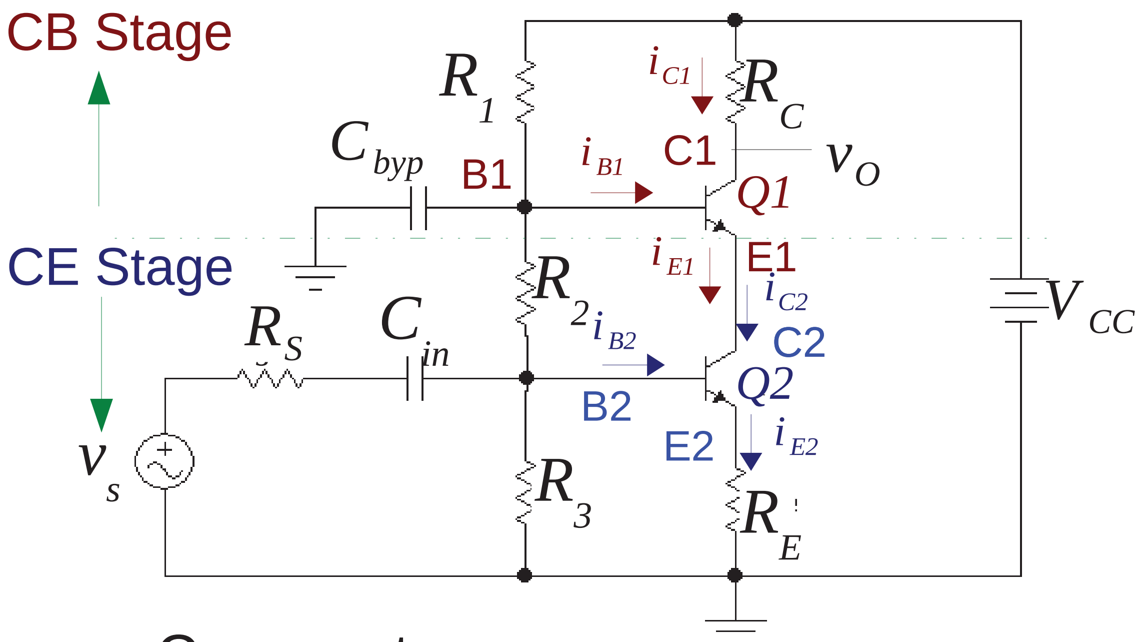
The Cascode Amplifier

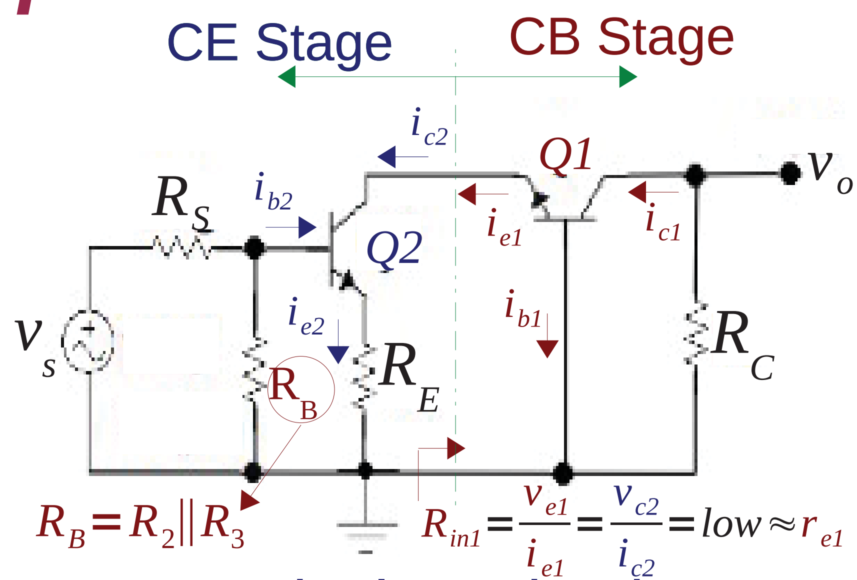
- A two transistor amplifier used to obtain simultaneously:
    1. Reasonably high input impedance.
    2. Reasonable voltage gain.
    3. Wide bandwidth.

- None of the conventional single transistor designs will satisfy all of the criteria above.
- The cascode amplifier will satisfy all of these criteria.
- A cascode is a CE Stage cascaded with a CB Stage.

(**Historical Note:** the cascode amplifier was a cascade of *grounded cathode* and *grounded grid* vacuum tube stages – hence the name "cascode," which has remained in modern terminology.)

The Cascode Amplifier





ac equivalent circuit

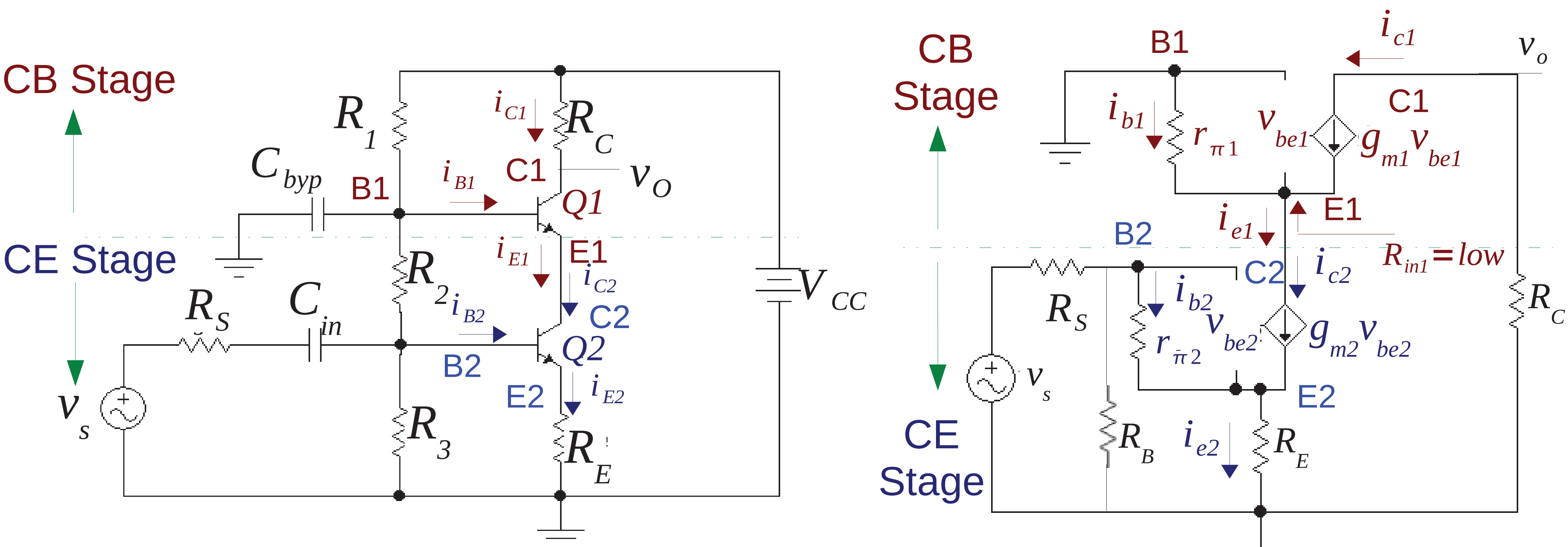
Comments:

1. R_1, R_2, R_3, and R_C set the bias levels for both Q1 and Q2.

2. Determine R_E for the desired voltage gain.

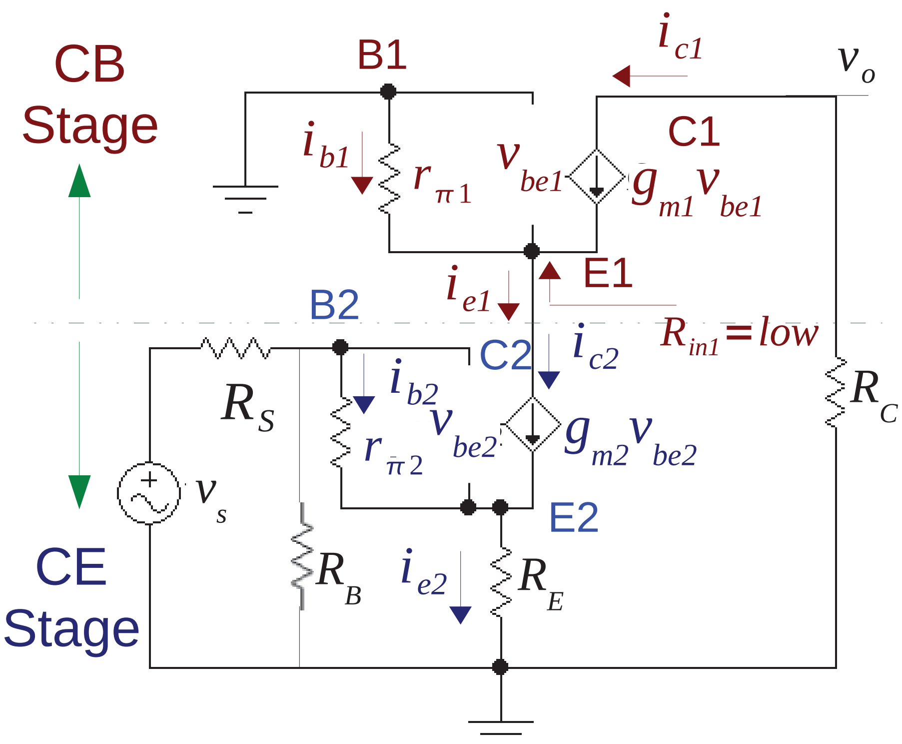
3. C_{in} and C_{byp} are to act as “open circuits” at dc and act as “short circuits” at all operating frequencies $f > f_{min}$.

Cascode Mid-Band Small Signal Model



$$R_B = R_2 \| R_3$$

Cascode Small Signal Analysis



$$g_{m1} = g_{m2} = g_m$$
$$r_{e1} = r_{e2} = r_e$$
$$r_{\pi 1} = r_{\pi 2} = r_\pi$$

1. Show reduction in Miller effect
2. Evaluate small-signal voltage gain

OBSERVATIONS

a. The emitter current of the CB Stage is the collector current of the CE Stage. (This also holds for the dc bias current.)

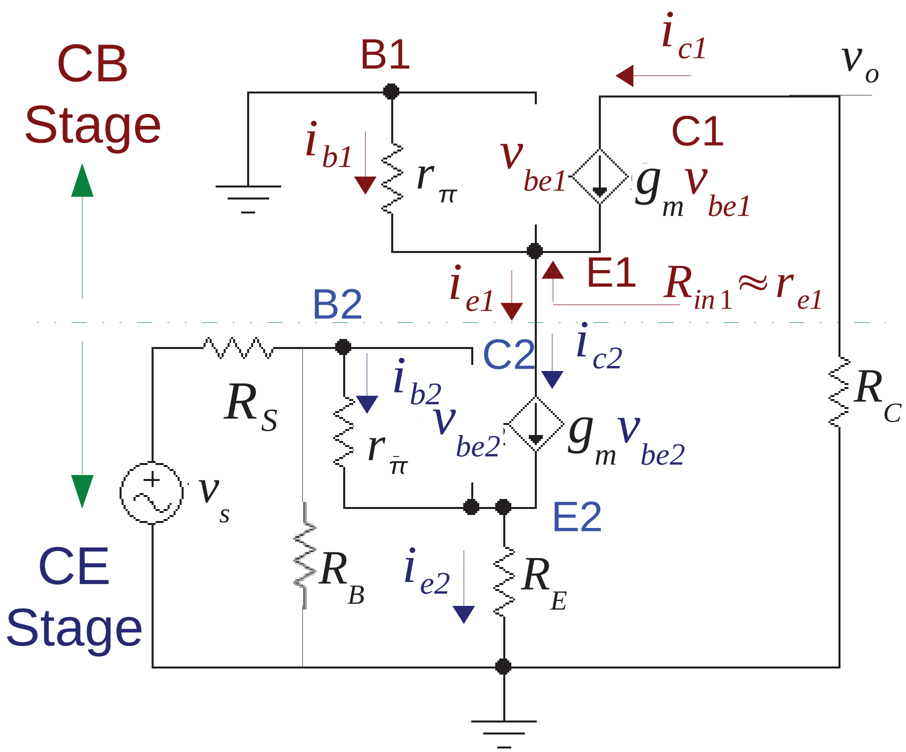
$$i_{e1} = i_{c2}$$

b. The base current of the CB Stage is:

$$i_{b1} = \frac{i_{e1}}{\beta + 1} = \frac{i_{c2}}{\beta + 1}$$

c. Hence, both stages have about same collector current $i_{c1} \approx i_{c2}$ and same g_m, r_e, r_π.

Cascode Small Signal Analysis cont.



The input resistance R_{in1} to the CB Stage is the small-signal "r_{e1}" for the CB Stage, i.e.

$$i_{b1} = \frac{i_{e1}}{\beta+1} = \frac{i_{c2}}{\beta+1}$$

The CE output voltage, the voltage drop from Q2 collector to ground, is:

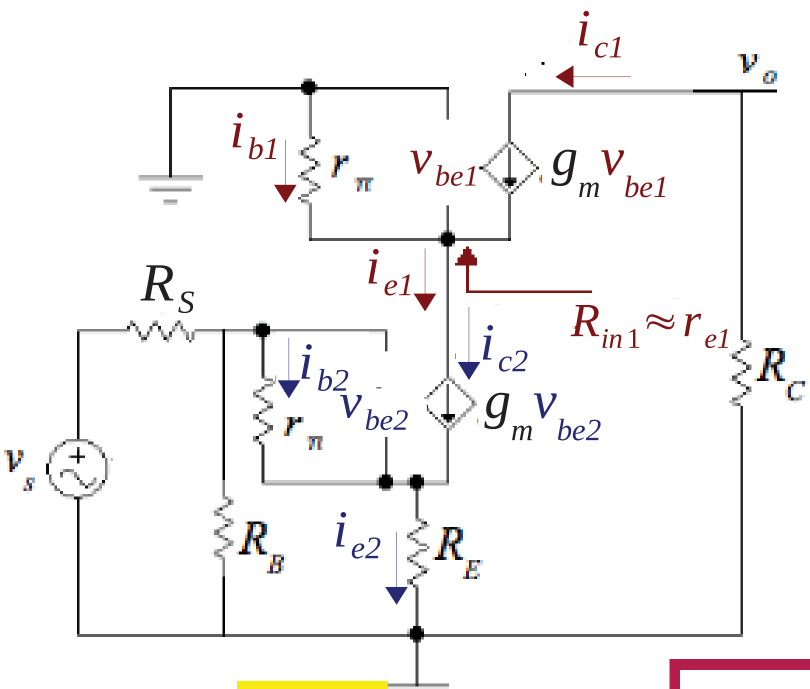
$$v_{c2} = v_{e1} = -r_\pi i_{b1} = -\frac{r_\pi}{\beta+1} i_{c2} = -\frac{r_\pi}{\beta+1} i_{e1}$$

herefore, the CB Stage input resistance is:

$$R_{in1} = \frac{v_{e1}}{-i_{e1}} = \frac{r_\pi}{\beta+1} = r_{e1}$$

$$A_{vCE-Stage} = \frac{v_{c2}}{v_s} \approx -\frac{R_{in1}}{R_E} = -\frac{r_e}{R_E} < 1 \quad \Rightarrow \quad C_{eq} = (1 + \frac{r_e}{R_E}) C_\mu < 2 C_\mu$$

Cascode Small Signal Analysis - cont.



Now, find the CE collector current in terms of the input voltage v_s: Recall $i_{c1} \approx i_{c2}$

$$i_{b2} \approx \frac{v_s}{R_S \| R_B + r_\pi + (\beta+1) R_E}$$

$$i_{c2} = \beta i_{b2} \approx \frac{\beta v_s}{R_S \| R_B + r_\pi + (\beta+1) R_E} \approx \frac{\beta v_s}{(\beta+1) R_E}$$

for bias insensitivity: $(\beta+1) R_E \gg R_S \| R_B + r_\pi$

$$i_{c1} \approx i_{e1} = i_{c2} \approx i_{e2}$$

$$i_{C2} \approx \frac{v_s}{R_E}$$

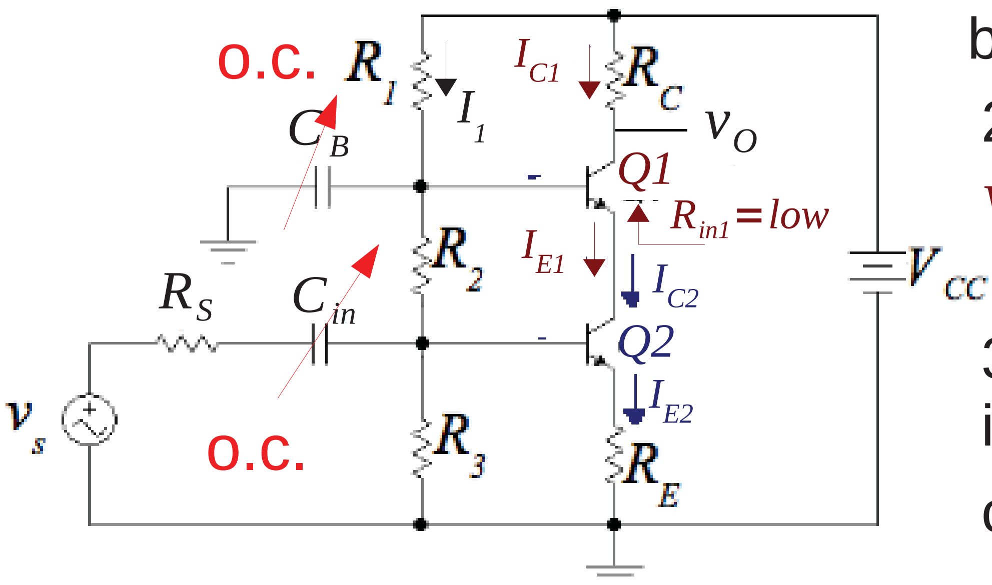
$$v_o = -i_{c2} R_C$$

=> $$A_v = \frac{v_o}{v_s} = \frac{-R_C}{R_E}$$

OBSERVATIONS:

1. Voltage gain A_v is about the same as a stand-along CE Amplifier.
2. HF cutoff is much higher then a CE Amplifier due to the reduced C_{eq}.

Cascode Biasing



$$\alpha_2 I_{E2} = I_{C2} = I_{E1} = \frac{1}{\alpha_1} I_{C1} \Rightarrow I_{C1} \approx I_{E2}$$

1. Choose I_{E1} – make it relatively large to reduce $R_{in1} = r_e = V_T / I_{E1}$ to push out HF break frequencies.

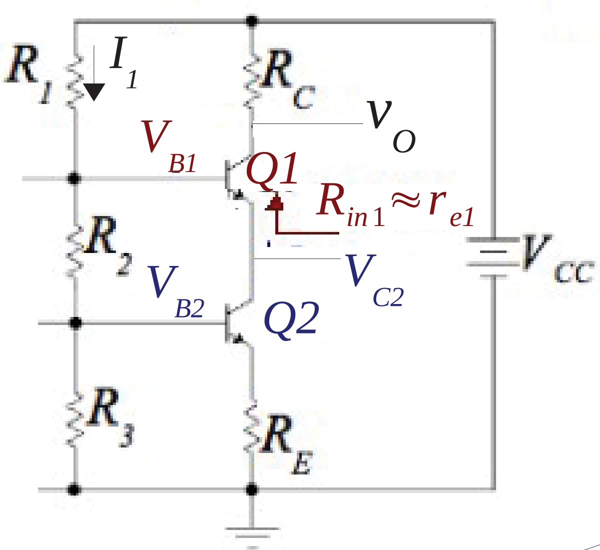
2. Choose R_C for suitable voltage swing V_{C1} and R_E for desired gain.

3. Choose bias resistor string such that its current I_1 is about 0.1 of the collector current I_{C1}.

4. Given R_E, I_{E2} *and* $V_{BE2} = 0.7\ V$ calc. R_3.

5. Need to also determine R_1 & R_2.

Cascode Biasing - cont.



Since the CE-Stage gain is very small:

a. The collector swing of Q2 will be small.

b. The Q2 collector bias $V_{C2} = V_{B1} - 0.7\,V$.

6. Set $V_{B1} - V_{B2} = 1\,V \Rightarrow V_{CE2} = 1\,V$

This will limit V_{CB2} $V_{CB2} = V_{CE2} - V_{BE2} = 0.3\,V$

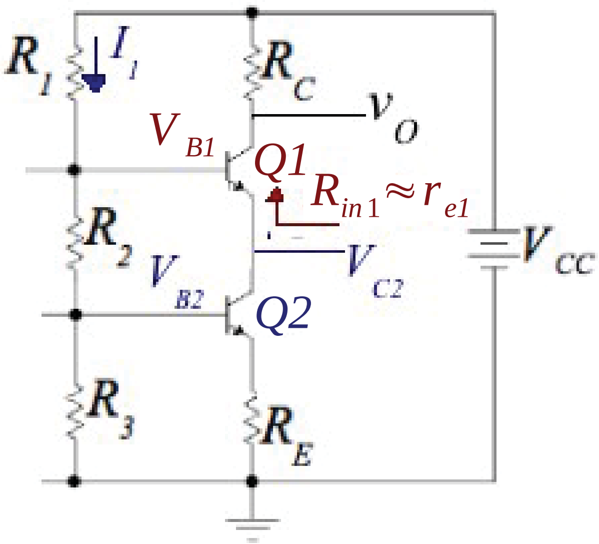
which will keep Q2 forward active.

$$V_{CE2} = V_{C2} - V_{Re} = V_{C2} - (V_{B2} - 0.7\,V)$$
$$= V_{B1} - 0.7\,V - V_{B2} + 0.7\,V$$
$$.= V_{B1} - V_{B2}$$

7. Next determine R_2. Its drop $V_{R2} = 1\,V$ with the known current.

$$R_2 = \frac{V_{B1} - V_{B2}}{I_1}$$

Cascode Biasing - cont.



$$R_2 = \frac{V_{B1} - V_{B2}}{I_1} = \frac{1\,V}{I_1}$$

8. Then calculate R_3. $R_3 = \frac{V_{B2}}{I_1}$

where $V_{B2} = 0.7\,V + I_E R_E$

Note: $R_1 + R_2 + R_3 = \frac{V_{CC}}{I_1}$

9. Then calculate R_1.

$$R_1 = \frac{V_{CC}}{0.1\,I_C} - R_2 - R_3$$

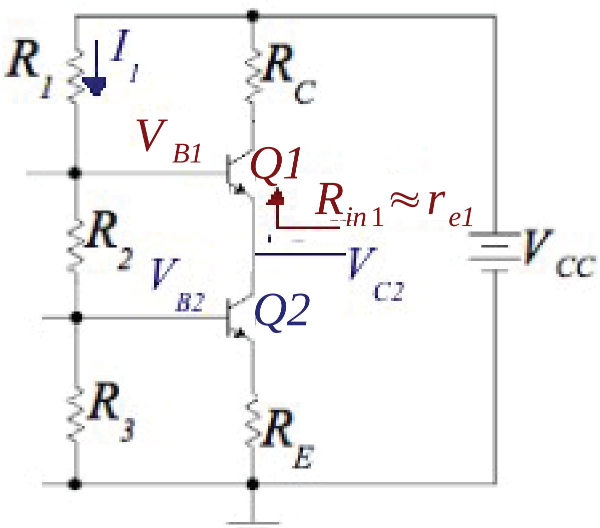
Cascode Bias Summary

SPECIFIED: A_v, V_{CC}, V_{C1} (CB collector voltage);

SPECIFIED: I_E (or I_C) directly or indirectly through BW.

DETERMINE: R_C, R_E, R_1, R_2 and R_3.

SET: $V_{B1} - V_{B2} = 1V \Rightarrow V_{CE2} = 1V$



$$I_{C2} = I_{E1} \approx I_{C1} \approx I_{E2} = I_C$$

STEP1: $$R_C = \frac{V_{C1}}{I_C} \qquad R_E = \frac{R_C}{|A_v|}$$

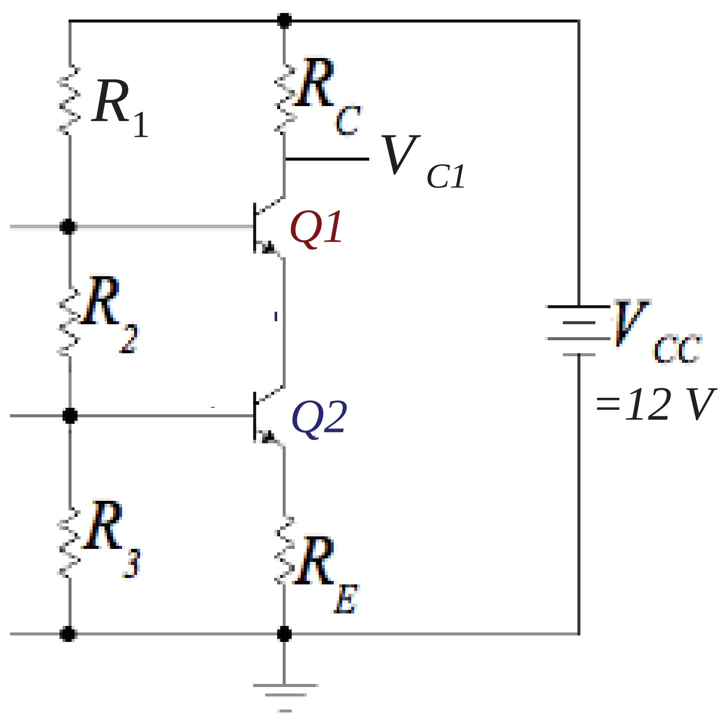
STEP2: $$R_2 = \frac{V_{B1} - V_{B2}}{I_1} = \frac{1V}{0.1 I_C}$$

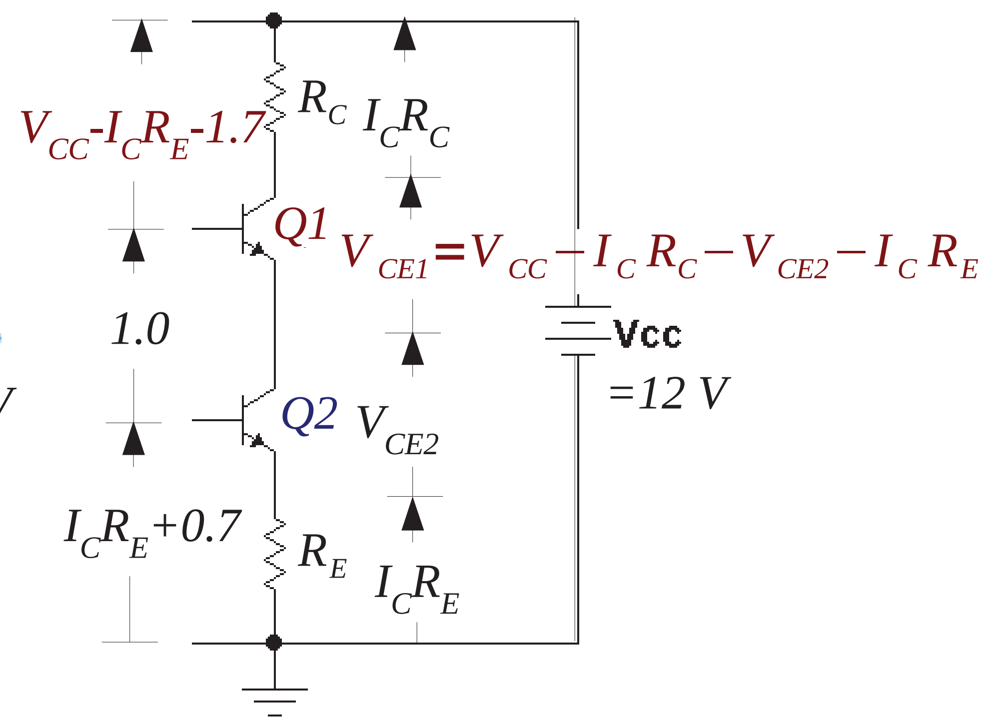
STEP3: $$R_3 = \frac{V_{B2}}{I_1} = \frac{0.7V + I_E R_E}{0.1 I_C}$$

$$R_1 + R_2 + R_3 = \frac{V_{CC}}{I_1} = \frac{V_{CC}}{0.1 I_C}$$

STEP4: $$R_1 = \frac{V_{CC}}{0.1 I_C} - R_2 - R_3$$

Cascode Bias Example



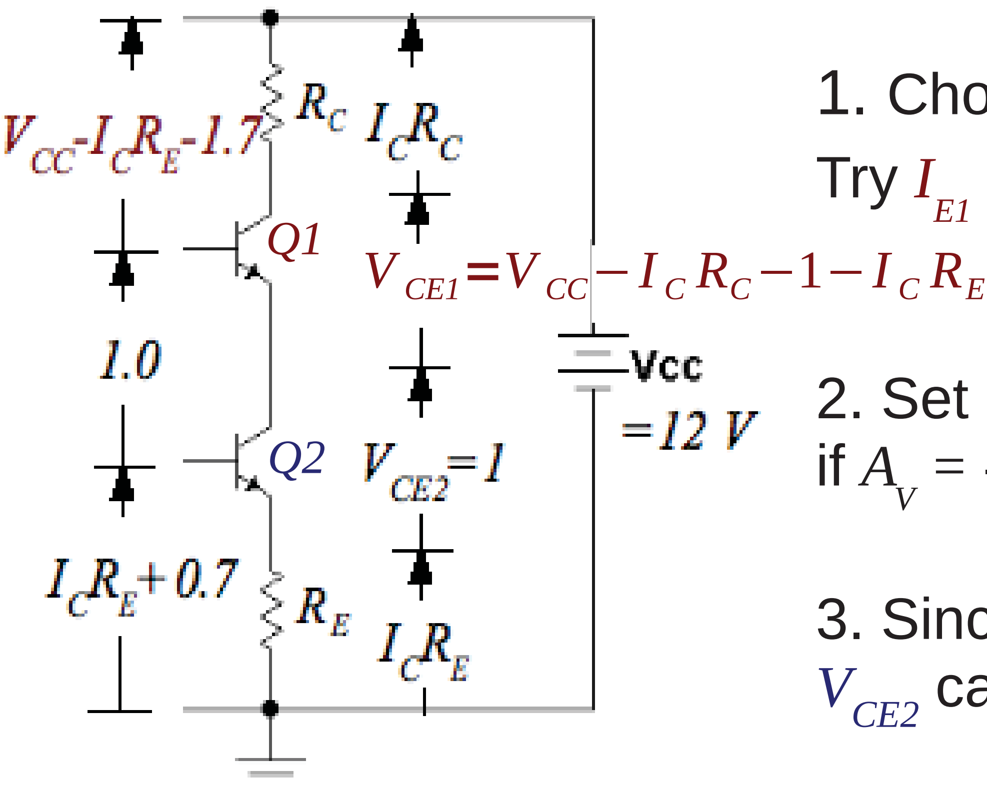


$$I_{E2} \approx I_{C2} = I_{E1} \approx I_{C1} \Rightarrow I_{C1} \approx I_{E2}$$

Cascode Amp

Typical Bias Conditions

Cascode Bias Example cont.

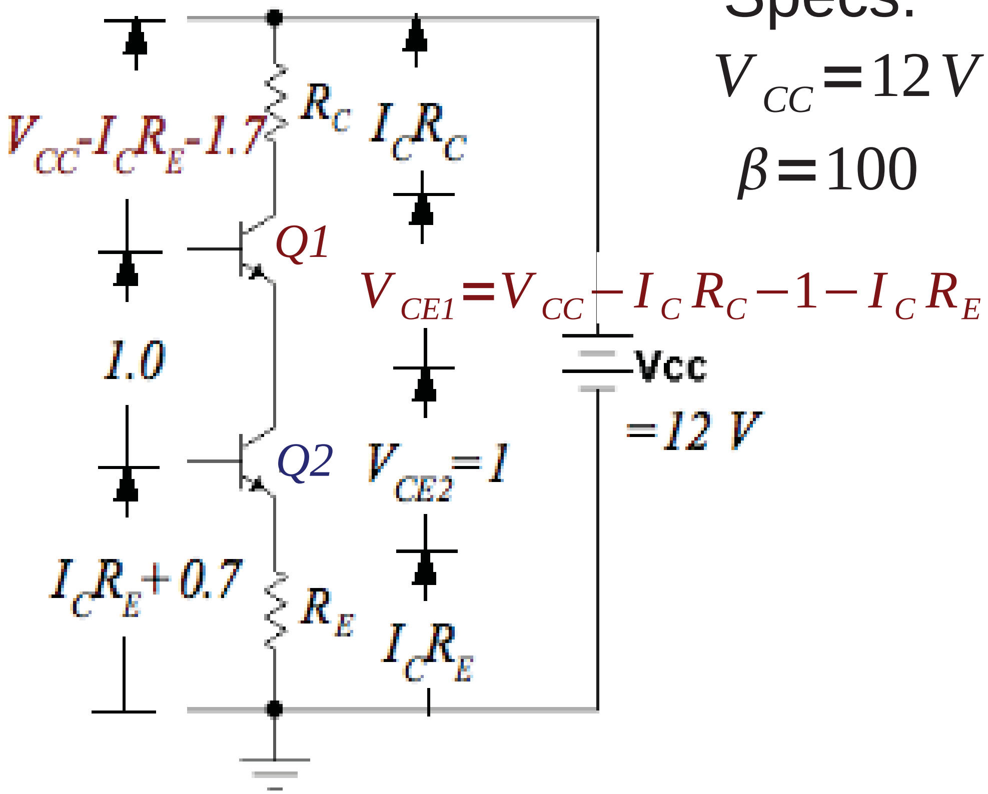


1. Choose I_{E1} – to set r_e.
Try $I_{E1} = 5\ mA$ => $r_e = 0.025\,V / I_E = 5\,\Omega$.

2. Set desired gain magnitude. For example if $A_V = -10$, then $R_C/R_E = 10$.

3. Since the CE stage gain is very small, V_{CE2} can be small, i.e. $V_{CE2} = V_{B1} - V_{B2} = 1\ V$.

Cascode Bias Example cont.



Specs:

$V_{CC}=12\,V$ $V_{C1}=7\,V$ $I_C=5\,mA$ $|A_v|=\frac{R_C}{R_E}=10$

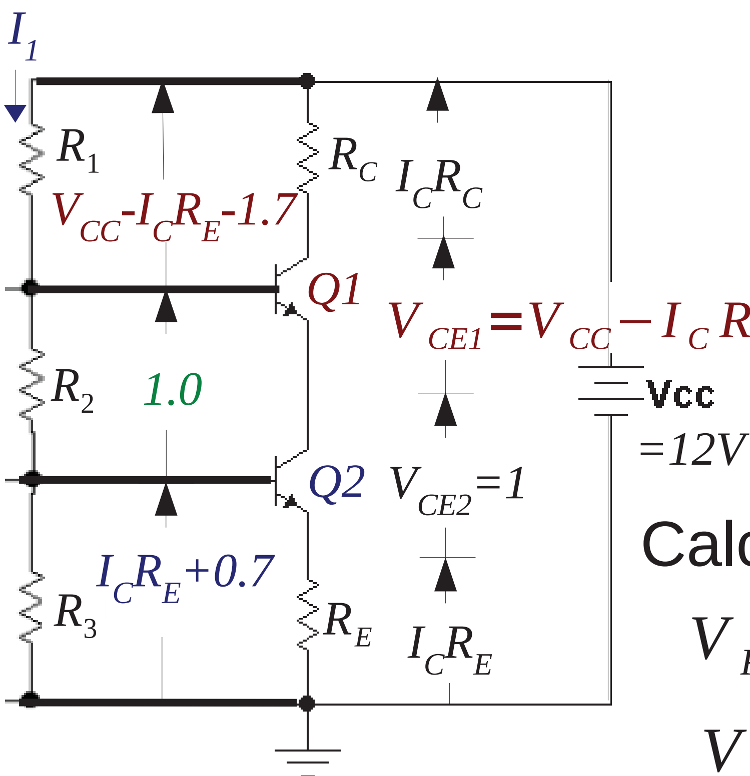
$\beta=100$

Determine R_C for V_{C1} = 7V .

$$R_C=\frac{V_{CC}-V_{C1}}{5\cdot 10^{-3}\,A}=\frac{5\,V}{5\cdot 10^{-3}\,A}=1000\,\Omega$$

$$R_E=\frac{R_C}{|A_v|}=\frac{R_C}{10}=100\,\Omega$$

Cascode Bias Example cont.



$$V_{CC} = 12 \quad R_C = 1\,k\,\Omega \quad I_C = 5\,mA. \quad R_E = 100\,\Omega$$

Make current through the string of bias resistors $I_1 = 0.1\, I_C = 0.5\, mA$.

$$R_1 + R_2 + R_3 = \frac{V_{CC}}{I_1} = \frac{12}{5 \cdot 10^{-4}} = 24\,k\,\Omega$$

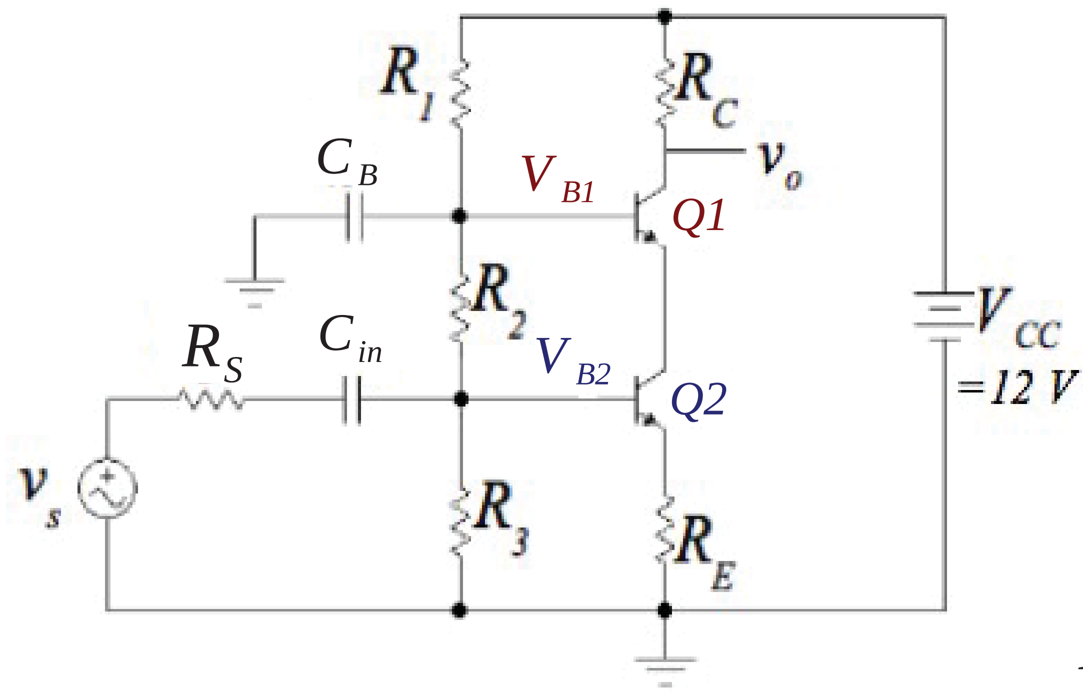
Calculate the bias voltages (base side of Q1, Q2):

$$V_{R1} = V_{CC} - I_C R_E - 1.7\,V = 12\,V - 0.5\,V - 1.7\,V = 9.8\,V$$

$$V_{R2} = V_{B1} - V_{B2} = 1\,V$$

$$V_{R3} = V_{B2} = I_C R_E + 0.7 = 5 \cdot 10^{-3} \cdot 100 + 0.7 = 1.2\,V$$

Cascode Bias Example cont.



$$V_{B2} = 5 \cdot 10^{-4} R_3 = 1.2\,V$$

$$R_3 = 2.4\,k\,\Omega$$

$$V_{B1} - V_{B2} = 5 \cdot 10^{-4} R_2 = 1.0\,V$$

$$R_2 = 2\,k\,\Omega$$

Recall: $R_1 + R_2 + R_3 = 24\,k\,\Omega$

$$R_1 = 24000 - 2.400 - 2000 = 19.6\,k\,\Omega$$

$V_{CC} = 12$, $R_C = 1\,k\,\Omega$, $V_{B2} = 1.2\,V$,

$I_C = 5\,mA$, $R_E = 100\,\Omega$, $V_{B1} - V_{B2} = 1.0\,V$

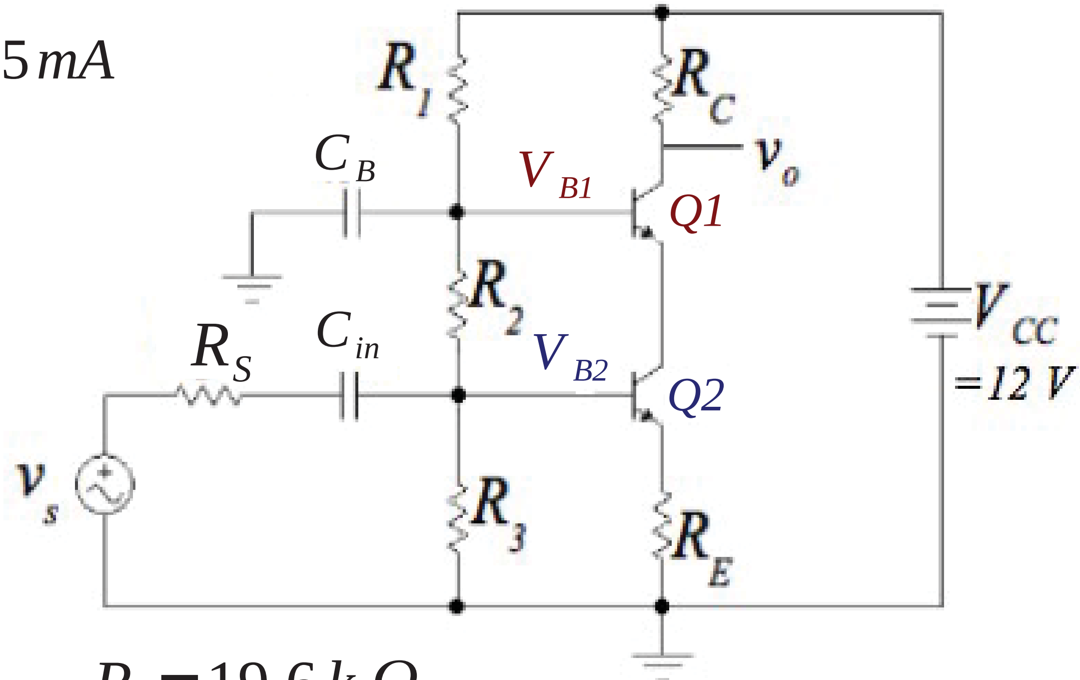
Completed Design

$\beta = 100$

$r_e = 5\,\Omega \Rightarrow I_C = 5\,mA$

$V_{C1} = 7\,V$

$|A_v| = \frac{R_C}{R_E} = 10$



$R_1 = 19.6\,k\,\Omega$

$R_2 = 2\,k\,\Omega$

$R_3 = 2.4\,k\,\Omega$

$R_C = 1\,k\,\Omega$

$R_E = 100\,\Omega$

NOTE: $R_B = R_2 \| R_3 = 1.09\,k\,\Omega \ll \beta R_E = 10\,k\,\Omega$

$$f_H = \frac{1}{2\pi C_{tot} R_S'}$$

$$C_{tot} = C_\pi + \left(1 + \frac{r_e}{R_E}\right) C_\mu$$

$$= C_\pi + 1.05\,C_\mu$$

If $C_\pi = 12\,pF$

$C_\mu = 2\,pF$

$C_{tot} = 14.1\,pF$

$f_{Hcascode} = 225.8\,MHz$

For CE with $|A_v| = 10$

$f_{HCE} = 94\,MHz$