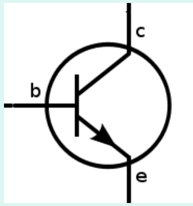
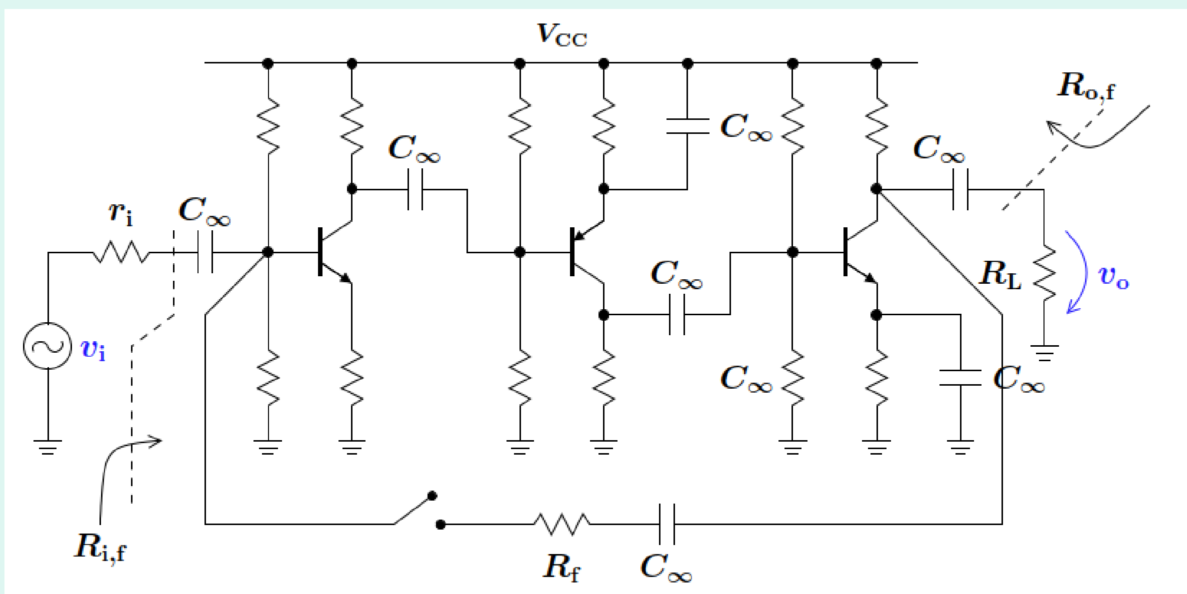
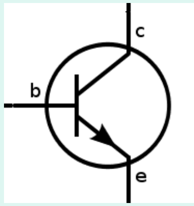


ELEC 301 - CE amplifier configuration

L13 - Oct 06

Instructor: Edmond Cretu



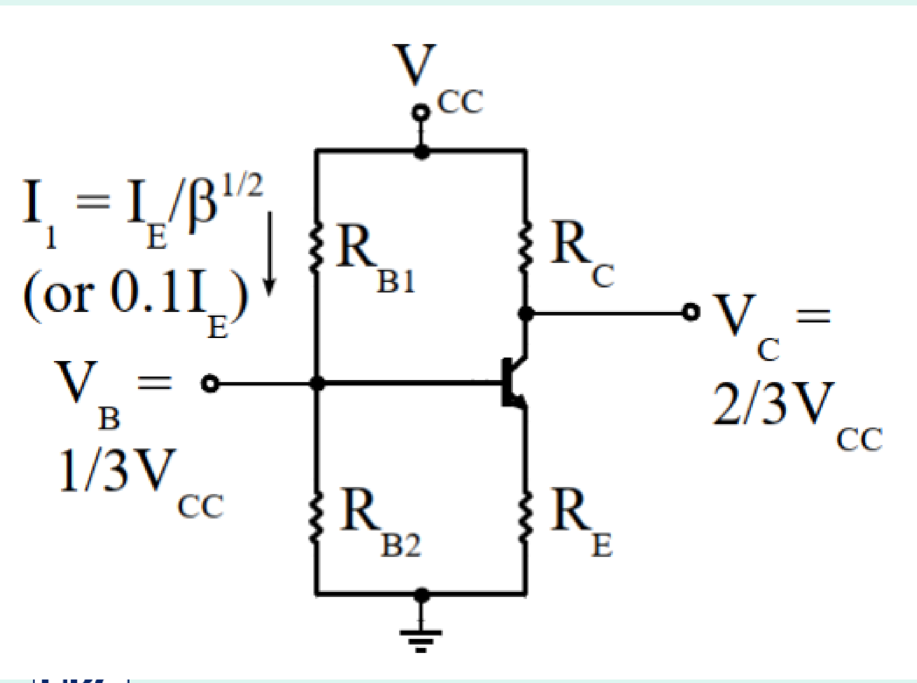


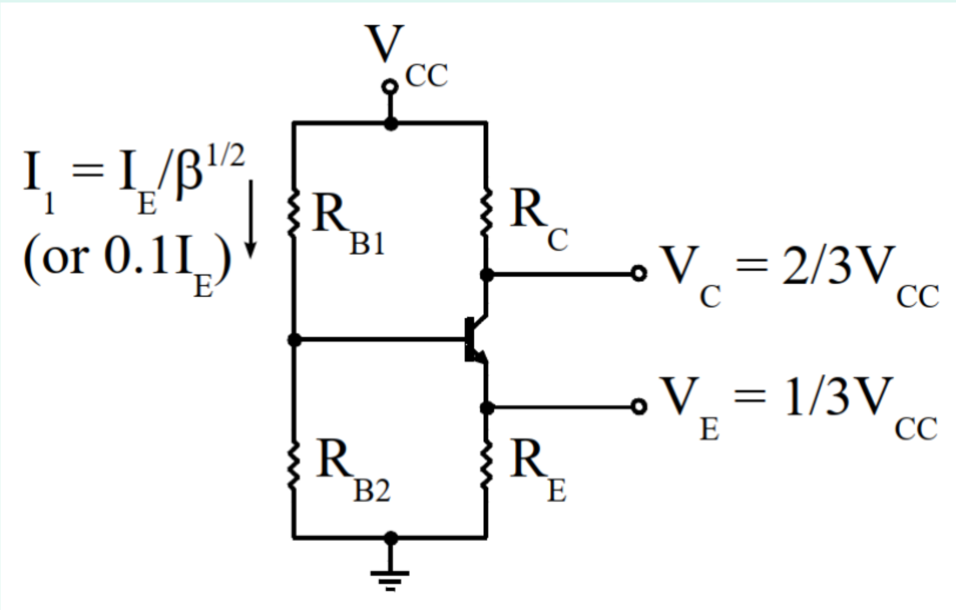
Administrative aspects

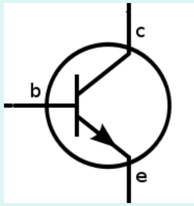
- Midterm - October 20, 3:30pm
- preparatory problems to be posted
- Topics - L01 - L15

Last time

- How to choose component values for setting the quiescent point of a BJT
- ⅓rd rule - two possible choices







L13 Q01 - ⅓ rule

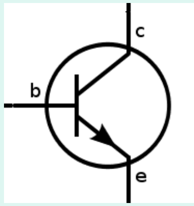
- What is the role of the ⅓ rule?

A. To maximize the gain of the amplifier stage

B. To maximize the bandwidth of the amplifier stage

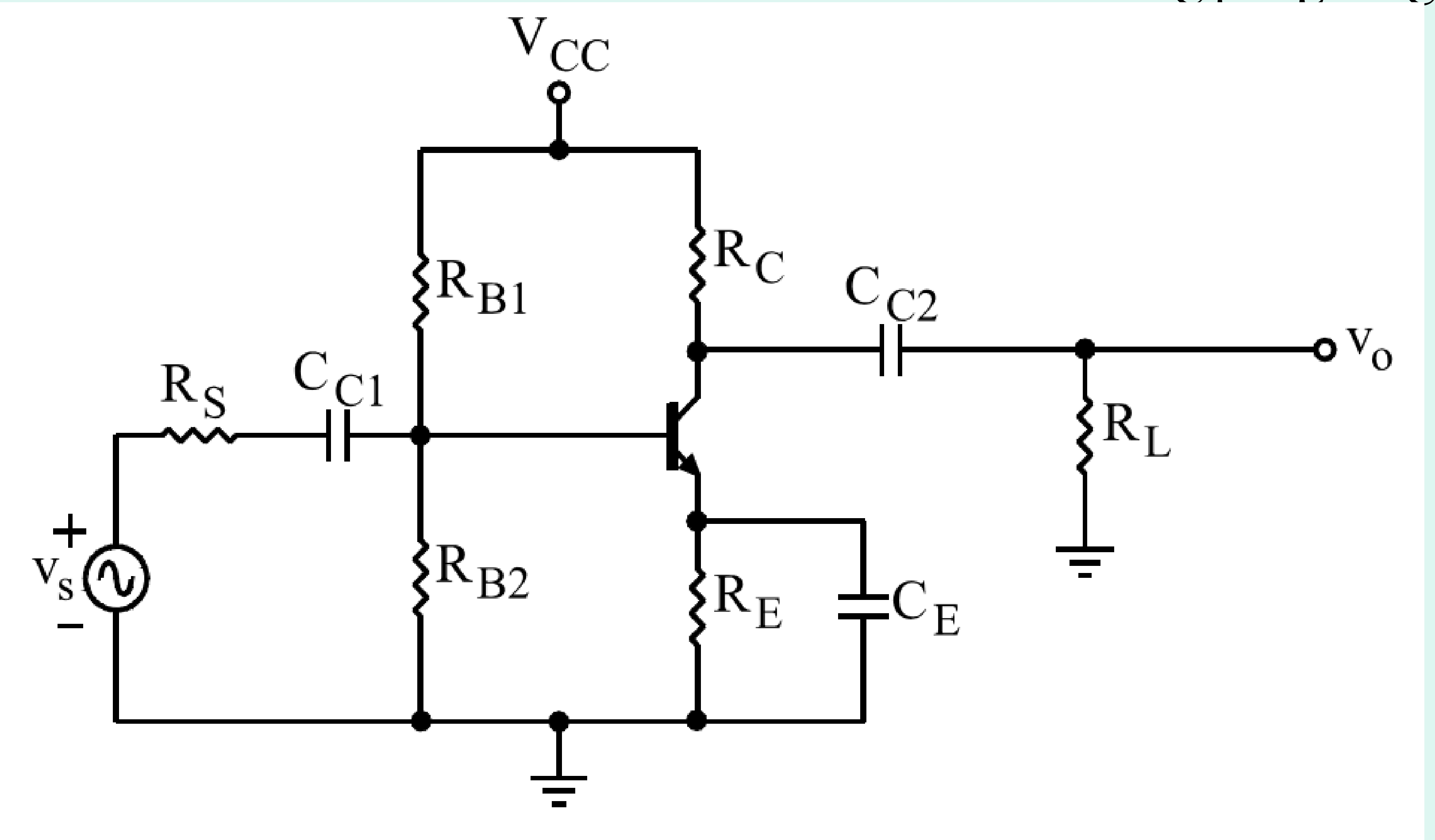
C. To simplify the computation of the resistor values that ensure a good quiescent point with a reasonable dynamic range

D. To compute the values of the capacitors for the AC gain



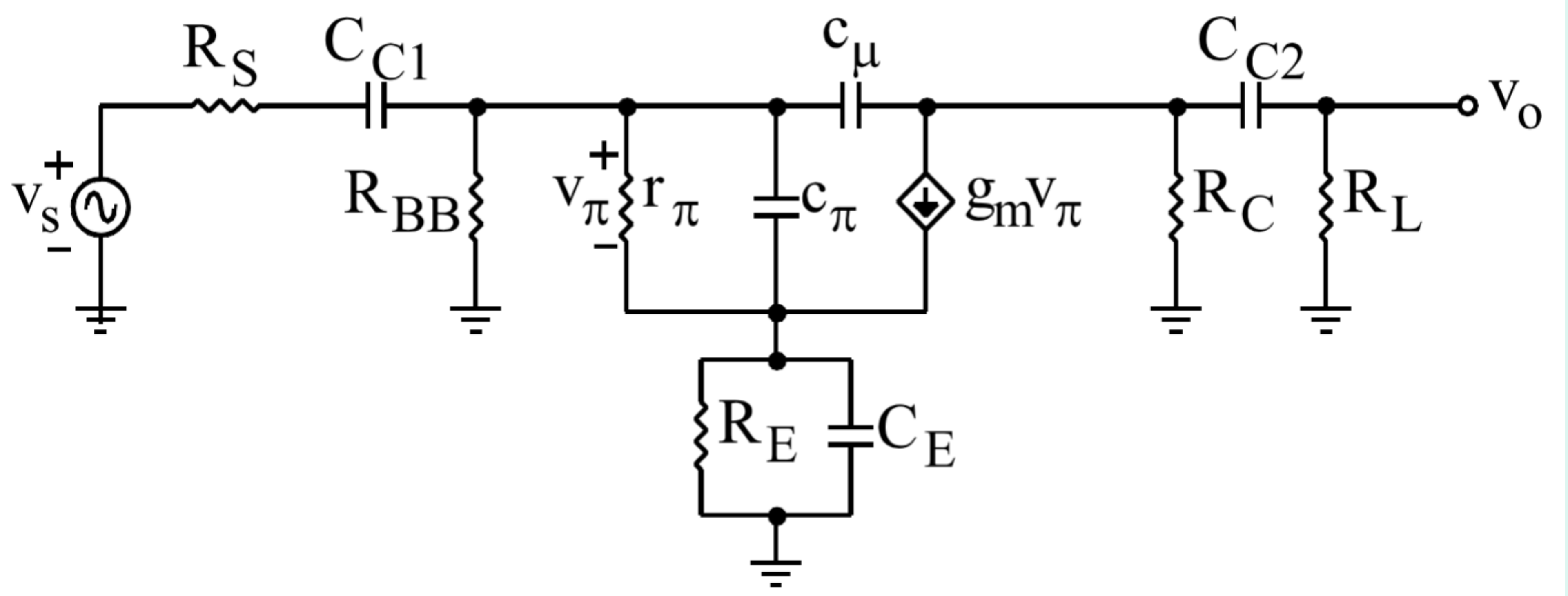
Common-emitter amplifier

- 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 - choosing C_{C1},C_E, C_{C2}



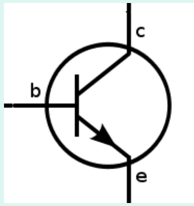
Complete small-signal model

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



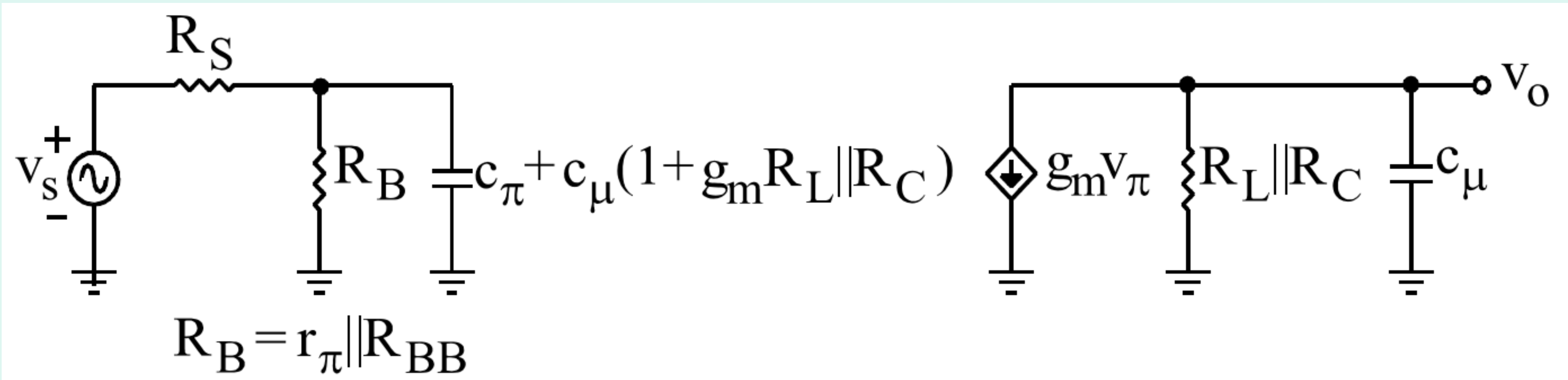
$$F(s) = \underbrace{F_L(s)}_{LF\ part} \underbrace{A_M}_{Midband} \underbrace{F_H(s)}_{HF\ part}$$

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

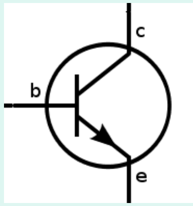


The HF small-signal model

- LF capacitances are short-circuited, Miller theorem applied

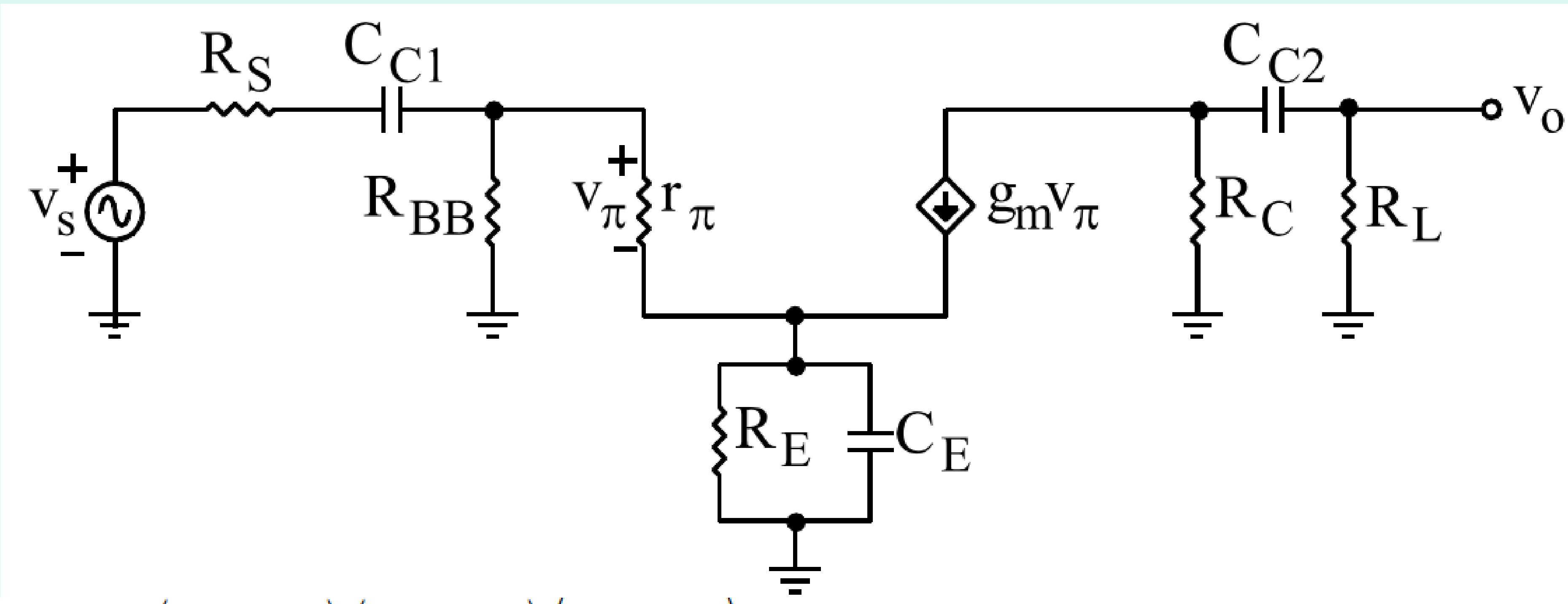


$$F_H(s) = \frac{\dfrac{1}{R_{BB}||r_\pi||R_S\left[c_\pi + c_\mu\left(1+g_m R_C||R_L\right)\right]}}{\left(s + \dfrac{1}{R_{BB}||r_\pi||R_S\left[c_\pi + c_\mu\left(1+g_m R_C||R_L\right)\right]}\right)} \cdot \frac{\dfrac{1}{R_C||R_L c_\mu}}{\left(s + \dfrac{1}{R_C||R_L c_\mu}\right)}$$



LF response $F_L(s)$

- FL(s) is not straightforward - 3 poles + 3 zeros



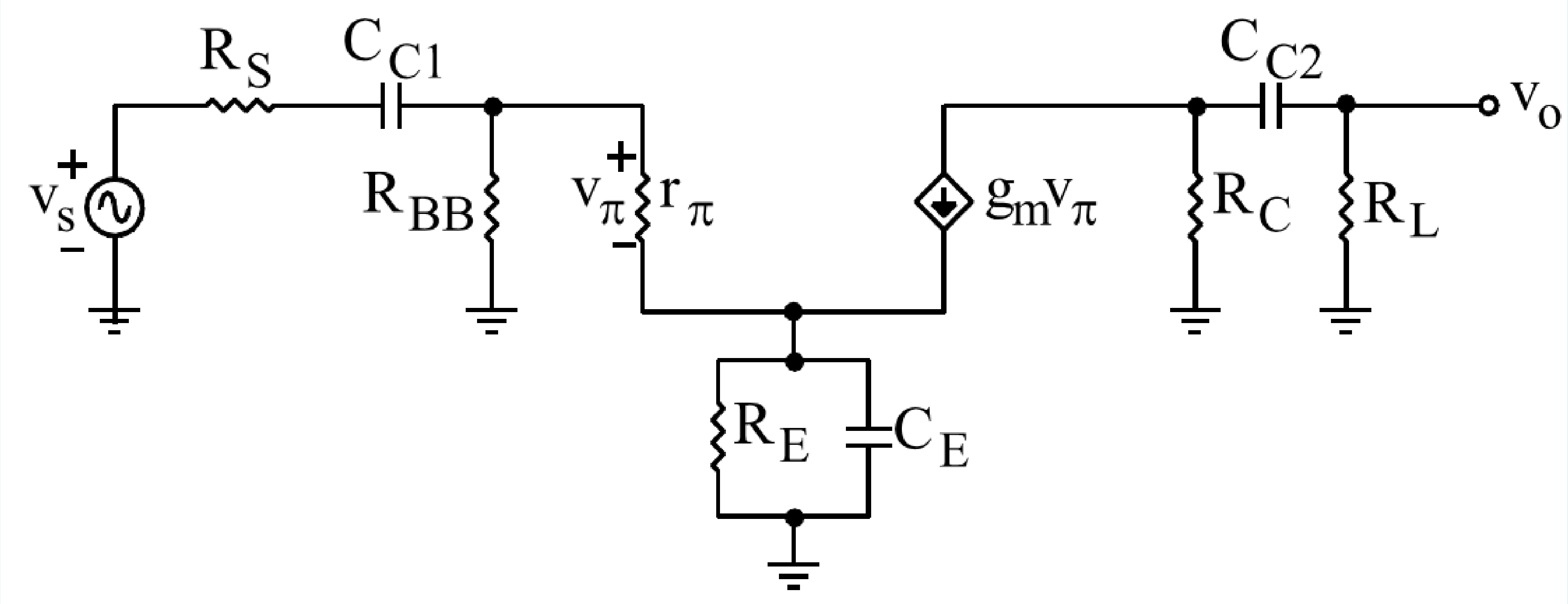
$$F_L(s) \approx \left(\frac{s}{s+\omega_{Lp1}}\right)\left(\frac{s}{s+\omega_{Lp2}}\right)\left(\frac{s+\omega_{Lz3}}{s+\omega_{Lp3}}\right)$$

C_{C1}, C_{C2} - introduce zeros at $\omega=0$ => $\omega_{Lz1}=\omega_{Lz2}=0$

- For C_E -zero when $Y_E=0$

$F_L(s)$ - zeros (2)

- Compute the 3rd zero:

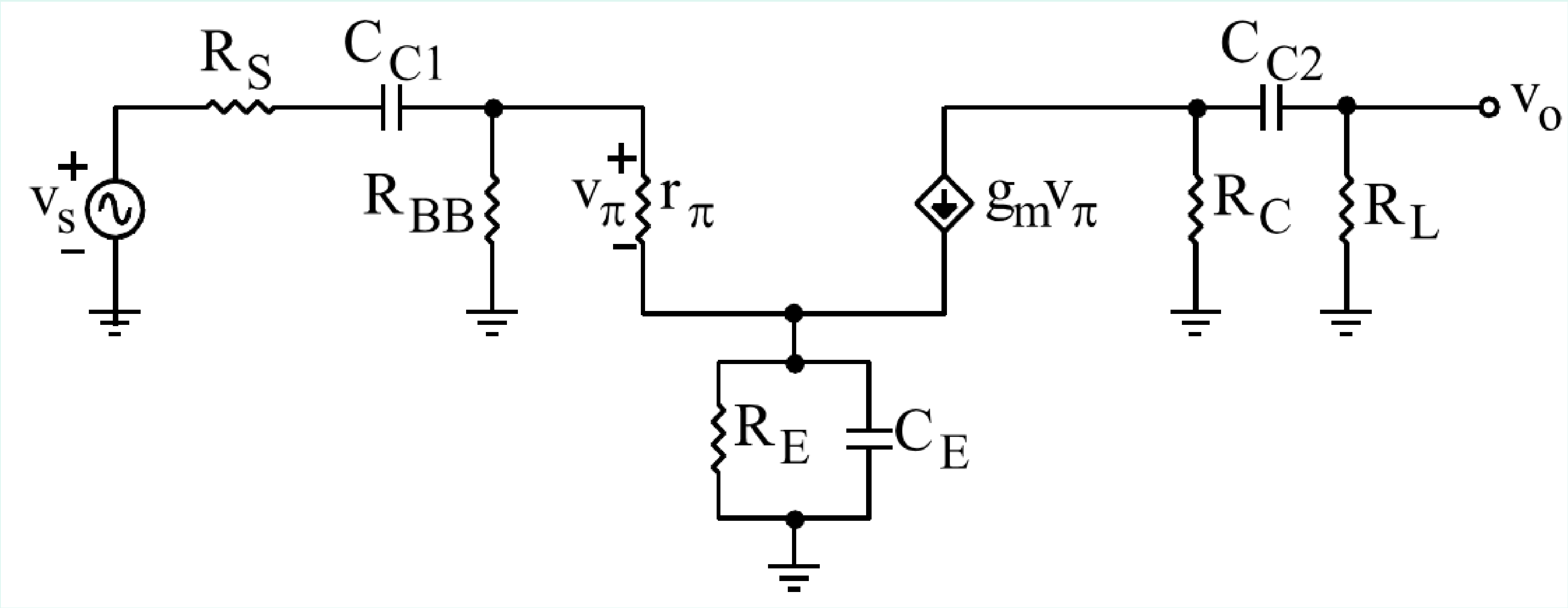


$$\omega_{Lz1} = \omega_{Lz2} = 0$$

$$Y_E = \frac{1}{R_E} + sC_E = 0 \Leftrightarrow s_z = -\frac{1}{R_E C_E} \Rightarrow \omega_{Lz3} = \frac{1}{R_E C_E}$$

$F_L(s)$ - poles

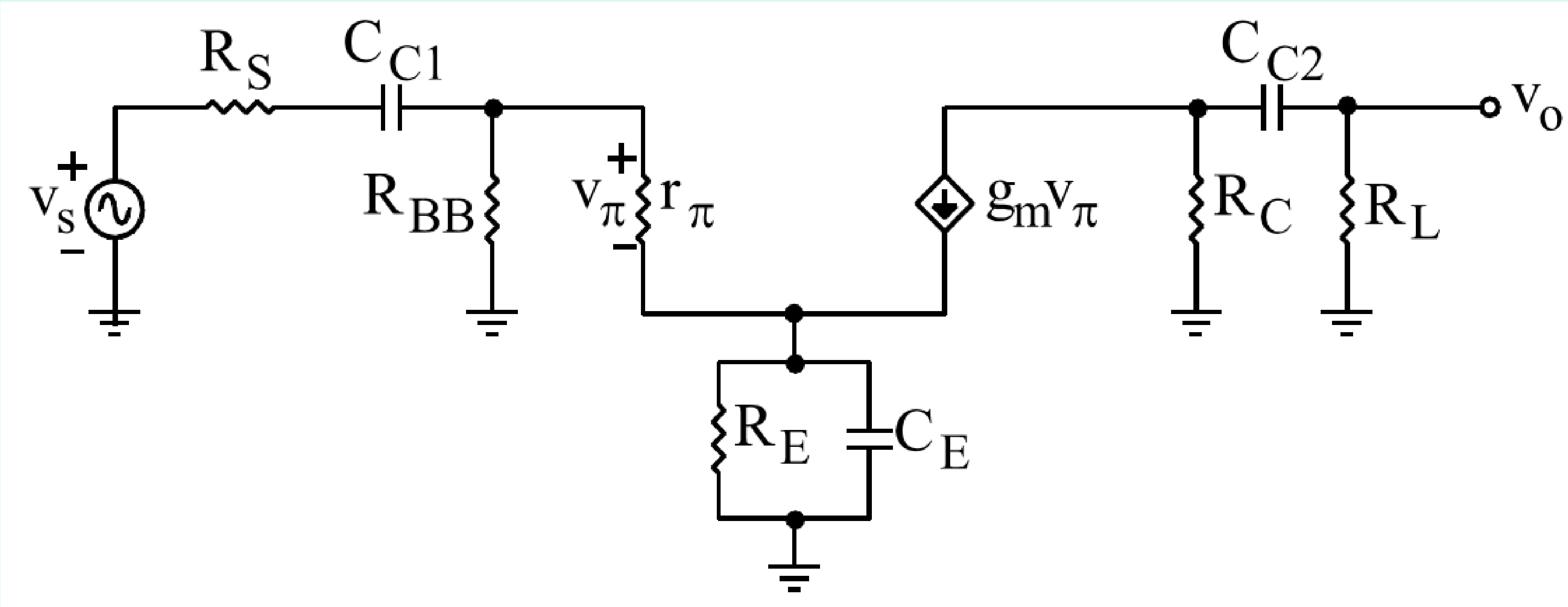
- Simple for C_{C2} - output section decoupled from the rest



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

FL(s) - poles (2)

- We use the SC time-constant method



$$\tau_{C_{C1}}^{sc} = \left(R_S + R_{BB} \parallel r_\pi \right) C_{C1}$$

L13 Q02 - controlled sources

- When we ‘passivate’ all the independent sources in the circuit, in order to compute an equivalent resistance, can we treat the controlled sources in the same way?

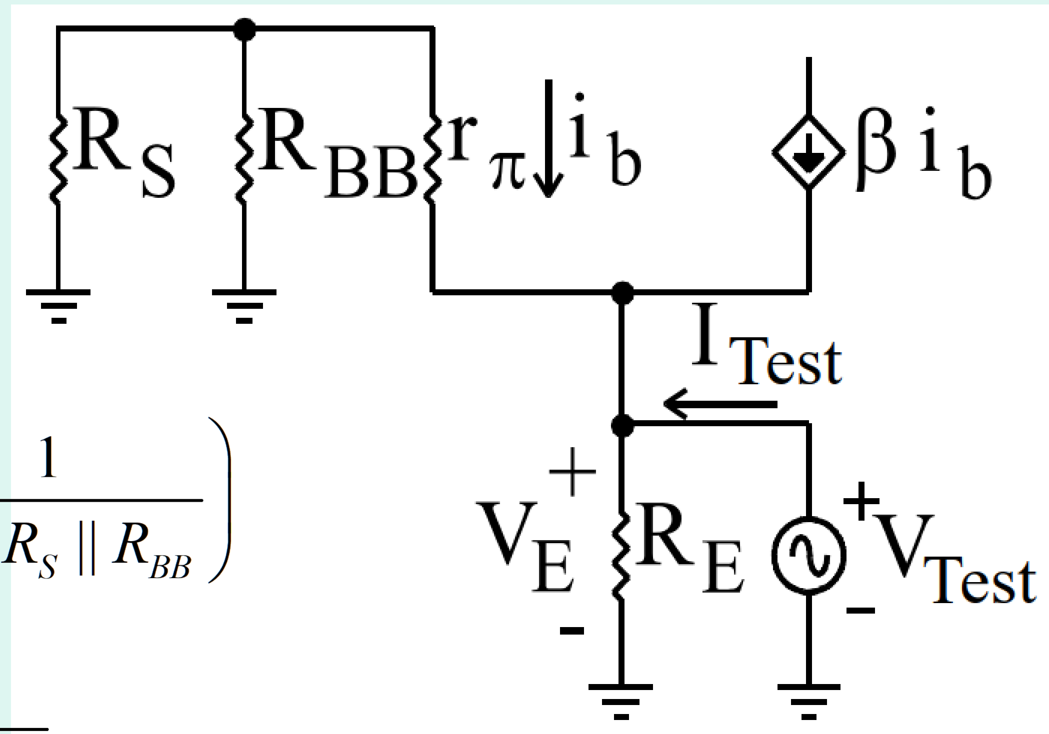
A. Yes, the same treatment applies to both independent and controlled sources

B. No, we should not ‘passivate’ the controlled sources

FL(s) - poles (3)

- The resistance seen across C_E:

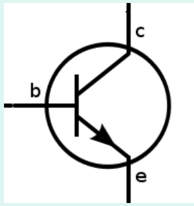
$$\begin{cases} I_{Test} = \dfrac{V_{Test}}{R_E} - (\beta+1)\, i_b \\ i_b = -\dfrac{V_{Test}}{r_\pi + R_S \,||\, R_{BB}} \end{cases}$$



$$\Rightarrow I_{Test} = V_{Test}\left(\frac{1}{R_E} + (\beta+1)\frac{1}{r_\pi + R_S \,||\, R_{BB}}\right)$$

$$\frac{1}{R^{sc}_{C_E}} = \frac{1}{R_E} + (\beta+1)\frac{1}{r_\pi + R_S \,||\, R_{BB}}$$

$$\tau^{sc}_{C_E} = \left(R_E \,||\, \frac{r_\pi + R_S \,||\, R_{BB}}{\beta+1}\right) C_E$$



FL(s) - SC method

- Short-circuit time constant method for LF part:

$$\omega_{Lp1}+\omega_{Lp2}+\omega_{Lp3}=\frac{1}{\tau^{sc}_{C_{C2}}}+\frac{1}{\tau^{sc}_{C_{C1}}}+\frac{1}{\tau^{sc}_{C_E}}$$

$$\omega_{Lp1}=\frac{1}{\tau^{sc}_{C_{C2}}}$$

The output part of the circuit is decoupled from the input:

- It remains to compute only for the other two poles:

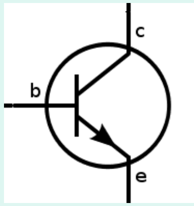
$$\omega_{Lp2}+\omega_{Lp3}=\frac{1}{\tau^{sc}_{C_{C1}}}+\frac{1}{\tau^{sc}_{C_E}}$$

- Typically the smallest time constant is for C_E

$$\tau^{sc}_{C_E}\ll\tau^{sc}_{C_{C1}}$$

$$\omega_{Lp2}+\omega_{Lp3}\approx\omega_{Lp3}$$

$$\omega_{Lp3}\approx\frac{1}{\tau^{sc}_{C_E}}=\frac{1}{\left(R_E\left|\right|\frac{r_\pi+R_{BB}\left|\right|R_S}{1+\beta}\right)C_E}$$



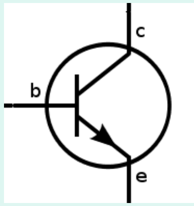
L13 Q03 - pole approximation

- Can we automatically approximate the remaining sub-dominant pole with $1/\tau_{CC1}$?

A. Yes

B. No

C. It does not matter



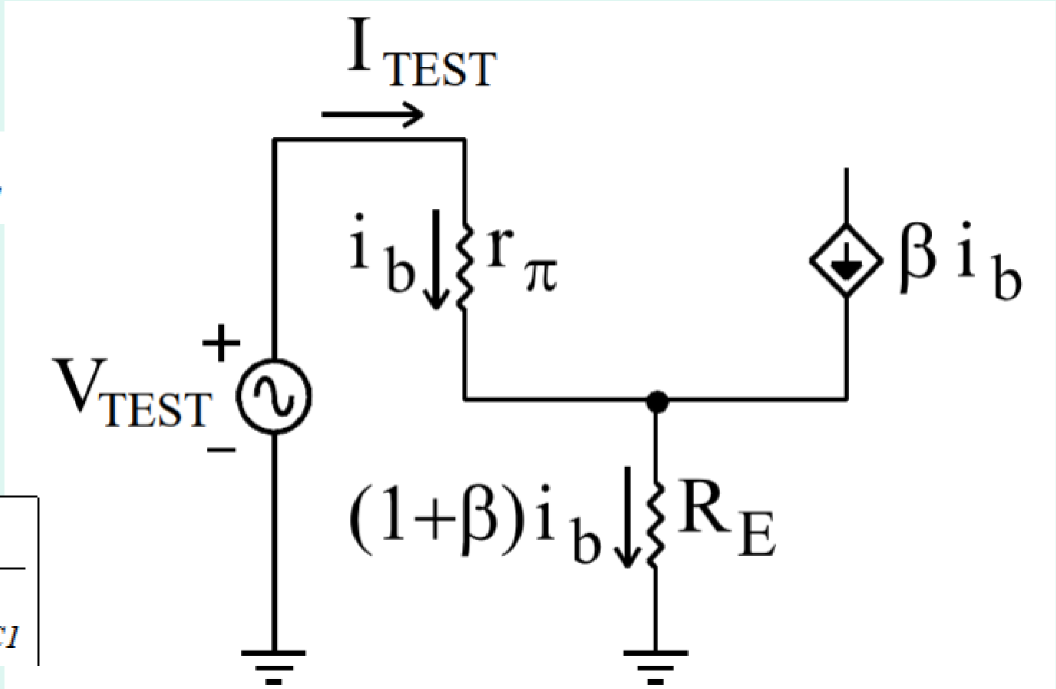
FL(s) - finding last pole

- We cannot automatically say that: $\omega_{Lp2} \approx \frac{1}{\tau_{C_{C1}}^{sc}}$
- When C_{C1} is starting to conduct, C_E must still look like an OC => we need to treat C_E as an OC (OC time constant)

$$\frac{V_{TEST}}{I_{TEST}} = r_\pi + (1+\beta) R_E$$

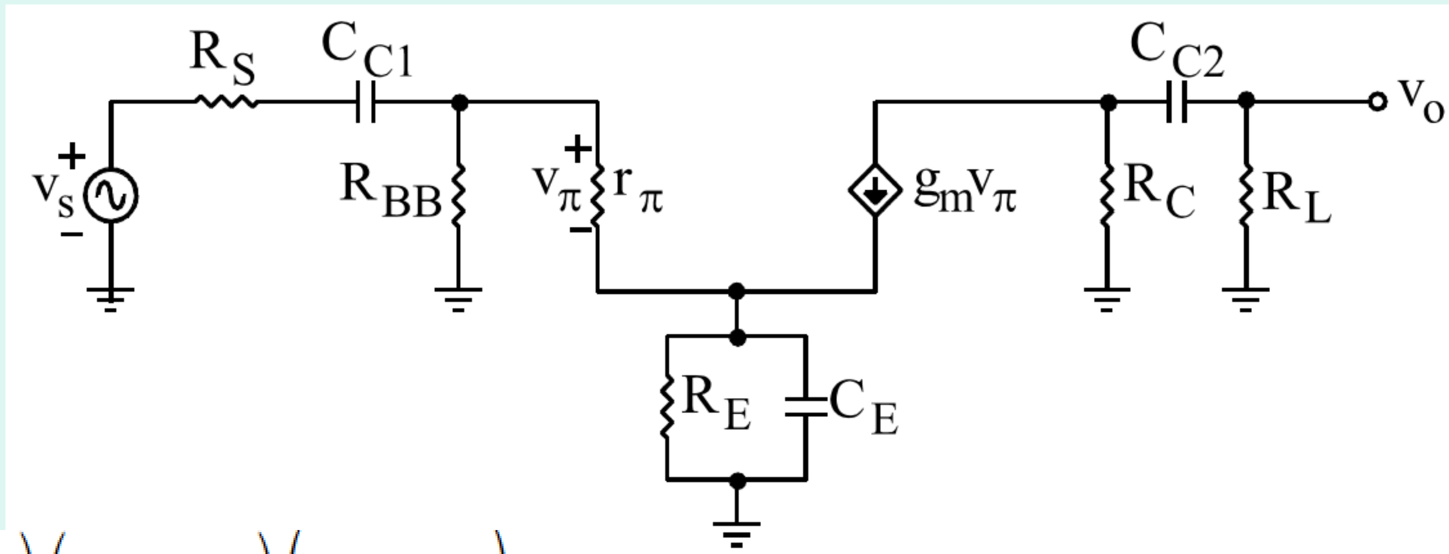
$$\tau_{C_{C1}}^{oc} = \left[R_S + R_{BB} \| \left(r_\pi + (1+\beta) R_E \right) \right] C_{C1}$$

$$\omega_{Lp2} = \frac{1}{\left[R_S + R_{BB} \| \left(r_\pi + (1+\beta) R_E \right) \right] C_{C1}}$$



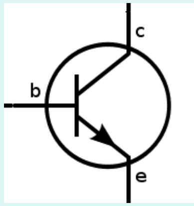
$F_L(s)$

- Final form:



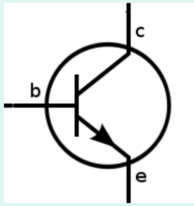
$$F_L(s) \approx \left(\frac{s}{s+\omega_{Lp1}}\right)\left(\frac{s}{s+\omega_{Lp2}}\right)\left(\frac{s+\omega_{Lz3}}{s+\omega_{Lp3}}\right)$$

$$F_L(s) \approx \left(\frac{s}{s+\frac{1}{(R_C+R_L)C_{C2}}}\right)\left(\frac{s}{s+\frac{1}{(R_S+R_{BB}\|[r_\pi+(1+\beta)R_E])C_{C1}}}\right)\left(\frac{s+\frac{1}{R_E C_E}}{s+\frac{1}{\left(R_E\|\frac{r_\pi+R_{BB}\|R_S}{1+\beta}\right)C_E}}\right)$$



Choosing capacitor values

- We made the choice C_E - ω_{Lp3} and C_{C1} - ω_{Lp2}, assuming $\omega_{Lp3} >> \omega_{Lp2}$
- C_E typically 'sees' the smallest resistance => ω_{Lp3} gives the dominant LF pole (highest frequency)
- C_{C1} typically 'sees' the largest resistance => ω_{Lp2} is typically chosen to be the lowest frequency
- C_{C2} typically 'sees' an intermediate resistance => ω_{Lp1} is typically chosen so that $\omega_{Lp3} > \omega_{Lp1} > \omega_{Lp2}$ (first sub-dominant pole)
- We can choose the values for C_E, C_{C1}, C_{C2} (with a reasonable spacing between poles) - the approach typically results in the lowest circuit cost


c
b
e