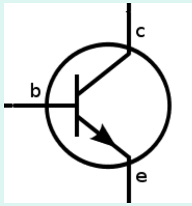
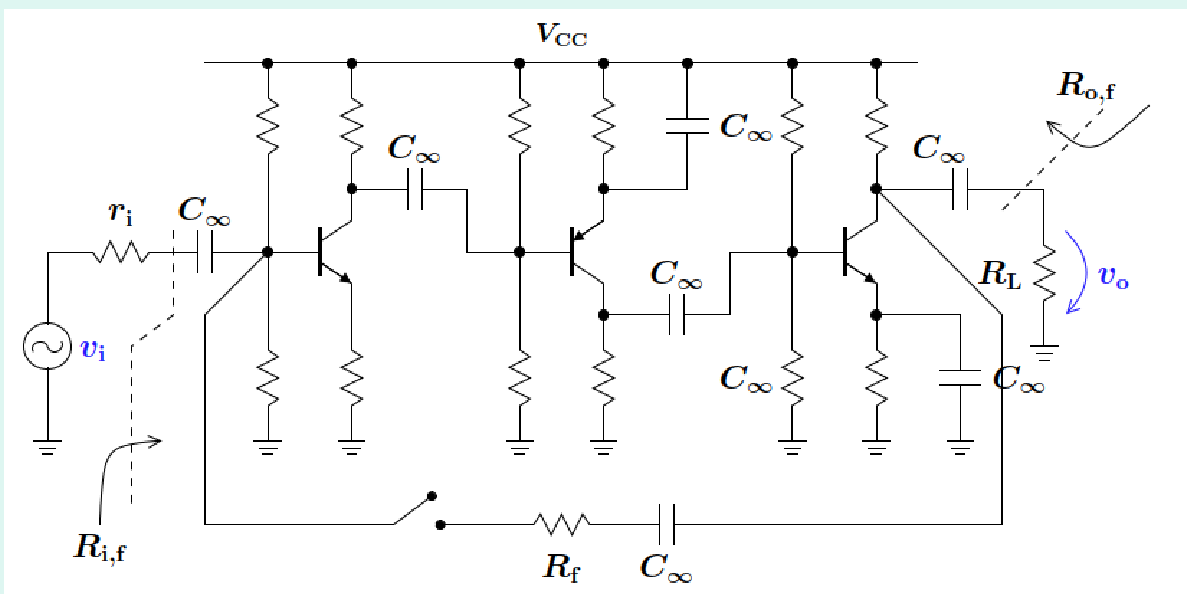
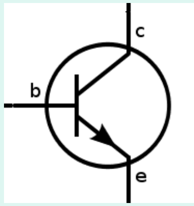


ELEC 301 - CB, CC amplifier configurations

L15 - Oct 09

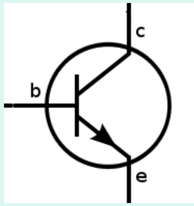
Instructor: Edmond Cretu





Administrative issues

- Midterm - Monday, Oct 20 - L1-15
- Sample problems to be posted on Canvas
- Office hours: after lectures or by email

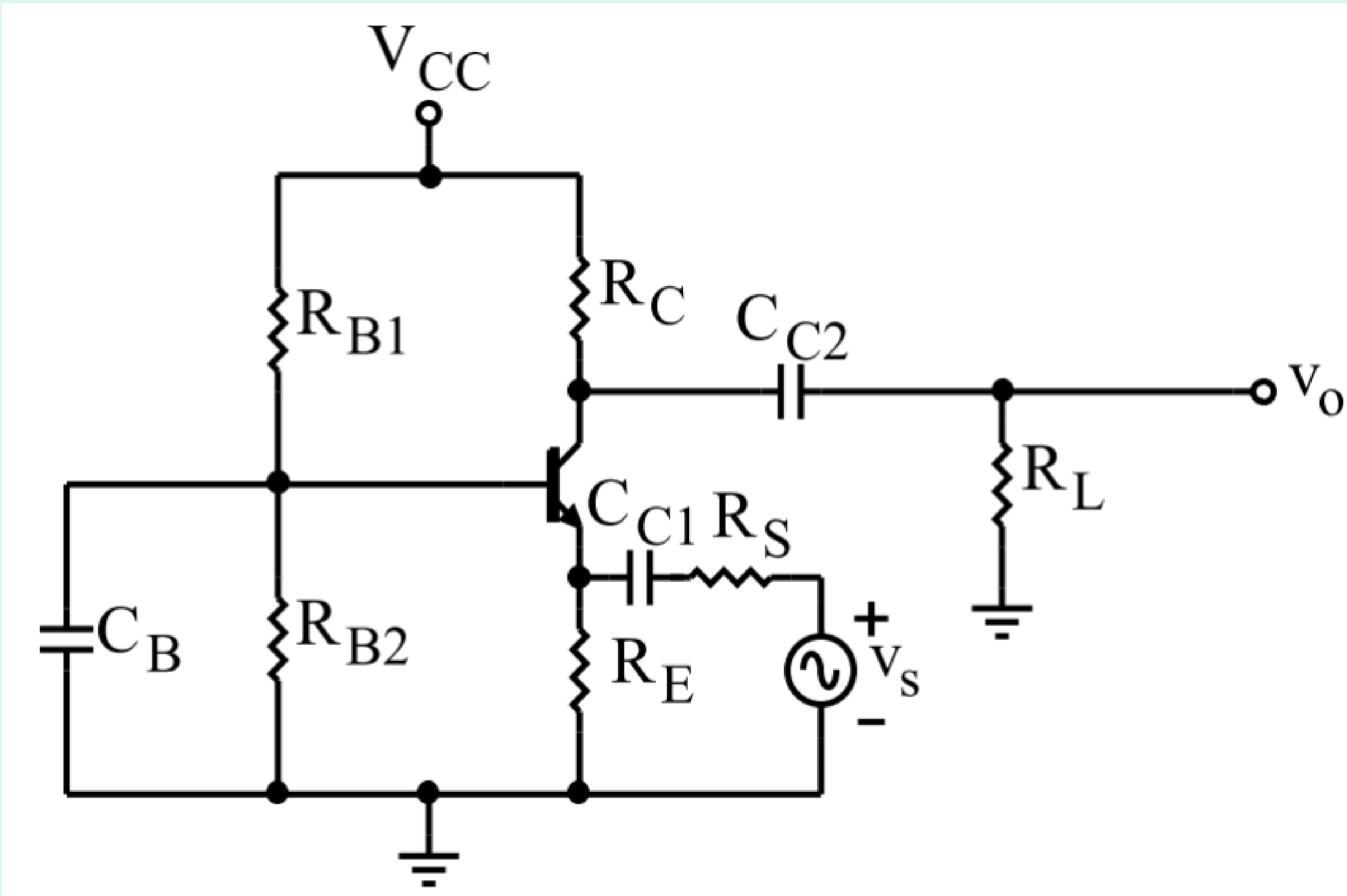


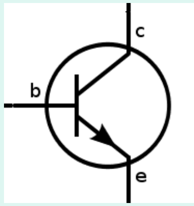
Last lecture

- CB amplifier
- General diports discussion
- Frequency response of the CB amplifier

The common-Base amplifier

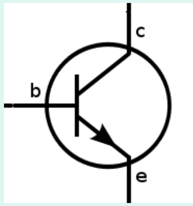
- Input port: E, Output port: C
- We assume proper biasing (1/3 rule); C_B to ground B in AC mode





Aspects of interest

- Mid band response: voltage gain, current gain
- Input impedance
- Output impedance
- General frequency response - what limits ω_L, ω_H
- Typical use



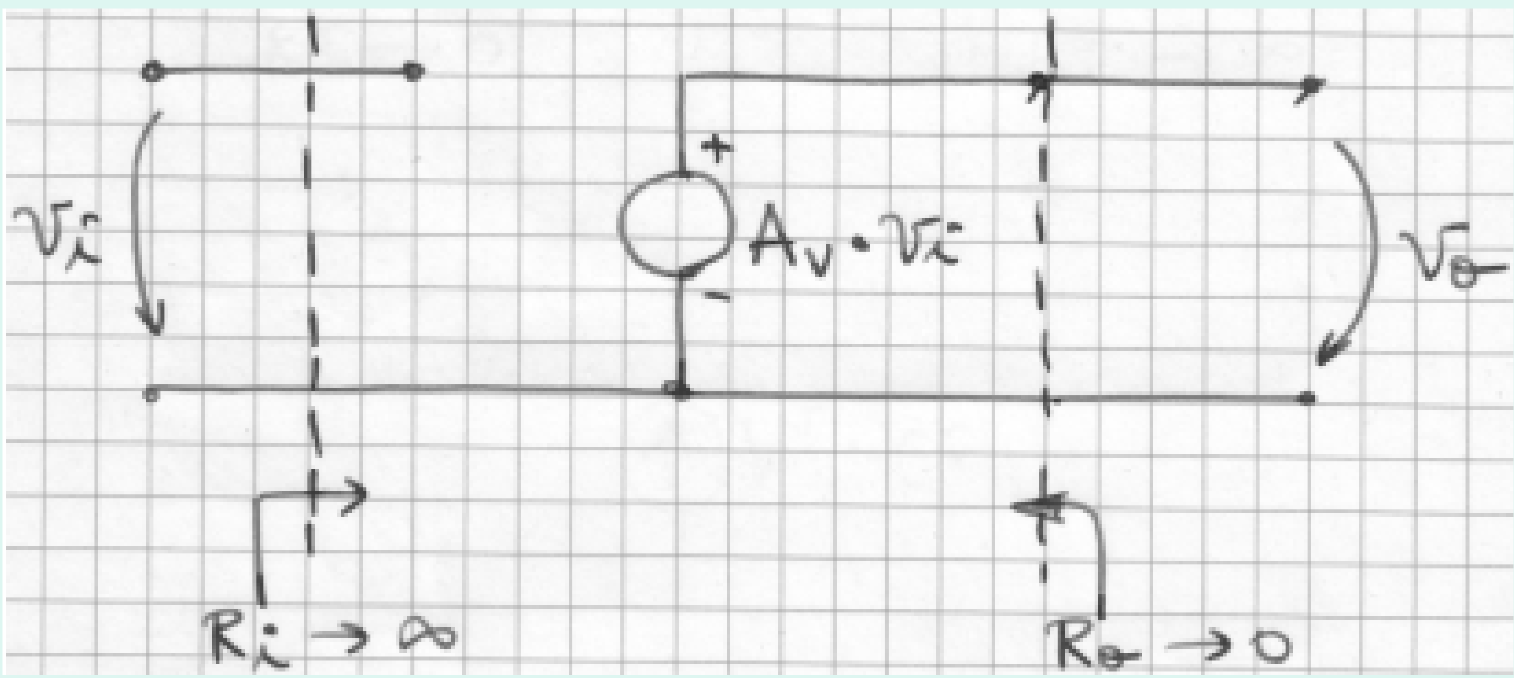
Recall: Ideal amplifiers - diports

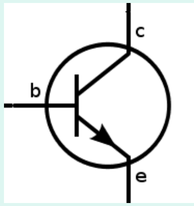
- Goal: to become an information/signal flow block/subsystem
- Requirements:
  - to not absorb power at the input port
  - to not lose power internally at the output port
  - to not have backward propagation from output to input (to not deliver power at the input port)
  - high gain, controlled with good accuracy and reproducibility
  - a frequency response that matches the bandwidth of the input signal
  - to not add any internal noise to the output signal (NF = 1)

$$Noise\ Factor\ (F) = \frac{\left(\frac{S_{in}}{N_{in}}\right)}{\left(\frac{S_{out}}{N_{out}}\right)}$$

Ideal voltage amplifier

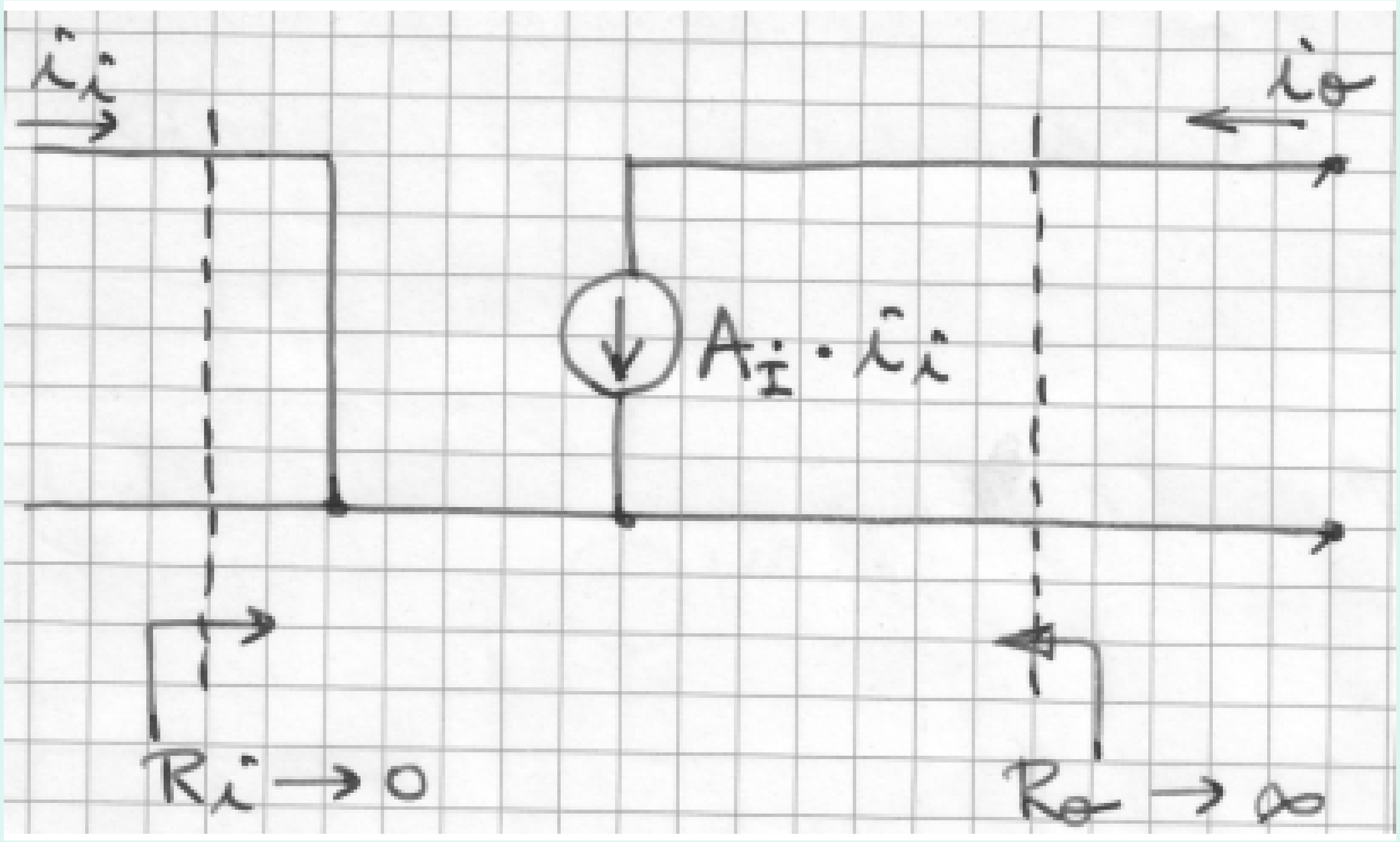
- Approximation of the real world, within given constraints
- Input port signal = voltage, output port signal = voltage
- $Z_{in}=\infty$, $Z_{out}=0$





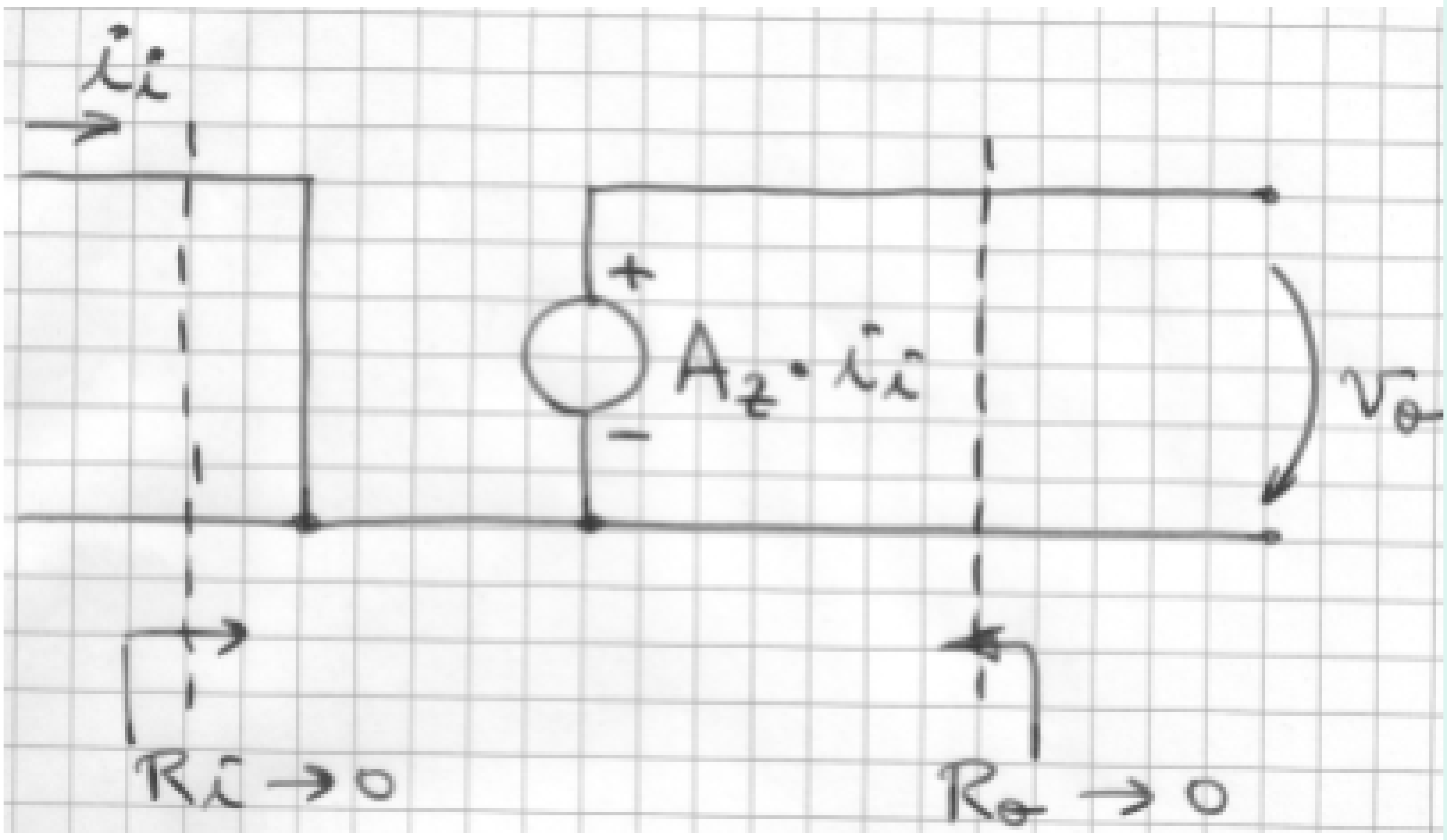
Ideal current amplifier

- Input port signal=current, output port signal=current
- Zin=0,Zout=∞



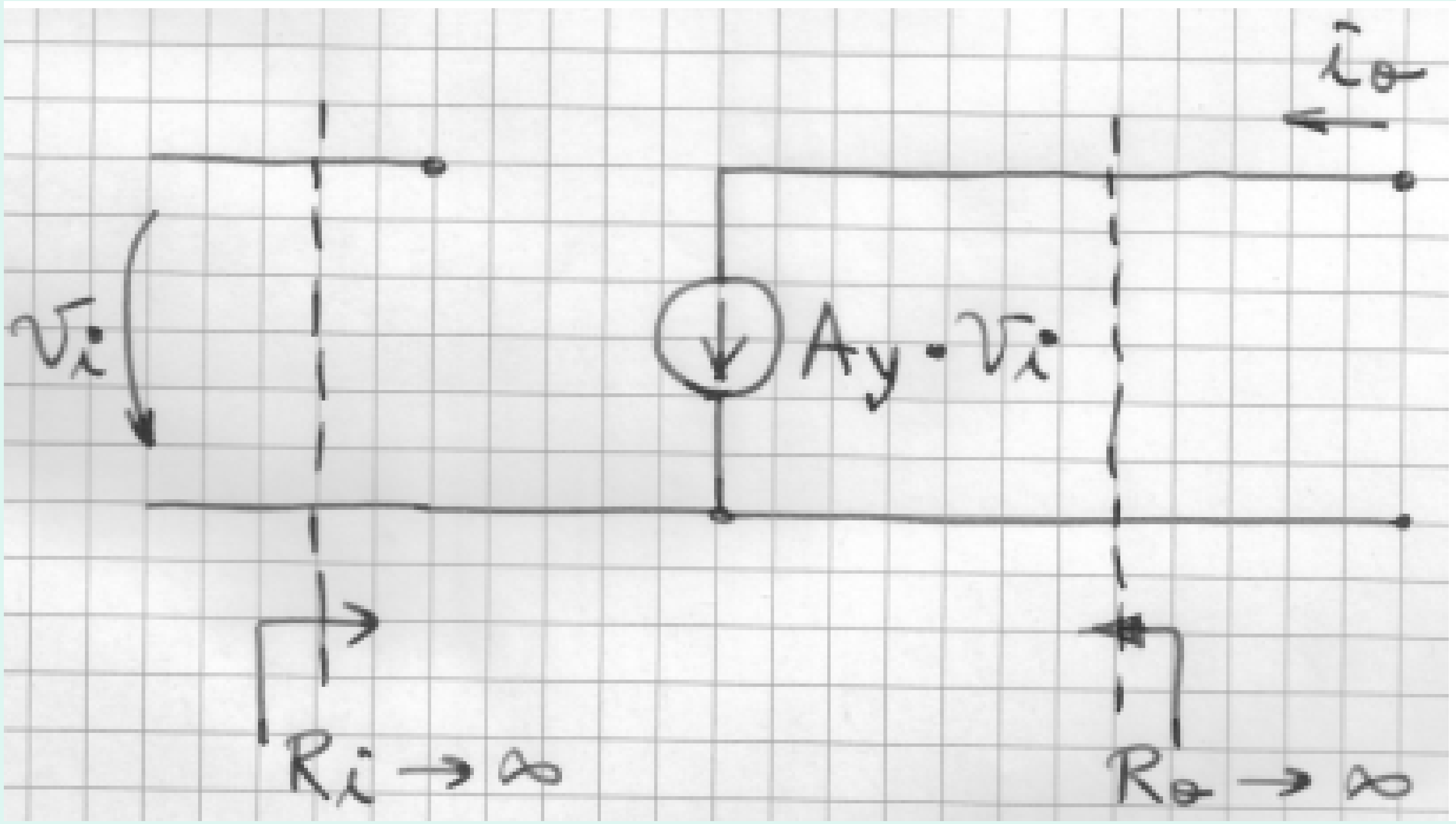
Ideal transimpedance amplifier

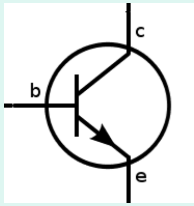
- Input port signal=current, output port signal=voltage
- Zin=0,Zout=0



Ideal transadmittance amplifier

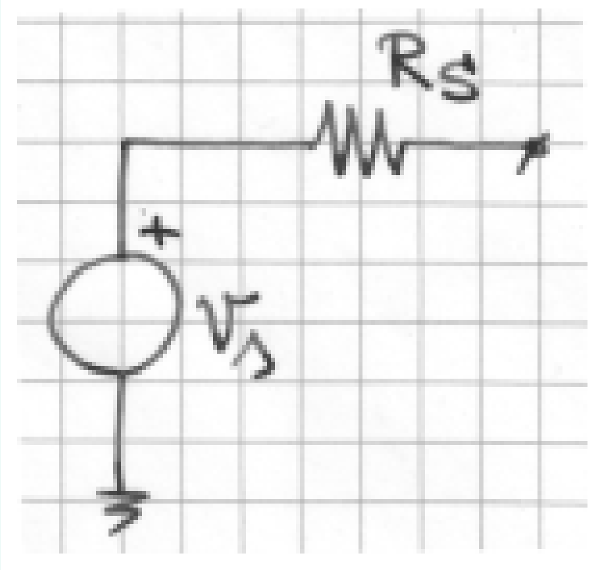
- Input port signal=voltage, output port signal=current
- $Z_{in}=\infty$, $Z_{out}=\infty$

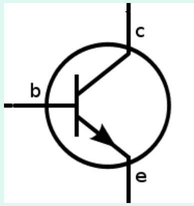




Design: choosing the right amplifier

- Choosing a particular category of amplifier depends on the application
  - input matching with the preceding stage
  - output matching with the characteristics of the subsequent block
- Exm: microphone amplifier: small signal, high input resistance





L15 Q01 - microphone amplifier

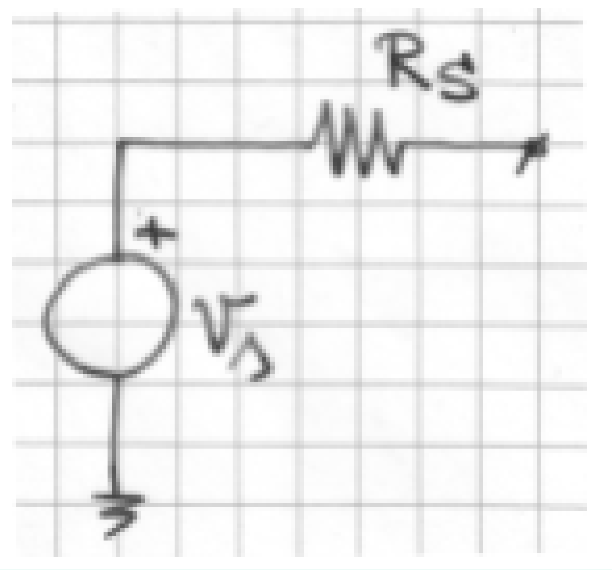
- If the desired output signal for a microphone amplifier is the voltage, what type of amplifier should we choose?

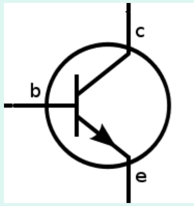
A. voltage amplifier

B. current amplifier

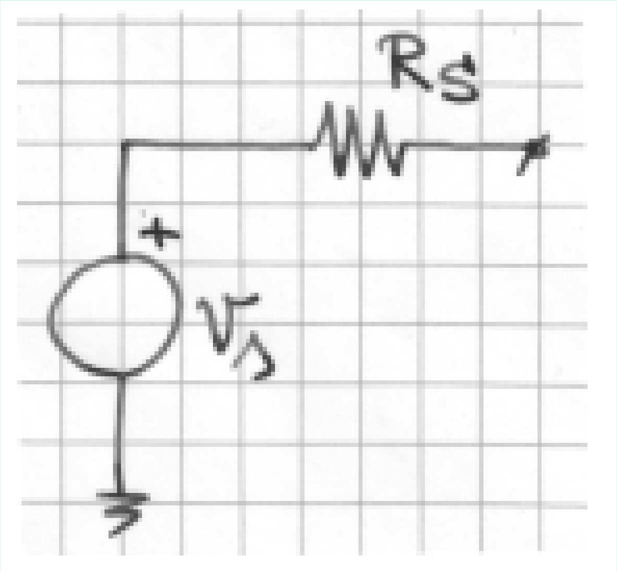
C. transimpedance amplifier

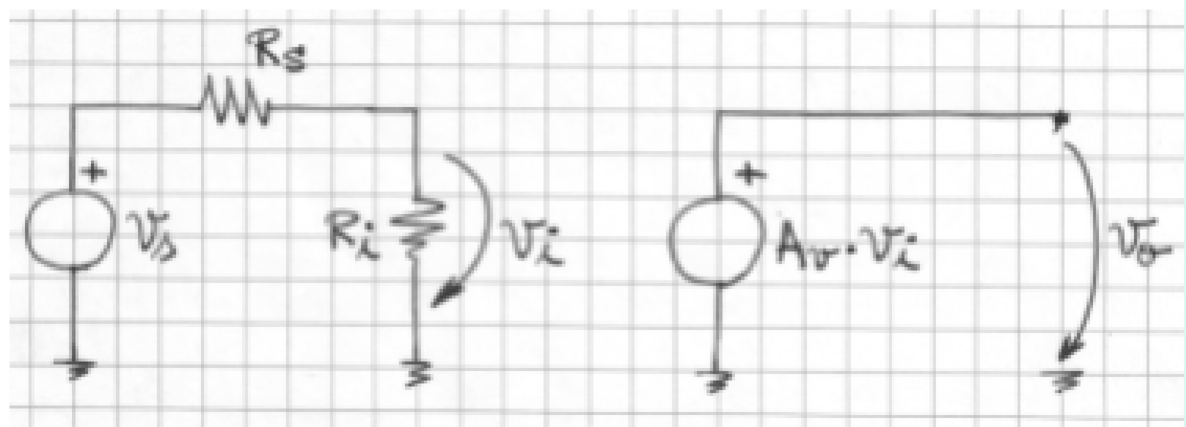
D. transadmittance amplifier





Microphone amplifier

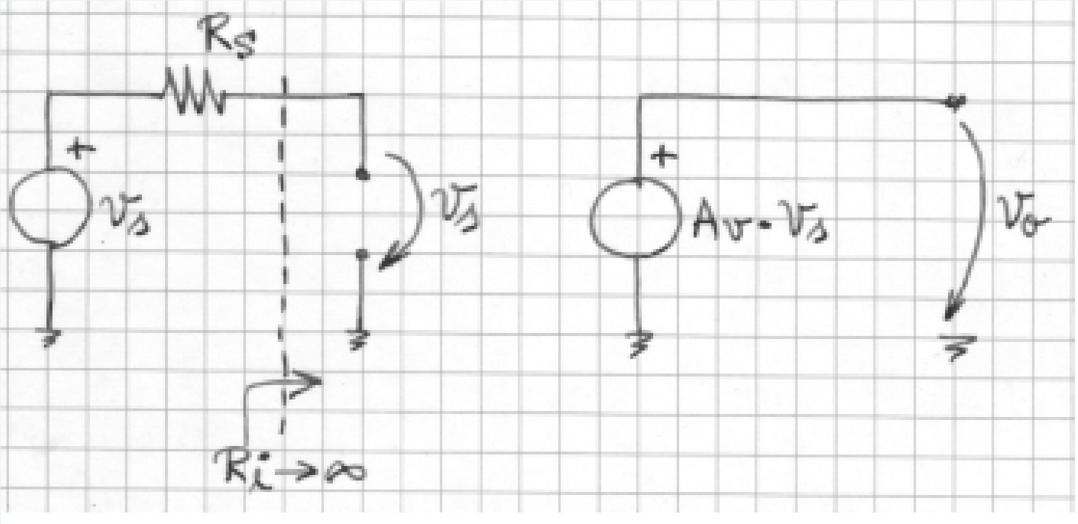




$$v_o = A_v \frac{R_i}{R_s + R_i} v_i = \frac{A_v}{1 + \frac{R_s}{R_i}} v_i$$

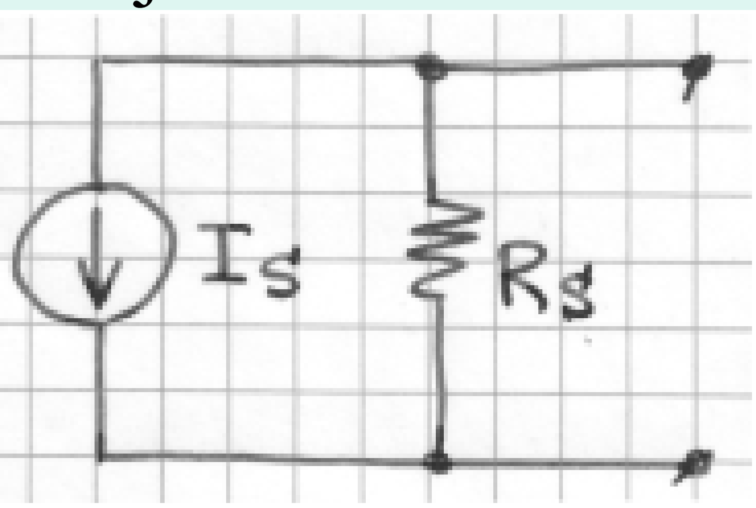
- Microphone equivalent circuit

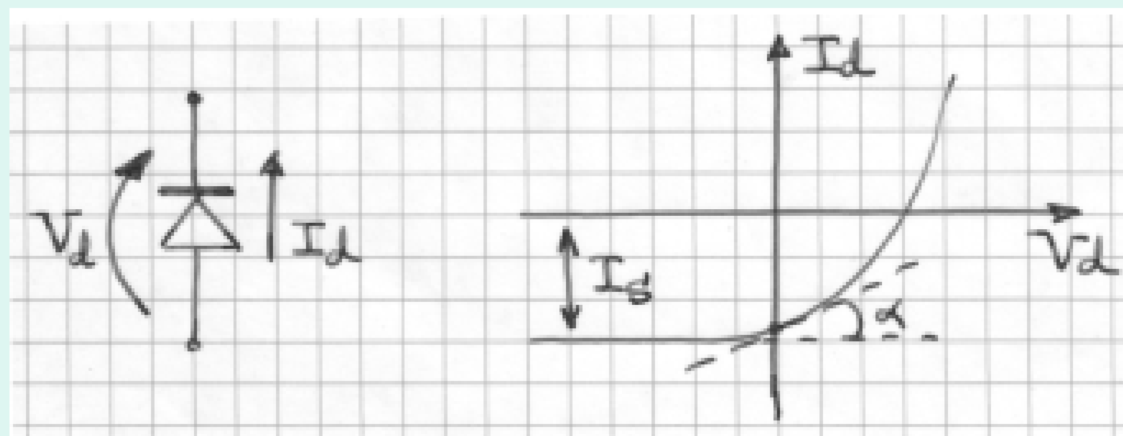
$$R_i \rightarrow \infty \Rightarrow v_o = A_v v_i$$



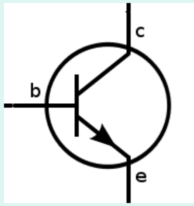
Exm2: photodiode amplifier

- very small current
- relatively small-moderate internal resistance
- Diode in reverse bias → the incident light on the pn junction increases the current I_s





$$R_s = \frac{1}{\tan\alpha} = \cot\alpha$$



L15 Q02 photodiode amplifier

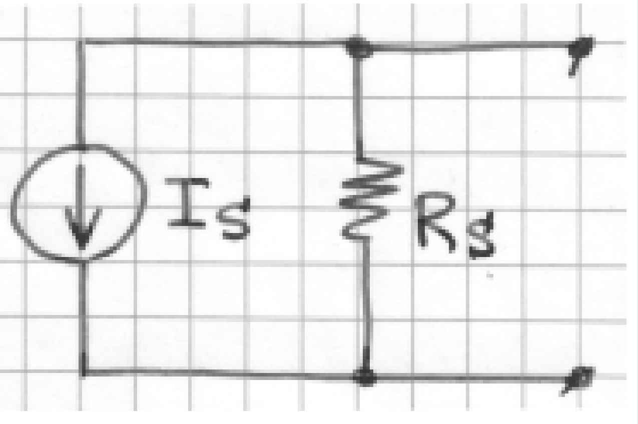
- What amplifier type is better suited as a photodiode amplifier, if the desired output signal is voltage?

A. voltage amplifier

B. current amplifier

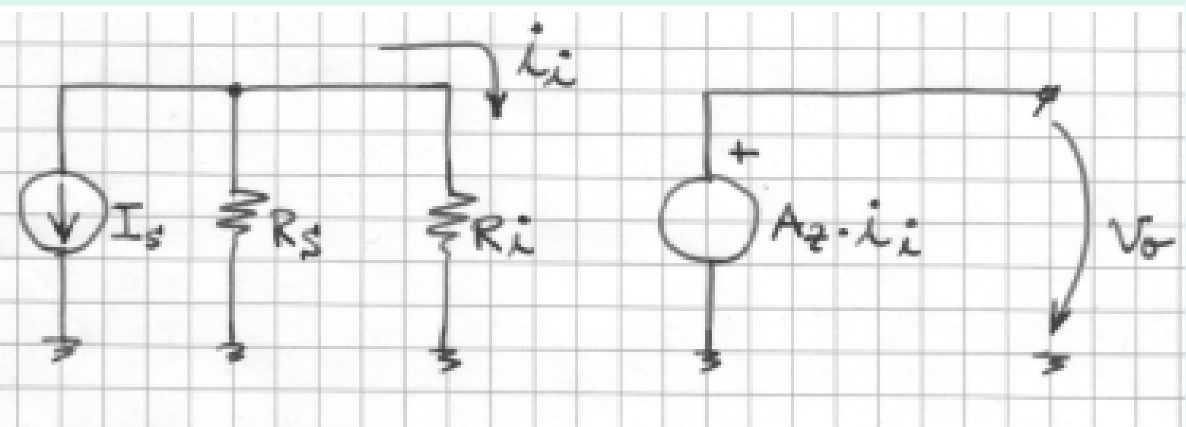
C. transimpedance amplifier

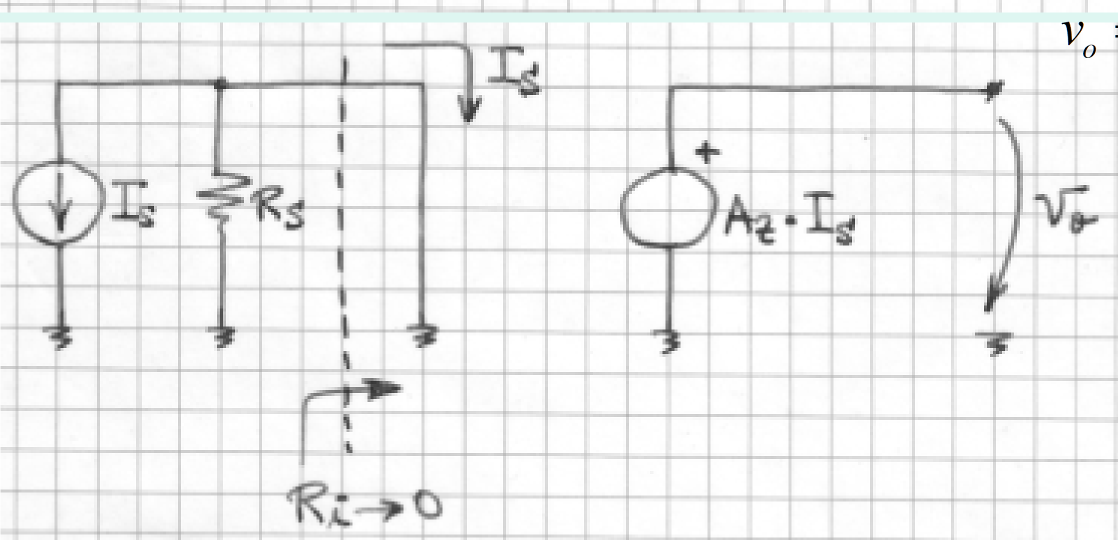
D. transadmittance amplifier



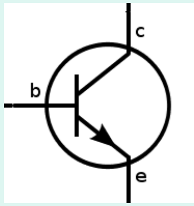
Photodiode amplifier

- Input = current, output = voltage => transimpedance amplifier



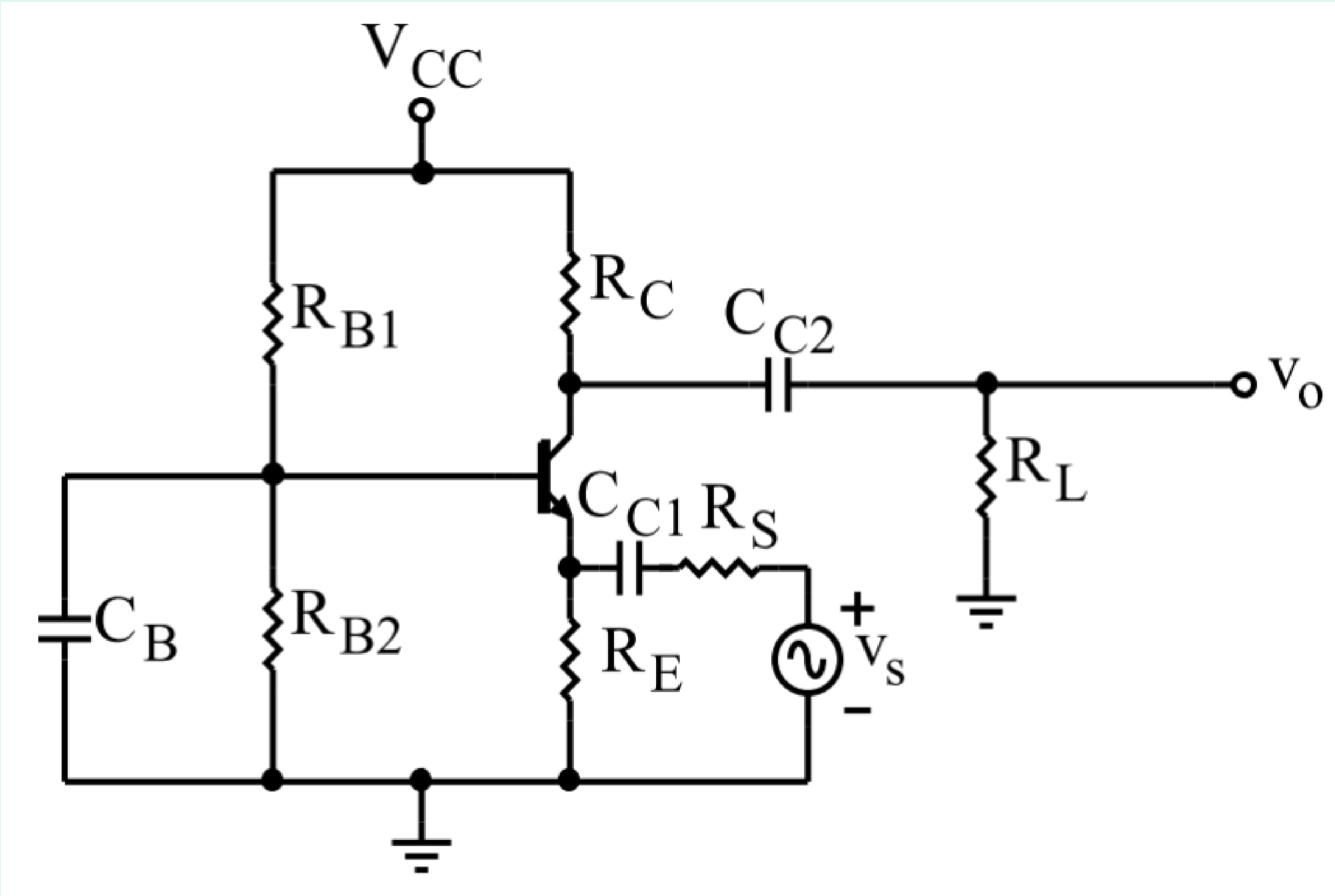


$$v_o = A_z \frac{R_s}{R_s + R_i} I_s = \frac{A_z}{1 + \frac{R_i}{R_s}} I_s \xrightarrow{R_i \to 0} A_z I_s$$



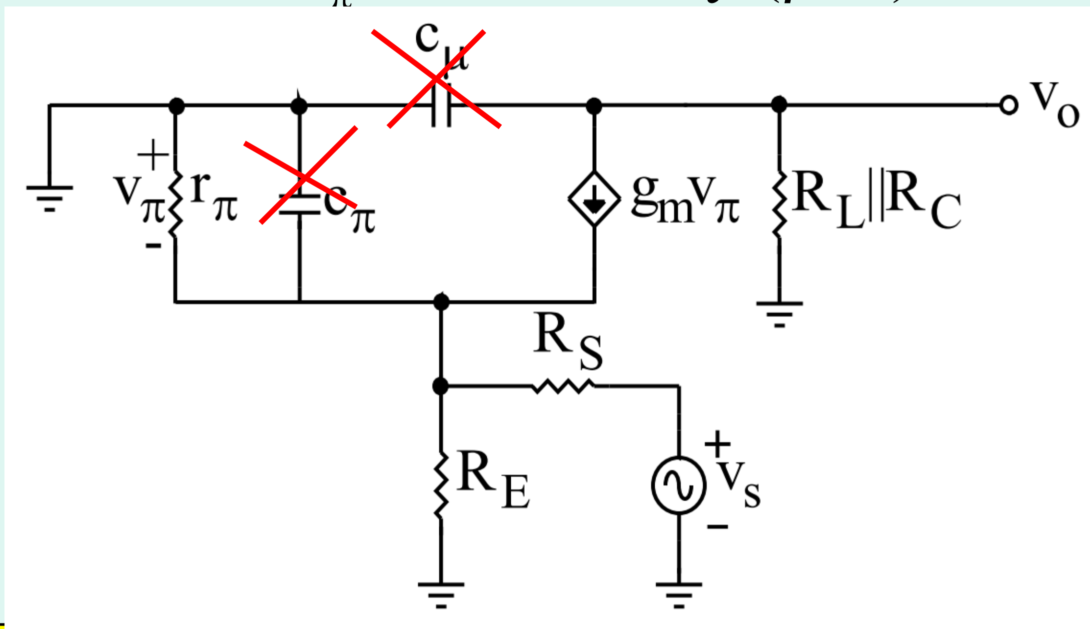
The common-Base amplifier

- Input port: E, Output port: C
- We assume proper biasing (1/3 rule); C_B to ground B in AC mode



Mid-band gain

- The junction capacitances c_μ, c_π treated as OC
- REM: r_π is reduced by $(\beta+1)$ times when looking from E



$$v_\pi = -\frac{\frac{r_\pi}{1+\beta} \| R_E}{R_S + \frac{r_\pi}{1+\beta} \| R_E} v_s \approx -\frac{\frac{r_\pi}{1+\beta}}{R_S + \frac{r_\pi}{1+\beta}} v_s$$

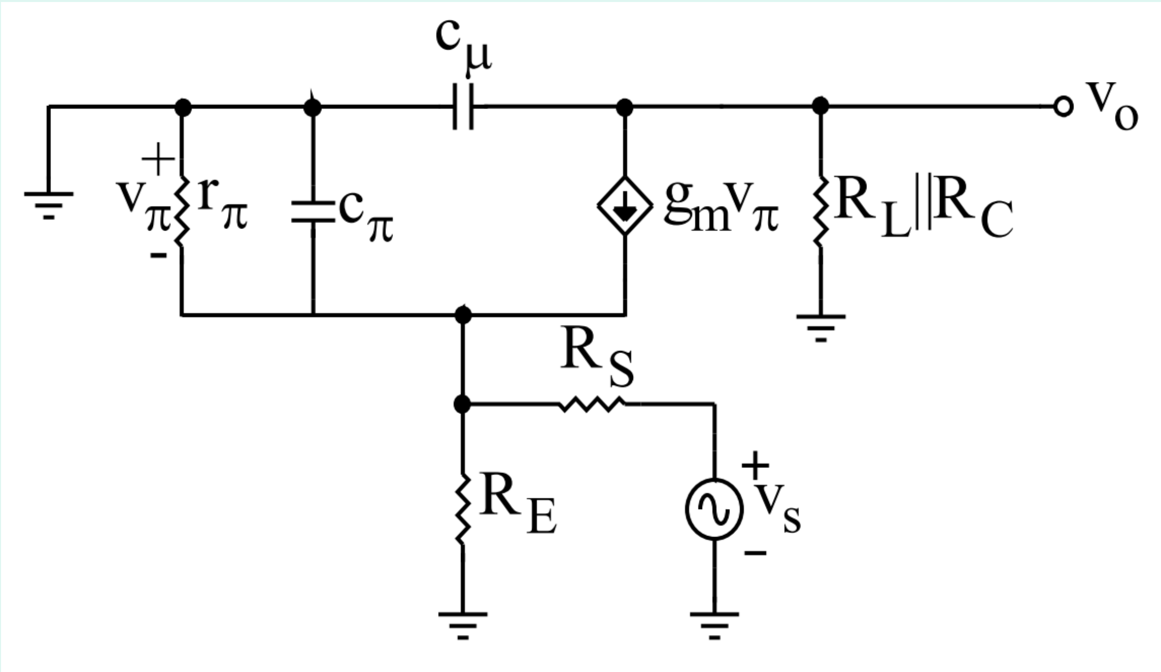
$$A_M\Big|_{CE} = -g_m R_C \| R_L \frac{R_{BB} \| r_\pi}{R_{BB} \| r_\pi + R_S}$$

$$R_{B,eq}\Big|_{CE} = R_{BB} \| \left(r_\pi + (\beta+1) R_E\right)$$

$$R_{E,eq}\Big|_{CB} = R_E \| \frac{r_\pi}{\beta+1}$$

$$A_M\Big|_{CB} = g_m R_C \| R_L \frac{\frac{r_\pi}{\beta+1} \| R_E}{R_S + \frac{r_\pi}{\beta+1} \| R_E}$$

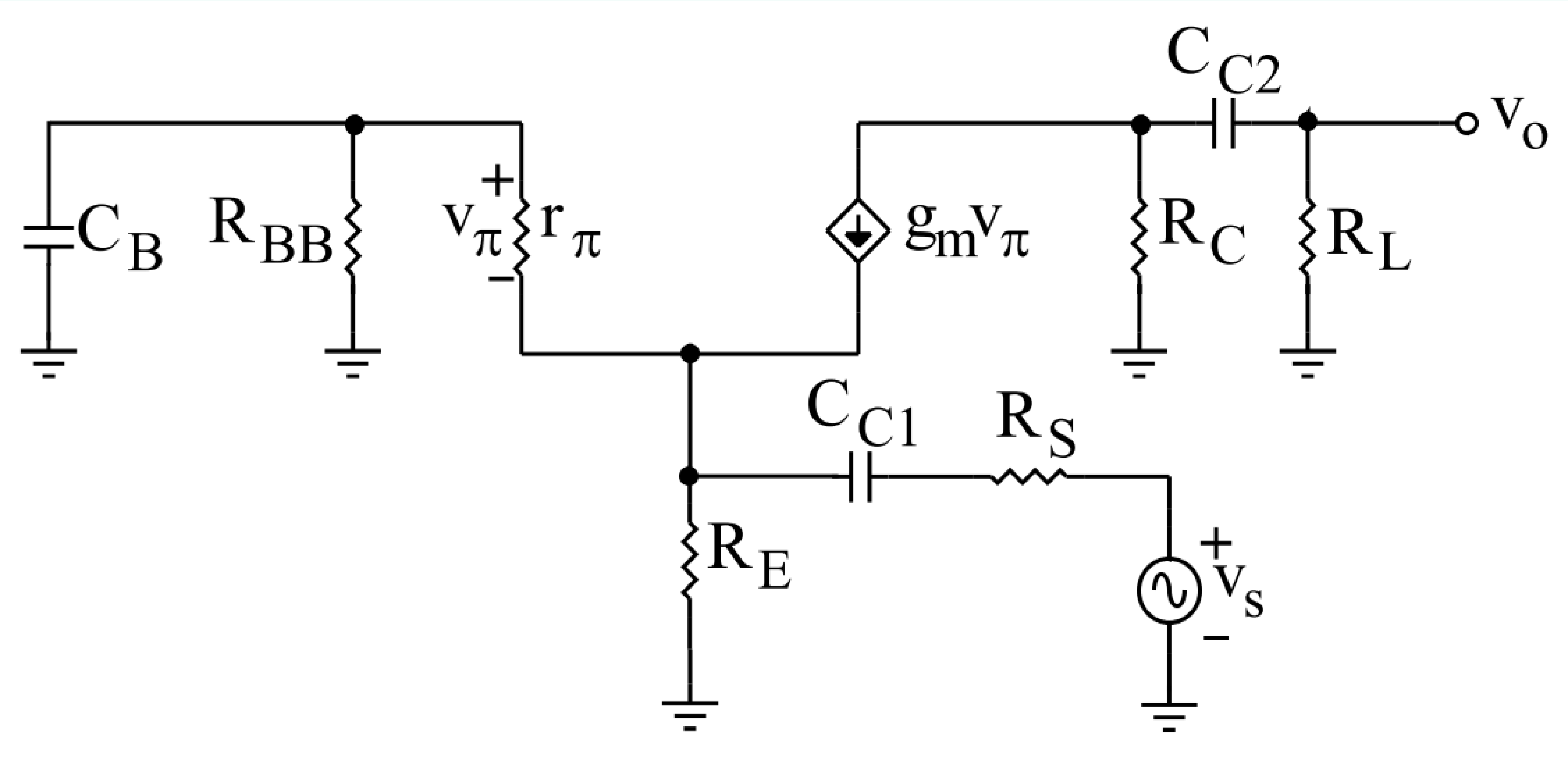
$F_H(s)$ - HF behavior



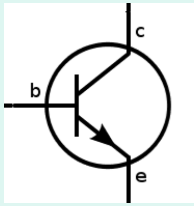
$$F_H(s) = \frac{1}{\left(1 + s\left(R_L \parallel R_C\right)C_\mu\right)\left(1 + s\left(R_S \parallel R_E \parallel \frac{r_\pi}{\beta + 1}\right)C_\pi\right)}$$

CB - LF behavior $F_L(s)$

- LF circuit - 3poles + 3 zeros

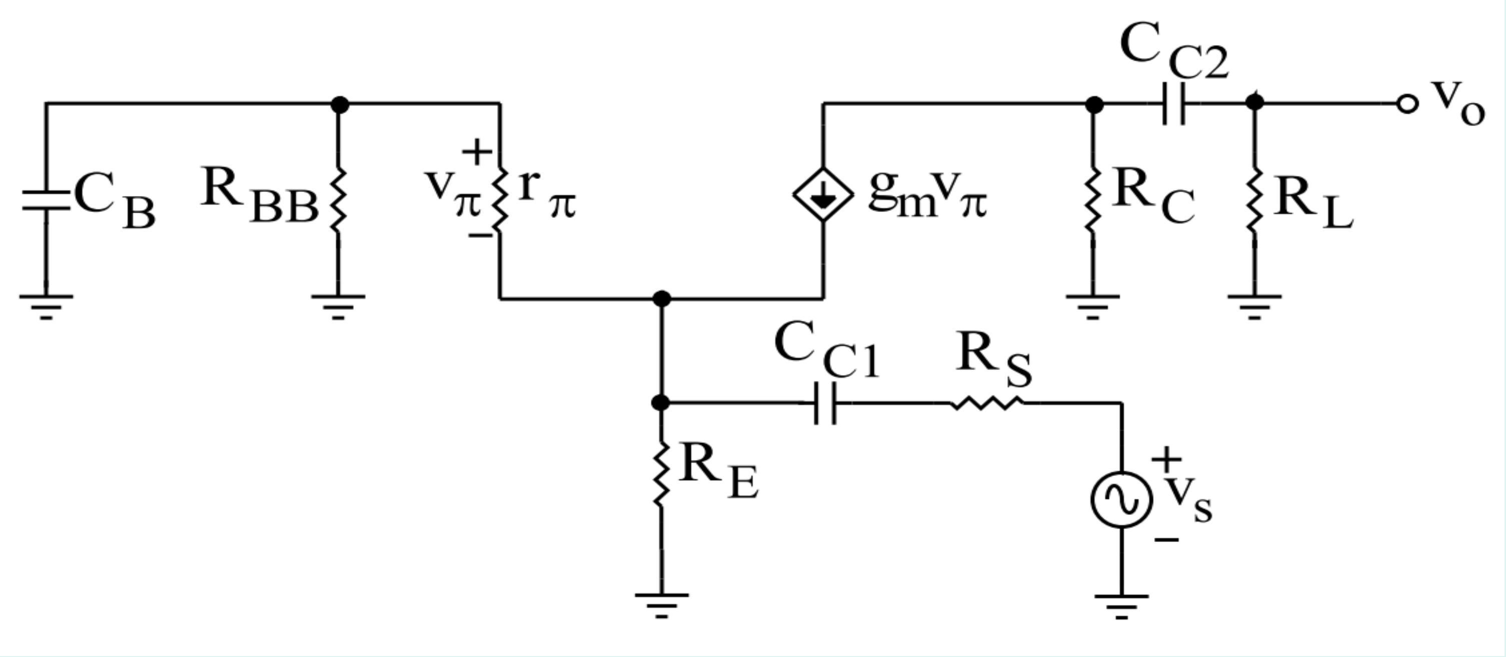


$$F_L(s) = \frac{(s+\omega_{Lz1})(s+\omega_{Lz2})(s+\omega_{Lz3})}{(s+\omega_{Lp1})(s+\omega_{Lp2})(s+\omega_{Lp3})}$$



FL(s) - zeros

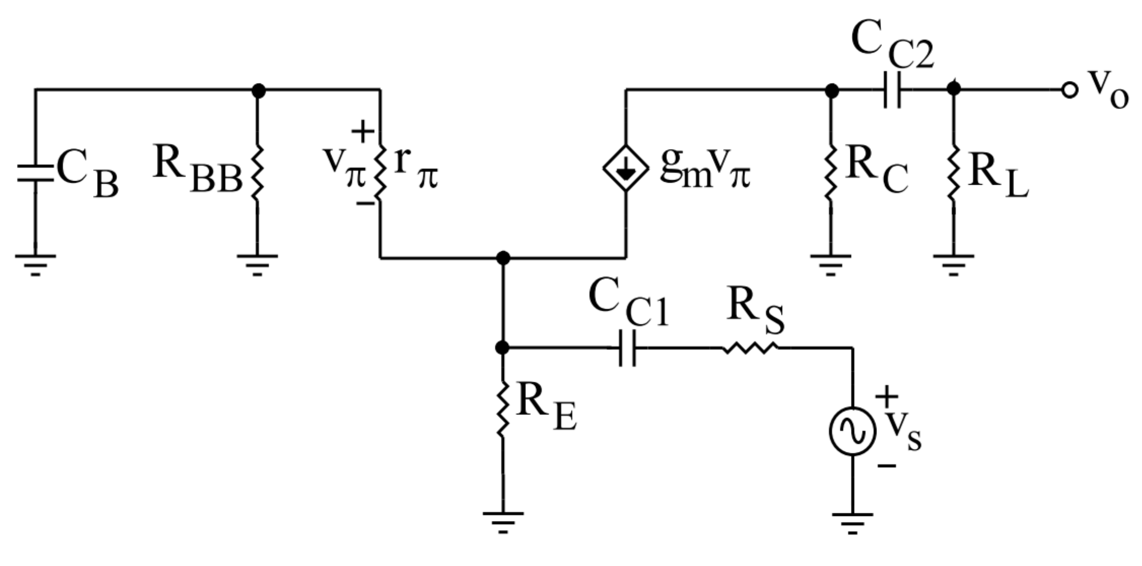
- Zeros: C_{C1}, C_{C2} introduce zeros at $\omega=0$
- For CB - zero located when $v_\pi=0$ (or $i_b=0$)



$$Y_B = s_z C_B + \frac{1}{R_{BB}} = 0 \Rightarrow s_z = -\frac{1}{R_{BB} C_B} \Rightarrow \omega_{Lz3} = \frac{1}{R_{BB} C_B}$$

$F_L(s)$ - poles

- The pole associated with the output stage (decoupled from input) is straight forward

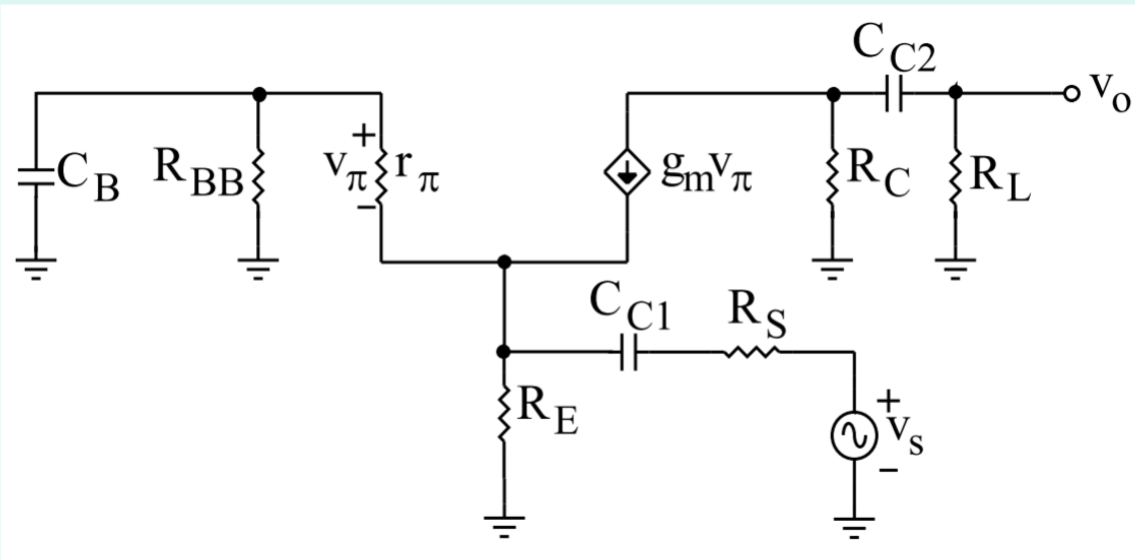


$$R_{C_{C2}} = R_C + R_L \Rightarrow \tau_{C_{C2}} = \left(R_C + R_L\right) C_{C2}$$

$$\omega_{Lp1} = \frac{1}{\left(R_C + R_L\right) C_{C2}}$$

$F_L(s)$ - remaining 2 poles

- We use the SC time constant method (assuming the poles are well distanced)

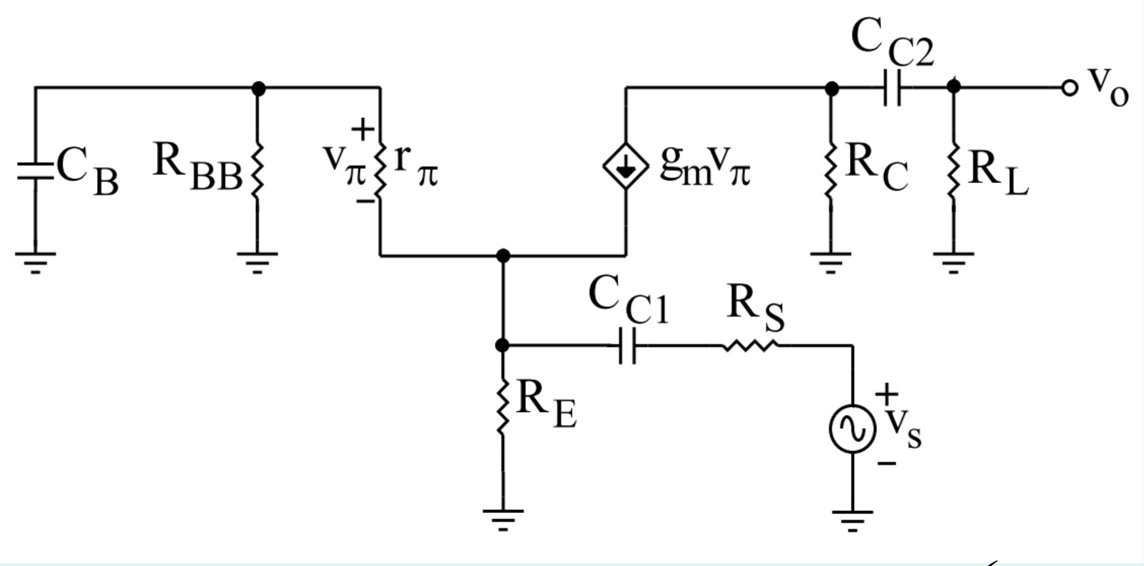


When C_{C1} is SC => $R_E||R_S$ reflected into the B

$$R_{C_B}^{SC} = R_{BB} \,||\, \left(r_\pi + \left(\beta+1\right) R_E \,||\, R_S\right) \Rightarrow \tau_{C_B}^{SC} = \left(R_{BB} \,||\, \left(r_\pi + \left(\beta+1\right) R_E \,||\, R_S\right)\right) C_B$$

$F_L(s)$ - poles

- With C_B short-circuited



$$R_{C_{C1}}^{sc} = R_S + R_E \,||\, \frac{r_\pi}{\beta+1} \Rightarrow \tau_{C_{C1}}^{sc} = \left(R_S + R_E \,||\, \frac{r_\pi}{\beta+1} \right) C_{C1}$$

$$\omega_{L3dB} = \omega_{C_B} + \omega_{C_{C1}} = \frac{1}{\left(R_{BB} \,||\, \left(r_\pi + (\beta+1) R_E \,||\, R_S\right)\right) C_B} + \frac{1}{\left(R_S + R_E \,||\, \frac{r_\pi}{\beta+1} \right) C_{C1}}$$

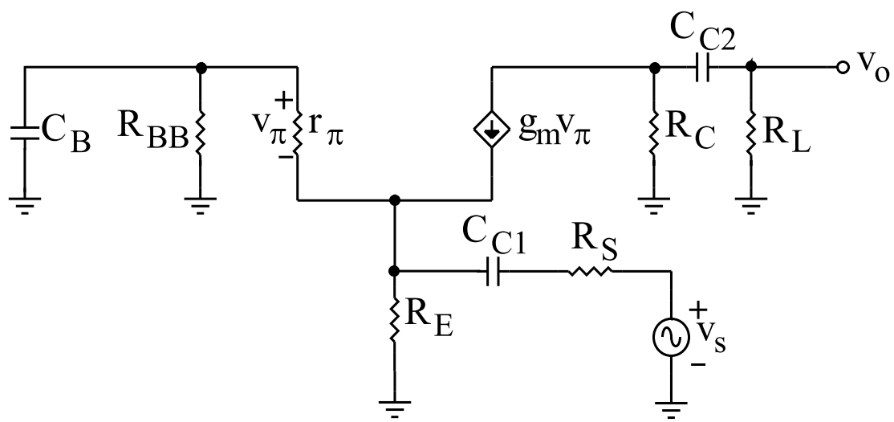
$F_L(s)$ - poles (2)

- C_{C2} pole is not affected by C_{C1} nor C_B
- If C_{C1} gives the higher frequency pole between C_{C1} and C_B:

$$\omega_{Dom,B-C1} = \omega_{C_B} + \omega_{C_{C1}} \approx \omega_{C_{C1}} = \frac{1}{\left(R_S + R_E \,\|\, \dfrac{r_\pi}{\beta+1}\right) C_{C1}}$$

We compute the sub-dominant pole with C_{C1} open-circuited

$$\tau_{C_B}^{oc} = (R_{BB} \| [r_\pi + (1+\beta)R_E]) C_B$$



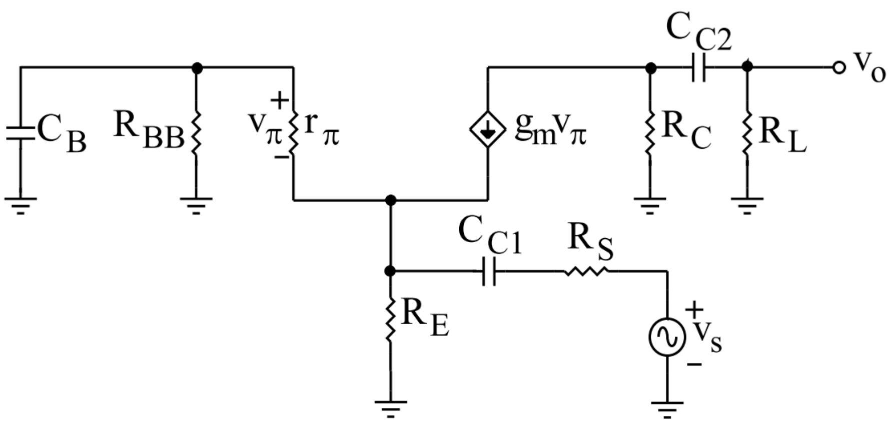
$F_L(s)$ - poles (3)

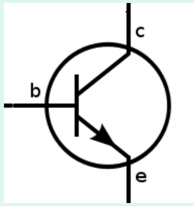
- If C_B gives the higher pole than C_B:

$$\omega_{L,B-C1} = \omega_{C_B} + \omega_{C_{C1}} \approx \omega_B = \frac{1}{\left(R_{BB} \,||\, \left(r_\pi + (\beta+1) R_E \,||\, R_S\right)\right) C_B}$$

We compute the sub-dominant pole with C_B open-circuited

$$\tau_{C_{C1}}^{oc} = \left(\frac{r_\pi + R_{BB}}{1+\beta} \,||\, R_E + R_S \right) C_{C1}$$



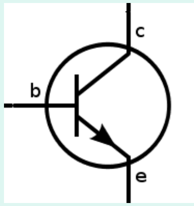


$F_L(s)$ - conclusions

- Depending on what capacitor (C_B or C_{C1}) sets the dominant pole in the input section, we have two versions:

$$F_L(s)\Big|_{\omega_{C_{C1}}^{sc} \gg \omega_{C_B}^{sc}} = \frac{1}{1+s\left(R_C+R_L\right)C_{C2}} \frac{1}{\left(1+s\left(R_S+R_E \parallel \dfrac{r_\pi}{\beta+1}\right)C_{C1}\right)\left(1+s\left(R_{BB}\parallel\left(r_\pi+\left(\beta+1\right)R_E\right)\right)C_B\right)}$$

$$F_L(s)\Big|_{\omega_{C_{C1}}^{sc} \ll \omega_{C_B}^{sc}} = \frac{1}{1+s\left(R_C+R_L\right)C_{C2}} \frac{1}{\left(1+s\left(R_{BB}\parallel\left(r_\pi+\left(\beta+1\right)R_E \parallel R_S\right)\right)C_B\right)\left(1+s\left(R_S+R_E \parallel \dfrac{r_\pi+R_{BB}}{\beta+1}\right)C_{C1}\right)}$$

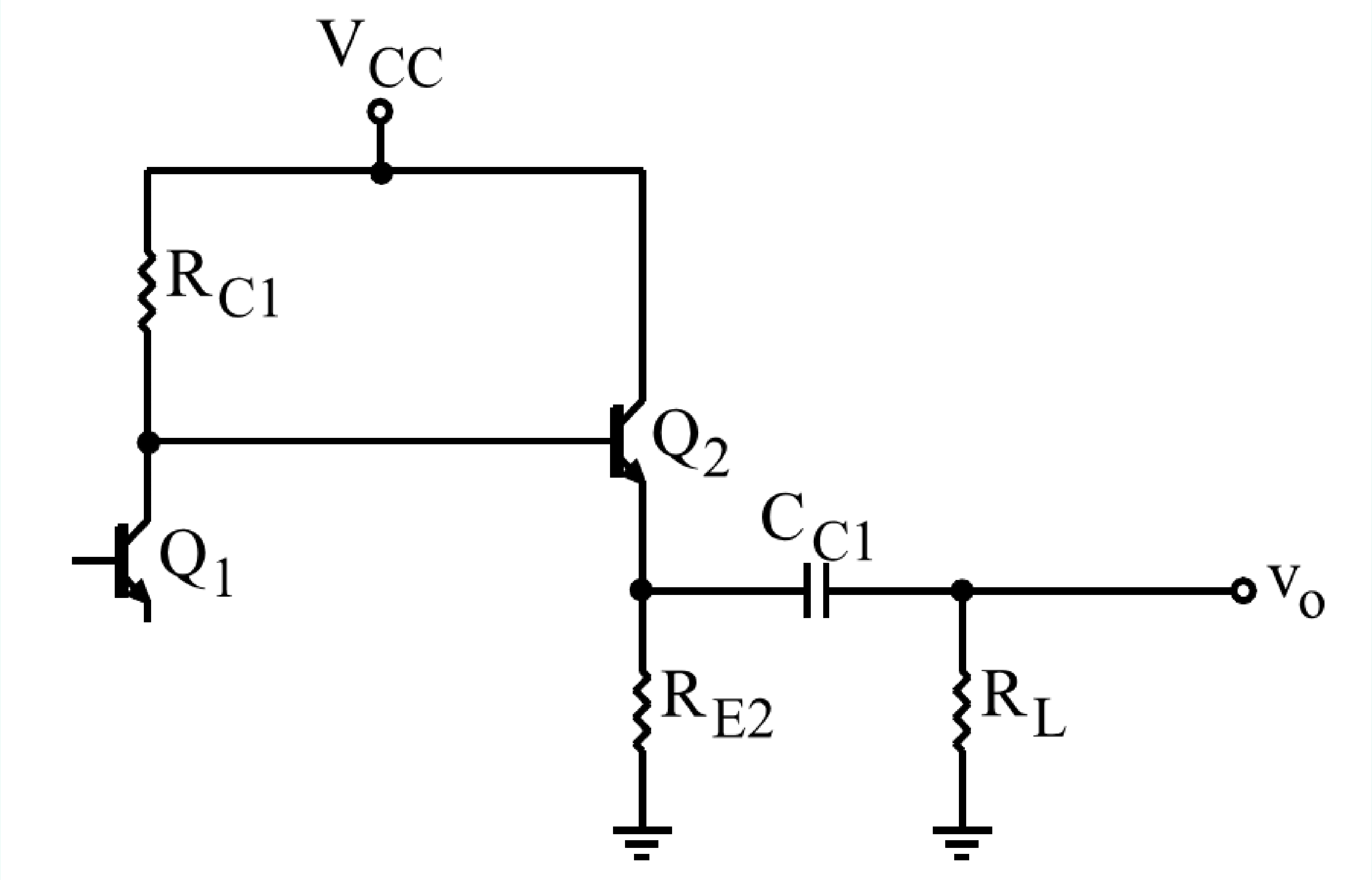


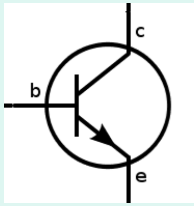
Common-Collector (CC) amplifier

- Principal use: to increase the output power - usually used at the output of a multistage amplifier
- Features: high input impedance, low output impedance, power gain, DC coupled at input, wide BW

Typical CC configuration

- Connected at the output of a previous stage
- CBJ is always reversed biased for $R_{C1}>0$

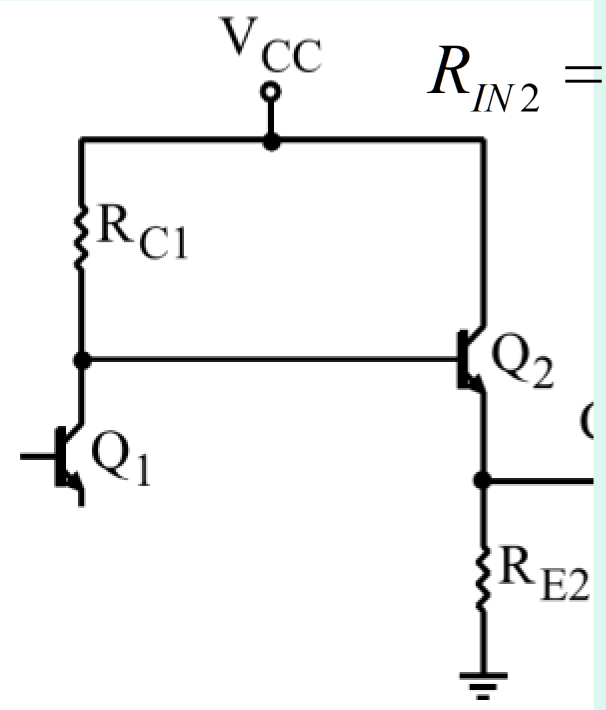




CC amplifier - DC behavior

- High input impedance at DC - does not significantly load the preceding stage at DC

$$I_{B2} = \frac{V_{B2} - 07V}{(\beta_2 + 1) R_{E2}} \qquad I_{C1} = \frac{V_{CC} - V_{C1}}{R_{C1}} - I_{B2} \approx \frac{V_{CC} - V_{C1}}{R_{C1}}$$



$$R_{IN2} = \frac{V_{B2}}{I_{B2}} = \frac{V_{B2}}{V_{B2} - 0.7V}(\beta_2 + 1) R_{E2} \approx (\beta_2 + 1) R_{E2}$$

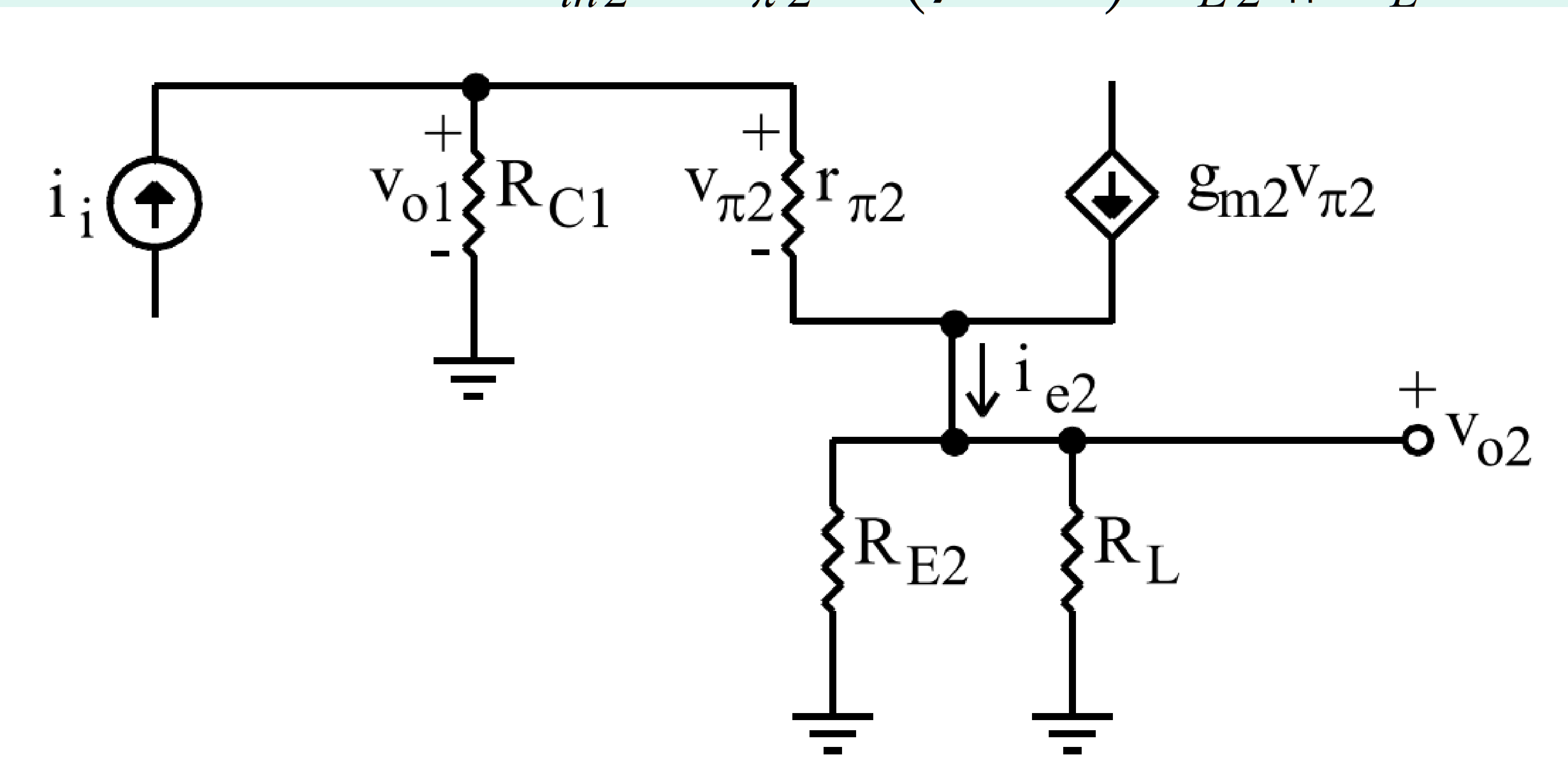
$R_{IN2} \sim (\beta_2 + 1) R_{E2}$

Typically $R_{IN2} \sim 10..200 k\Omega$

CC - small-signal model at midband

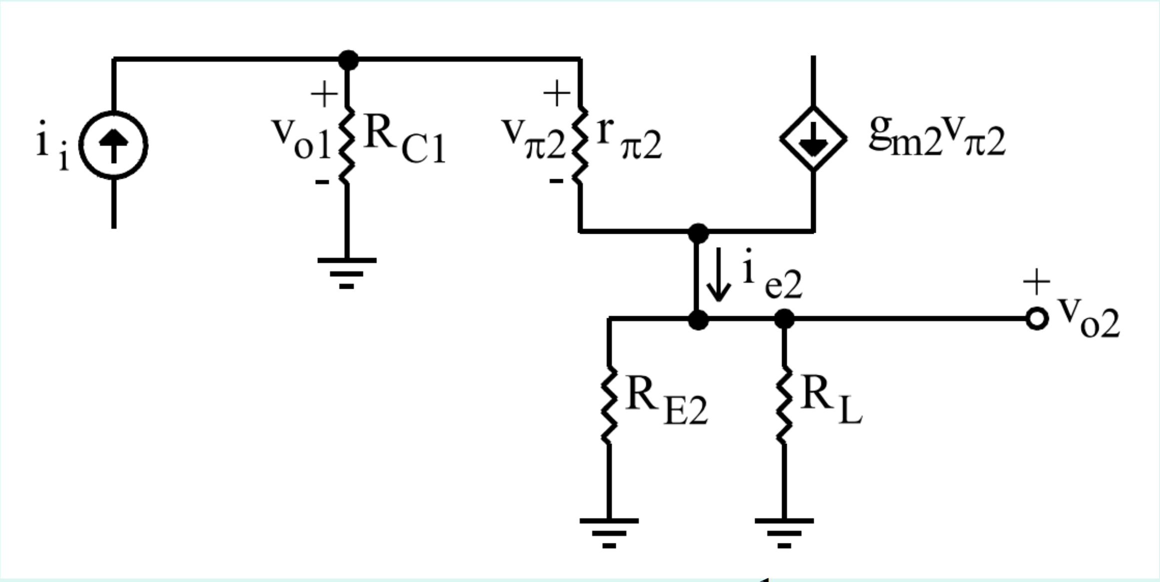
- We SC C_{C1}

$$R_{in2} = r_{\pi 2} + \left(\beta + 1\right) R_{E2} \parallel R_L$$



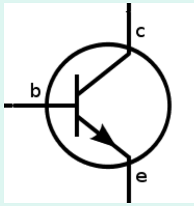
CC stage - current gain in midband

- Current gain i_{e2}/i_i



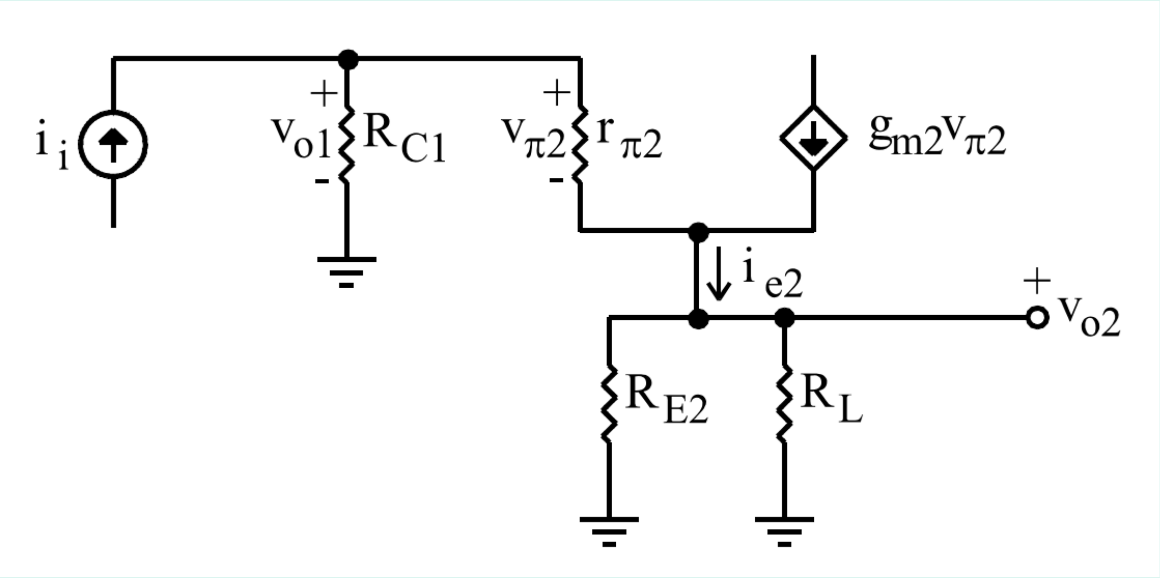
$$i_{e2} = (\beta+1) i_{b2} = (\beta+1) i_i \frac{\dfrac{1}{r_{\pi 2} + (\beta+1) R_{E2} \| R_L}}{\dfrac{1}{R_{C1}} + \dfrac{1}{r_{\pi 2} + (\beta+1) R_{E2} \| R_L}}$$

$$A_i = \frac{i_{e2}}{i_i} = \frac{\beta+1}{1 + \dfrac{r_{\pi 2} + (\beta+1) R_{E2} \| R_L}{R_{C1}}} \approx \frac{R_{C1}}{R_{E2} \| R_L}$$



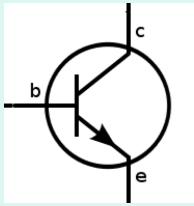
CC amplifier - voltage gain

- $A_{v2}=v_{o2}/v_{o1}\sim 1$ => the power gain is given by the current gain



$$v_{o2}=\left(R_{E2}\,\|\,R_L\right)i_{e2}=\left(R_{E2}\,\|\,R_L\right)\frac{\left(\beta+1\right)v_{o1}}{r_{\pi 2}+\left(\beta+1\right)R_{E2}\,\|\,R_L}$$

$$A_{v2}=\frac{v_{o2}}{v_{o1}}=\frac{\left(\beta+1\right)\left(R_{E2}\,\|\,R_L\right)}{r_{\pi 2}+\left(\beta+1\right)R_{E2}\,\|\,R_L}\leq 1$$


c
b
e