# Outline of Chapter 5, Section 5.8-5.9

- 1- High-Frequency Model of BJT
- 2- Frequency Response of CEA
- Note: Frequency response of CBA and CCA are covered in EC2

# High-Frequency Model

- The small signal model discussed was assumed to be instantaneous and no reactive element was included.
- We add the capacitive effects due to the pn junctions to the hybrid-π model
- The average time that a charge carrier spends in crossing the base is called **forward base-transit time $\tau_F$**
  - This represent the small-signal diffusion capacitance $C_{de}$

$$C_{de} = \tau_F g_m = \tau_F \frac{I_C}{V_T}$$

- The total BEJ capacitance is called $C_\pi$ and is composed of two parts:

$$C_\pi = C_{de} + C_{je}$$

# High-Frequency Model

- There is also the Base-Emitter junction capacitance in the forward bias $C_{je}$

$$C_{je} \cong 2C_{je0}$$

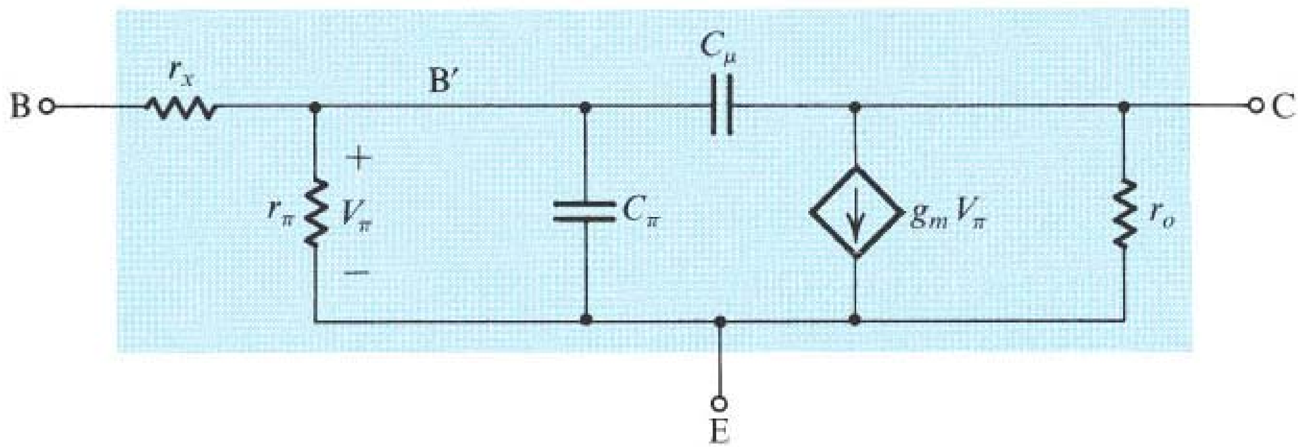
- Where $C_{je0}$ is the value of $C_{je}$ when zero voltage is applied to EBJ
- CBJ is reverse biased and its junction depletion capacitance is

$$C_{\mu} = \frac{C_{\mu 0}}{\left(1 + \frac{V_{CB}}{V_{0c}}\right)^{m}} \qquad 0.2 \leq m \leq 0.5$$

- Where $V_{0c}$ is the CBJ built-in voltage (0.75V), $C_{\mu 0}$ is the value of $C_{\mu}$ when zero voltage is applied and m is the grading coefficient

# High-Frequency Hybrid-π Model

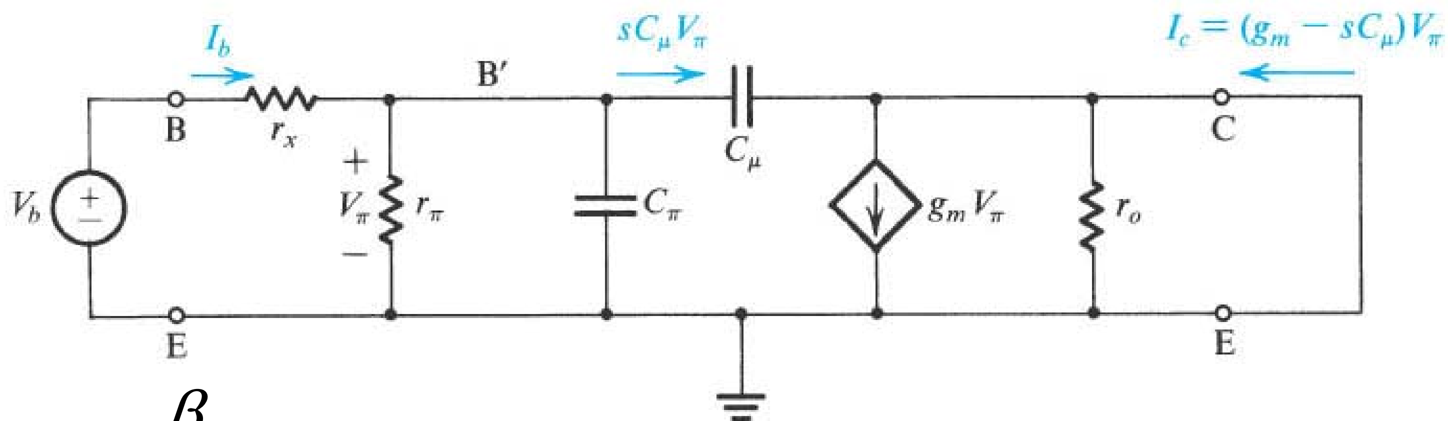
- Two capacitances: Capacitance $C_\pi$ is usually larger than Cμ (Fig. 5.67):




- Note: There is new high-frequency component, resistor $\mathbf{r_x}$
  - $r_x$ represents the resistance of the Silicon in the base region.
  - It is a few tens of Ohms.
- Since $r_x \ll r_\pi$, it is neglected at low frequencies

# BJT Unity-Gain Bandwidth

- Unity-gain bandwidth, $f_T$, is a figure of merit for high-frequency operation.
- It is found from the short circuit current gain of CEA, $h_{fe}=I_c/I_b$

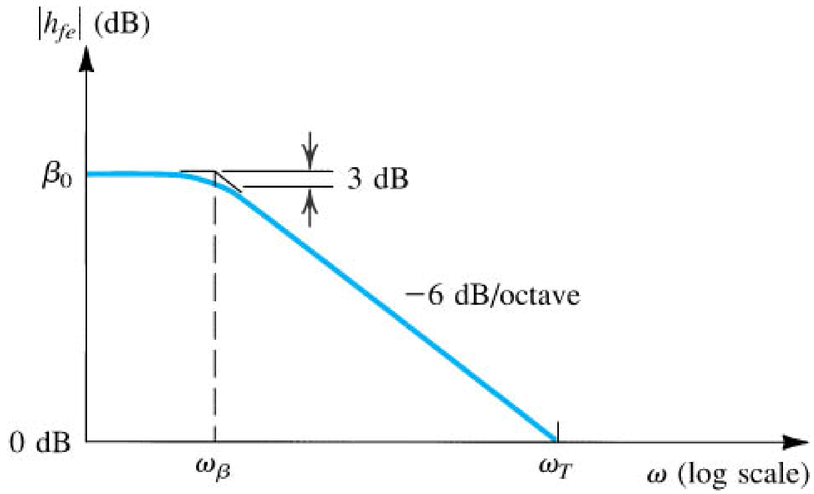



$$h_{fe} = \frac{\beta_0}{1 + s(C_\pi + C_\mu) r_\pi}$$

$$\omega_{3dB-cutoff} = \omega_\beta = \frac{1}{(C_\pi + C_\mu) r_\pi}$$

**Lowpass STC**

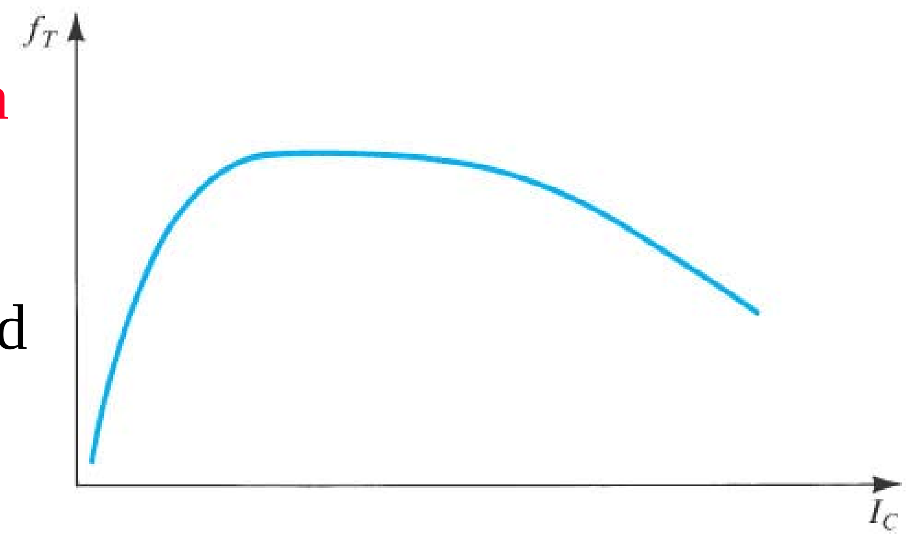
# BJT Unity-Gain Bandwidth




$$\omega_T = \beta_0 \omega_\beta$$

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

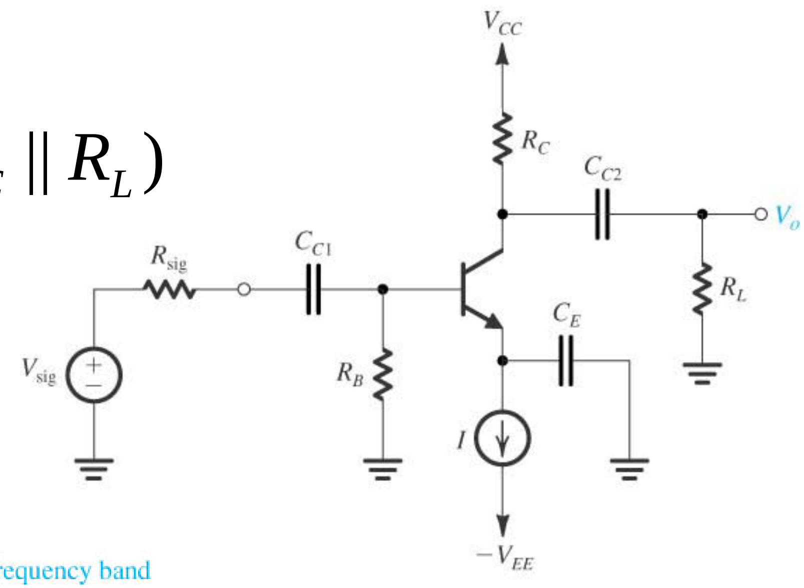
- $f_T$ is called the unity-gain bandwidth
- It is given as function of $I_C$ in data sheets
- The behavior is due to few combined effects
- $f_T$ is from 100 MHz to tens of GHz



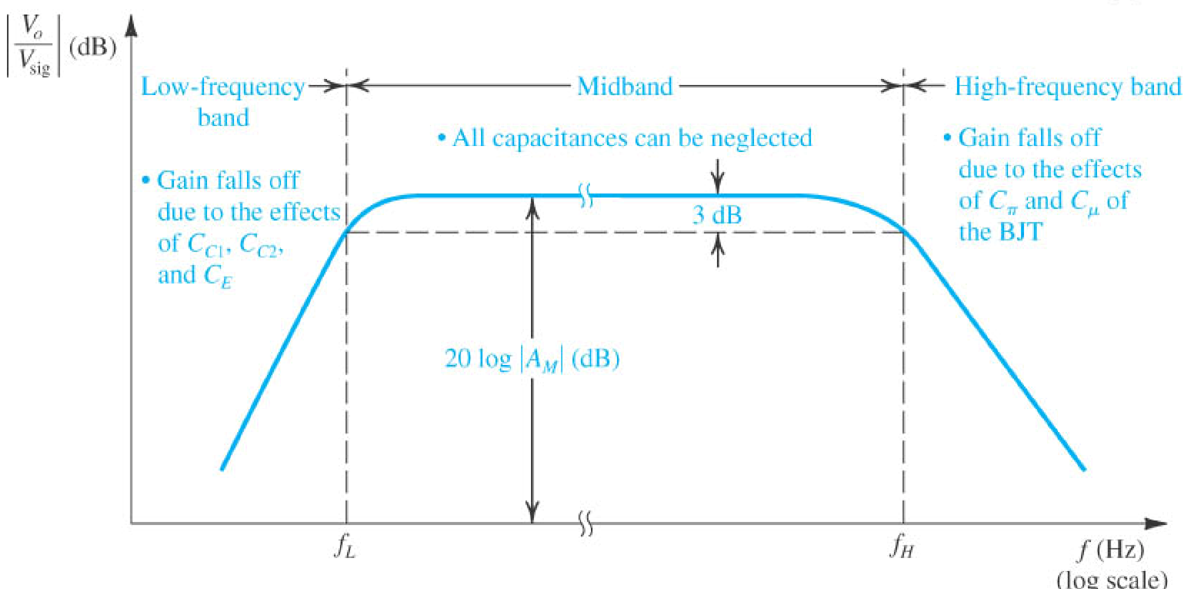
# Frequency Response of CEA

- Midband gain:

$$A_M = \frac{V_o}{V_{sig}} = -\frac{(R_B \parallel r_\pi)}{(R_B \parallel r_\pi) + R_{sig}} g_m (r_o \parallel R_C \parallel R_L)$$



(a)



(b)

# High-Frequency Response (CEA)

- $f_H$ and $f_L$ are frequencies at which gain is 3 dB lower than the midband value $|gain| = |A_M| / \sqrt{2}$
- 3dB bandwidth is:

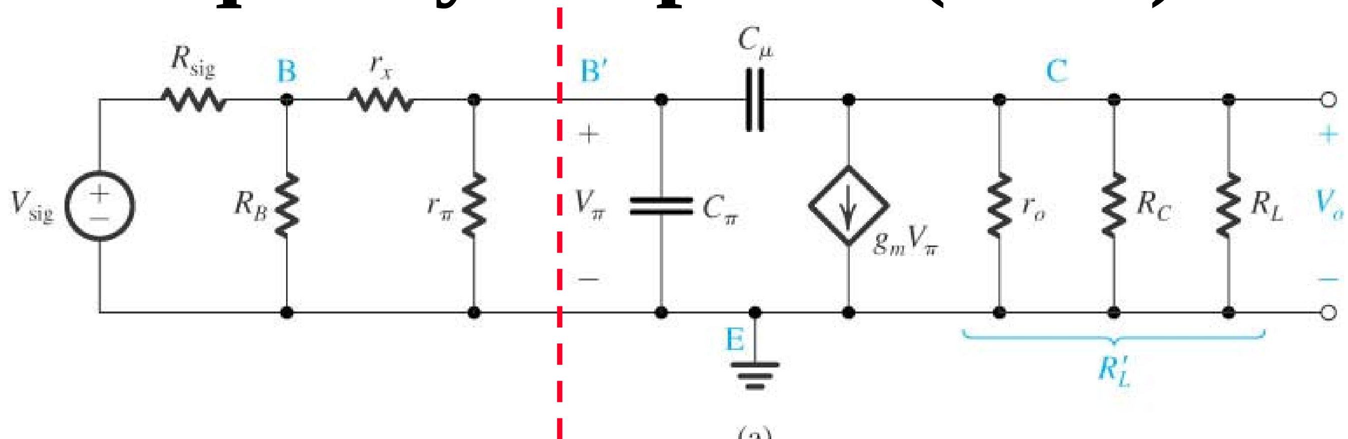
$$BW \equiv f_H - f_L$$

- If $f_L << f_H$ then $BW \cong f_H$
- A figure of merit for an amplifier is gain-bandwidth product

$$GB \equiv |A_M| BW$$

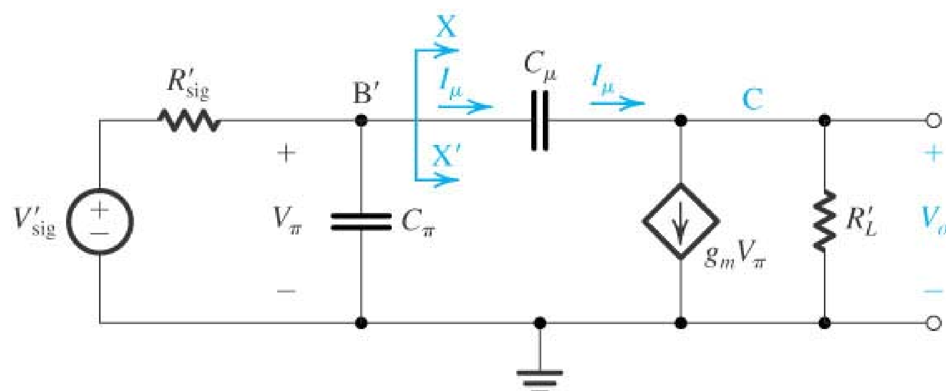
# High-Frequency Response (CEA)

- CEA




(a)

- Using Thevenin Theorem




$$V'_{sig} = V_{sig} \frac{R_B}{R_B + R_{sig}} \frac{r_\pi}{r_\pi + r_x + (R_{sig} /\!/ R_B)}$$

$$R'_L = r_o /\!/ R_C /\!/ R_L$$

$$R'_{sig} = r_\pi /\!/ [r_x + (R_B /\!/ R_{sig})]$$

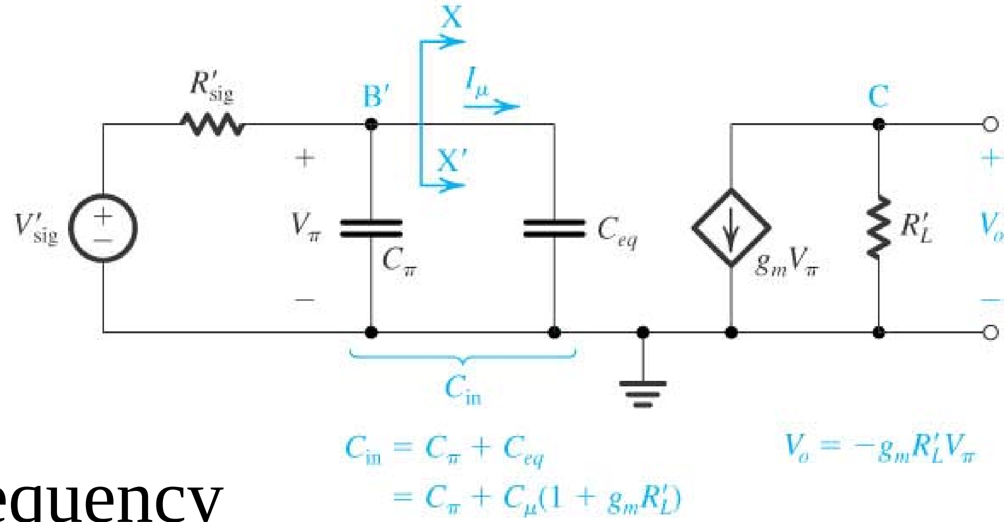
(b)

# High-Frequency Response (CEA)

- Find equivalent for $C_\mu$

**Miller Effect**

**Miller Multiplier= $(1+g_m R'_L)$**

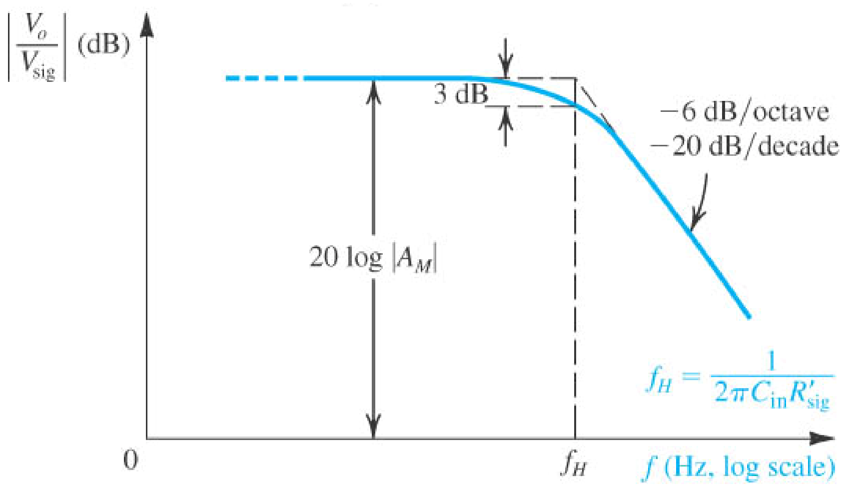



- Lowpass STC: Corner frequency

$$\omega_H = \omega_0 = \frac{1}{C_{in} R'_{sig}} = \frac{1}{(C_\pi + C_{eq}) R'_{sig}}$$

- High-frequency gain of CEA

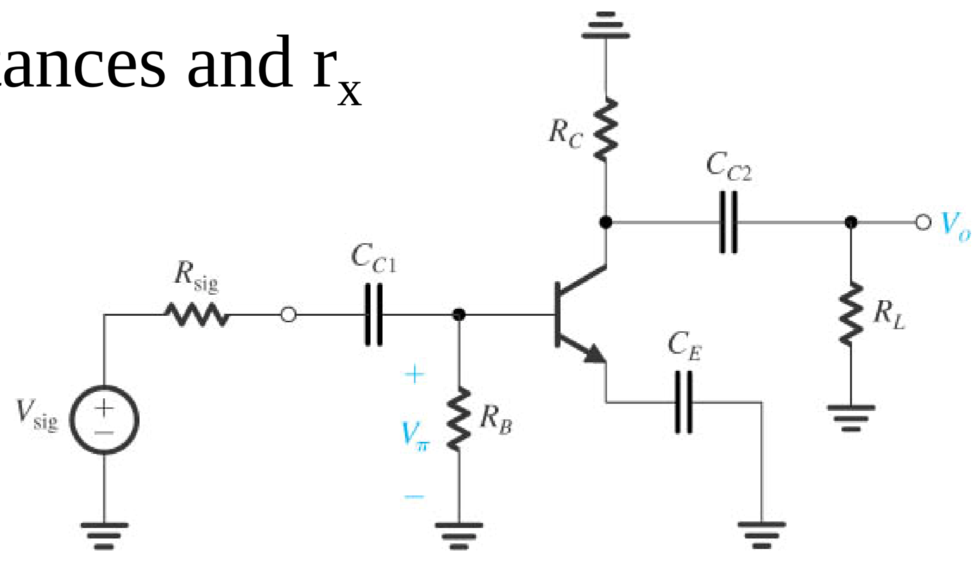
$$\frac{V_o}{V_{sig}} = \frac{A_M}{1 + \frac{s}{\omega_H}}$$



(d)

# Low-Frequency Response (CEA)

- Ignoring internal capacitances and $r_x$

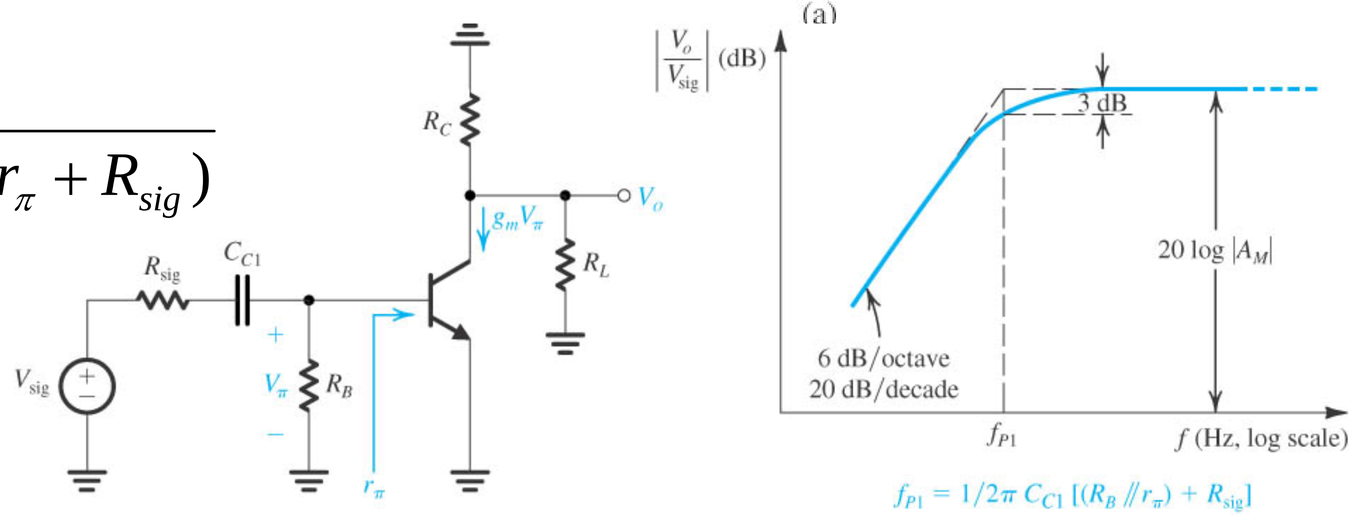


(a)

- Consider:
  - Other Cs are sort circuit
  - $V_{sig}$ is zero

$$f_{P1} = \frac{1}{2\pi C_{C1}(R_B \| r_\pi + R_{sig})}$$

**Highpass STC**

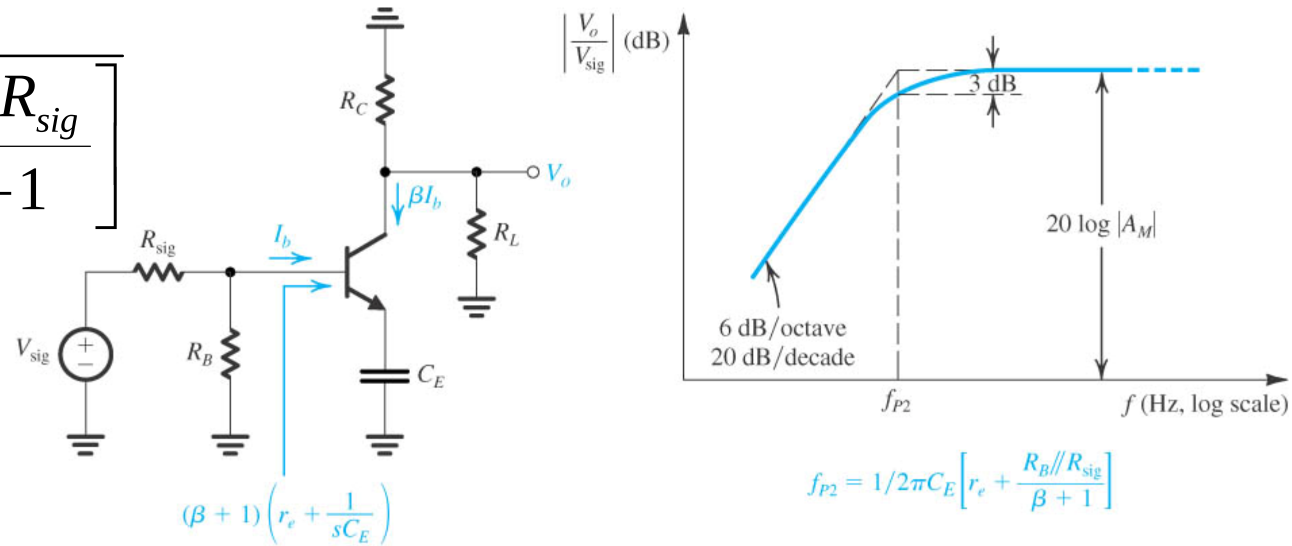


(b)

# Low-Frequency Response (CEA)

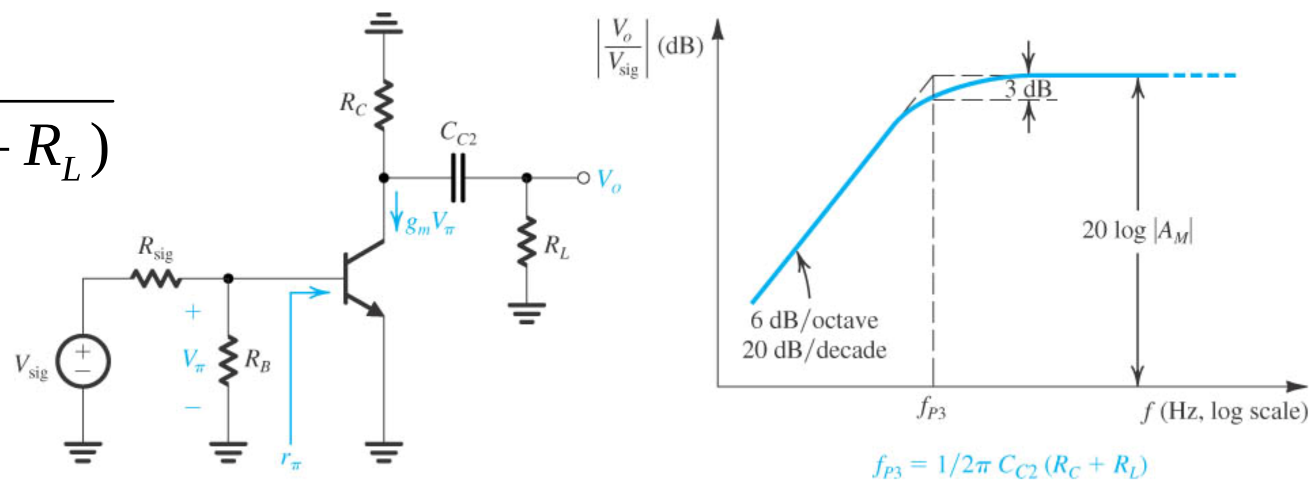
$$f_{P2} = \frac{1}{2\pi C_E\left[r_e + \dfrac{R_B \parallel R_{sig}}{\beta + 1}\right]}$$

**Highpass STC**



(c)

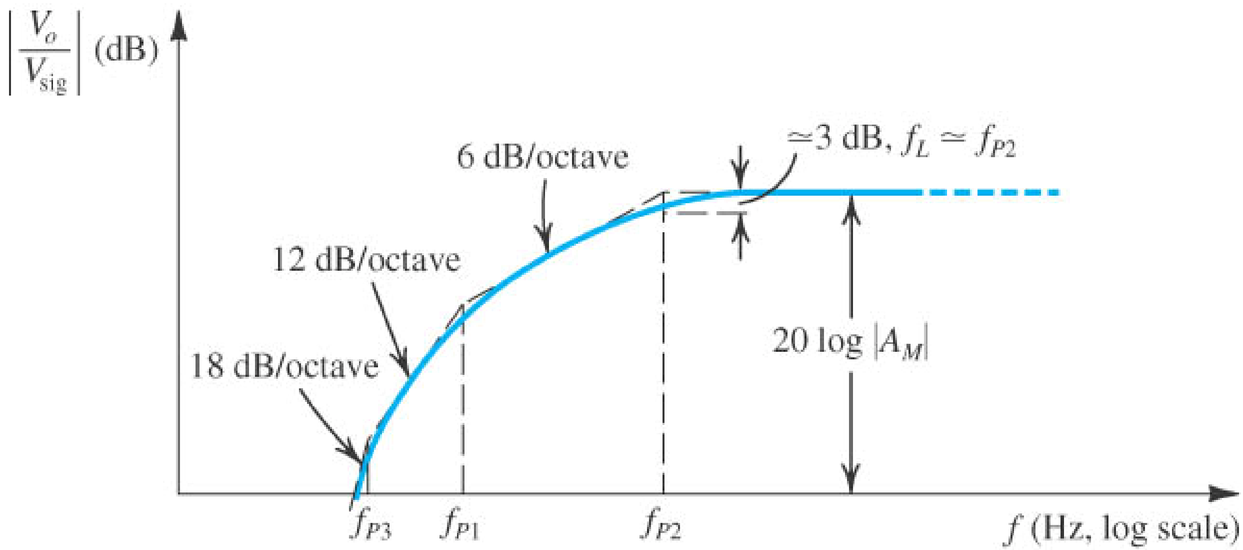
$$f_{P3} = \frac{1}{2\pi C_E (R_C + R_L)}$$



(d)

# Low-Frequency Response (CEA)

- To find the time constant for poles $f_{p1}$, $f_{p2}$ and $f_{p3}$
  - Set source to zero
  - Consider each C separately (others are short circuit)
  - Find the total resistance seen between the two terminals of C




(e)

# Low-Frequency Response (CEA)

- When all three Cs are present and do not interact;

$$\frac{V_o}{V_{sig}} = -A_M \frac{s}{s+\omega_{P1}} \frac{s}{s+\omega_{P2}} \frac{s}{s+\omega_{P3}}$$

- The $f_L$ is determined by the highest $f_P$ (Often $f_{P2}$)
- When the three Cs interact, the $f_L$ is considered as the summation of $f_{P1}$, $f_{P2}$, $f_{P3}$ for approximate hand calculations or SPICE simulations are used to find it.
- If it is not mentioned in the problem, consider that the Cs do not interact