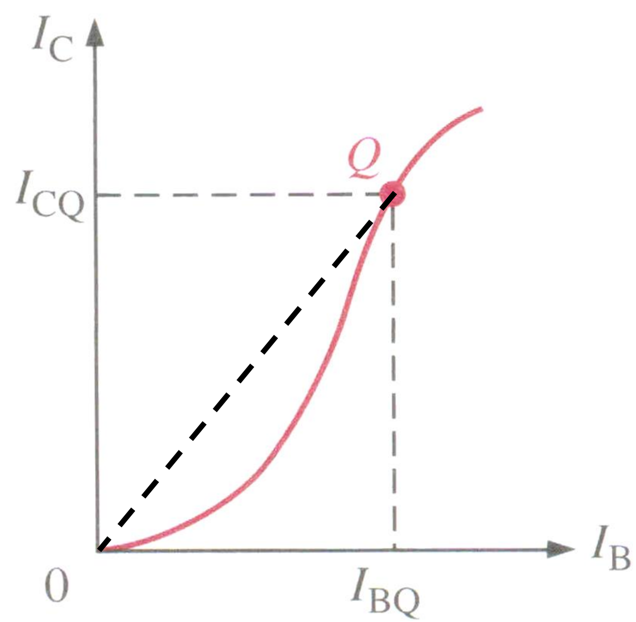
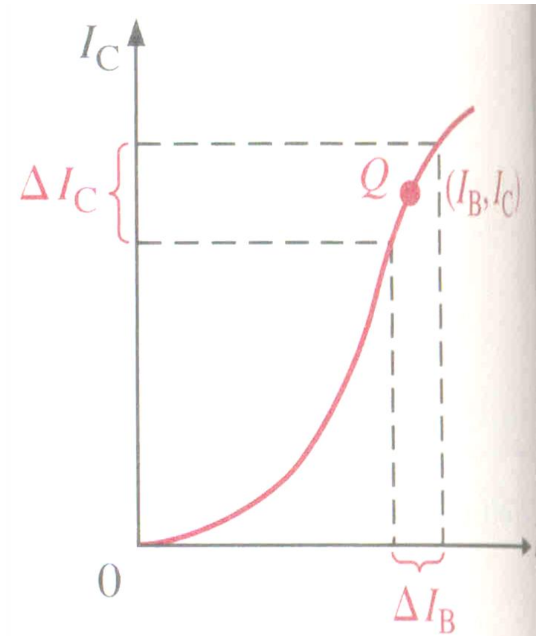
Lecture 27: Bipolar Amplifiers (1)

DC gain vs. AC gain, Common Emitter Amplifier, Examples

DC vs. AC Current Gain





$$\beta_{DC} = \frac{I_C}{I_B}\bigg|_{\text{at the Q-point}} = \frac{I_{CQ}}{I_{BQ}}$$

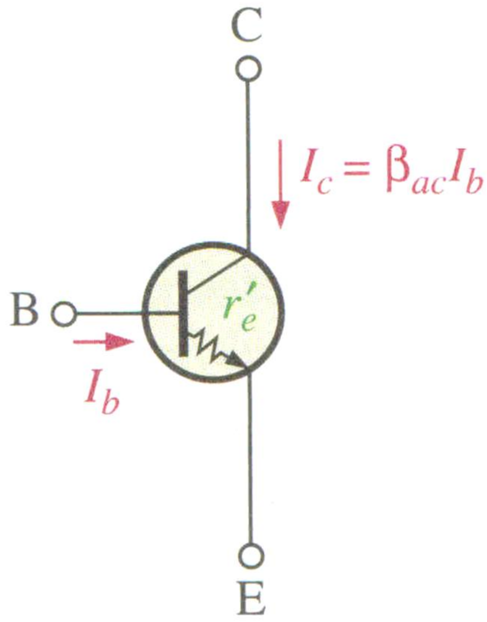
$=$ slope of the line from the origin to the Q-point.

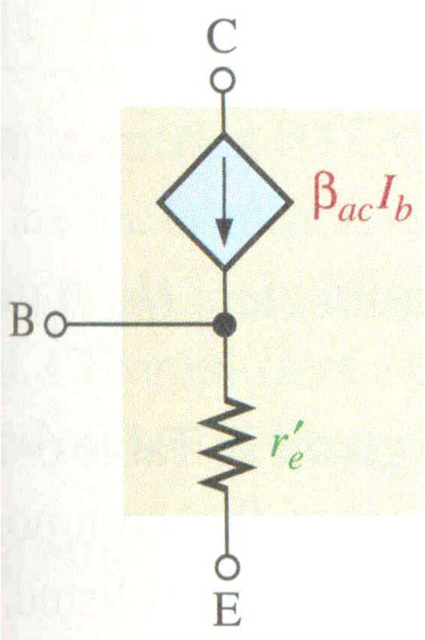
$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\bigg|_{\text{around the Q-point}} = \frac{I_{c(pp)}}{I_{b(pp)}}$$

$=$ slope of the tangential line to the curve at the Q-point.

AC Equivalent of a BJT

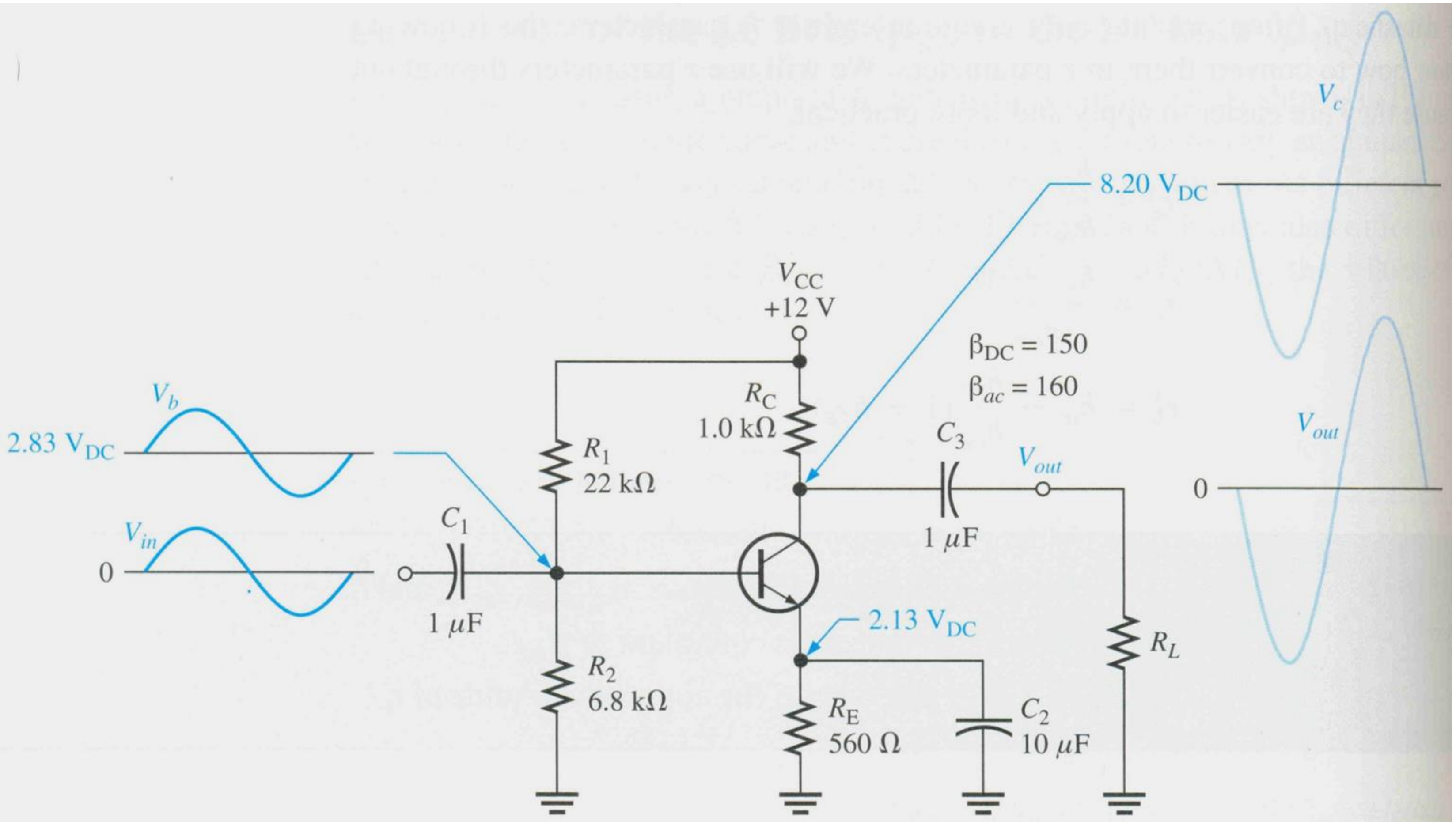
since the total (DC + AC) voltage difference across the forward-biased BE junction should be around 0.7 V, the AC part (V_{be}) alone should be very small and is represented by an extremely small resistance.





$$r'_e \cong \frac{25\text{ mV}}{I_E},$$ where I_E is the DC emitter current.

Common Emitter Amplifier

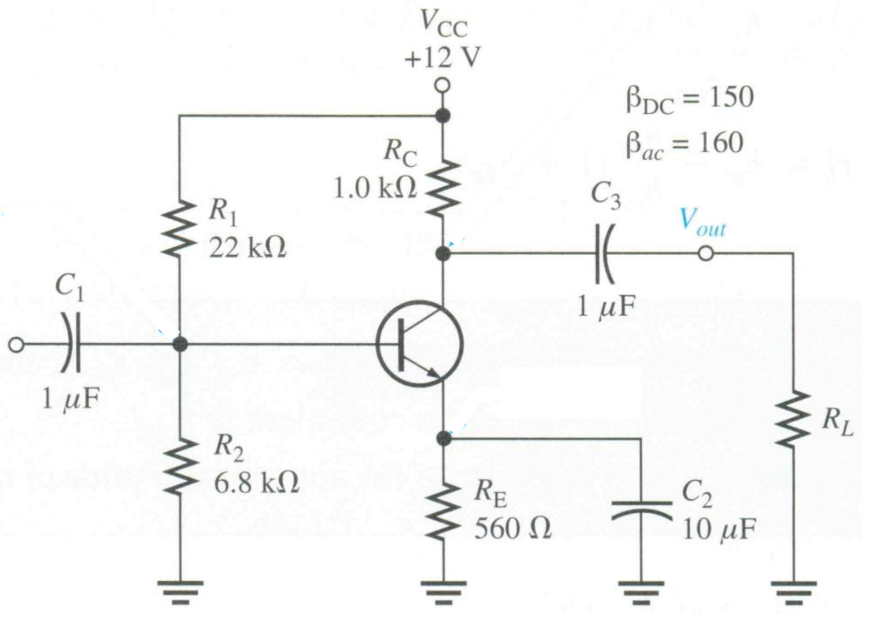


Original Circuit

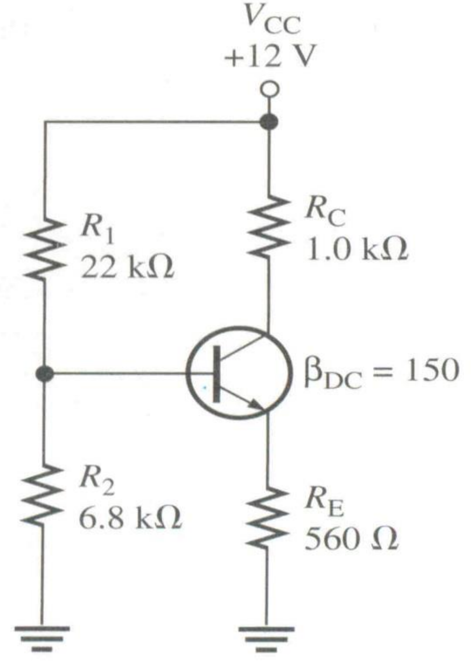
two sources (DC and AC) are present in the original circuit.

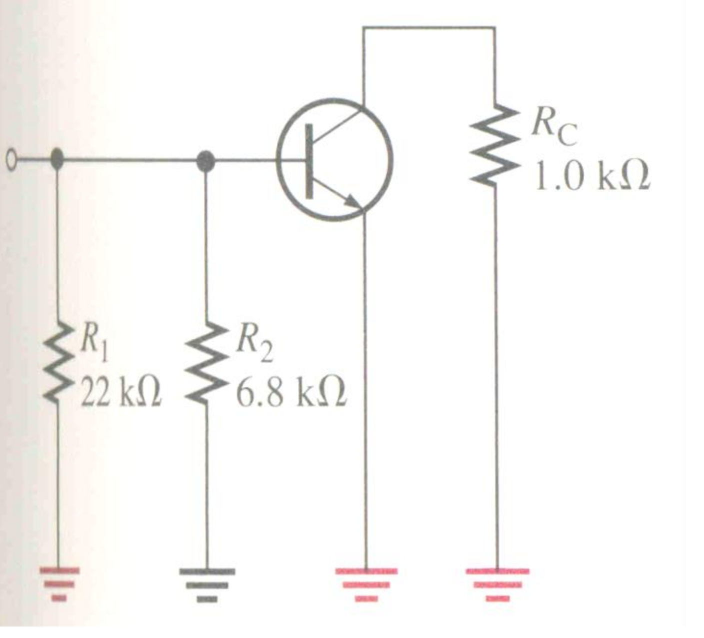
it is equivalent to the superposition of two sub-circuits.

only one source is kept in each sub-circuit, the other one is replaced by a s.c.



DC/AC Circuit

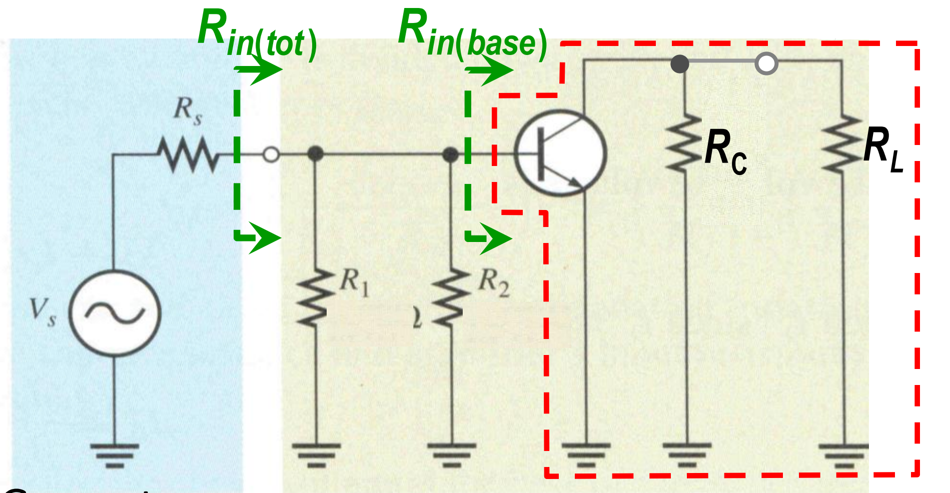




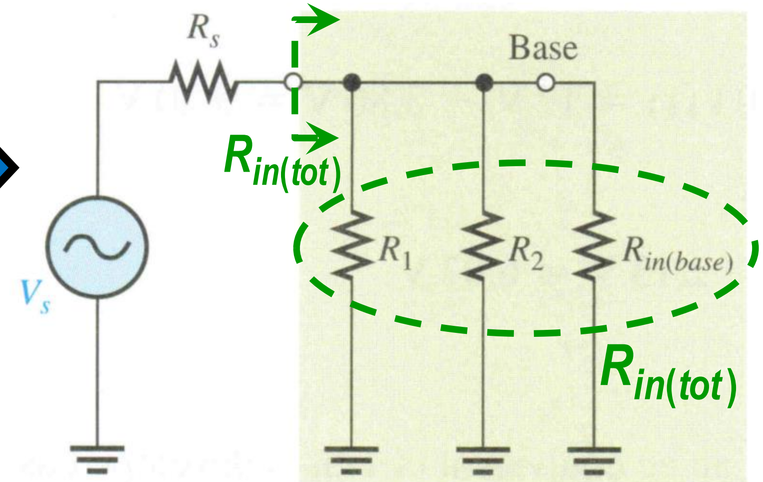
solve the DC circuit for the bias (operating) point. All capacitors are open circuit.

solve the AC circuit for the gain, input resistance, and output resistance. All capacitors are short circuit.

Input Resistance



Generator

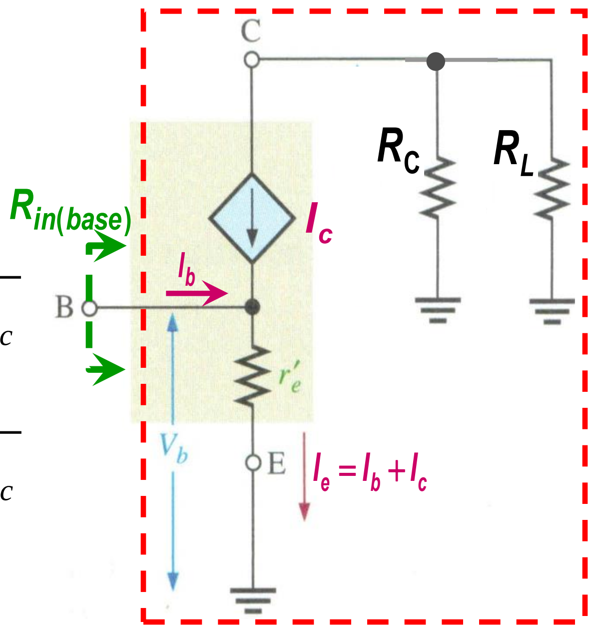


$$R_{in(base)} = \frac{V_b}{I_b}$$

$$= \frac{I_e r_e'}{I_c / \beta_{ac}}$$

$$\cong \frac{I_e r_e'}{I_e / \beta_{ac}}$$

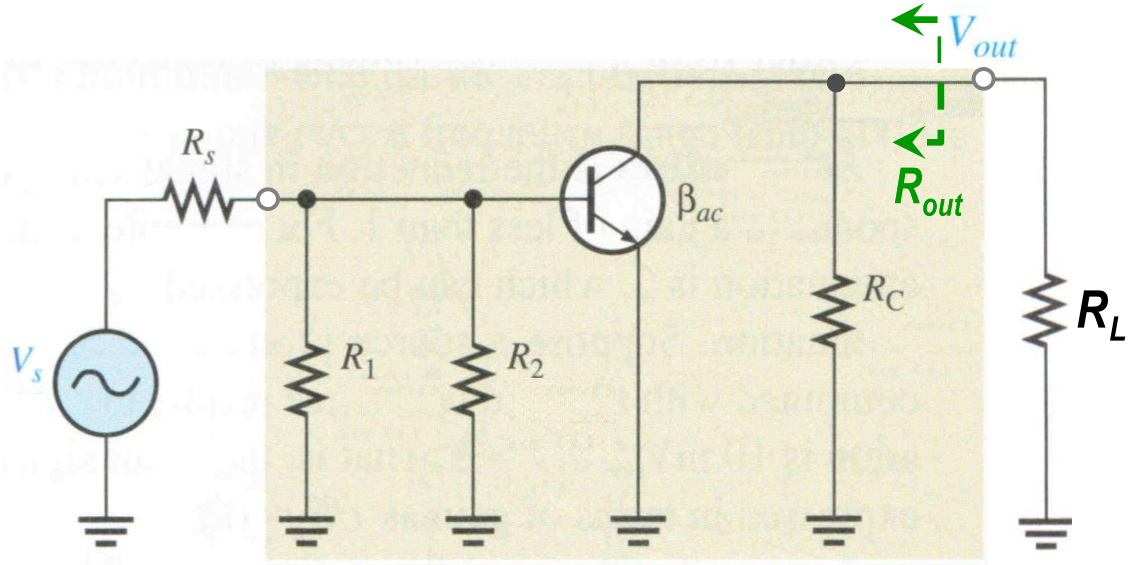
$$\therefore R_{in(base)} = \beta_{ac} r_e'$$



$$R_{in(tot)} = R_1 \| R_2 \| R_{in(base)}$$

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}} \right) V_s$$

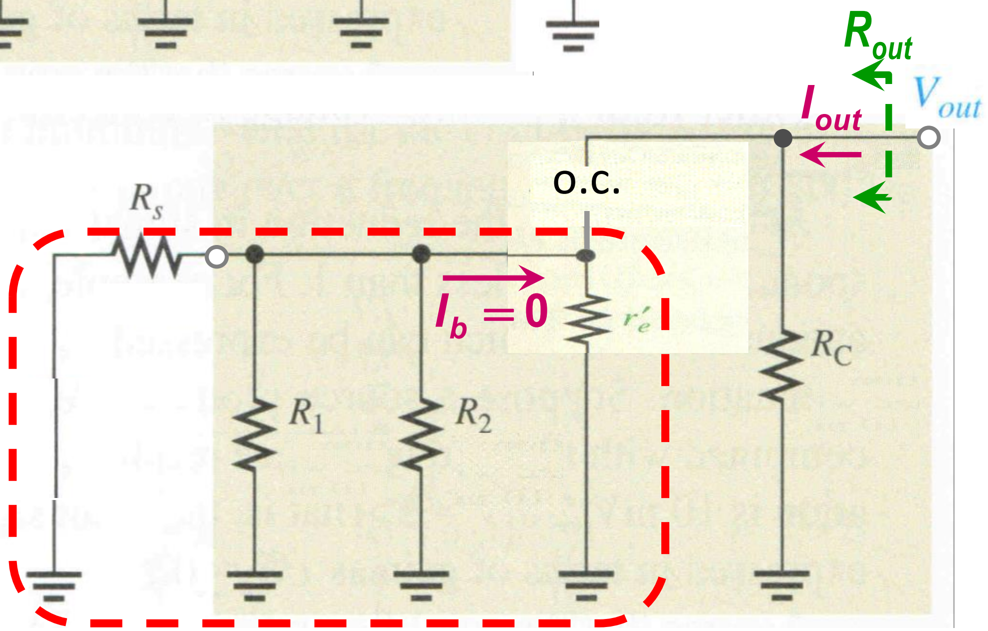
Output Resistance



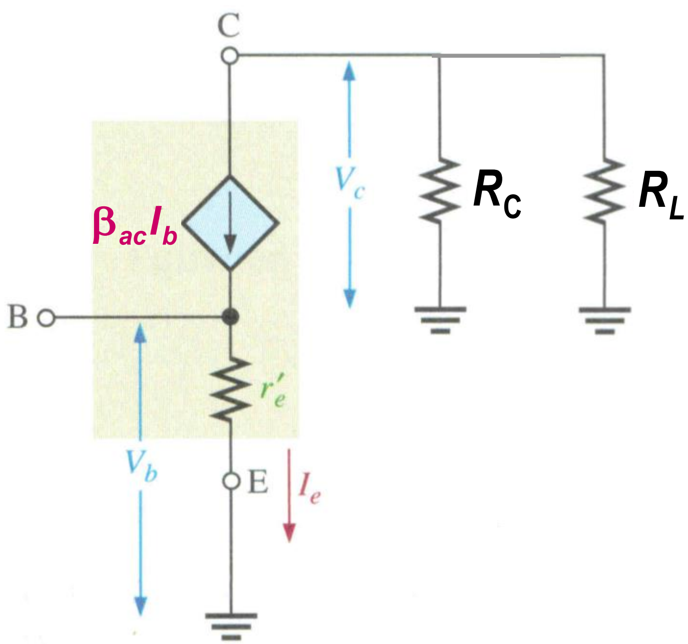
$$R_{out} = \left. \frac{V_{out}}{I_{out}} \right|_{V_s \to \text{s.c.}}$$

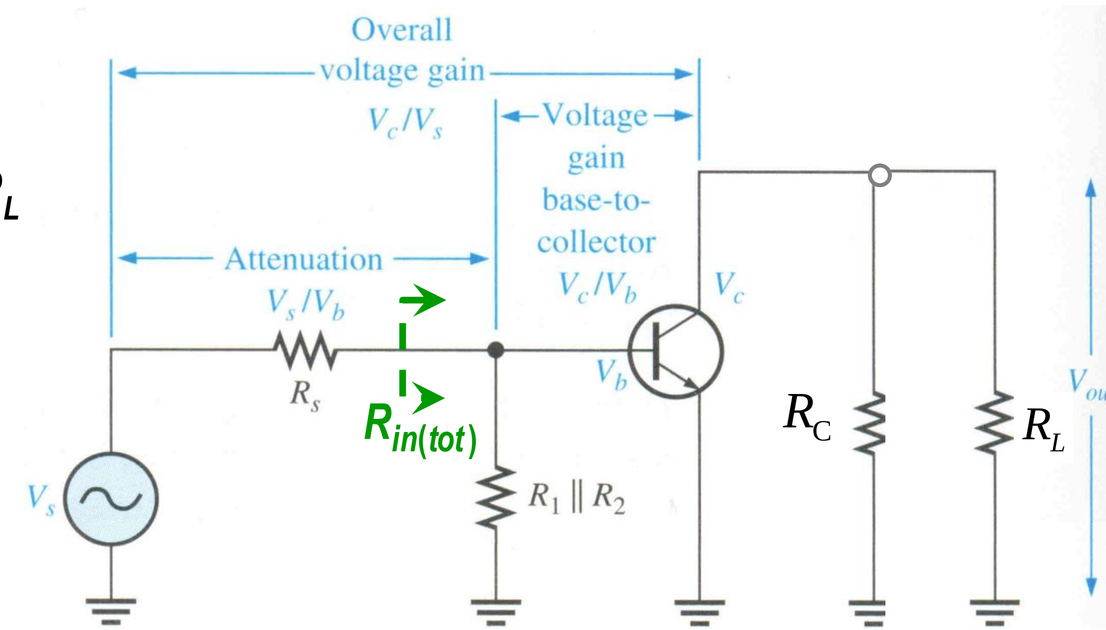
$$= \frac{I_{out} R_C}{I_{out}}$$

$$\therefore R_{out} = R_C$$



Voltage Gain





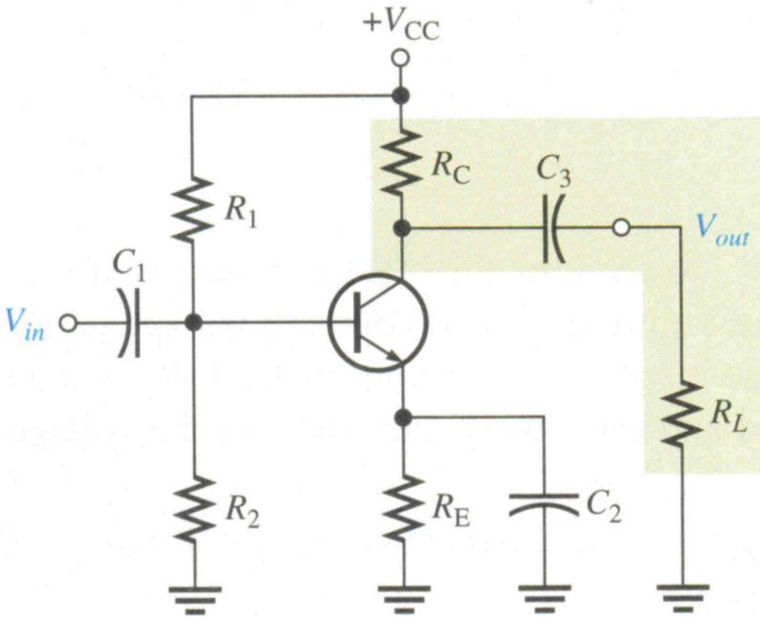
$$A_v \equiv \text{ideal voltage gain} = \frac{V_c}{V_b}$$

$$= \frac{I_c\left(R_C \| R_L\right)}{I_e r_e'} \cong \frac{R_C \| R_L}{r_e'}$$

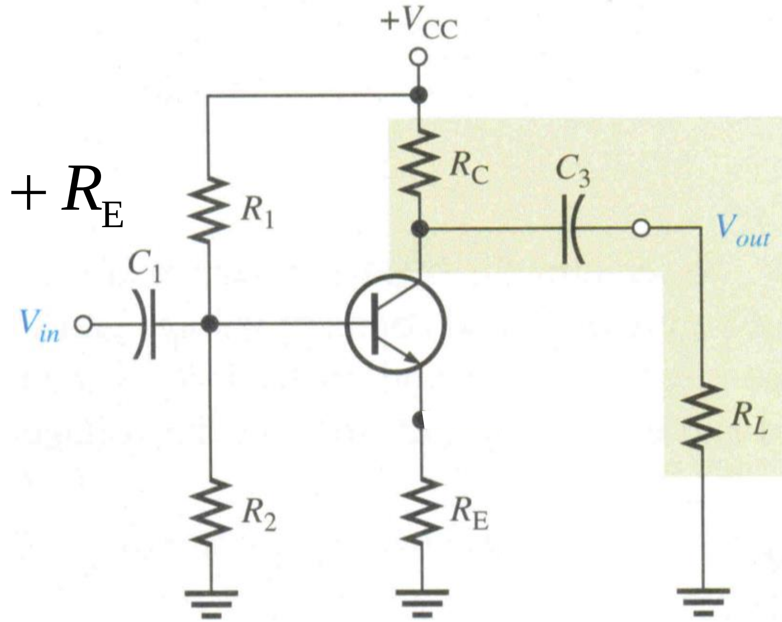
$$A_v' \equiv \text{overall voltage gain} = \frac{V_c}{V_s} = \left(\frac{V_c}{V_b}\right)\left(\frac{V_b}{V_s}\right) = \frac{A_v}{\text{Attenuation}},$$

<u>where:</u> $\text{Attenuation} = \frac{V_s}{V_b} = \frac{R_s + R_{in(tot)}}{R_{in(tot)}} \geq 1 \quad \Rightarrow \quad A_v' \leq A_v$

Effect of Bypass Capacitor



$$r_e' \Rightarrow r_e' + R_E$$



$$A_v = \left(R_C \| R_L\right)/r_e', \quad R_{in(base)} = \beta_{ac} r_e' \qquad A_v = \left(R_C \| R_L\right)/\left(r_e' + R_E\right), \quad R_{in(base)} = \beta_{ac}\left(r_e' + R_E\right)$$

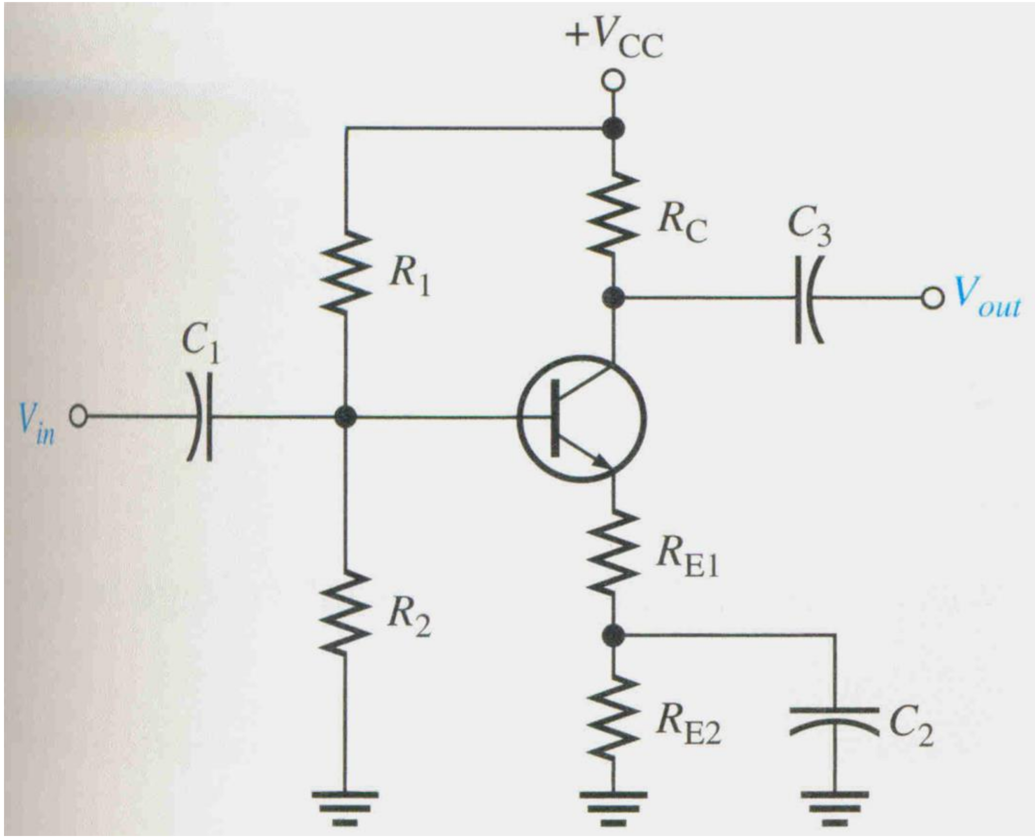
the effect of the emitter bypass capacitor is to increase A_v and to decrease $R_{in(\text{base})}$.

$$X_{C(\max)} << R_E \quad \Rightarrow \quad X_{C(\max)} < 0.1R_E \quad \Rightarrow \quad \frac{1}{2\pi f_{\min} C_2} < 0.1R_E$$

Voltage Gain Stability

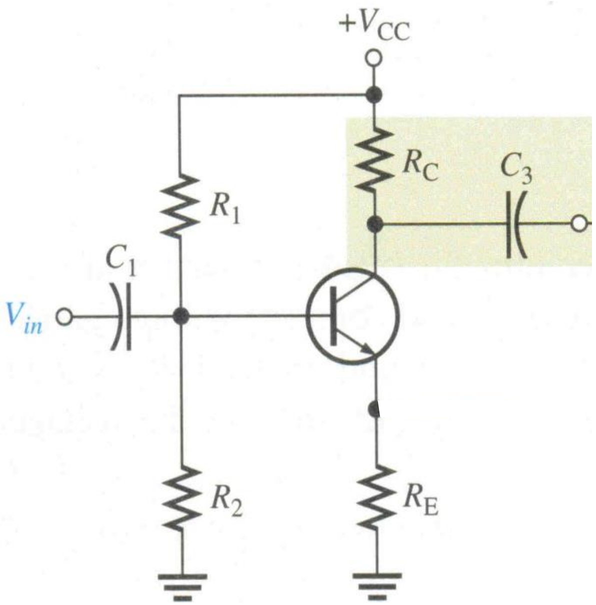
the voltage gain A_v depends on r_e' which depends on temperature. This makes A_v unstable with temperature.

one way to overcome this problem without reducing A_v too much is to partially swamp r_e', which means that R_E is partially bypassed.



$$A_v = \frac{R_C}{r_e' + R_{E1}}, \quad R_{in(base)} = \beta_{ac}\left(r_e' + R_{E1}\right)$$

Gain Stability (Cont'd)



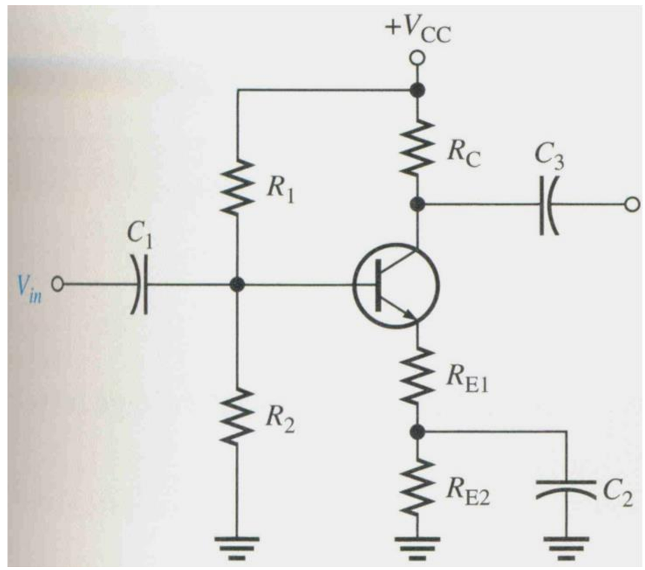
$$R_{in(base)} = \beta_{ac}\left(r_e' + R_E\right)$$

$$A_v = \frac{R_C}{r_e' + R_E}$$

Maximum Input Resistance

Minimum Ideal Gain

Maximum Stability



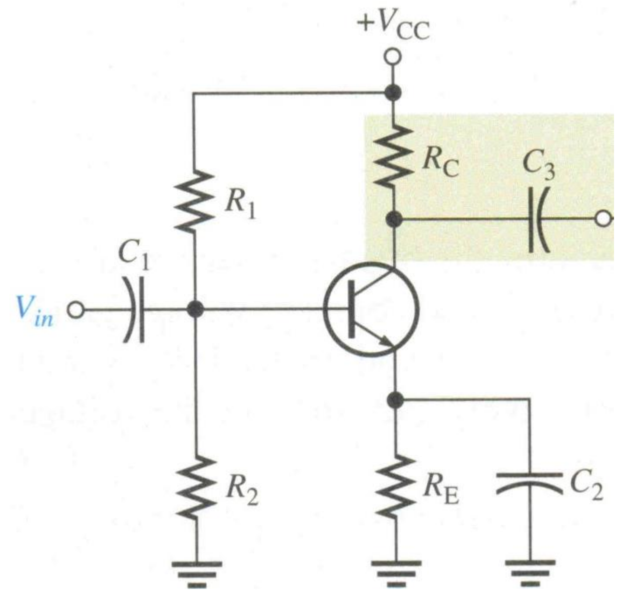
$$R_{in(base)} = \beta_{ac}\left(r_e' + R_{E1}\right)$$

$$A_v = \frac{R_C}{r_e' + R_{E1}}$$

Moderate Input Resistance

Moderate Ideal Gain

Moderate Stability



$$R_{in(base)} = \beta_{ac}\ r_e'$$

$$A_v = \frac{R_C}{r_e'}$$

Minimum Input Resistance

Maximum Ideal Gain

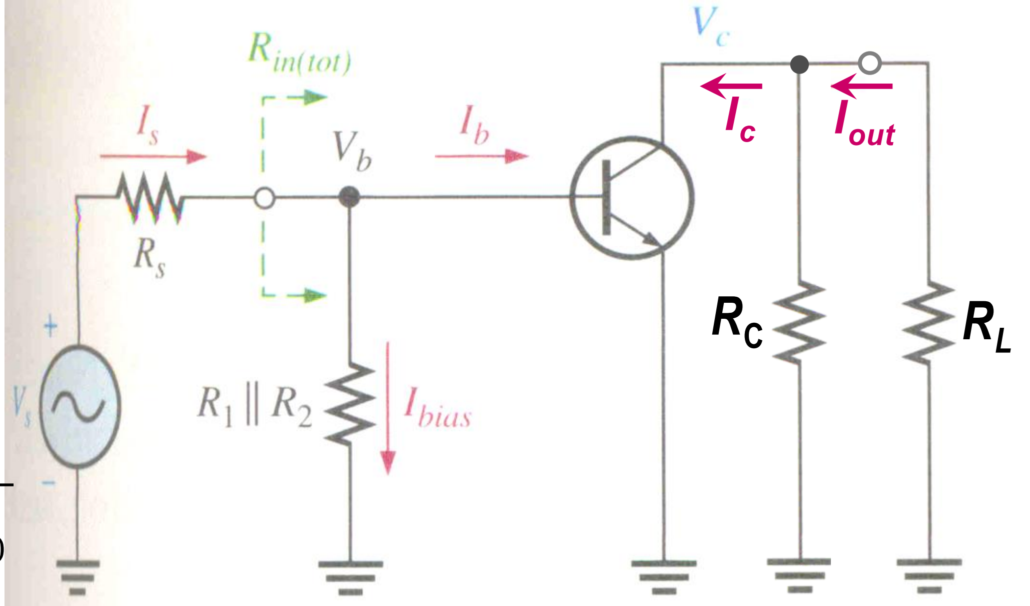
Minimum Stability

Current and Power Gains

$$A_i \equiv \text{ideal current gain} = \frac{I_c}{I_b} = \beta_{ac}$$

$$A_i' \equiv \text{overall current gain} = \frac{I_{out}}{I_s},$$

<u>where:</u> $I_{out} = \dfrac{V_c}{R_L}, \quad I_s = \dfrac{V_s}{R_s + R_{in(tot)}}$



$$A_p' \equiv \text{overall power gain} = \frac{\text{amplifier output power}}{\text{amplifier input power}} = \frac{V_c\ I_{out}}{V_s\ I_s} = \left(\frac{V_c}{V_s}\right)\left(\frac{I_{out}}{I_s}\right) = A_v'\ A_i'$$

CE Amplifier Summary

$$R_{in(base)} \equiv \text{input base resistance} = \frac{V_b}{I_b}$$

$$R_{in(tot)} \equiv \text{total input resistance} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_s}$$

$$R_{out} \equiv \text{output resistance} = \left.\frac{V_{out}}{I_{out}}\right|_{V_s \to \text{s.c.}}$$

$$A_v \equiv \text{ideal voltage gain} = \frac{V_c}{V_b}$$

$$A_v' \equiv \text{overall voltage gain} = \frac{V_{out}}{V_s} = \frac{V_c}{V_s}$$

$$\text{Attenuation} \equiv \frac{A_v}{A_v'} = \frac{V_s}{V_b} = \frac{R_s + R_{in(tot)}}{R_{in(tot)}} \geq 1$$

$$A_i \equiv \text{ideal current gain} = \frac{I_c}{I_b} \cong \beta_{ac}$$

$$A_i' \equiv \text{overall current gain} = \frac{I_{out}}{I_s}$$