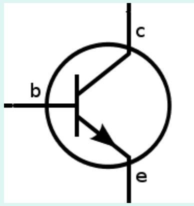
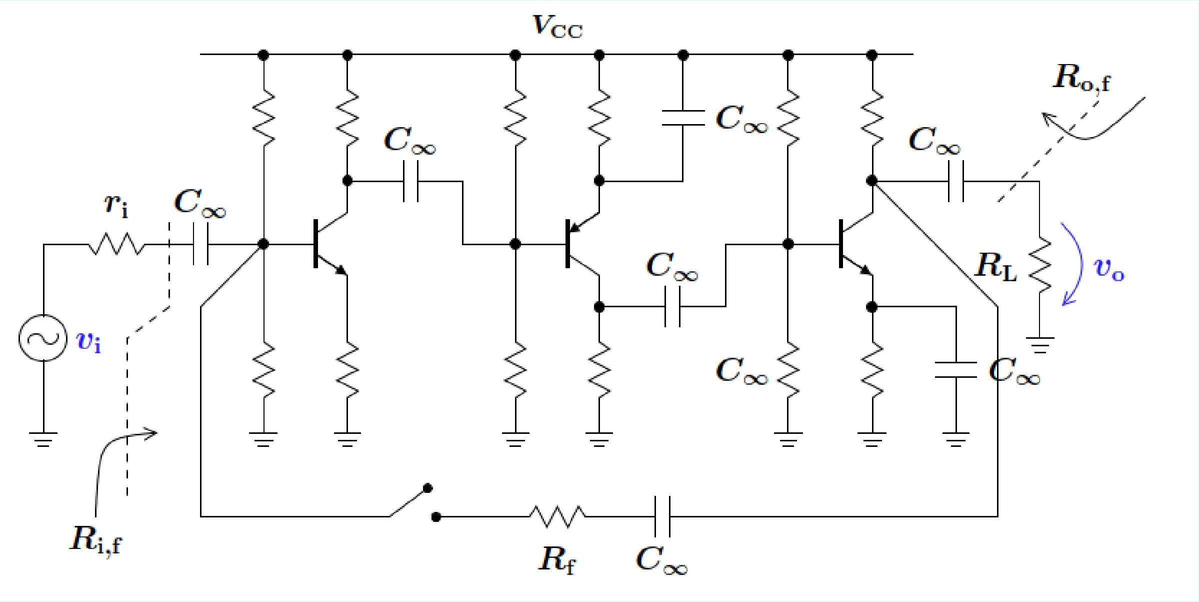
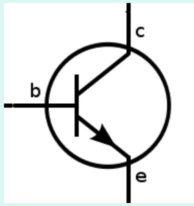


ELEC 301 - BJT bias circuit, CE configuration

L12 - Oct 02

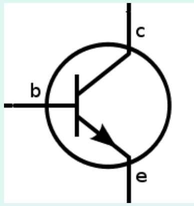
Instructor: Edmond Cretu





Last time

- hybrid-π BJT small signal model
- Circuit for setting the quiescent point for a BJT (trade-offs between gain, dynamic range, operating point stability, etc.)



Complete Hybrid-π small-signal model

Typical values: C_{je0}=10fF, $C_{\mu 0}$=10fF, τ_F=10ps, ψ_0=0.65V

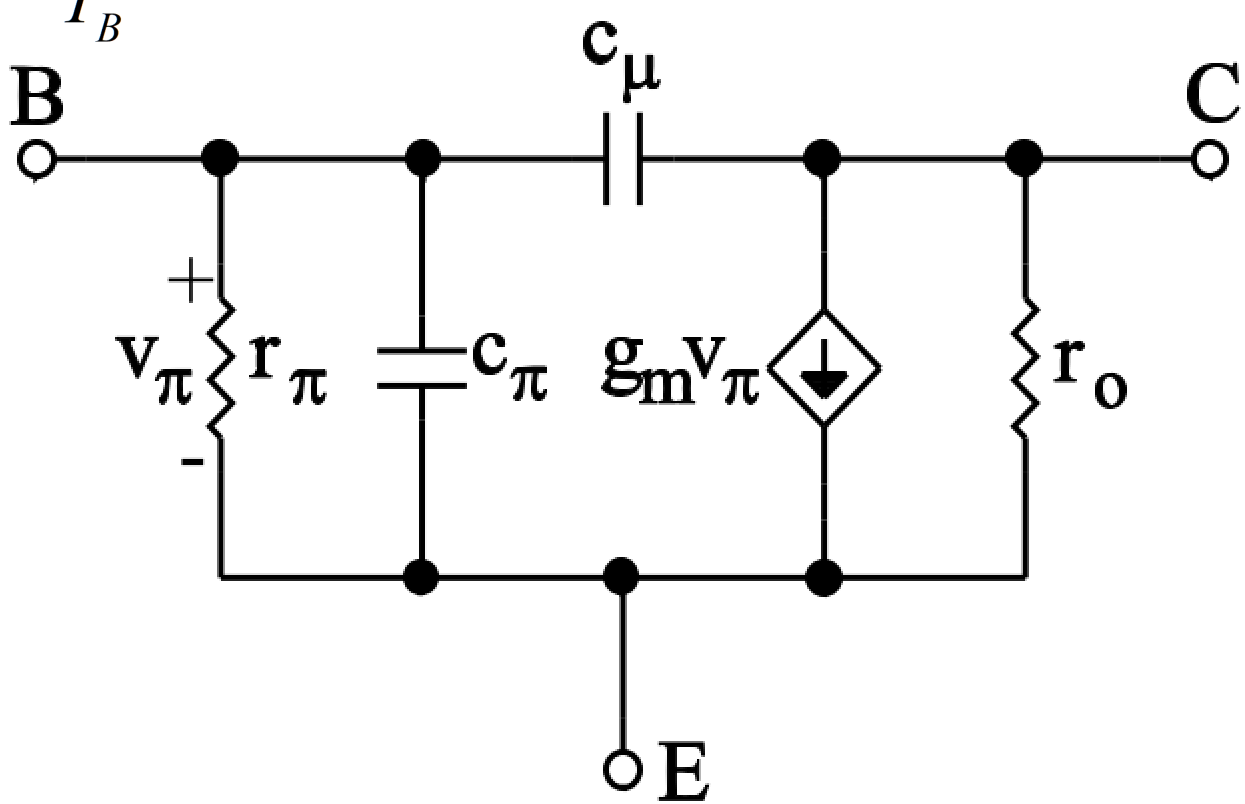
$$C_\mu = \frac{C_{\mu 0}}{\sqrt{1+\frac{V_{CB}}{\psi_0}}}, \quad \psi_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

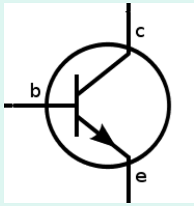
$$r_\pi = \frac{v_{be}}{i_{be}} = \frac{\beta}{g_m} = \beta\frac{V_T}{I_C} = \frac{V_T}{I_B}$$

$$C_\pi = C_b + C_{je} = \tau_F g_m + C_{je}$$

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

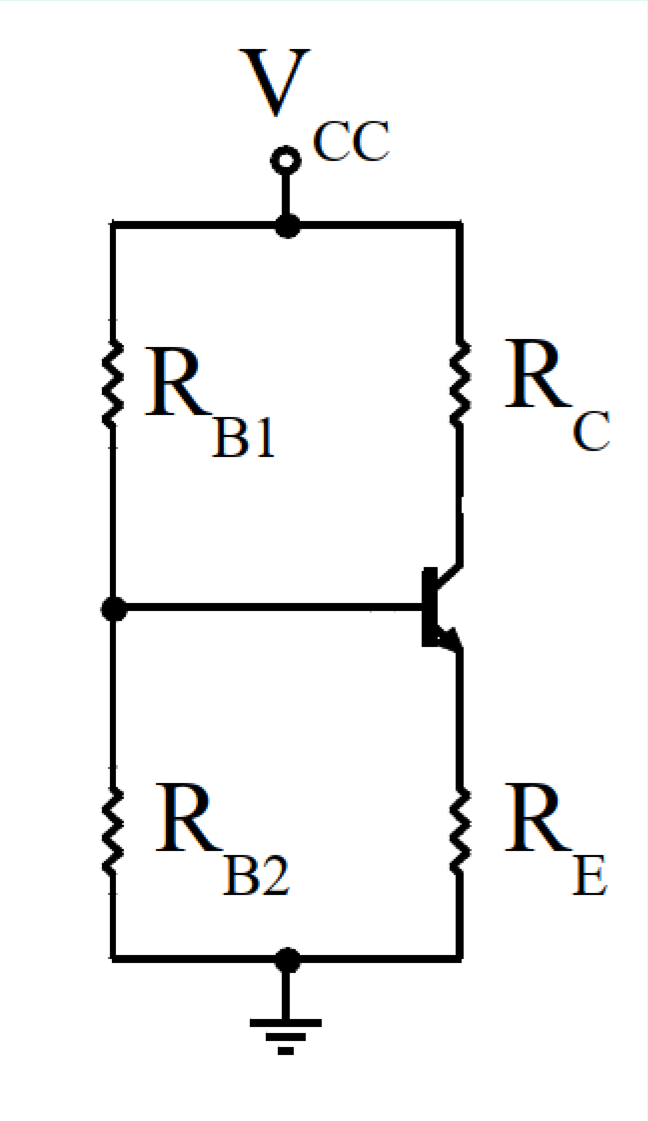
$$r_o \simeq \frac{V_A}{I_C}$$

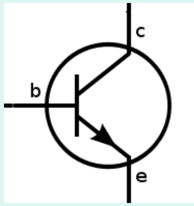




BJT biasing

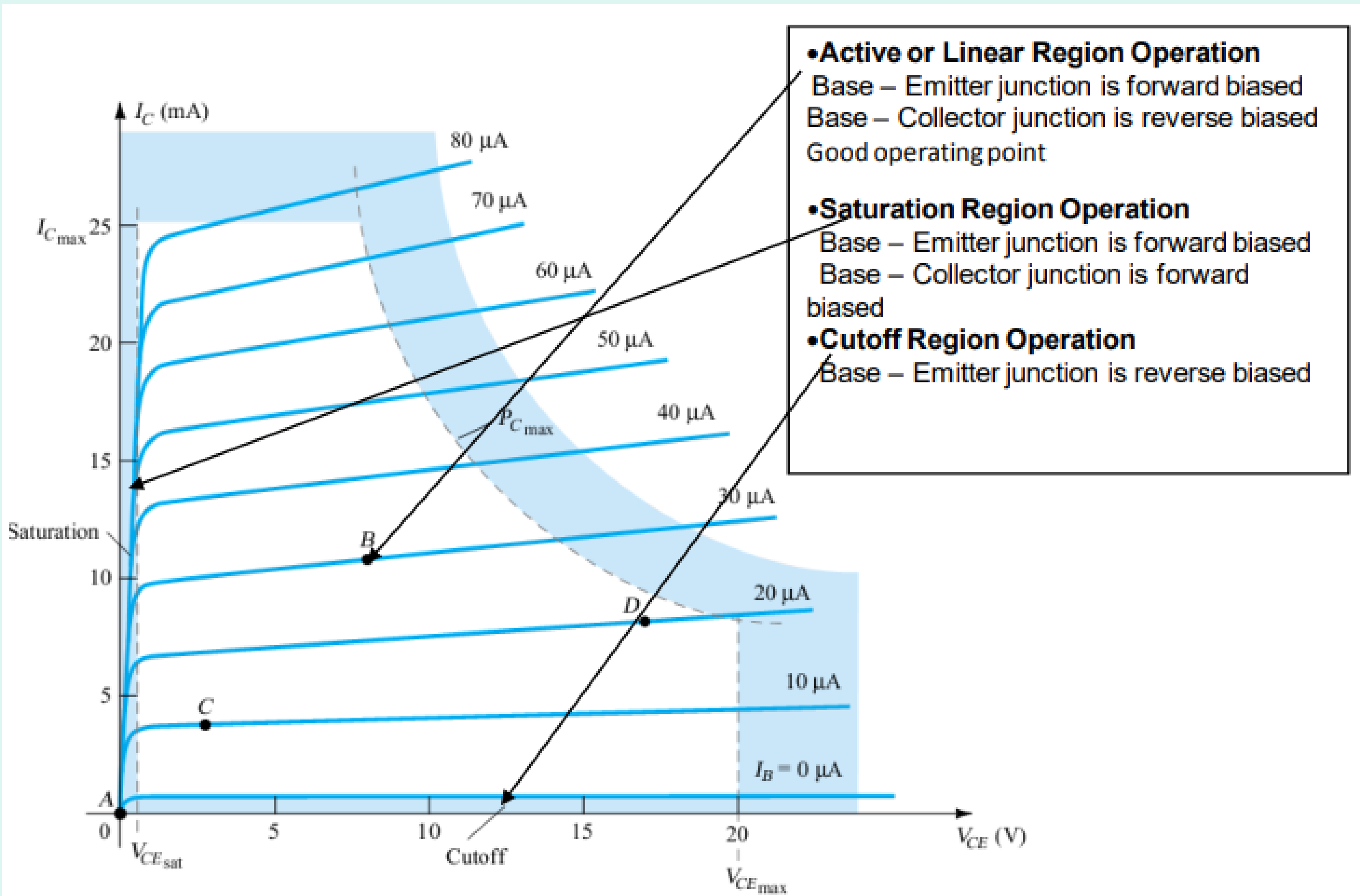
- The basic bias circuit
- V_{CC} often imposed by application
- Biasing trade-off:
  - operation in active mode
  - gain
  - dynamic operating range
  - power consumption
  - input impedance
  - quiescent point stability to variations in β





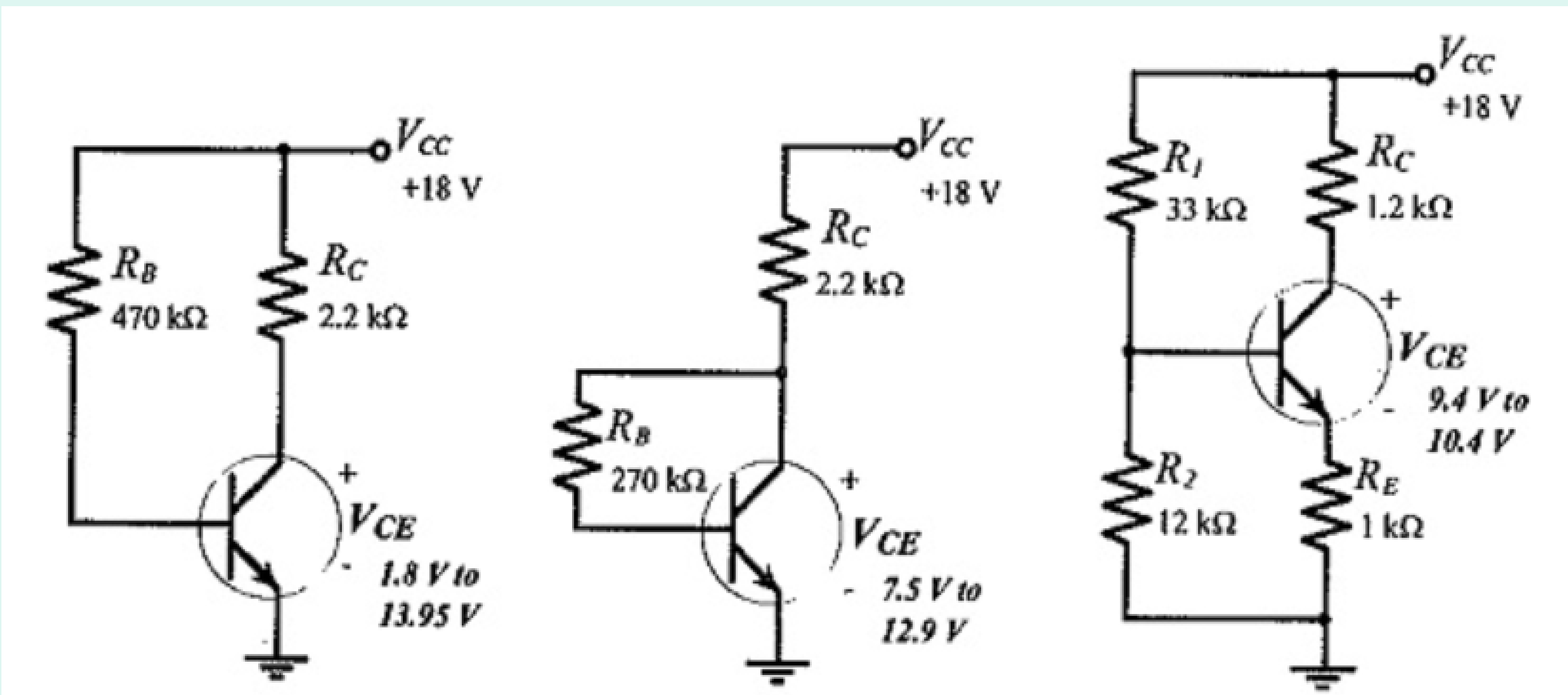
Operating point (quiescent point)

- Role of biasing: setting the fixed DC levels of currents and voltages (for the small ac signal model

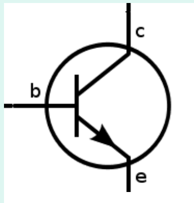


Alternative BJT bias circuits

- We have chosen a good performance bias circuits, but there are other alternatives you may encounter in practice (even using Zener diodes)

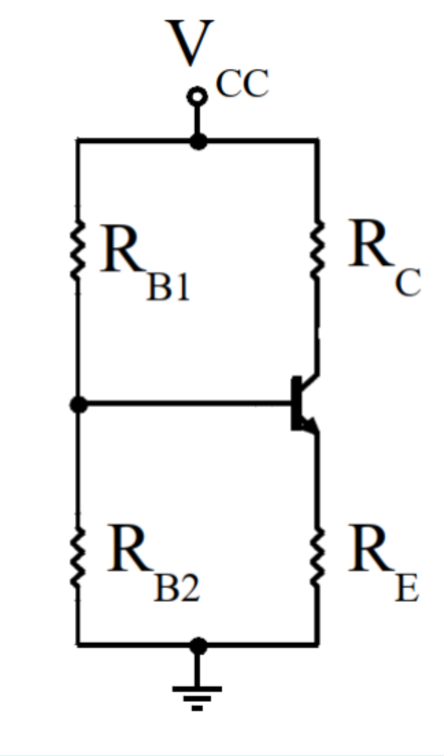


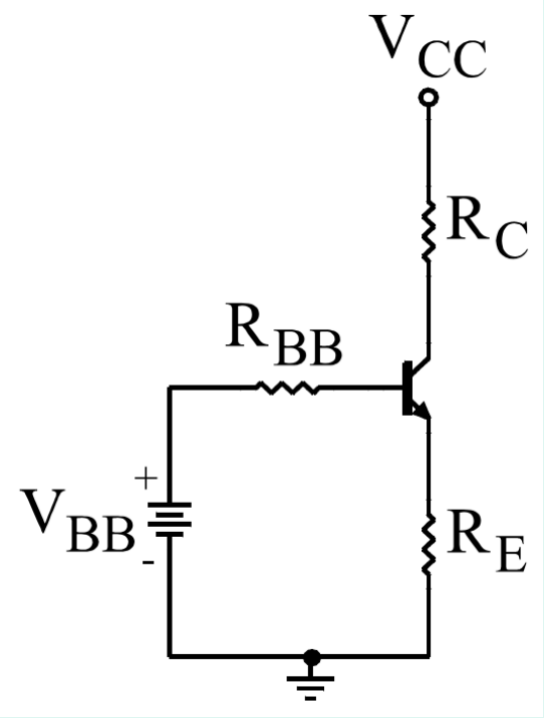
(a) Base Bias (b) Collector-to-base bias (c) Voltage divider bias



BJT biasing

$$I_B = -\frac{V_{BE}}{(1+\beta)\,R_E + R_{BB}} + \frac{V_{BB}}{(1+\beta)\,R_E + R_{BB}}$$



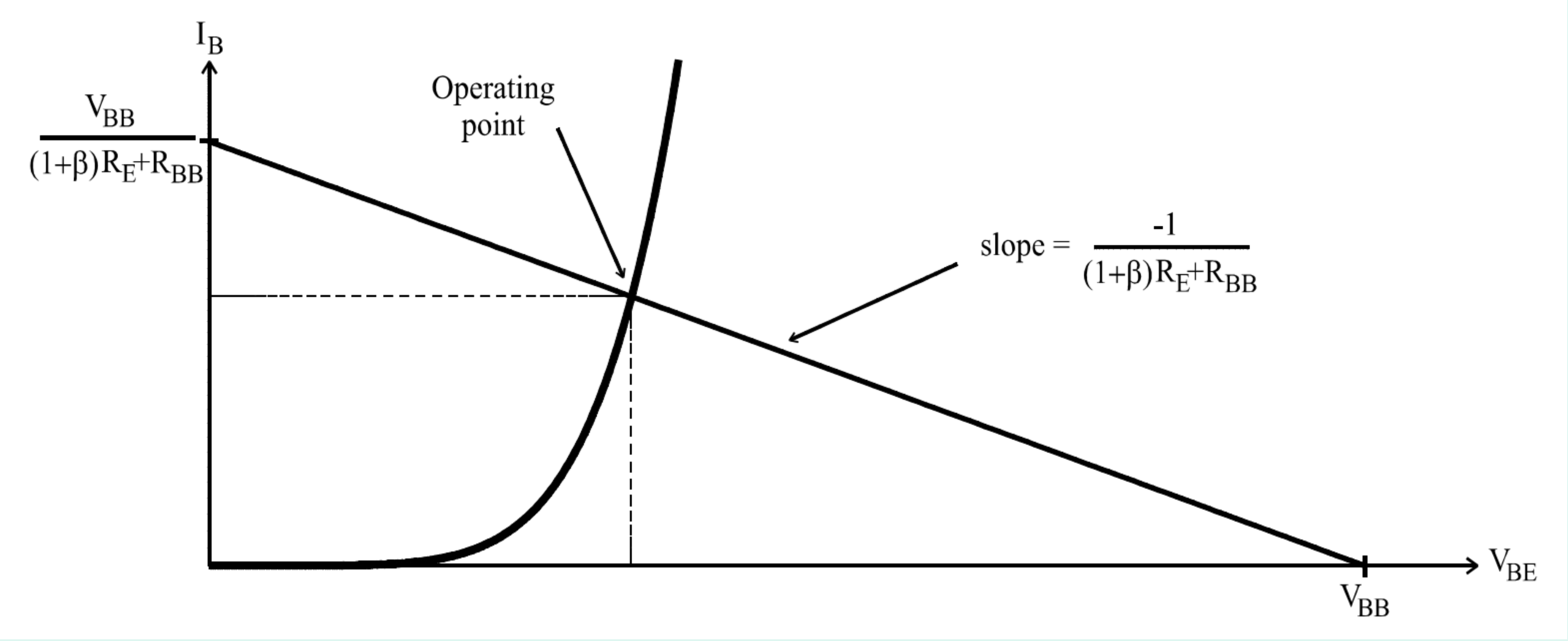


$$I_B = \frac{I_C}{\beta} = \frac{I_S}{\beta} e^{\frac{V_{BE}}{V_T}}$$

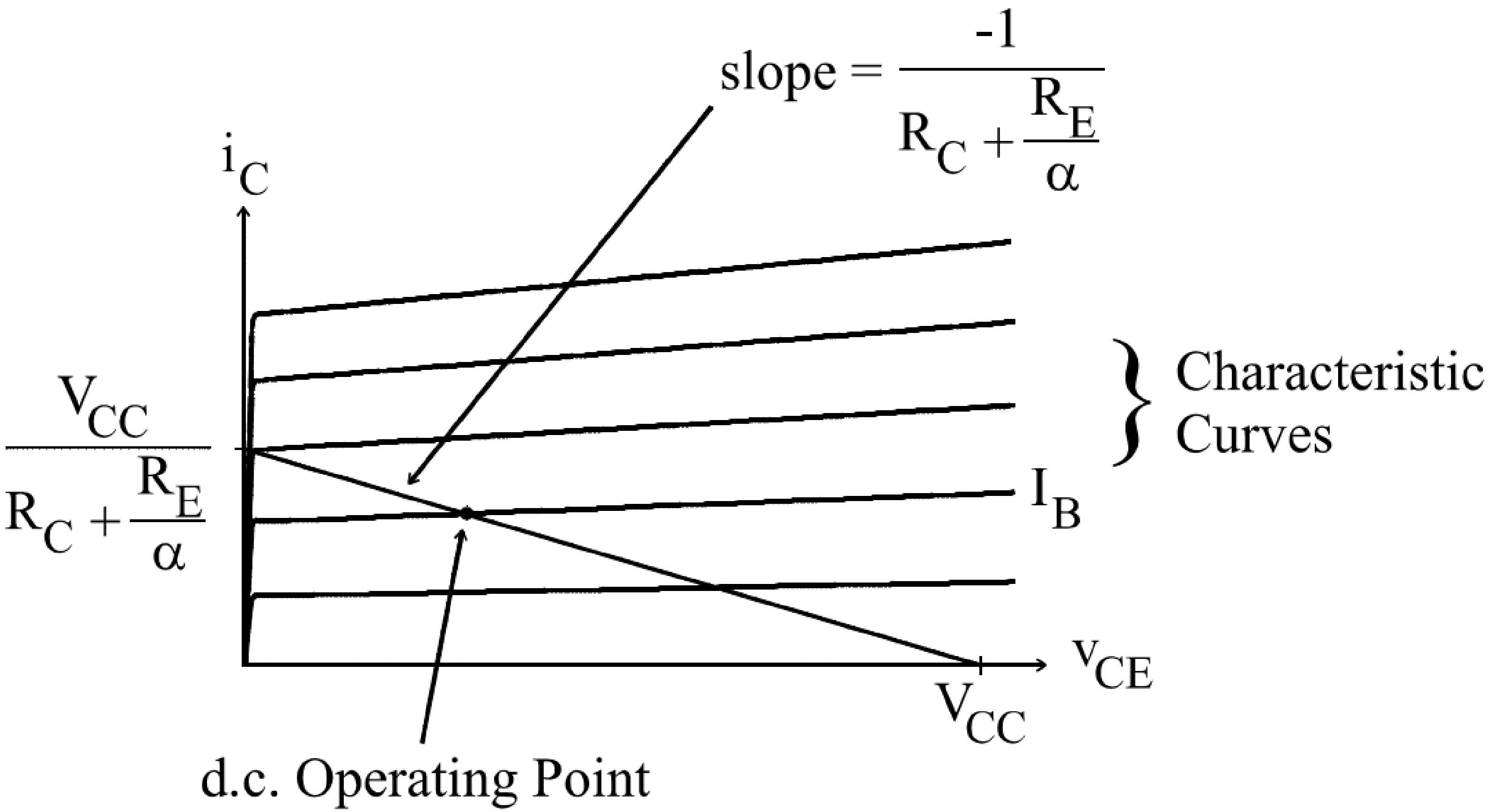
$$V_{BB} = V_{CC}\frac{R_{B2}}{R_{B1} + R_{B2}}, \; R_{BB} = R_{B1} \,||\, R_{B2}$$

Operating point - (V_{BE}, I_B)

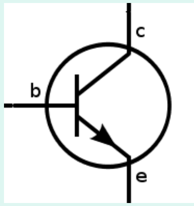
- I_B vs V_{BE}



Operating point (V_{CE}, I_C)



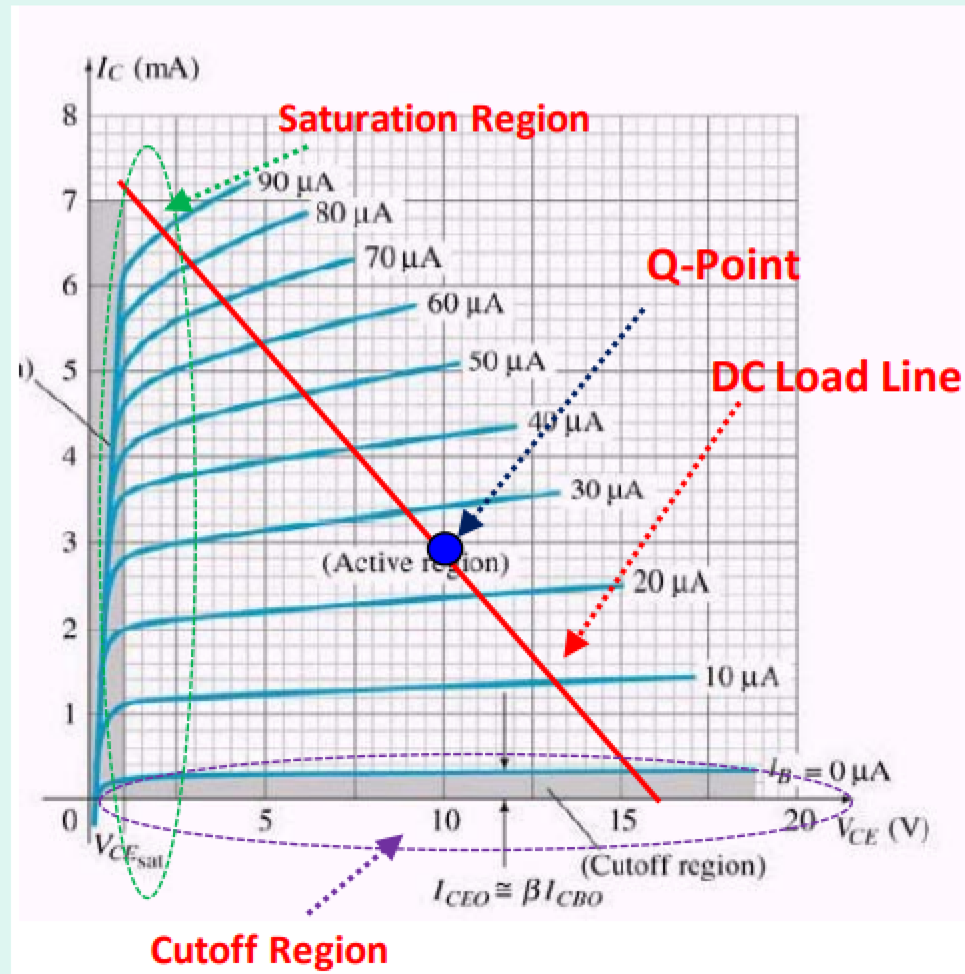
$$I_C = -\frac{V_{CE}}{\left(R_C + \frac{R_E}{\alpha}\right)} + \frac{V_{CC}}{\left(R_C + \frac{R_E}{\alpha}\right)}$$

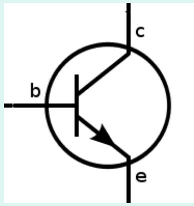


Load line analysis

- Graphical visualization of the dependence between I_C and V_{CE} (for different bias parameters values)

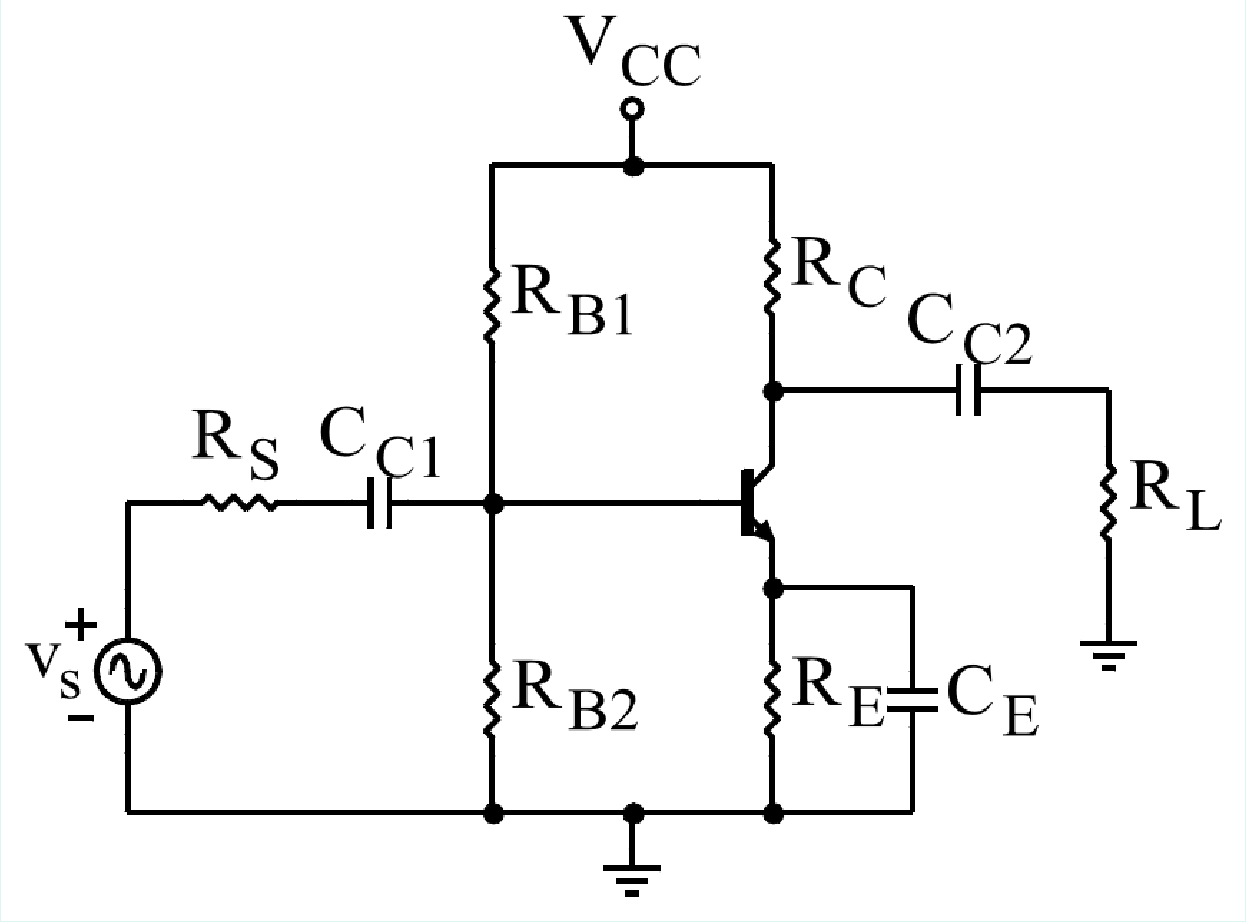
$$I_C = -\frac{V_{CE}}{\left(R_C + \frac{R_E}{\alpha}\right)} + \frac{V_{CC}}{\left(R_C + \frac{R_E}{\alpha}\right)}$$

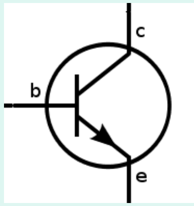




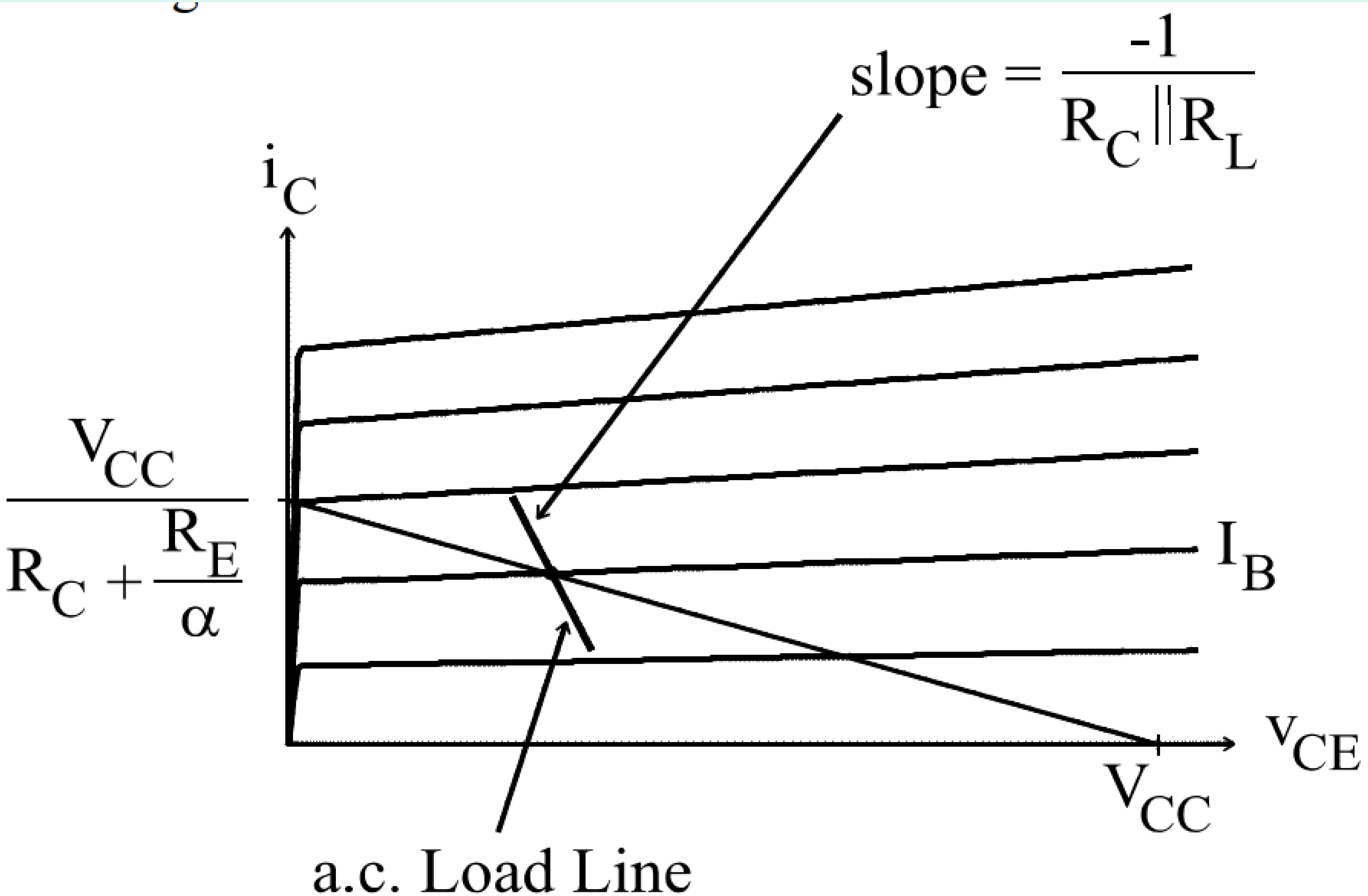
AC circuit

- Addition of coupling and bypass capacitors



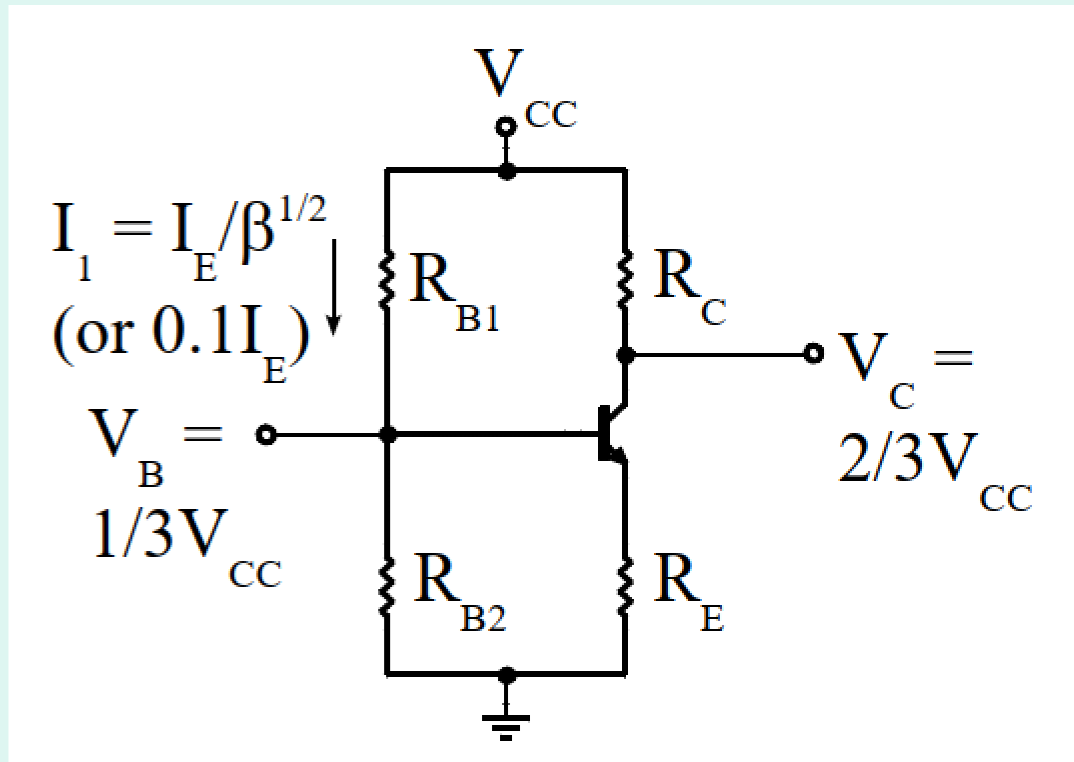


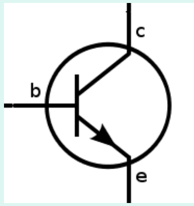
AC load line $i_C(v_{CE})$



Simplify bias circuit approach

- "1/3rd rule" - requires little knowledge of the transistor being used
- First version:
  1. $V_B = 1/3 V_{CC}$,
  2. $V_C = 2/3 V_{CC}$
  3. $I_1 = I_E/\mathrm{sqrt}(\beta)$ (or $I_1 = 0.1 I_E$)





Choices for the bias resistors

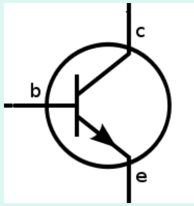
- R_E must be chosen so that EBJ is forward biased

$$I_C = \frac{V_{CC} - V_C}{R_C} = \frac{1}{3}\frac{V_{CC}}{R_C}$$

$$I_1 = \frac{I_E}{\sqrt{\beta}} = \frac{V_{CC} - V_B}{R_{B1}} = \frac{V_{CC} - \frac{1}{3}V_{CC}}{R_{B1}} = \frac{2}{3}\frac{V_{CC}}{R_{B1}}$$

$$I_B = I_1 - \frac{V_B}{R_{B2}} = I_1 - \frac{1}{3}\frac{V_{CC}}{R_{B2}} = \frac{I_E}{\sqrt{\beta}} - \frac{1}{3}\frac{V_{CC}}{R_{B2}}$$

$$I_E = \frac{V_E}{R_E} = \frac{\frac{1}{3}V_{CC} - V_{BE}}{R_E}$$



Bias resistors (2)

- Approximate V_{BE}=0.7V, select I_C to achieve a given transconductance, typical β known

$$R_C = \frac{1}{3}\frac{V_{CC}}{I_C}$$

$$R_{B2} = \frac{\frac{1}{3}V_{CC}}{I_1 - I_B} = \frac{\frac{1}{3}V_{CC}}{\frac{I_E}{\sqrt{\beta}} - \frac{I_E}{\beta}} = \frac{R_{B1}}{2}\left(\frac{1}{1 - \frac{1}{\sqrt{\beta}}}\right)$$

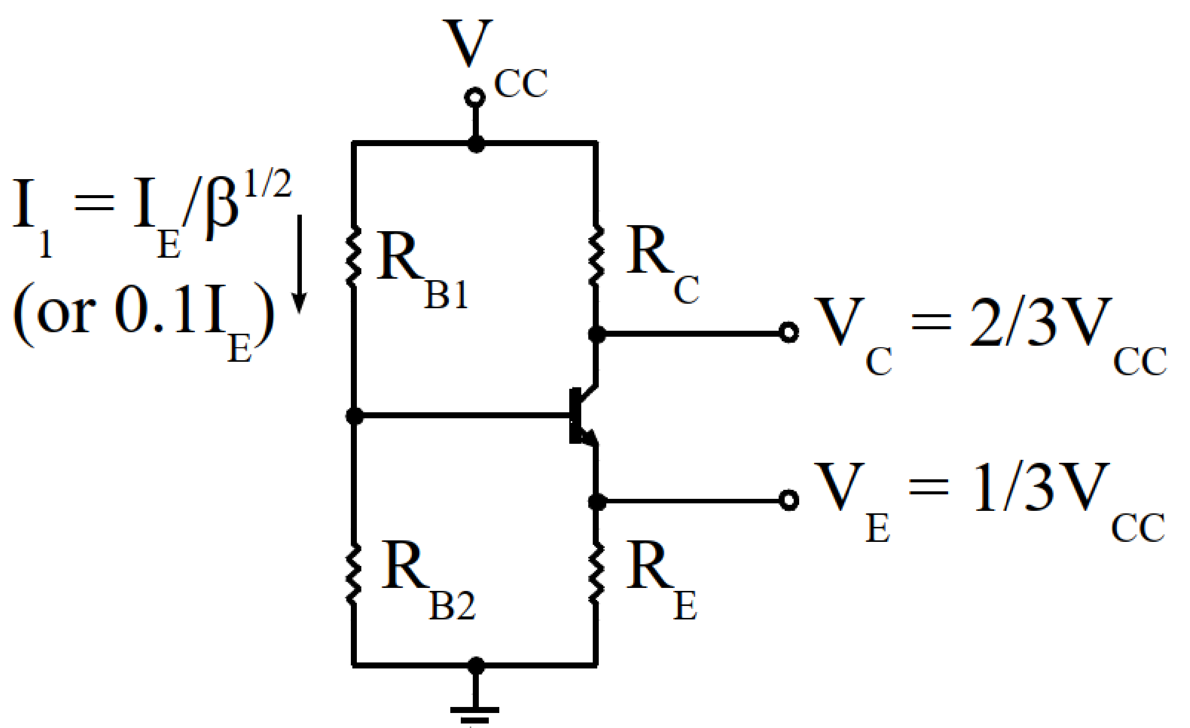
$$R_{B1} = \frac{\frac{2}{3}V_{CC}}{I_1} = \frac{\frac{2}{3}V_{CC}}{\frac{I_E}{\sqrt{\beta}}}$$

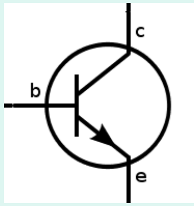
$$R_E = \frac{\frac{1}{3}V_{CC} - V_{BE}}{I_E} = \frac{\frac{1}{3}V_{CC} - 0.7\ V}{I_E}$$

⅓rd rule - second version

- Easier to apply

1. $V_C = 2/3 V_{CC}$
2. $V_E = 1/3 V_{CC}$
3. $I_1 = I_E/\text{sqrt}(\beta)$ (or $I_1 = 0.1 I_E$)

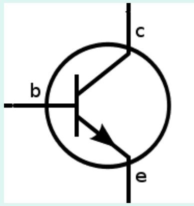




Bias resistors

- Computing the required resistance values:
- the forward current gain β is known (data sheet), V_{CC} determined by application, I_C chosen to achieve a given transconductance
- $V_{BE} \approx 0.7V$, $I_B = I_C/\beta$, $I_1 = I_E/(\mathrm{sqrt}(\beta)$ or $0.1 I_E$

$$\left.\begin{aligned} I_E &= \frac{I_C}{\alpha} \approx I_C \\ V_C &= \frac{1}{3} V_{CC} = V_E \end{aligned}\right\} \Rightarrow R_E \approx R_C = \frac{1}{3}\frac{V_{CC}}{I_C}$$



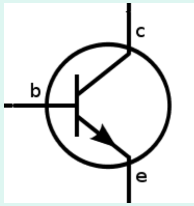
Bias resistors (2)

- The remaining values for R_{B1}, R_{B2}
- We ensure EBJ is forward biased

$$R_{B1}=\frac{V_{CC}-V_{B}}{\frac{I_E}{\sqrt{\beta}}}=\frac{V_{CC}-(V_E+V_{BE})}{\frac{I_E}{\sqrt{\beta}}}=\frac{\frac{2}{3}V_{CC}-V_{BE}}{\frac{I_E}{\sqrt{\beta}}}=\frac{\frac{2}{3}V_{CC}-0.7\mathrm{V}}{\frac{I_E}{\sqrt{\beta}}}$$

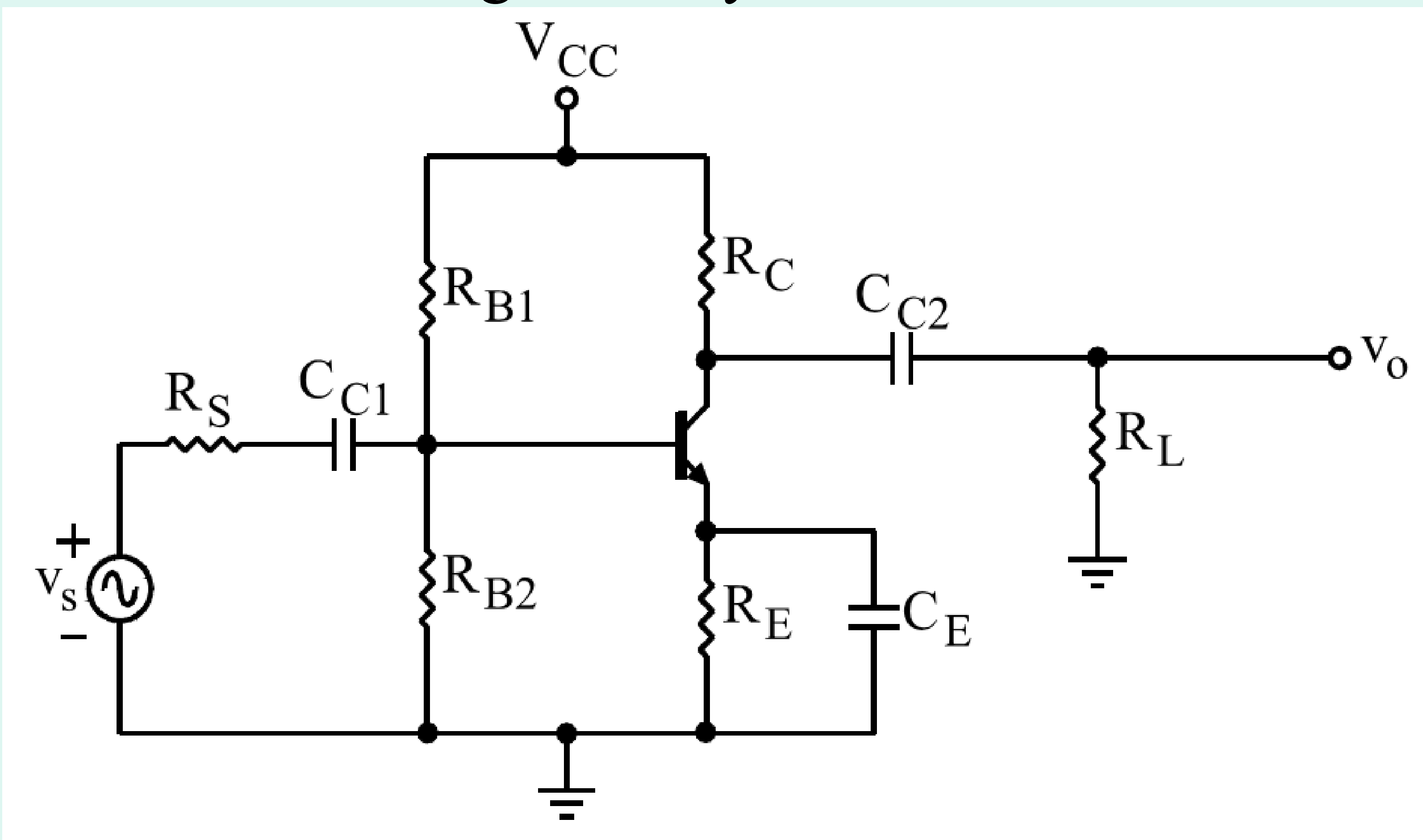
$$R_{B2}=\frac{V_E+V_{BE}}{\frac{I_E}{\sqrt{\beta}}-I_B}=\frac{\frac{1}{3}V_{CC}+V_{BE}}{\frac{I_E}{\sqrt{\beta}}-I_B}=\frac{\frac{1}{3}V_{CC}+0.7\ V}{\left(\frac{1}{\sqrt{\beta}}-\frac{1}{\beta+1}\right)I_E}$$

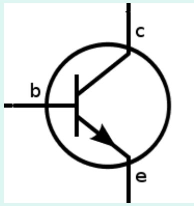
$$R_{B2}\overset{\beta>>1}{\simeq}\frac{\frac{1}{3}V_{CC}+0.7V}{\frac{I_E}{\sqrt{\beta}}}$$



Common-emitter amplifier

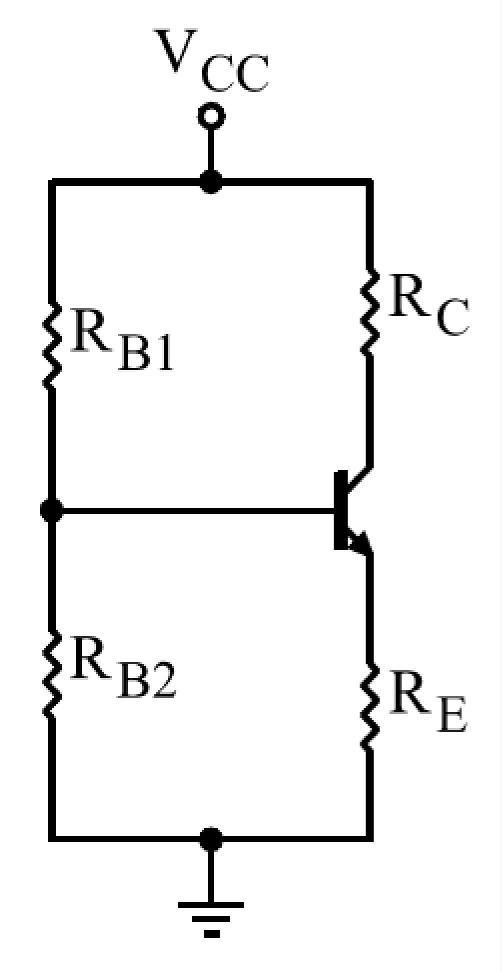
- We assume we have established the quiescent point (I_C, R_C, R_E, R_{B1}, R_{B2} are known)
- Focus now on small signal analysis

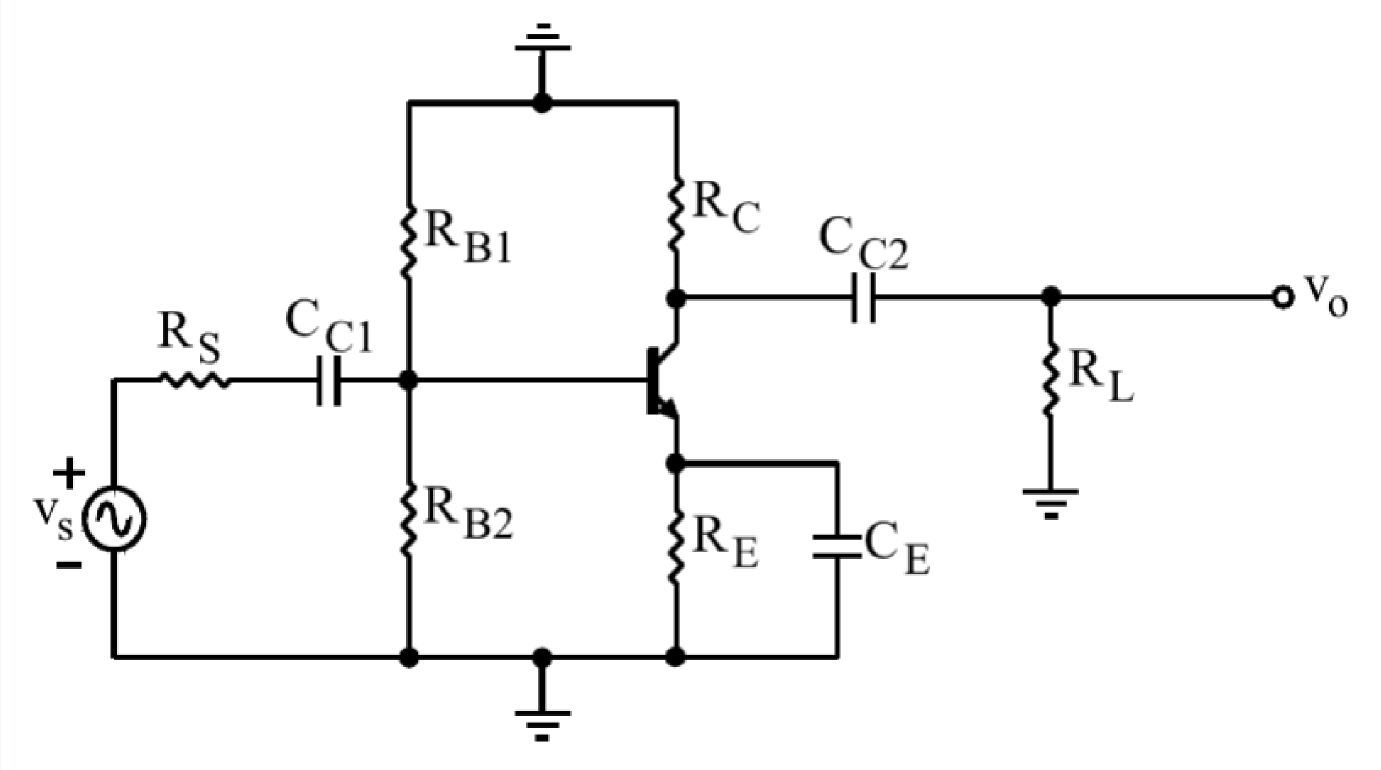


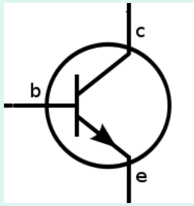


Recall

- The DC circuit vs. the AC circuit

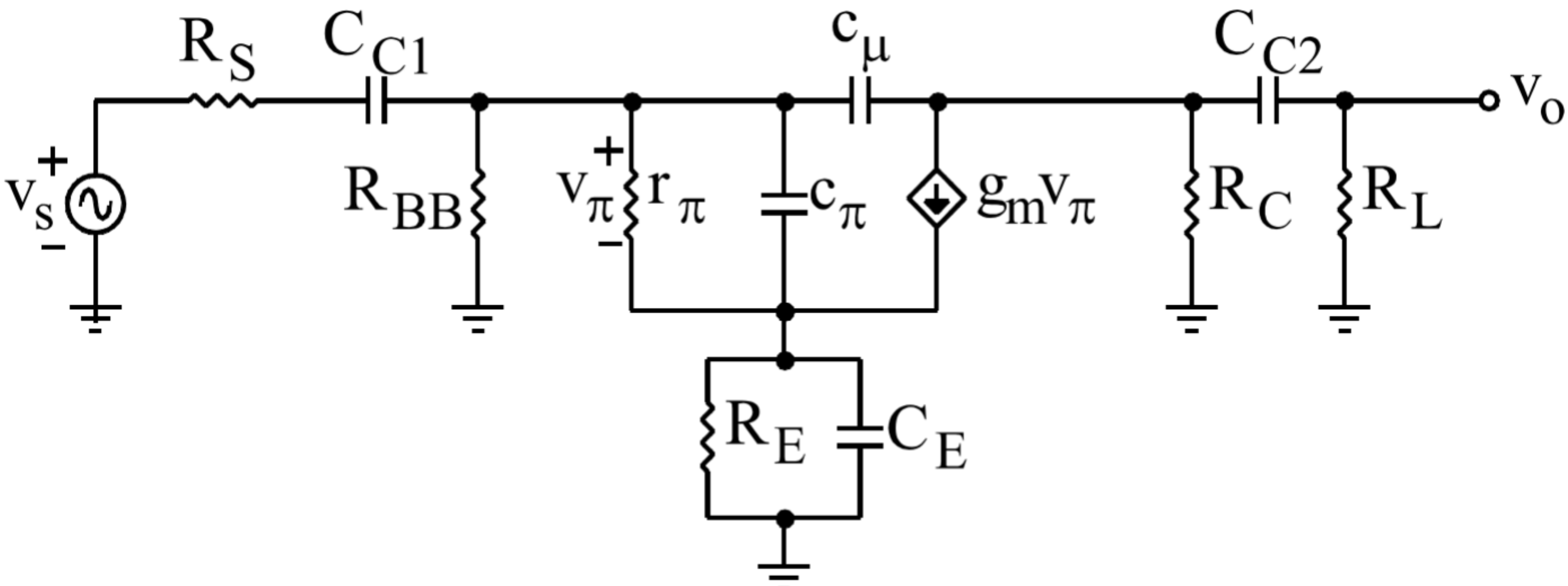






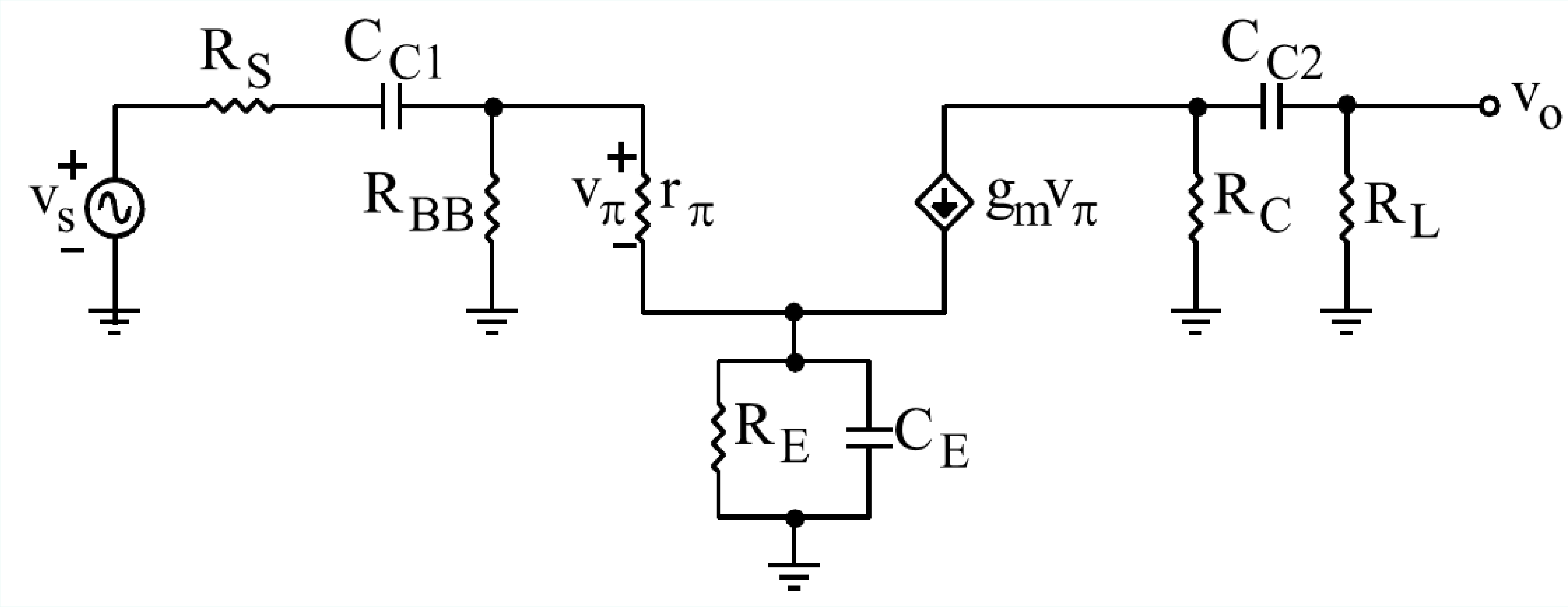
Complete small-signal model

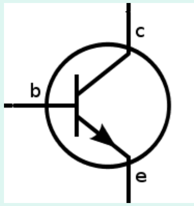
- We use the hybrid-π BJT model ($r_o=\infty$)



LF, MF, HF bandwidths

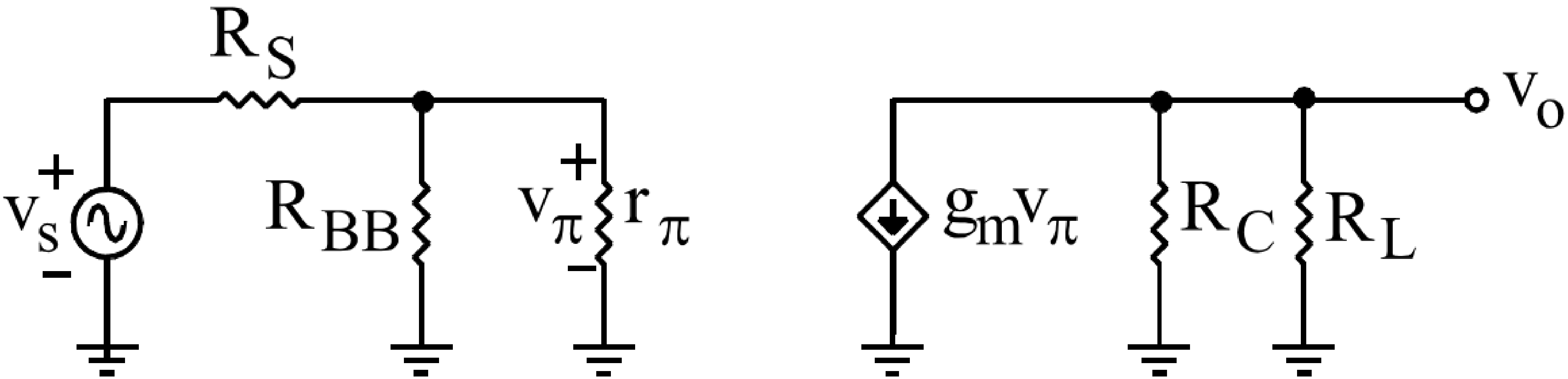
- LF model - all HF capacitors replaced by open circuits



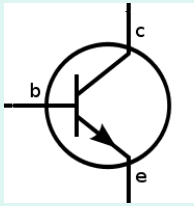


The midband small-signal model

- LF are short-circuited, HF are open-circuited

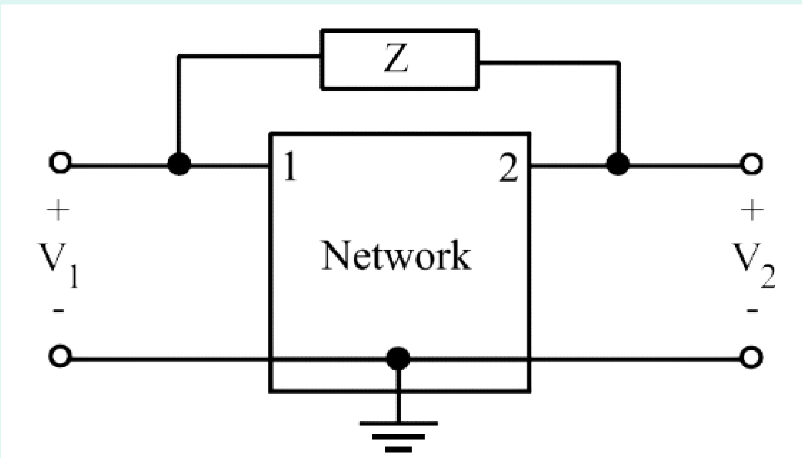


$$A_M = \frac{v_o}{v_s} = \frac{v_o}{v_\pi} \cdot \frac{v_\pi}{v_s} = -g_m R_C \| R_L \frac{R_{BB} \| r_\pi}{R_{BB} \| r_\pi + R_S}$$



Recall: Miller's theorem

- Replace the Z feedback with two impedances Z1 and Z2



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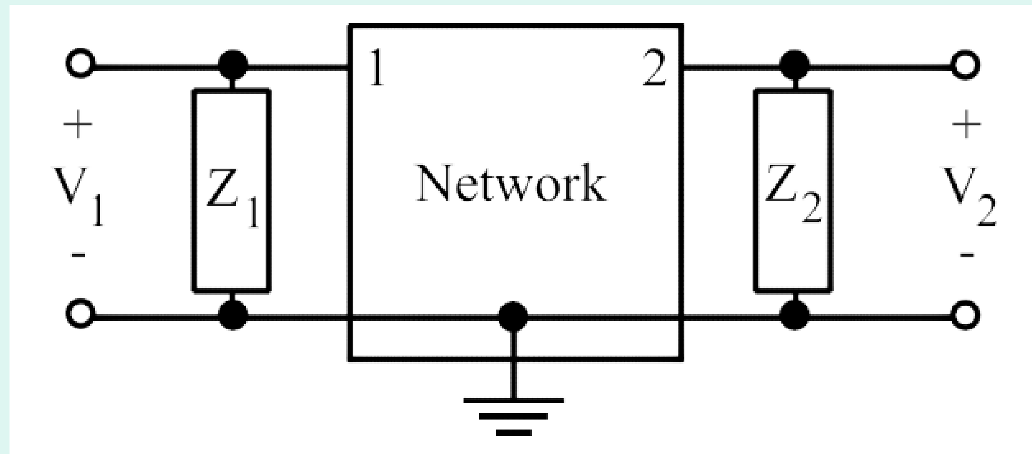


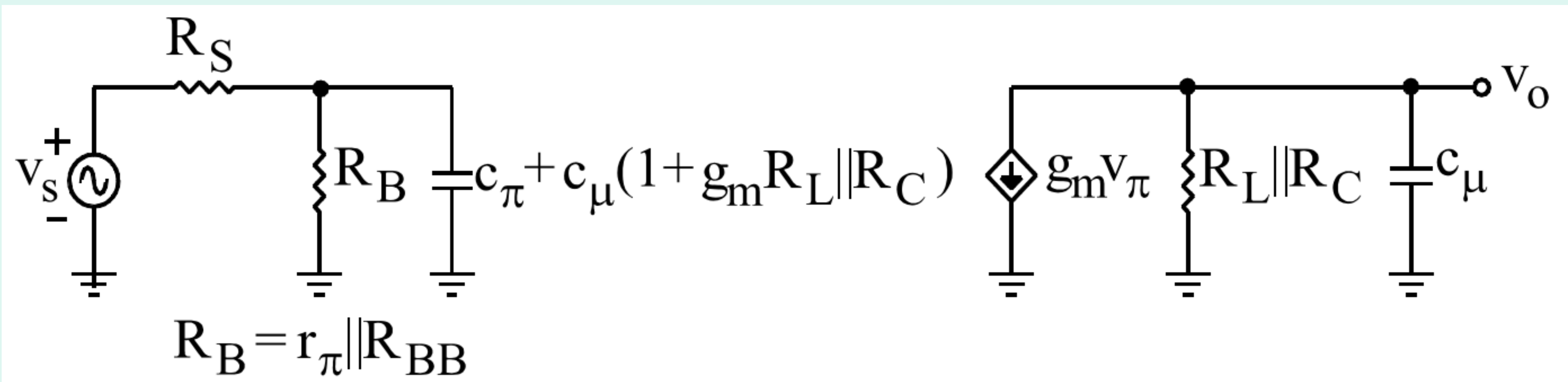
$$V_2 = kV_1$$

$$V_2 = kV_1$$

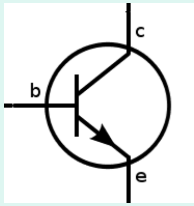
$$Z_1 = Z\frac{1}{1-k} \qquad Z_2 = Z\frac{k}{k-1}$$

The HF small-signal model

- LF capacitances are short-circuited, Miller theorem applied



$$F_H(s)=\frac{\dfrac{1}{R_{BB}||r_\pi||R_S\left[c_\pi+c_\mu\left(1+g_m R_C||R_L\right)\right]}}{\left(s+\dfrac{1}{R_{BB}||r_\pi||R_S\left[c_\pi+c_\mu\left(1+g_m R_C||R_L\right)\right]}\right)}\cdot\frac{\dfrac{1}{R_C||R_L c_\mu}}{\left(s+\dfrac{1}{R_C||R_L c_\mu}\right)}$$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