EE210: Microelectronics-I

Lecture-33: Operational Amplifiers_1

https://youtu.be/ehekdOHOIZ0

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BJT Operational Amplifier

- Simple BJT Opamp
- Compensation
- Buffer and Non-inverting amplifier

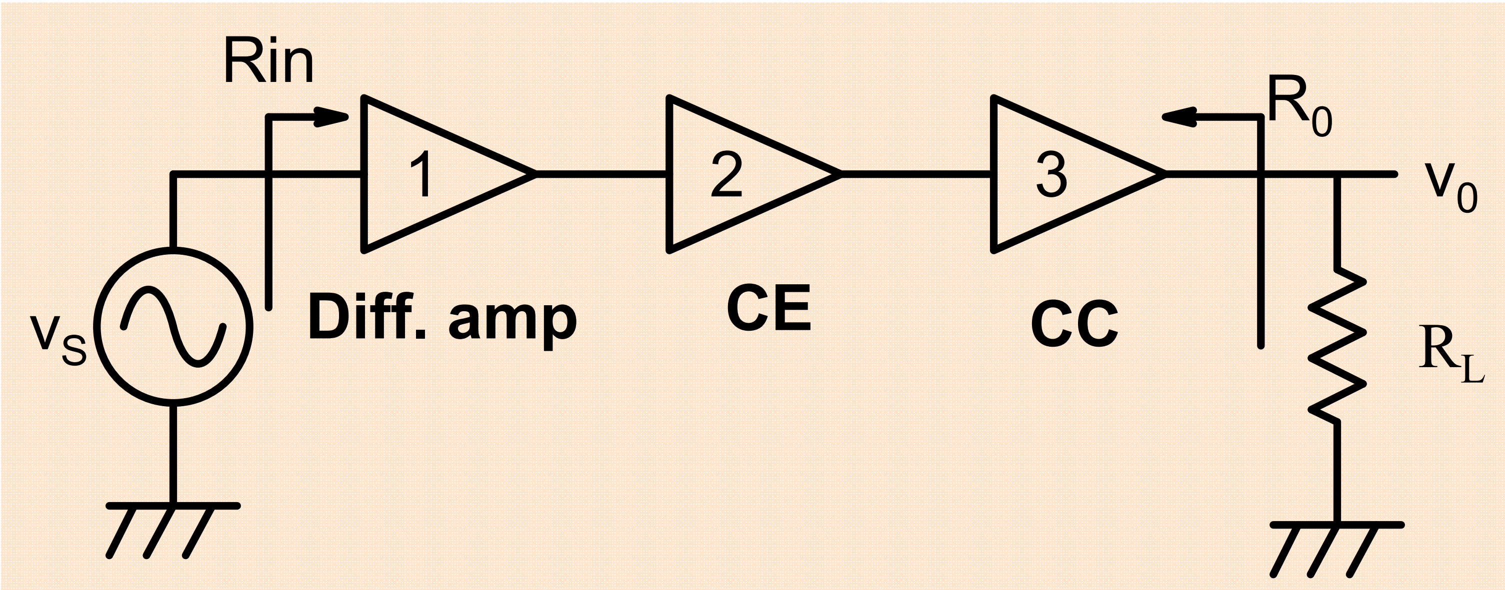
Specifications:

$$A_V \sim 10^3 \;;\; R_{in} \sim 100K\Omega \;;\; R_O = 100\Omega$$

Supply : ±12V

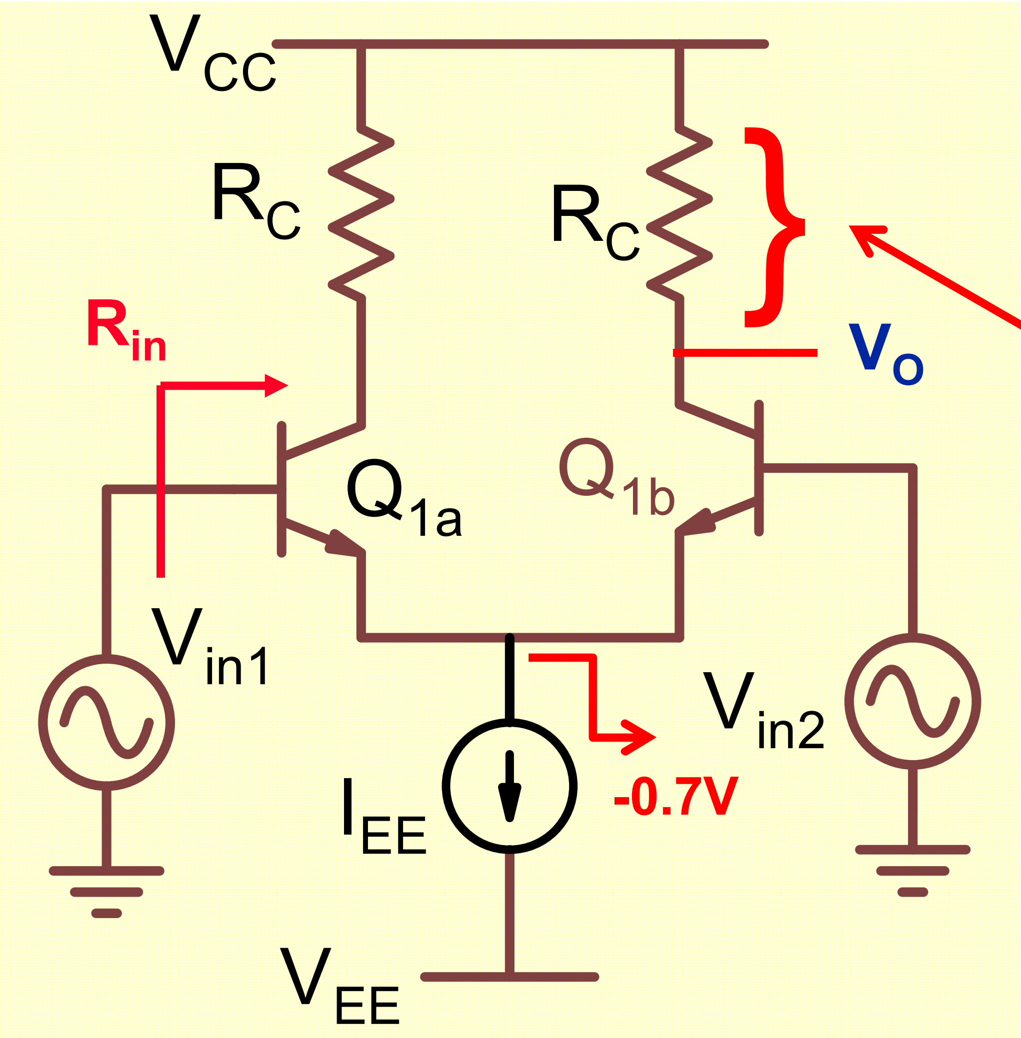
In the simple opamp, no active load would be used

General architecture:



Input Stage

$$A_V \sim 10^3 \ ; \ R_{in} \sim 100K\Omega \ ; \ R_O = 100\Omega$$

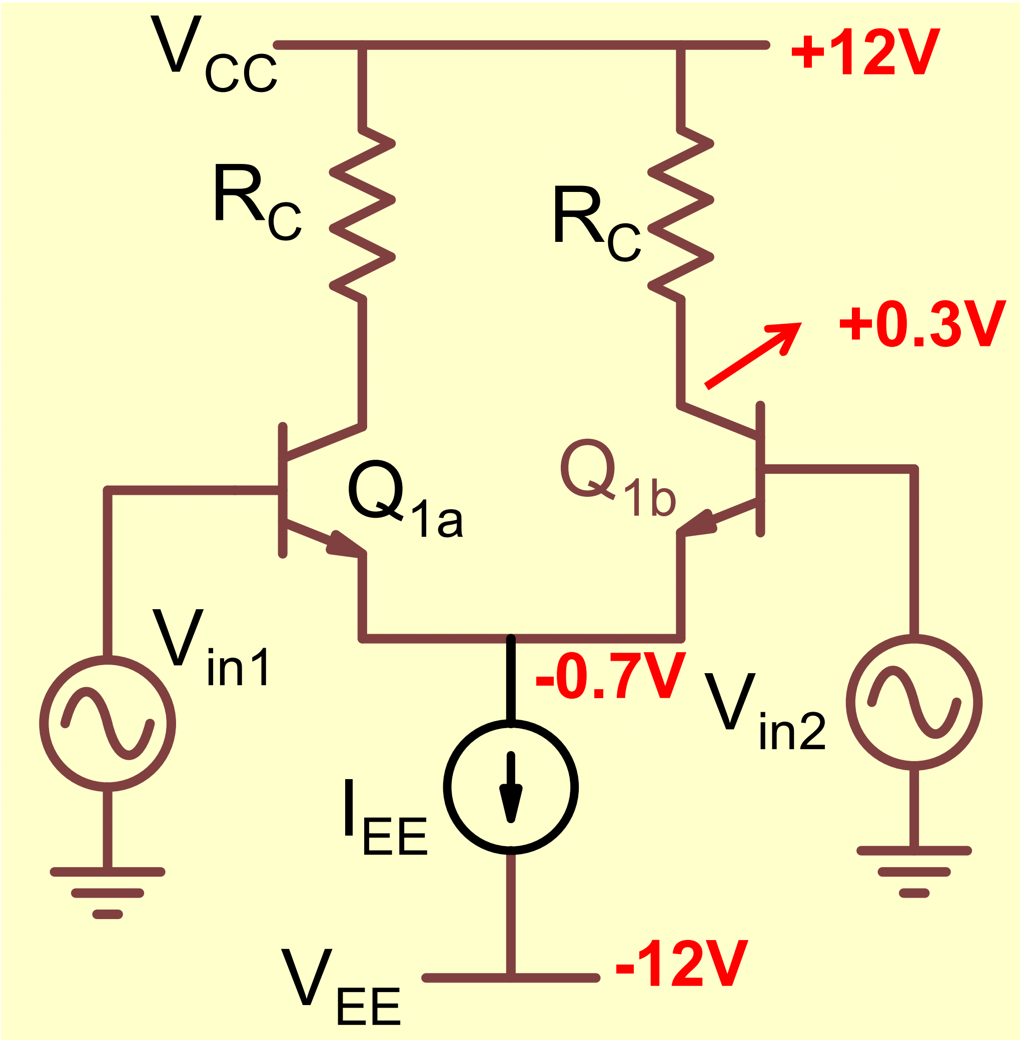


$$R_{in} = 2r_\pi = 2\frac{V_T}{I_{CQ1}}\beta = 10^5\ \Omega$$

$$I_{EE} = 2I_{CQ1} = 0.1mA$$

R_C = ?

$$A_{dm} = 0.5 g_m R_C = 0.5\frac{I_{CQ1}R_C}{V_T}$$



$$I_{EE} = 2I_{CQ1} = 0.1mA$$

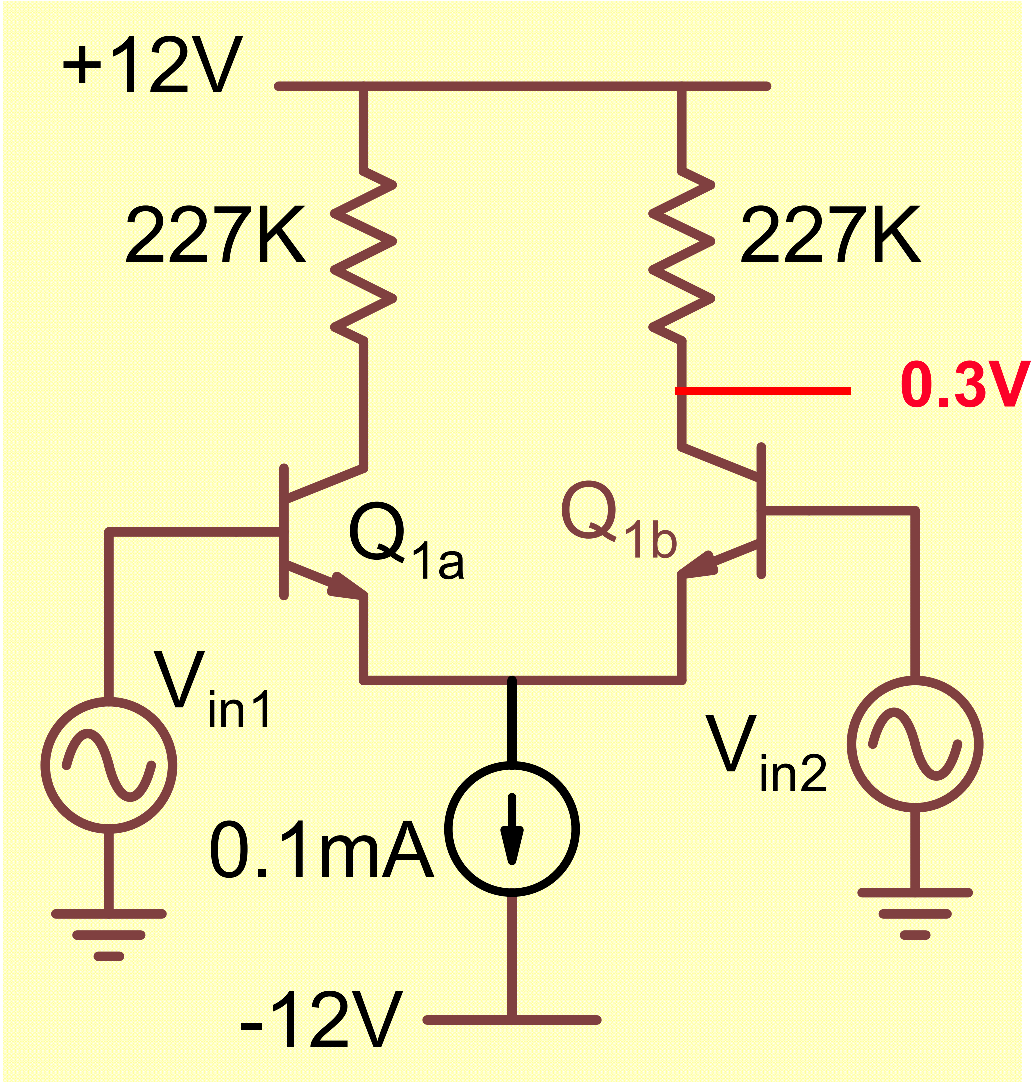
$$A_{V1} = 0.5\frac{I_{CQ1}R_C}{V_T}$$

Say V_{CE1} = 1V

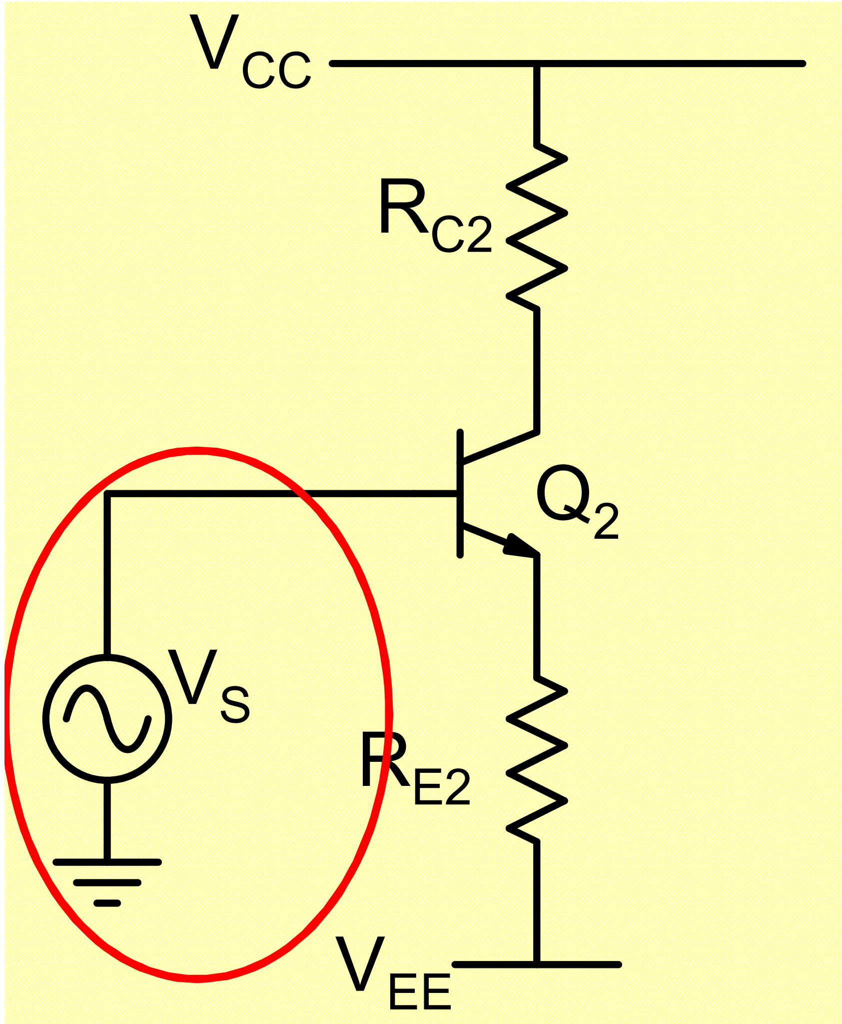
$$A_{V1} = 227$$

$$R_C = \frac{V_{CC} - V_{C1b}}{I_{CQ1}} = 227K$$

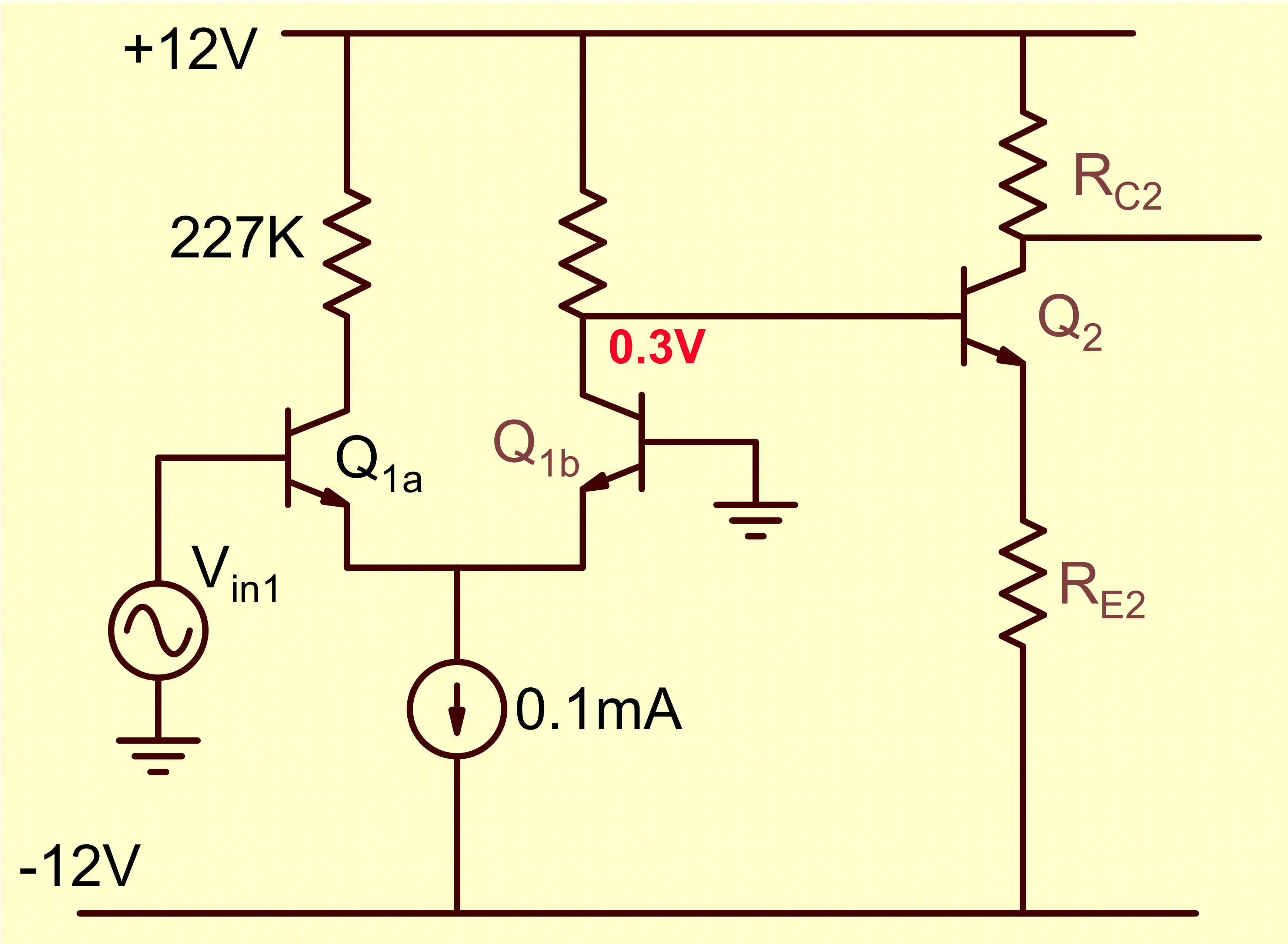
Differential Amplifier



CE Gain Stage



We have to see how to interface it to previous stage



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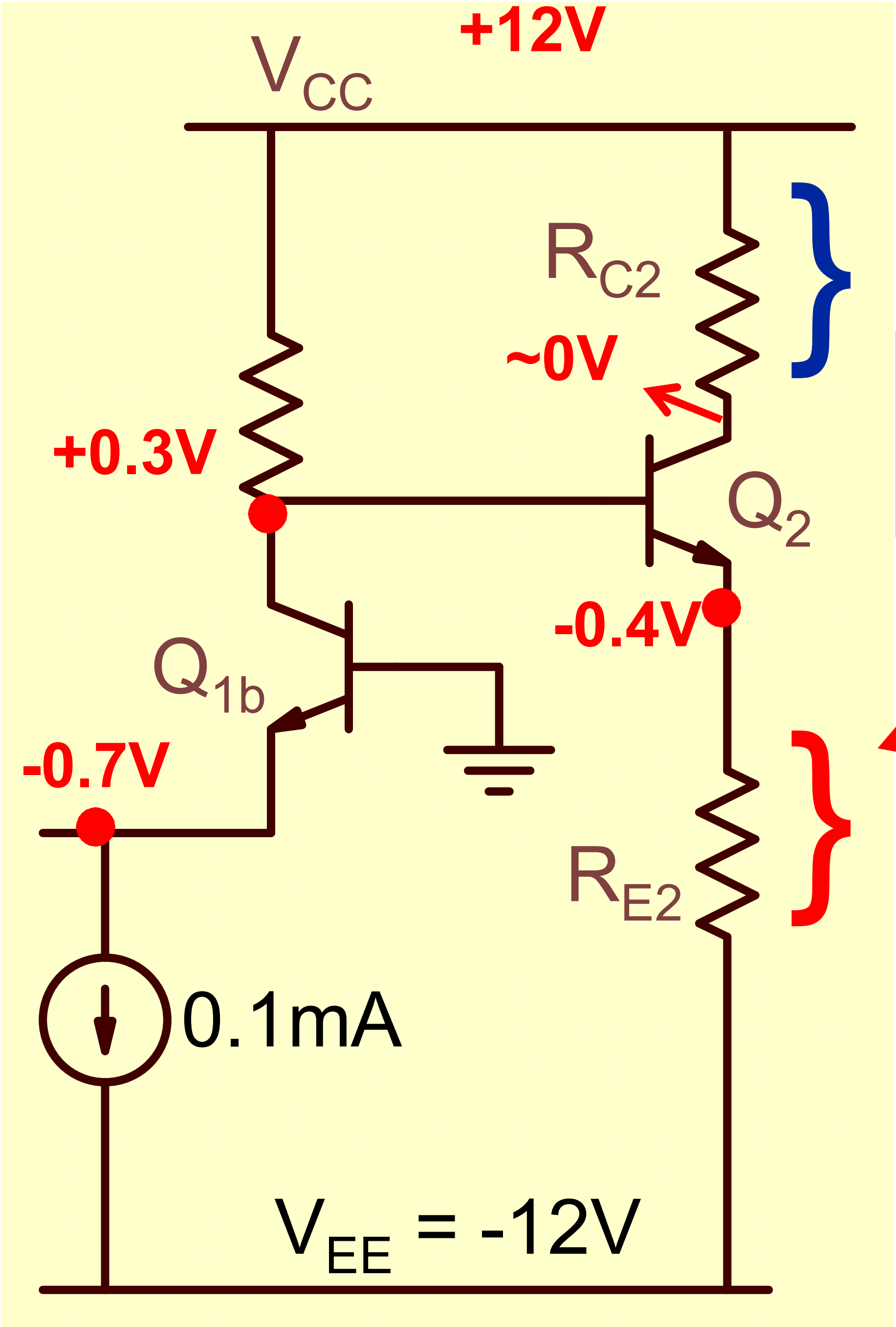

$$A_{V2} = \frac{g_{m2} \times R_{C2}}{1 + g_{m2} \times R_{E2}} \cong \frac{R_{C2}}{R_{E2}}$$

$$A_{V2} \cong \frac{I_{CQ2} \times R_{C2}}{I_{CQ2} \times R_{E2}} = \frac{\Delta V_C}{\Delta V_E}$$

$$A_{V2} \sim \frac{12}{11.6}$$

Negligible Gain !

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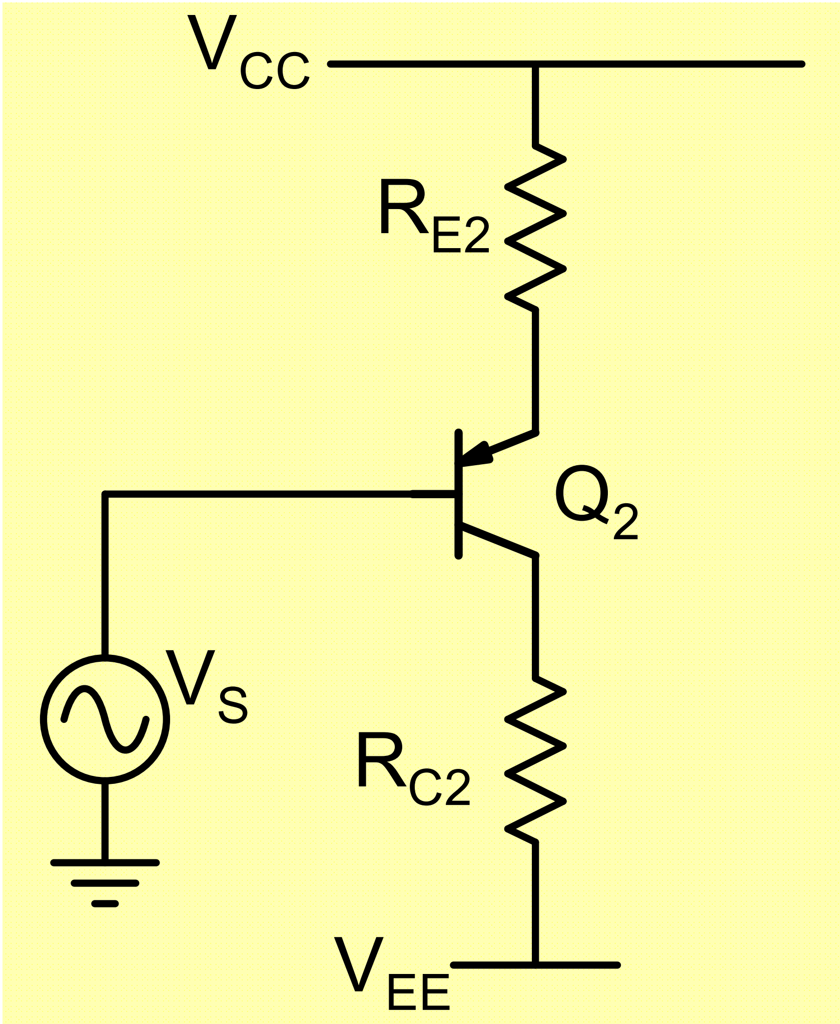
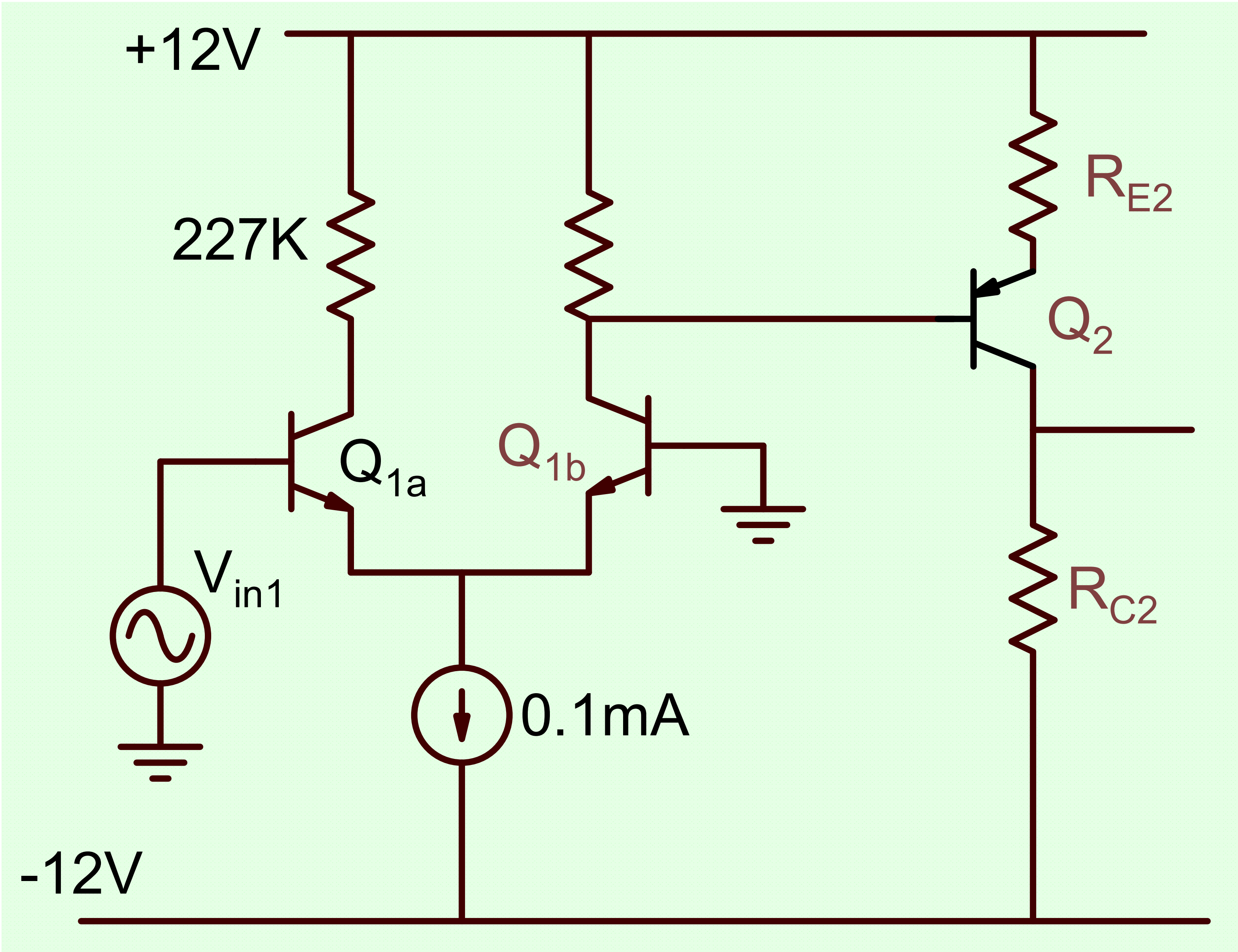
PNP Gain Stage:





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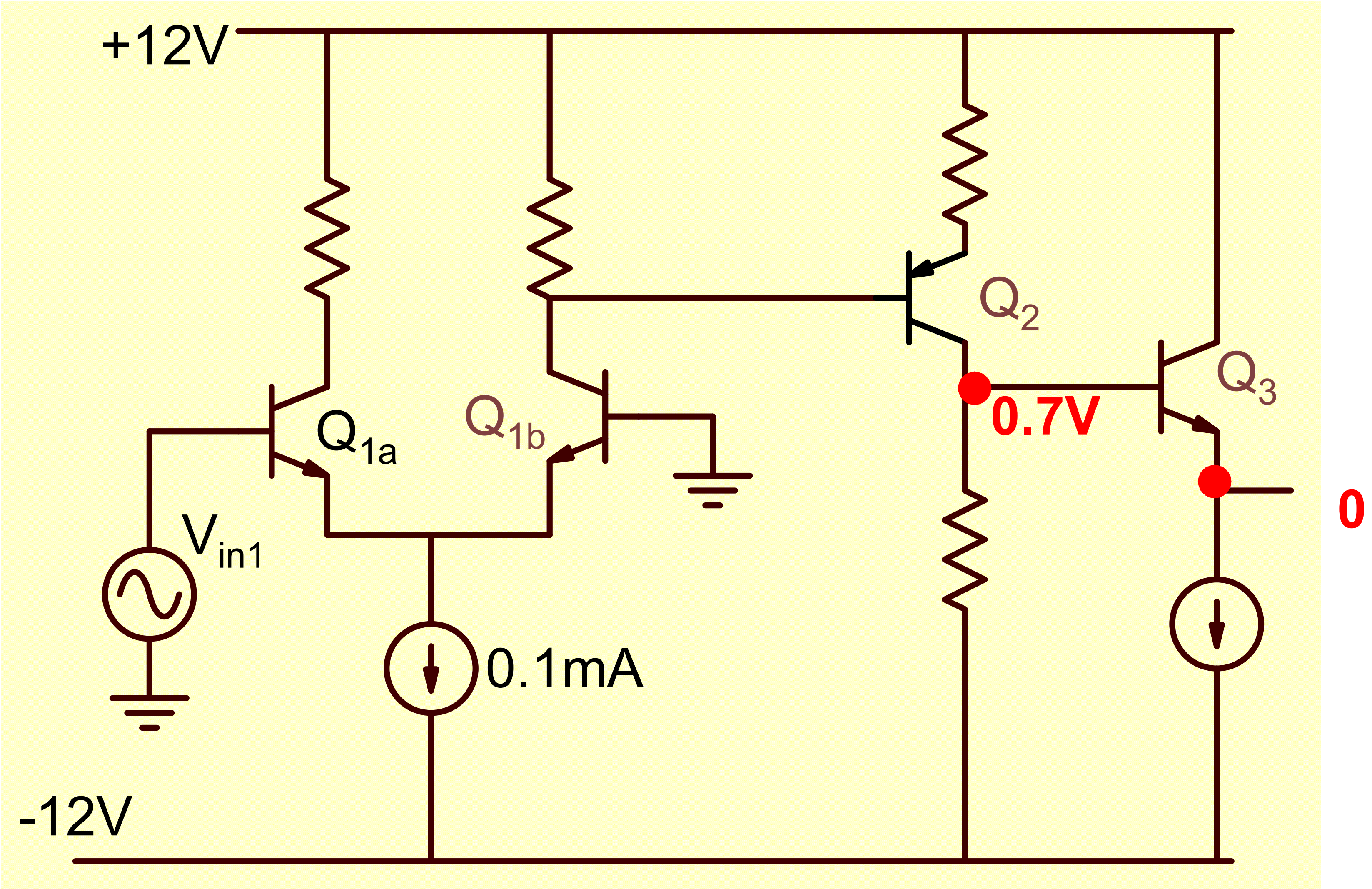

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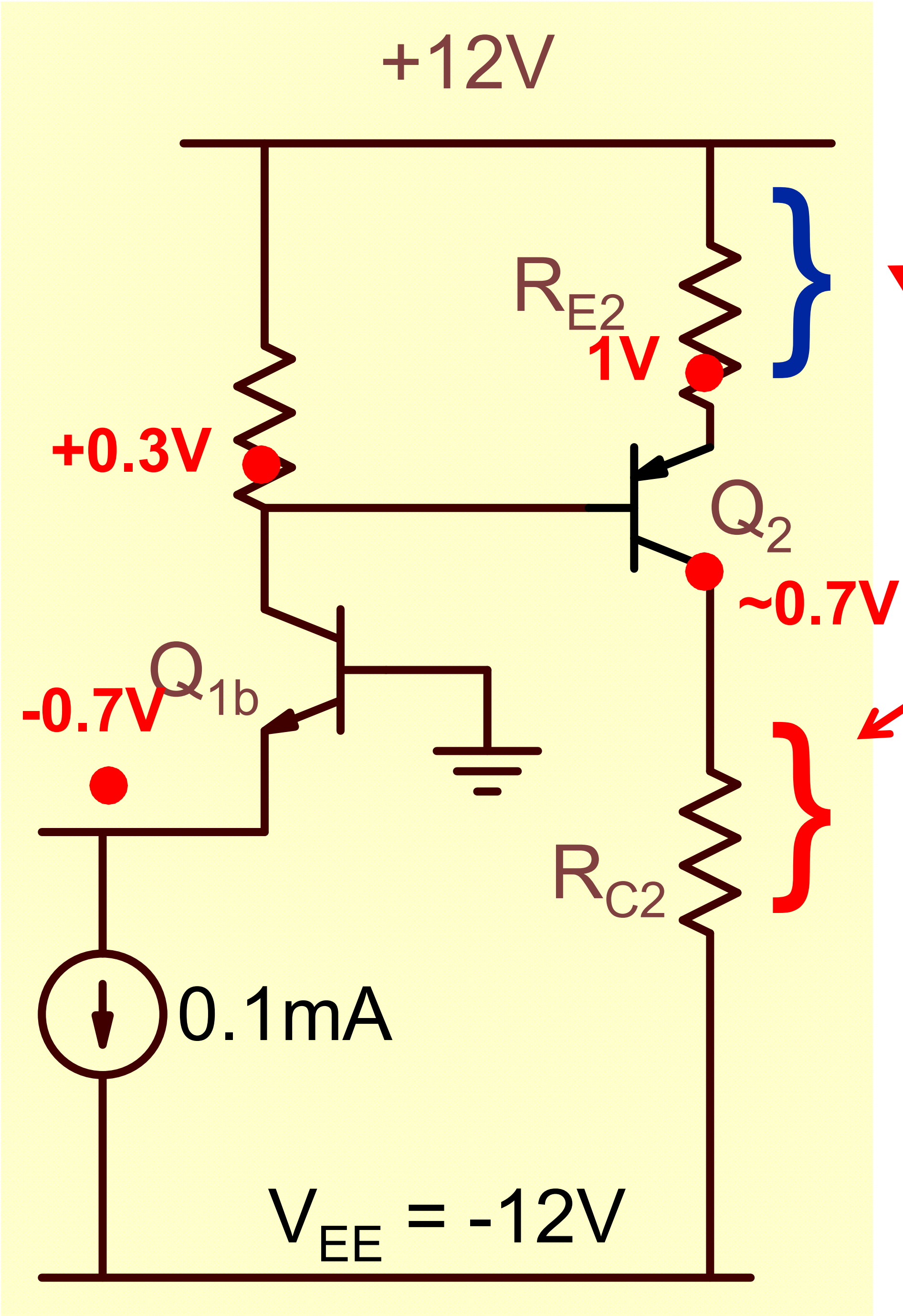

$$A_{V2} \cong \frac{R_{C2}}{R_{E2}} = \frac{I_{CQ2} \times R_{C2}}{I_{CQ2} \times R_{E2}}$$

$$A_{V2} \cong \frac{\Delta V_C}{\Delta V_E}$$

$$A_{V2} \sim \frac{12.7}{11}$$

Gain negligible again

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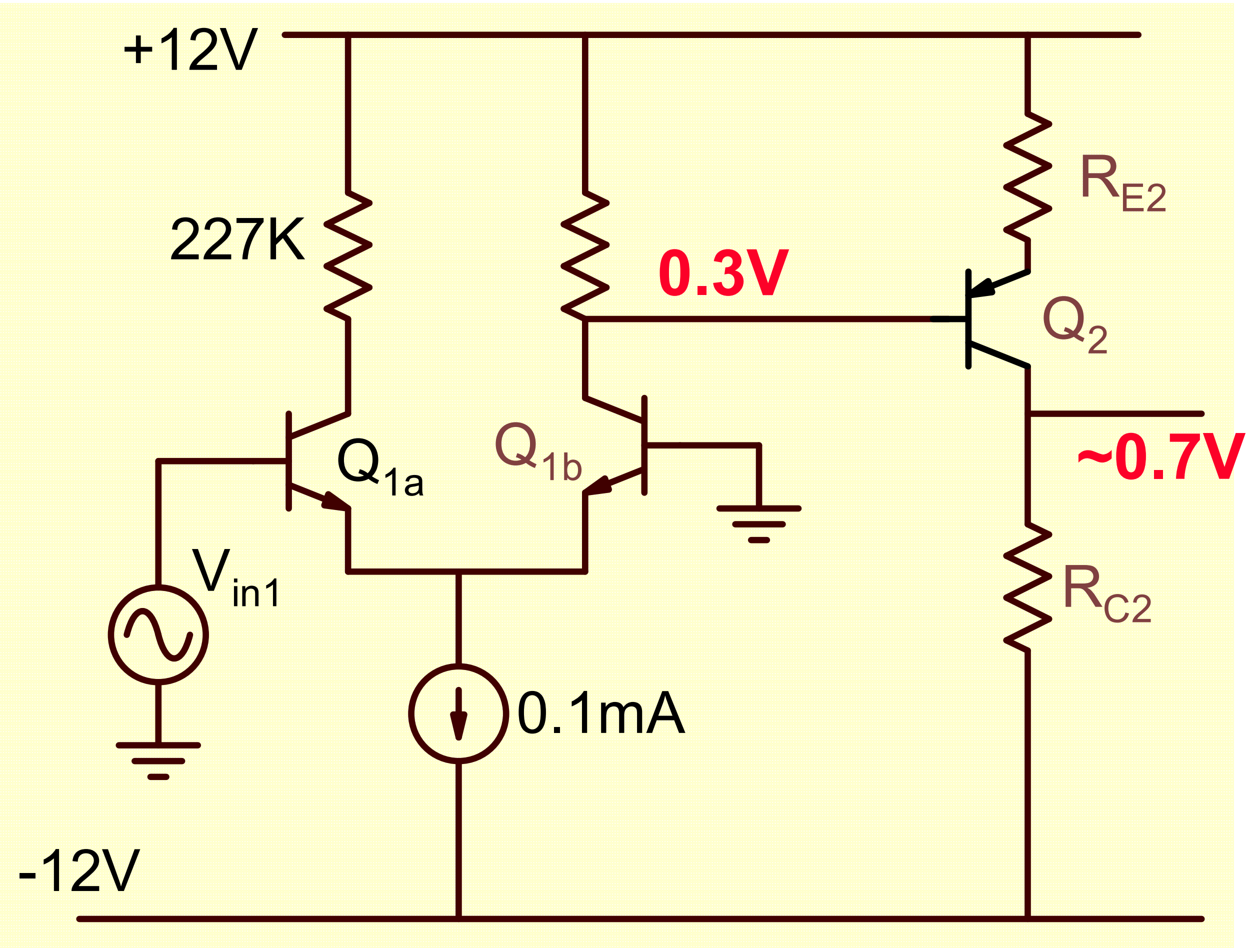
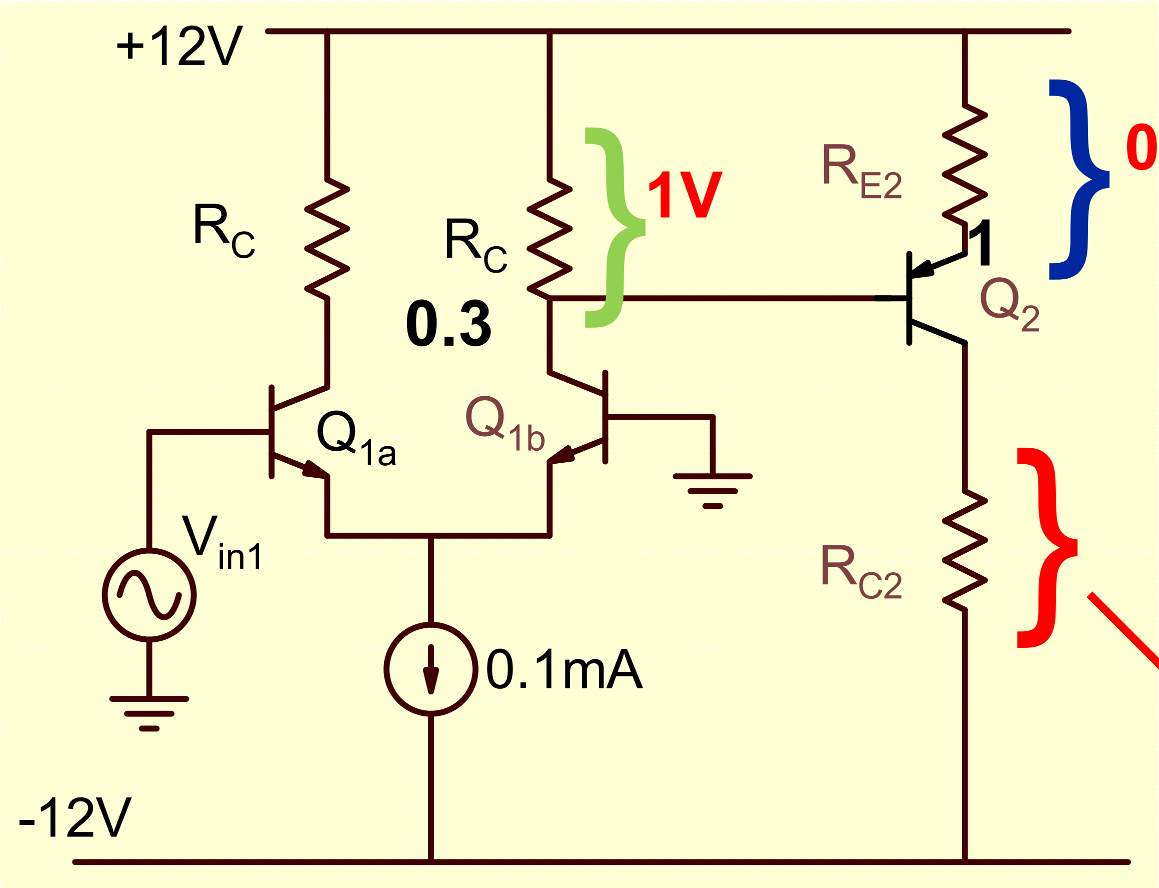
With present first stage design, gain of second stage is still negligible



$$A_{V2} = \frac{R_{C2}}{R_{E2}} = \sim 1$$

Re-look at design of first stage



$$A_{V1} = 0.5\frac{\Delta V_{C1}}{V_T}$$

$$A_{V2} = \frac{R_{C2}}{R_{E2}} = \frac{\Delta V_{C2}}{\Delta V_{E2}}$$

Assuming no loading :

Total gain: A_{V1} x A_{V2}

Constant ~12.7V

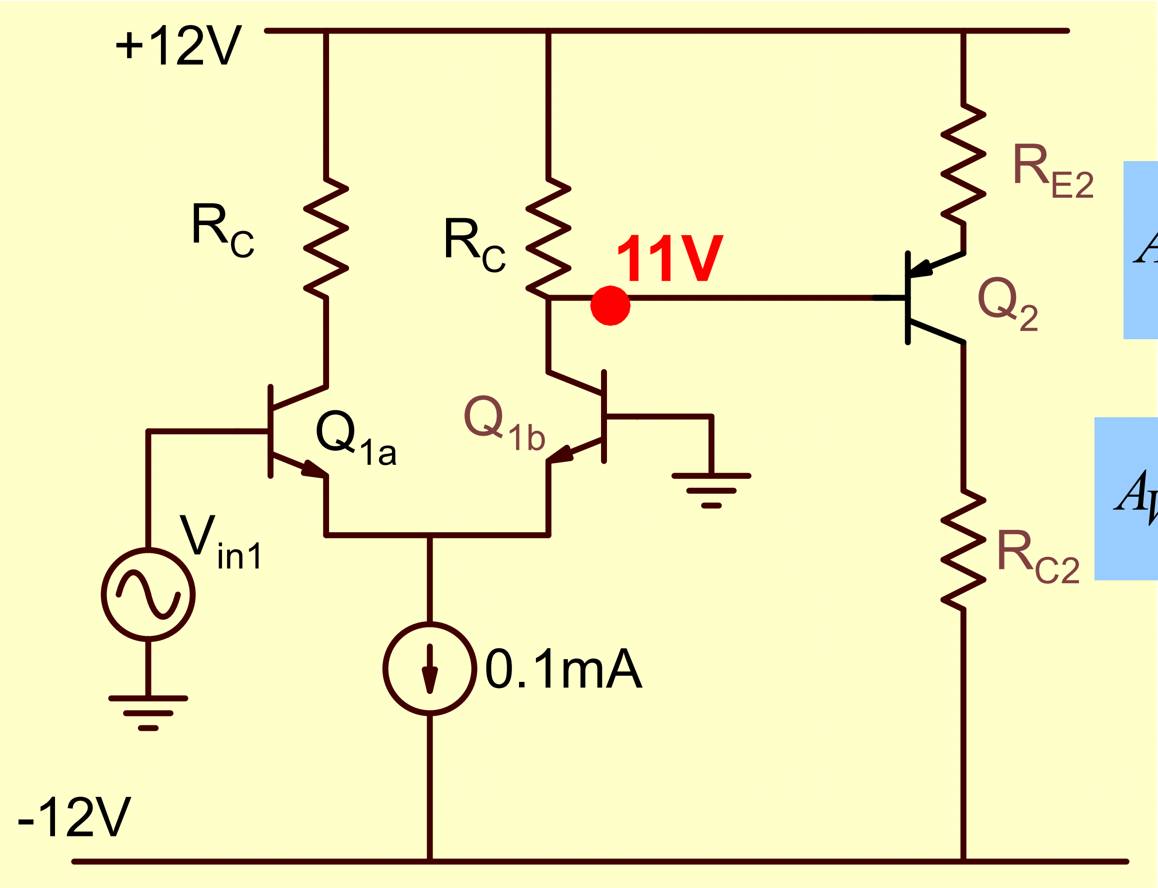
$$\text{Earlier} \quad A_V = \left(0.5\frac{11.7}{V_T}\right)\times\left(\frac{12.7}{11}\right)$$

~225 x 1.15=260

$$\text{Now} \quad A_V = \left(0.5\frac{1}{V_T}\right)\times\left(\frac{12.7}{0.3}\right)$$

~19.2 x 42.3 = 814

For V_{C1b} = 11V choice:

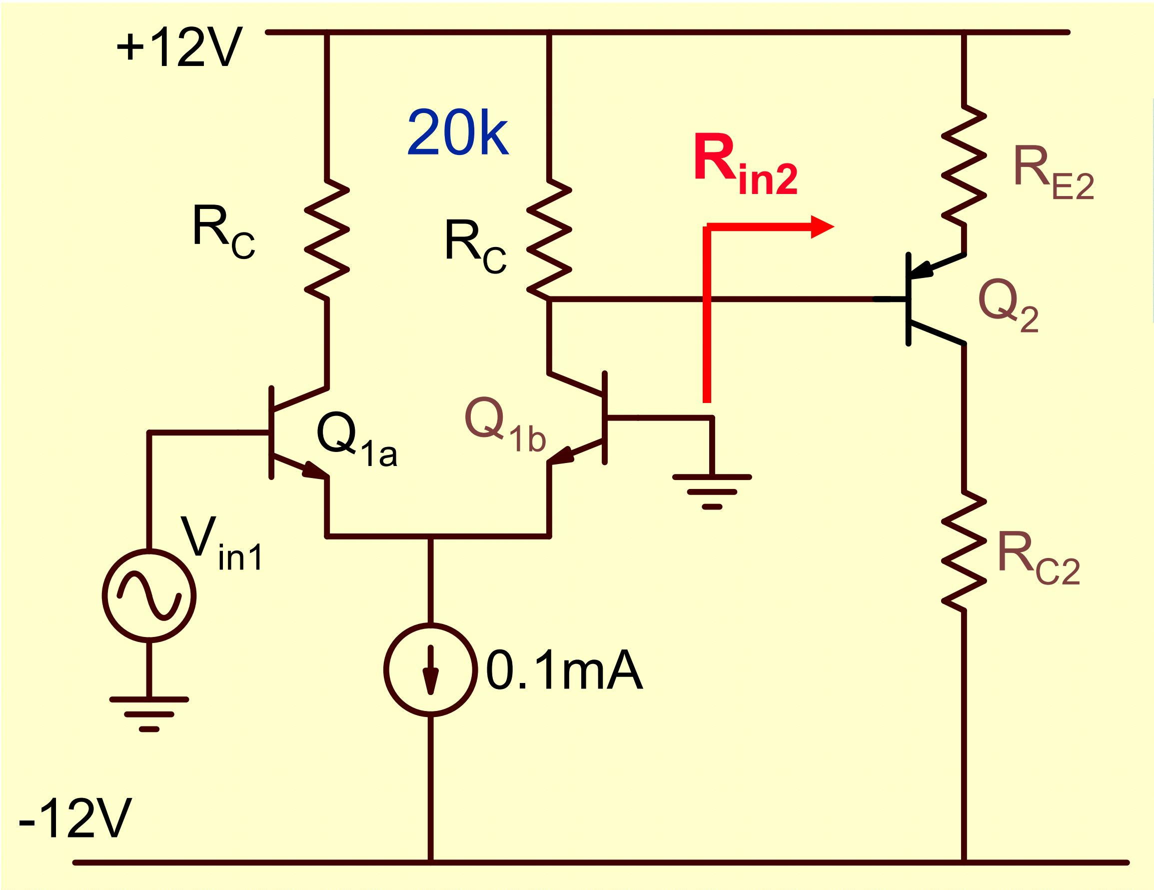


$$A_{V1} = 0.5\frac{V_{CC} - V_{C1b}}{V_T} = 19.2$$

$$A_{V2} = \frac{R_{C2}}{R_{E2}} = \frac{12.7}{11.3 - V_{C1b}} = 42.33$$

$$R_C = \frac{V_{CC} - V_{C1b}}{I_{CQ1}} = 20K\Omega$$

R_{E2} and R_{C2} ?



$$A_{V2} = \frac{R_{C2}}{R_{E2}} = \frac{12.7}{11.3 - V_{C1b}}$$
$$= 42.33$$

R_{E2} = ?

$$R_{in2} >> R_C$$

$$R_{in2} \cong \beta R_{E2} >> R_C = 20K$$
$$R_{E2} >> 200\Omega$$

Choose R_{E2} = 2K

$$\Rightarrow R_{C2} = 84.7K$$

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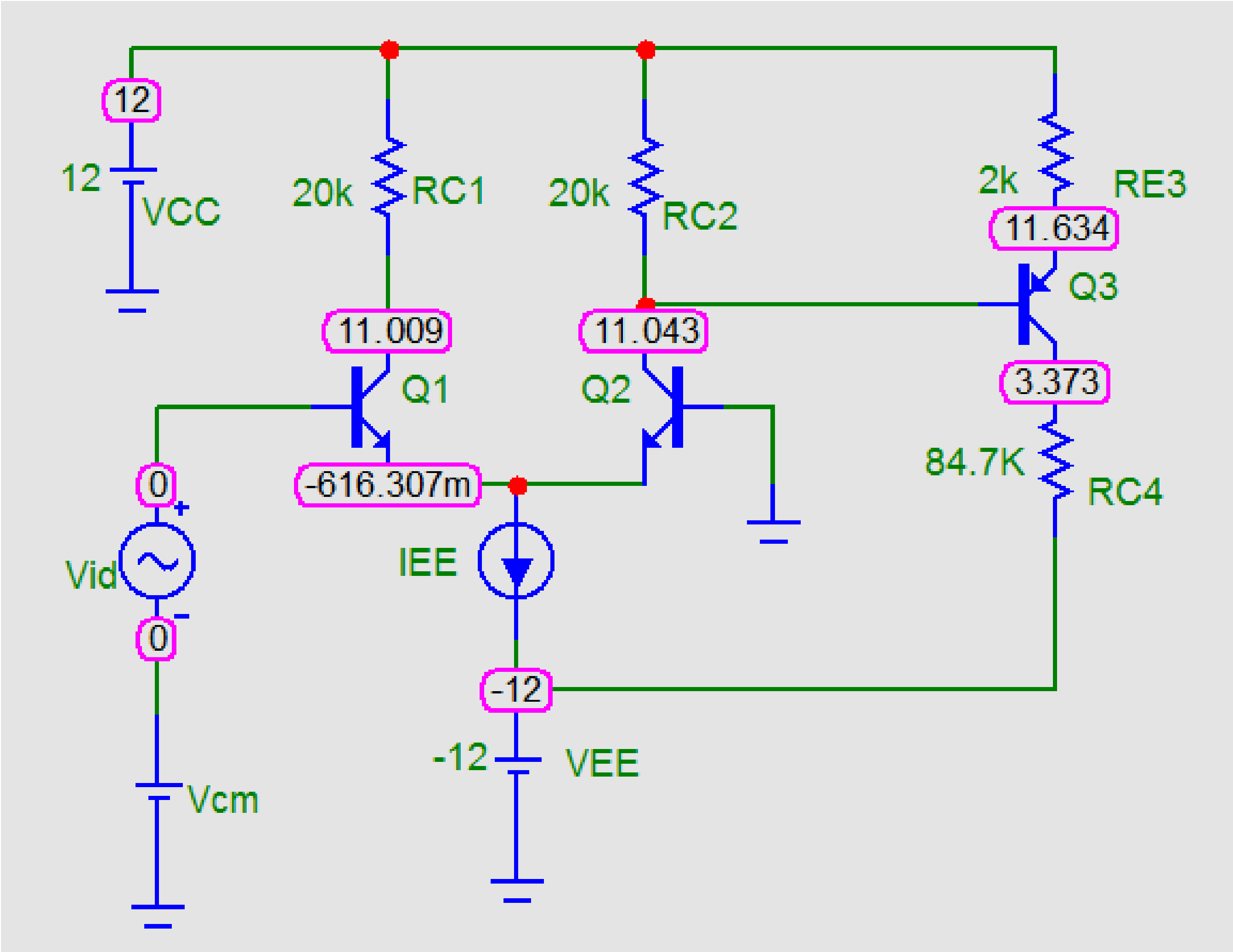
Simulation Results

$$A_V \sim 10^3 \; ; \; R_{in} \sim 100K\Omega \; ; \quad R_O = 100\Omega$$



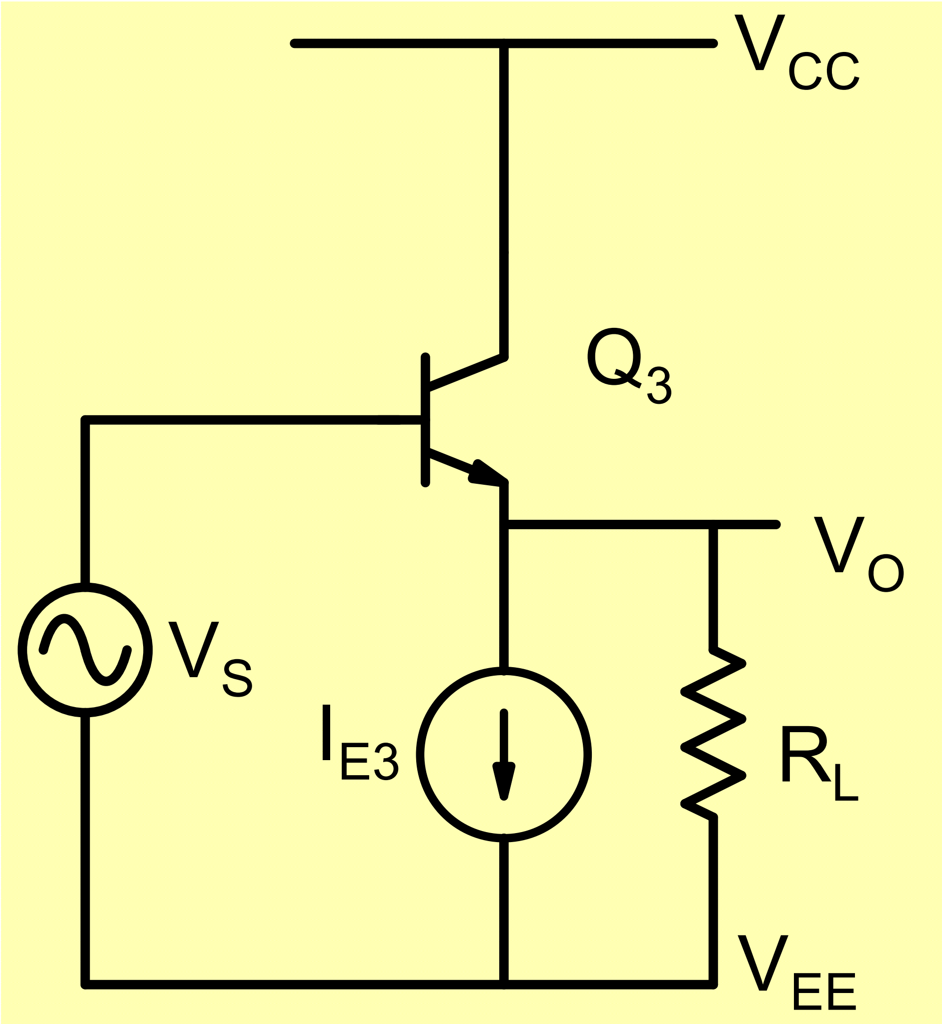
$$A_V = 671$$
$$= 17.3 \times 38.8$$

$$R_{in1} = 116K\Omega$$

$$R_O = 82.9K\Omega$$

Expected Gain~19.2 x 42.3 = 814

Output Stage: CC Amplifier



V_O is directly coupled so
V_O (dc) = 0V

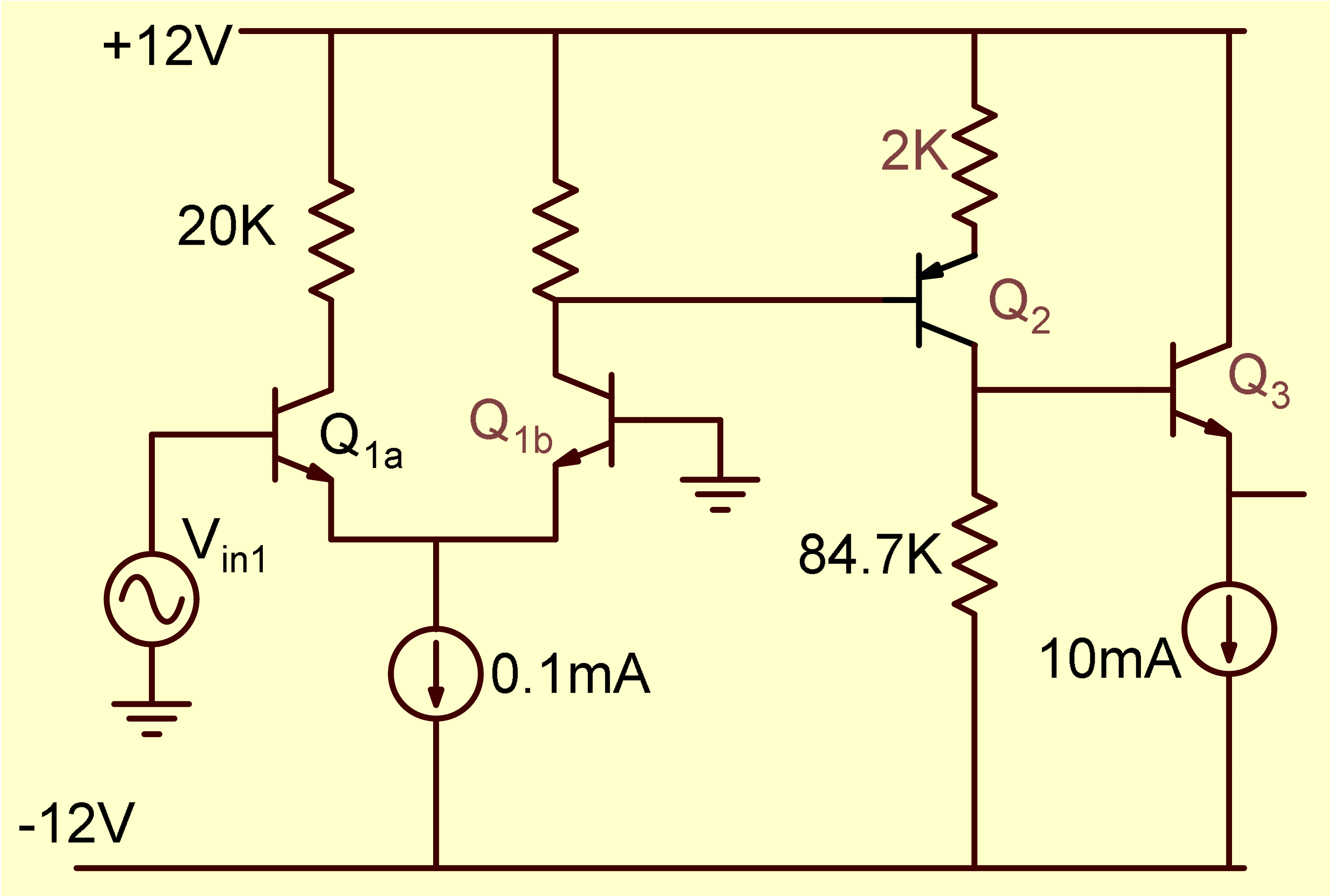
Current source bias gives better swing for a given bias current

Suppose $R_L \geq 1K\Omega$

For a ± 10V Swing $I_{E3} \geq 10mA$

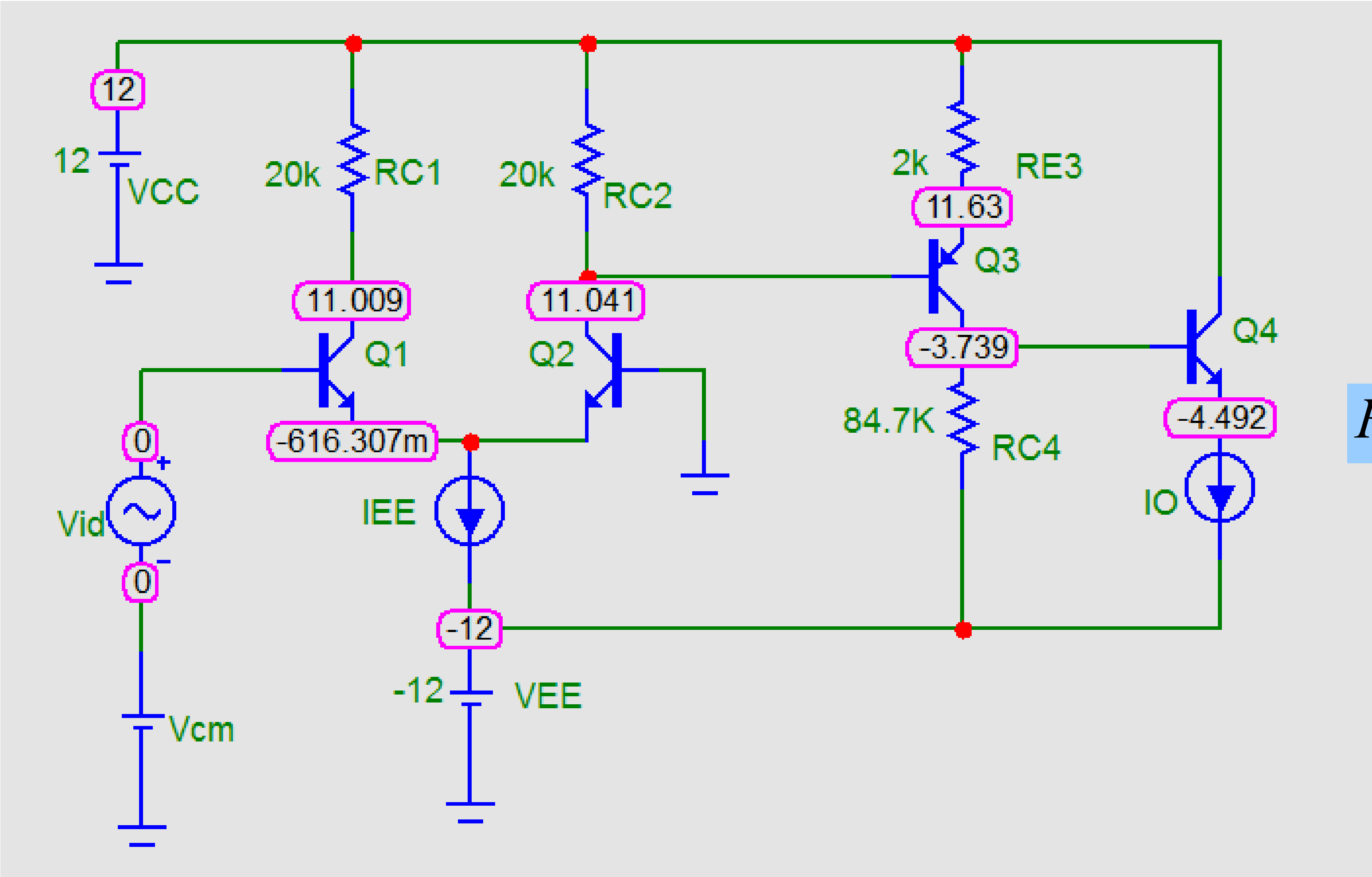
Choose 10mA

Complete Amplifier



Simulation Results

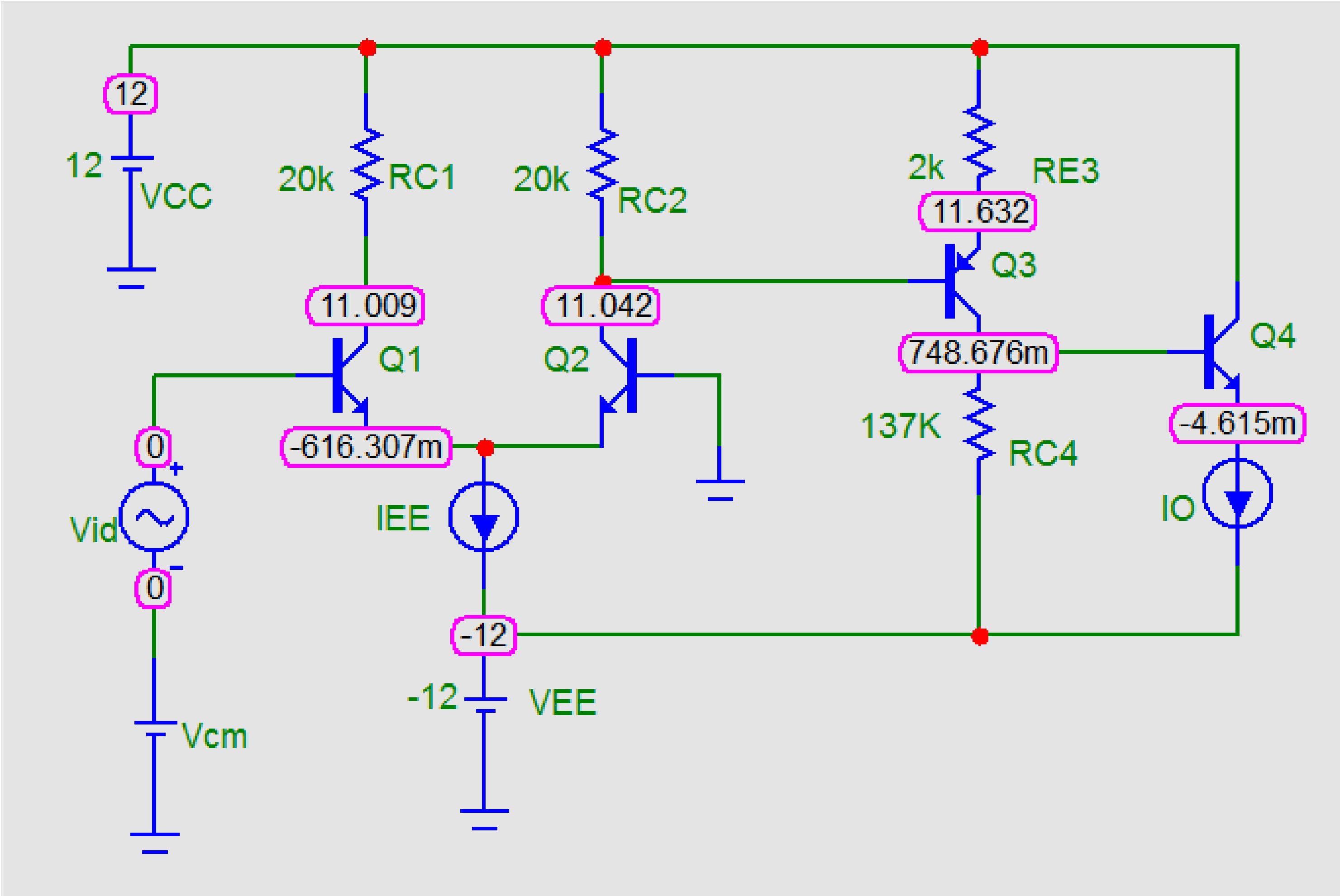
$$A_V \sim 10^3 \;;\; R_{in} \sim 100K\Omega \;;\;\; R_O = 100\Omega$$



$$A_V = 637$$

$$R_O = 673\Omega$$

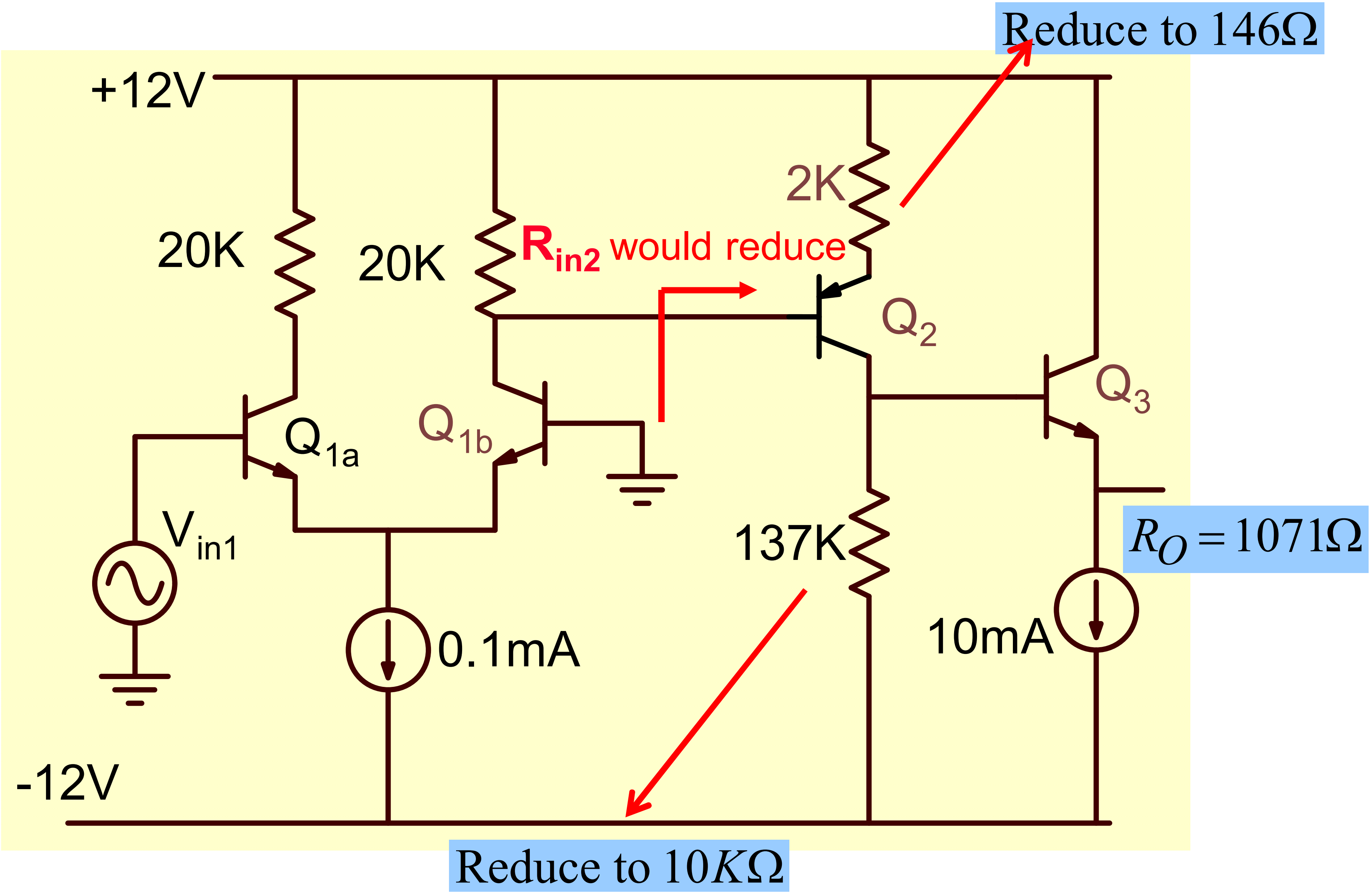
After tuning to obtain ~zero dc output voltage



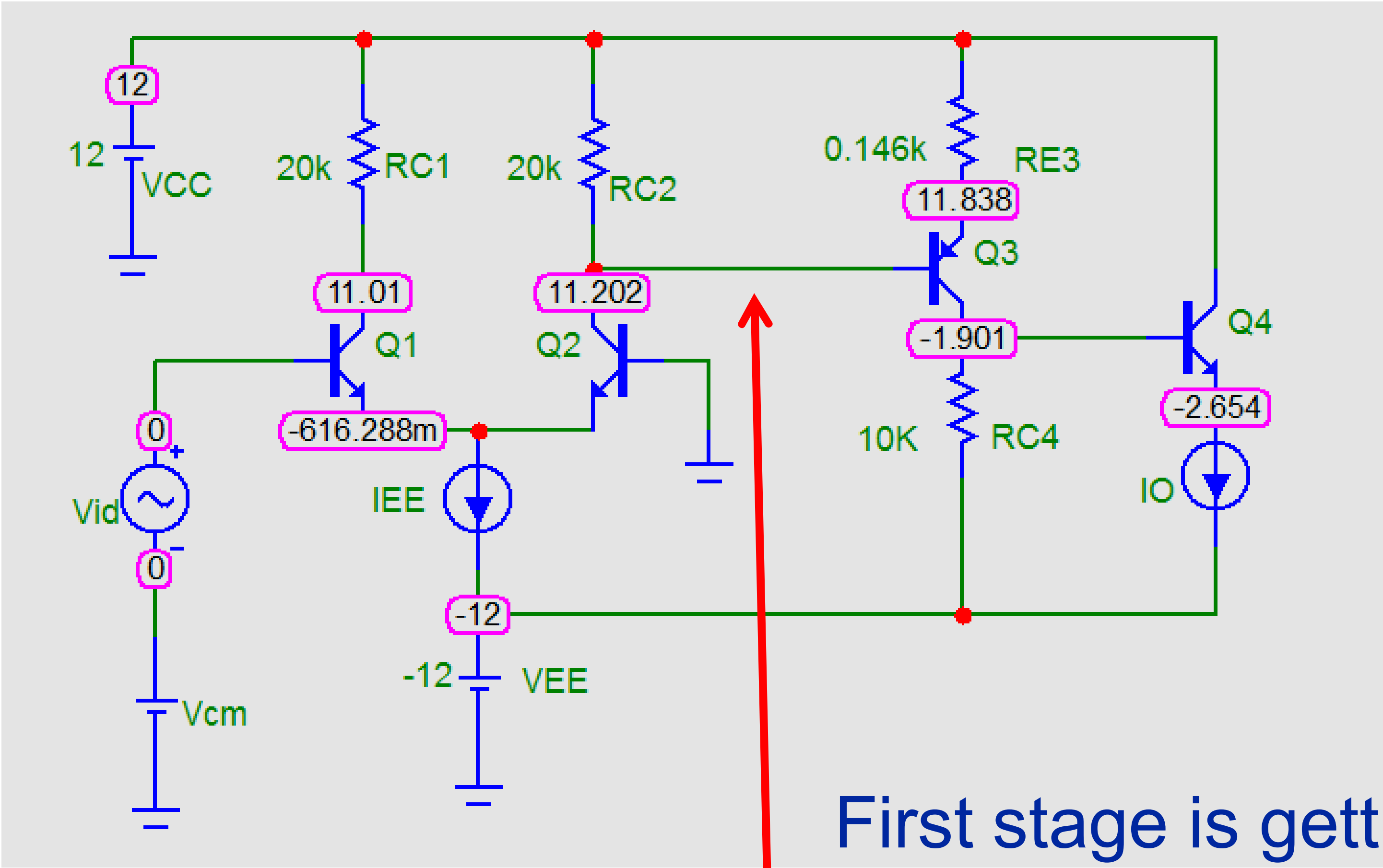
$$A_V = 972.6$$

$$R_O = 1071\Omega$$

Present design



Simulation Results



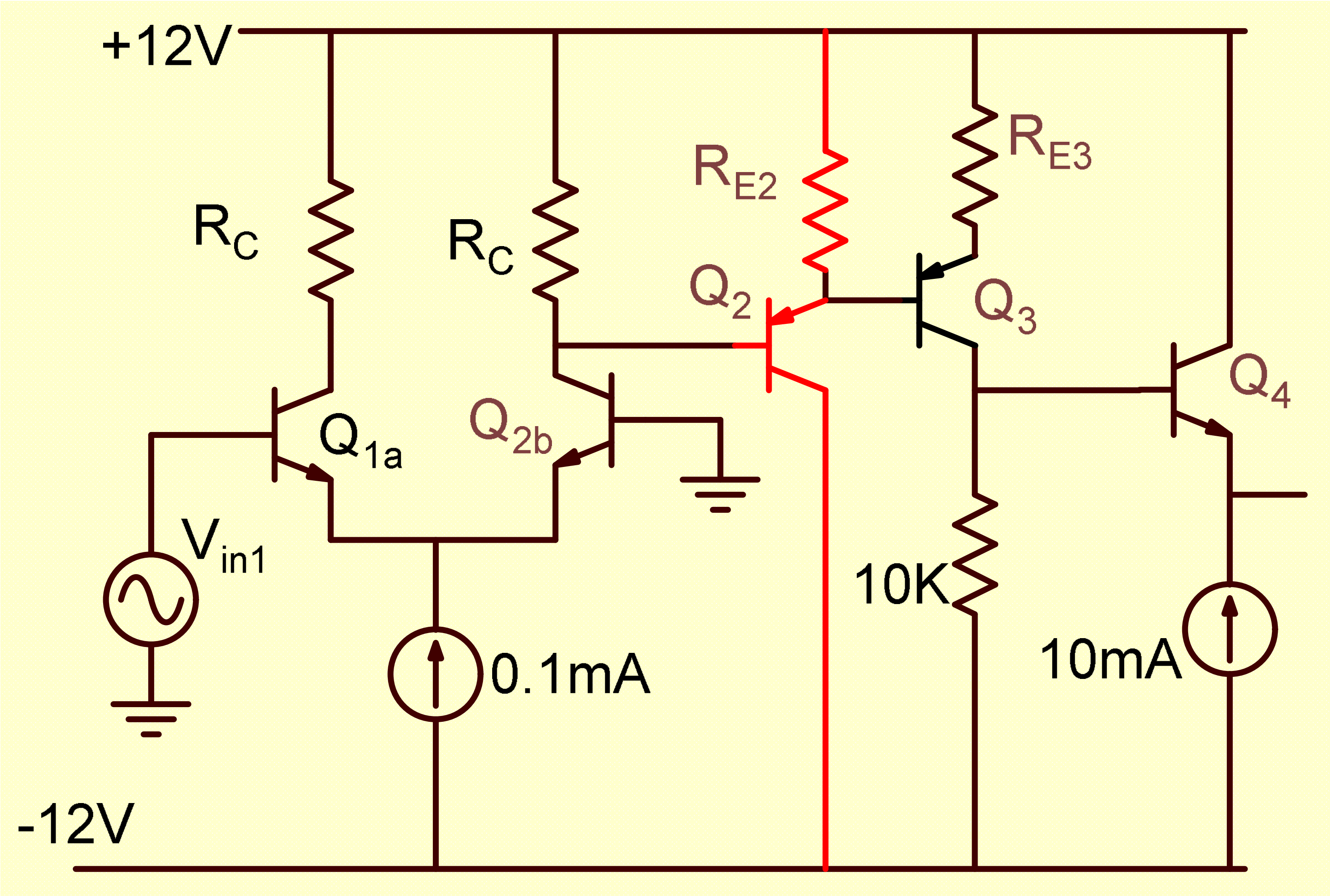
$$A_V = 513$$
$$= 9 \times 57$$

$$R_O = 84\Omega$$

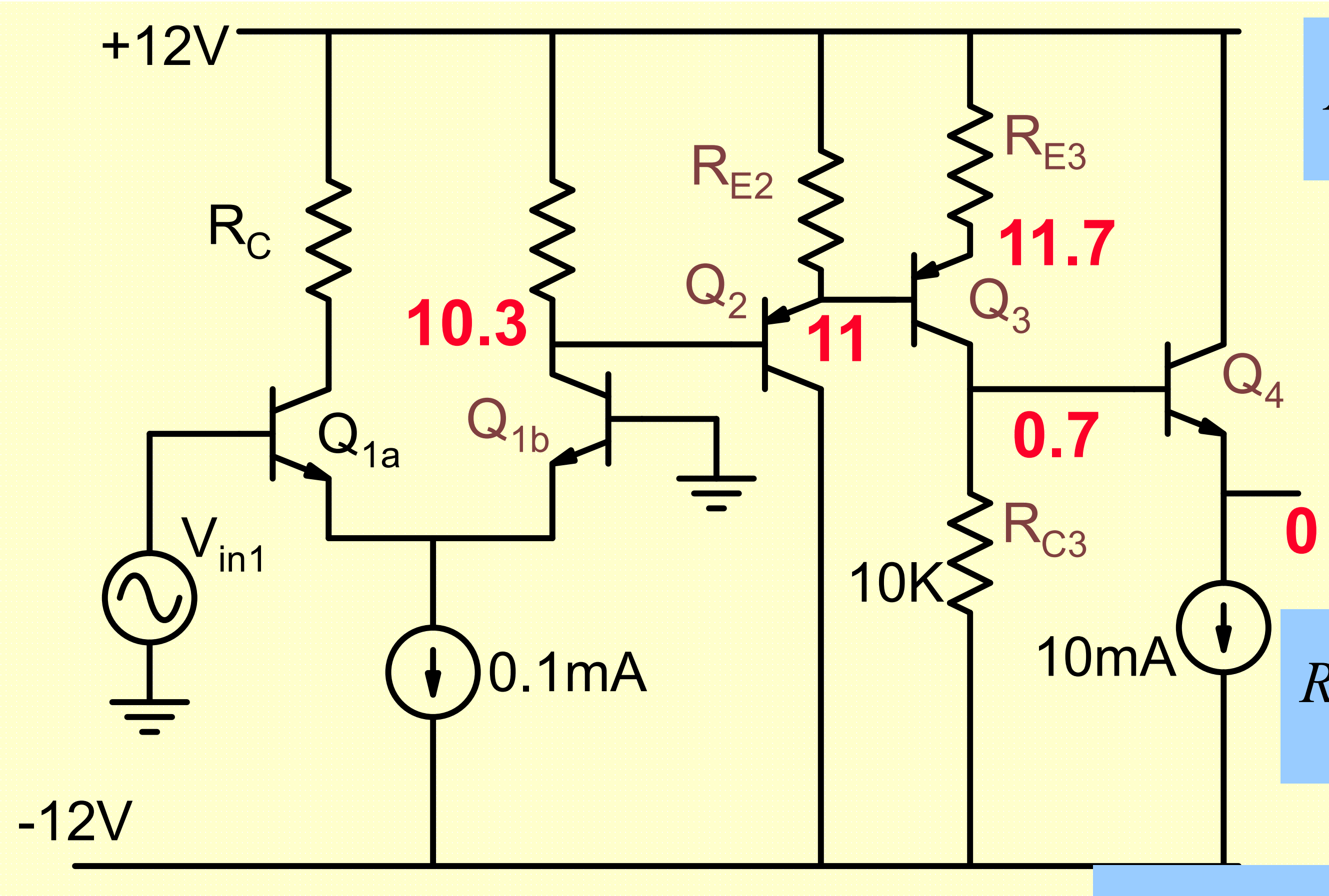
First stage is getting loaded

To prevent loading of first stage, add a CC intermediate stage

New Opamp Schematic



Design



$$A_{V3} = \frac{R_{C3}}{R_{E3}} = \frac{12.7}{12 - V_{E3}}$$

Set V_{E3} = 11.7V

$$A_{V3} = 42.3$$
$$R_{E3} = 236\Omega$$

$$R_C = \frac{12 - 10.3}{I_{CQ1}} = 34K\Omega$$

$$A_{V1} = 0.5\frac{V_{CC} - V_{C1b}}{V_T} = 32.7$$

$$\beta R_{E2} >> R_C = 34K\,;\; R_{E2} >> 340\Omega$$

Let R_{E2} = 3.4K

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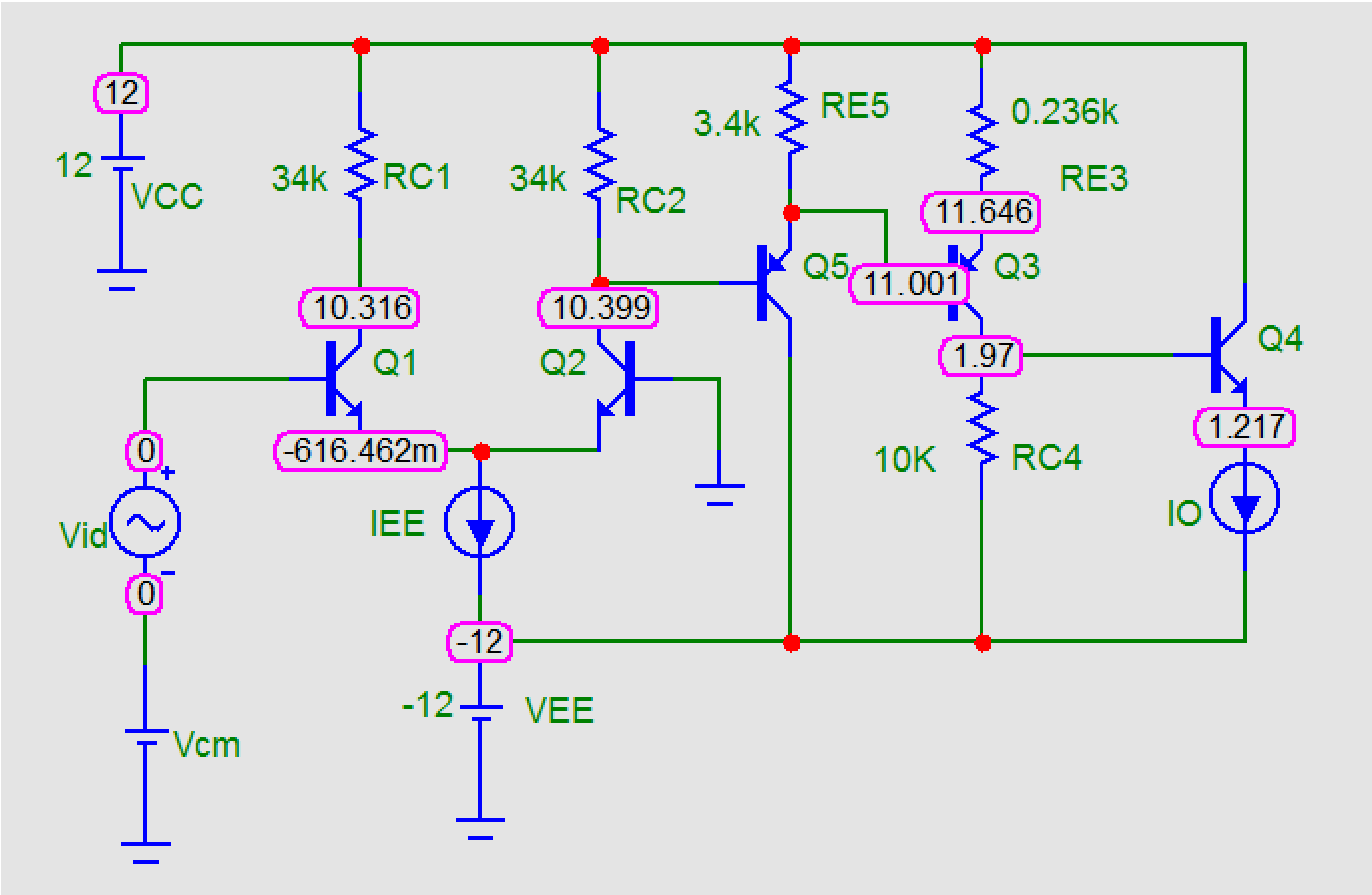
Simulation Results



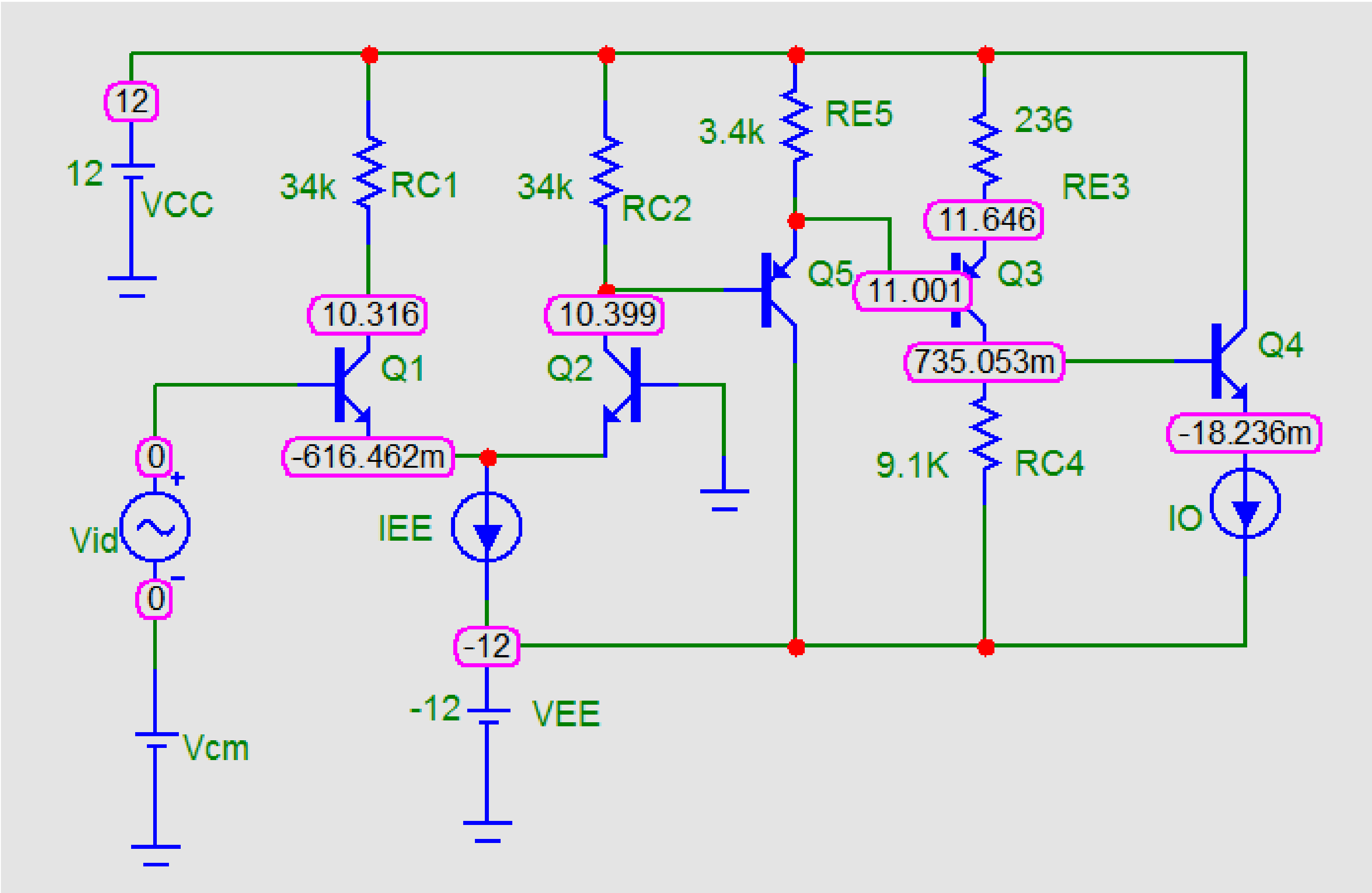
$$A_V = 1099$$

$$R_{in1} = 115K\Omega$$

$$R_O = 90.86K\Omega$$

Some fine tuning is required to bring output closer to zero

After tuning

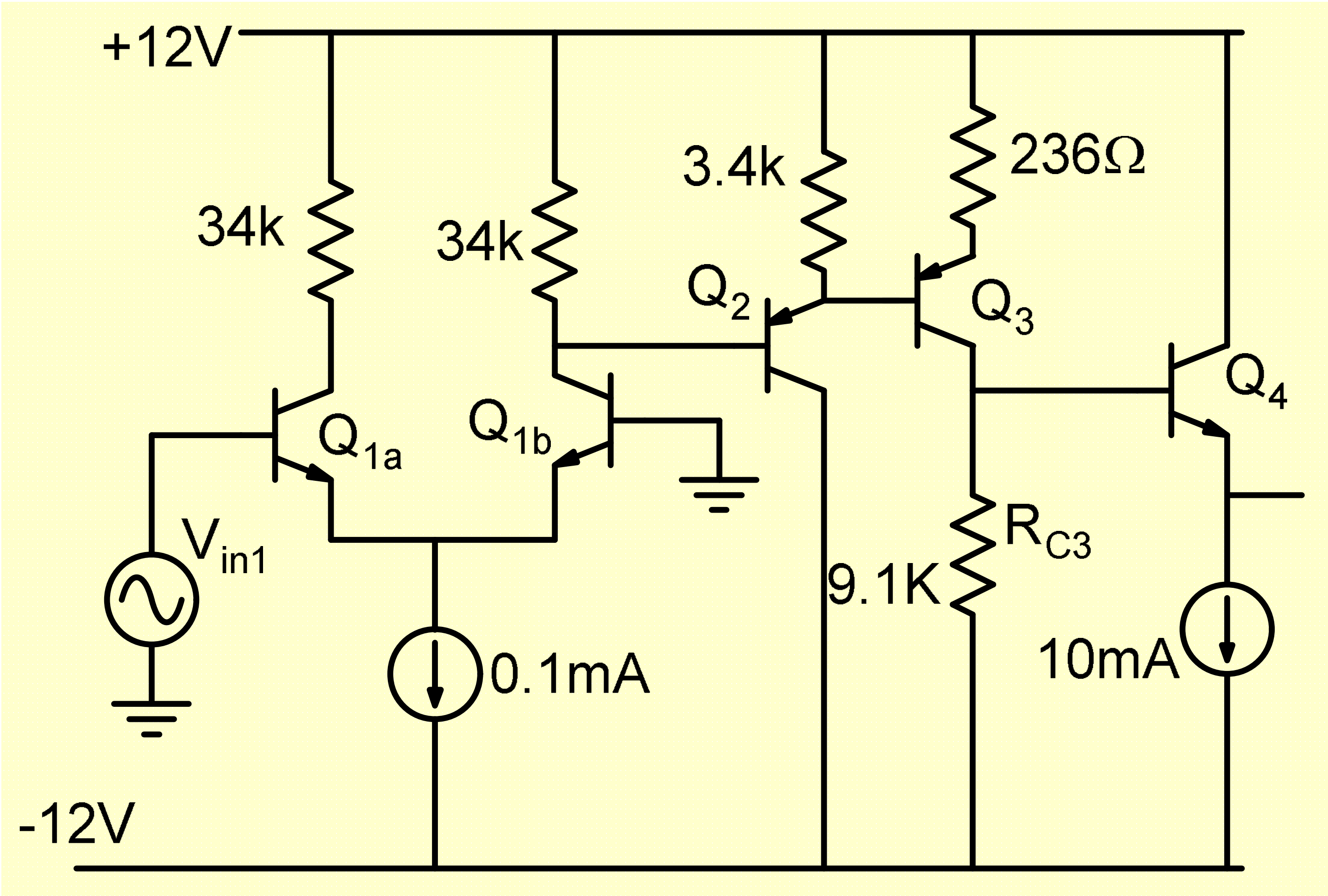


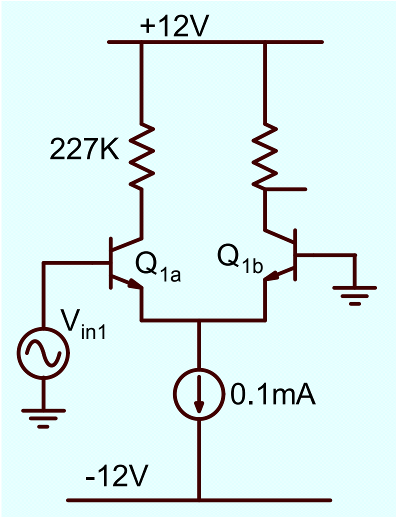
$A_V = 1002$

$R_{in1} = 115K\Omega$

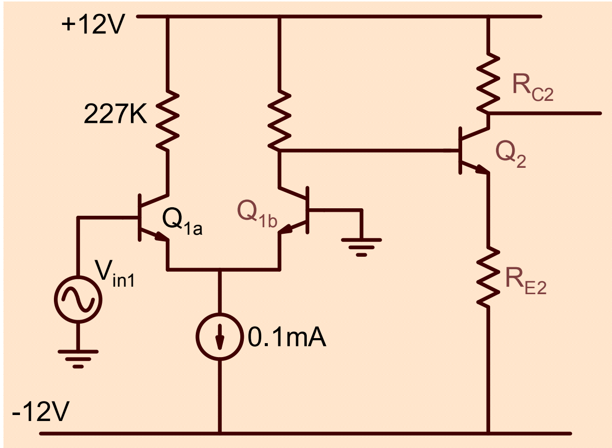
$R_O = 82.2K\Omega$

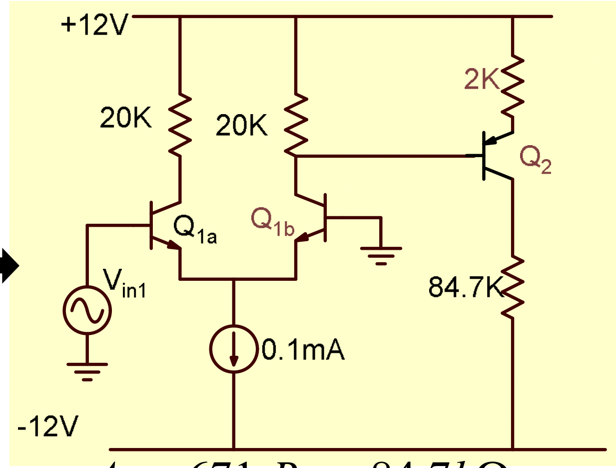
Final Design



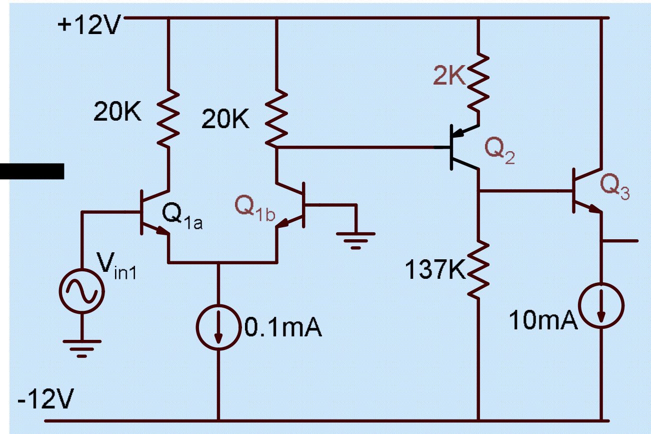


$A_V = 227; R_{in} = 100k; R_O = 227k\Omega$

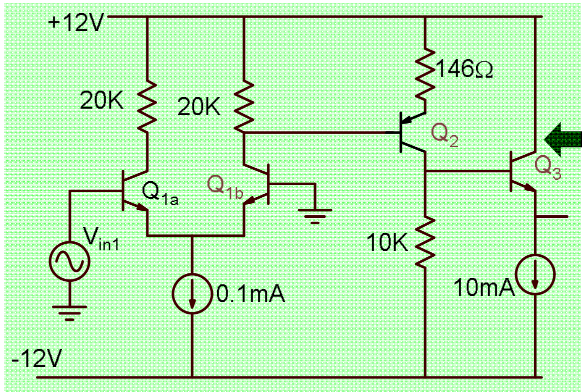




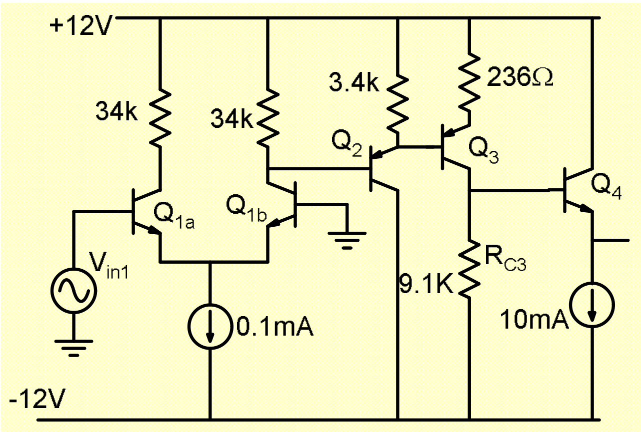
$A_V = 671; R_O = 84.7k\Omega$



$A_V = 972; R_O = 1071\Omega$



$A_V = 513; R_O = 84\Omega$



$A_V = 1002; R_{in} = 115k; R_O = 82\Omega$