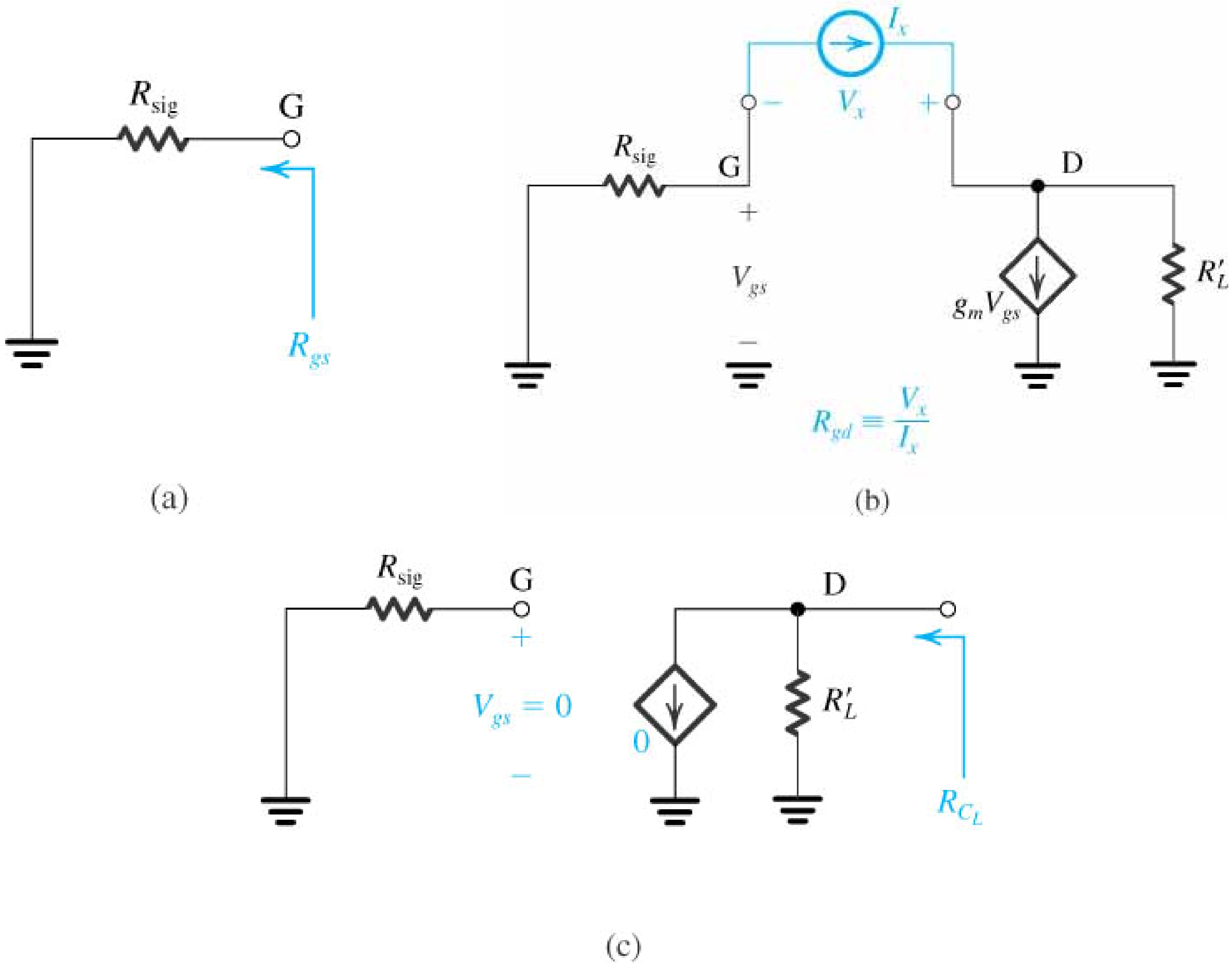
• High-frequency response



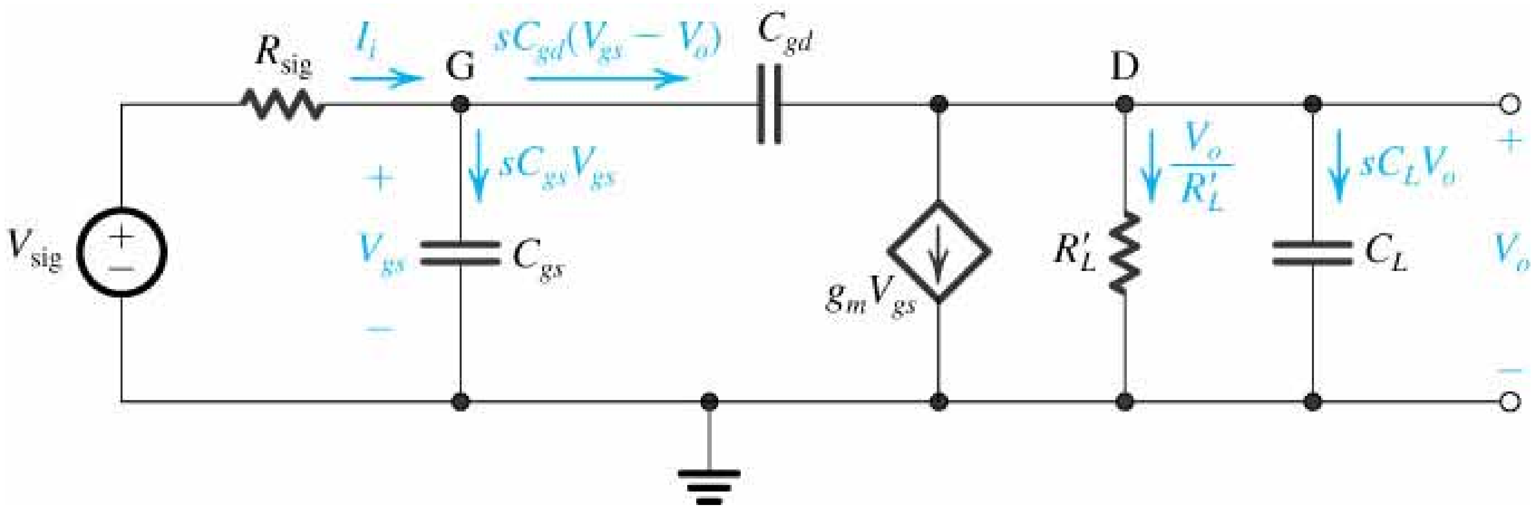
(i) Analysis by **Miller's Theorem**



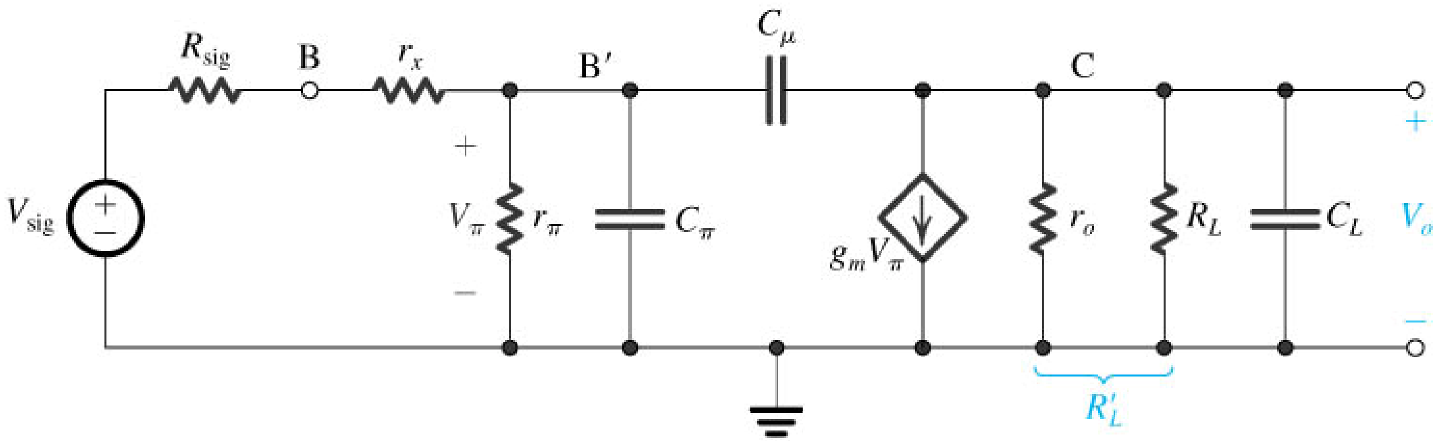
(ii) Analysis by **Open-circuit time constants**



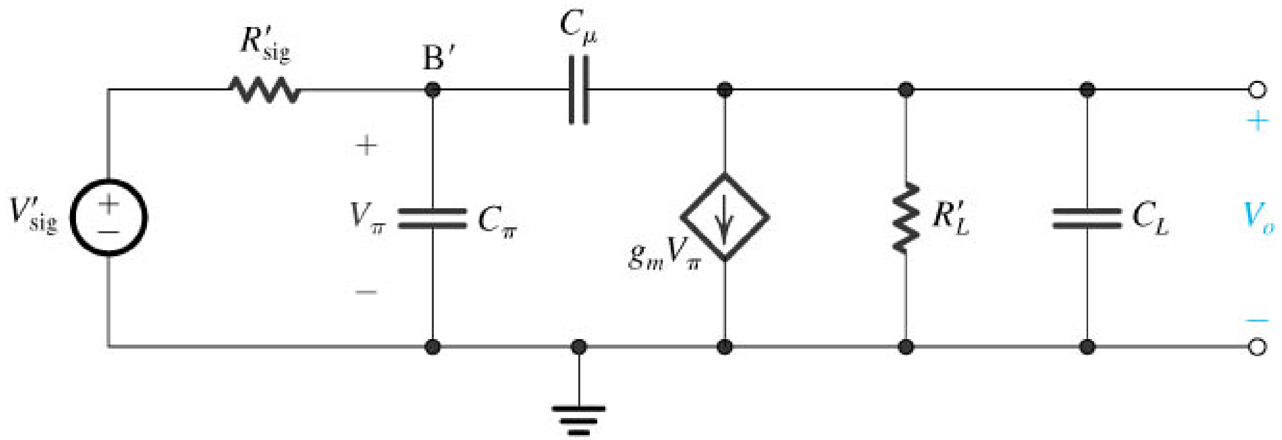
(iii) Exact analysis



Formulas for Common-Emitter amplifier with active load



(a)



(b)