EE210: Microelectronics-I

Lecture-28: Differential Amplifiers_1

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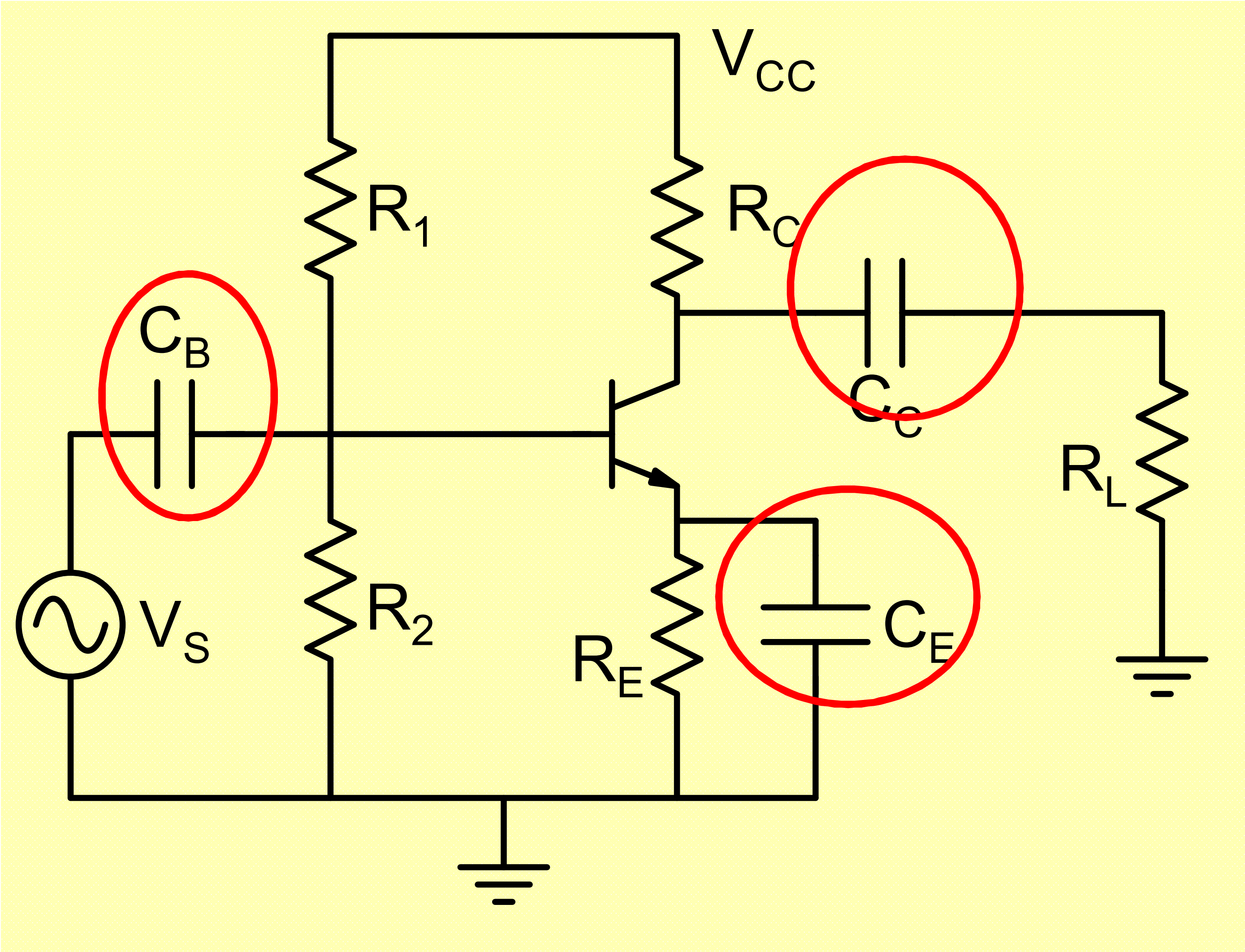
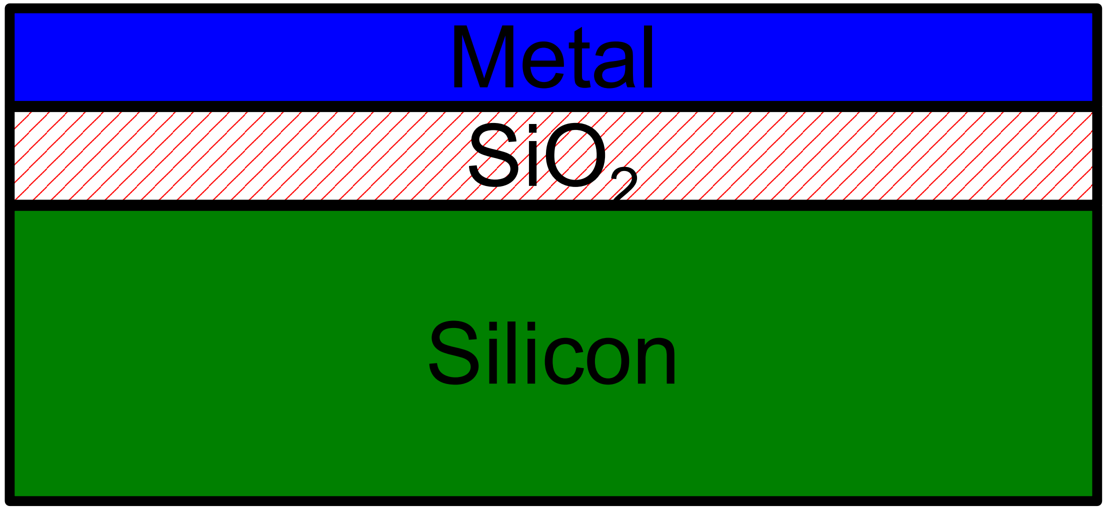
How do we bias without using coupling capacitors?



Making large capacitors (μF) on chip is impossible !



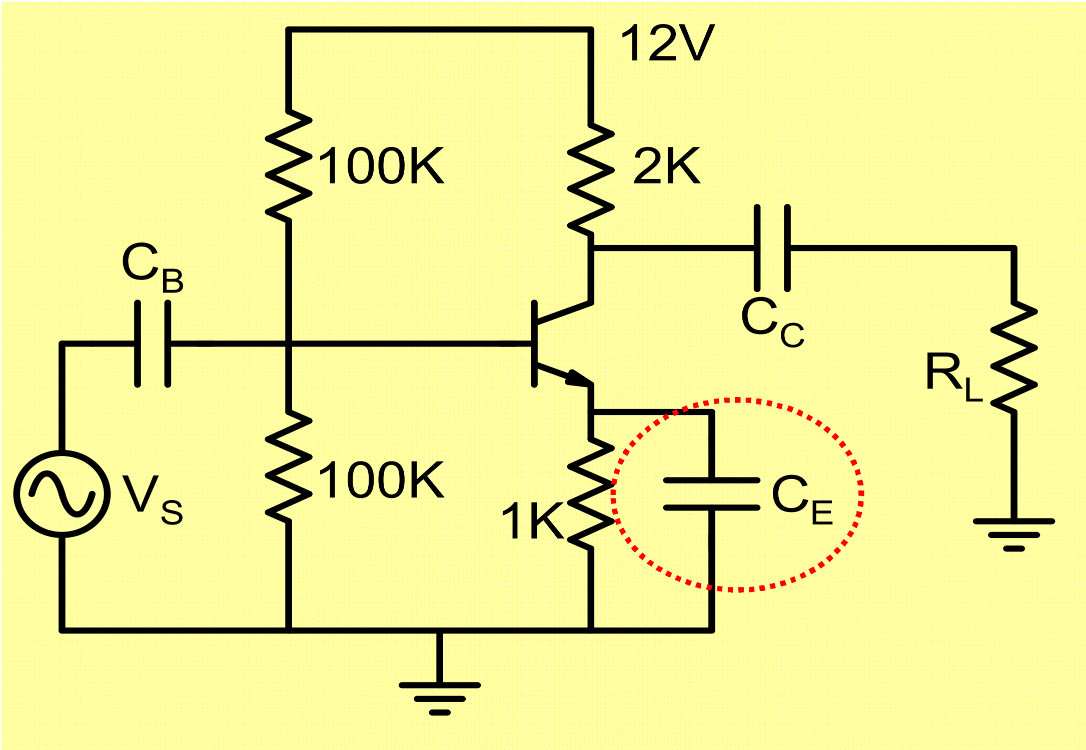
$$C = \frac{\varepsilon_{ox}}{t_{ox}} \times Area$$

$$\varepsilon_{ox} = 3.9 \times 8.85 \times 10^{-14} F/cm \; ; \; t_{ox} = 20nm$$

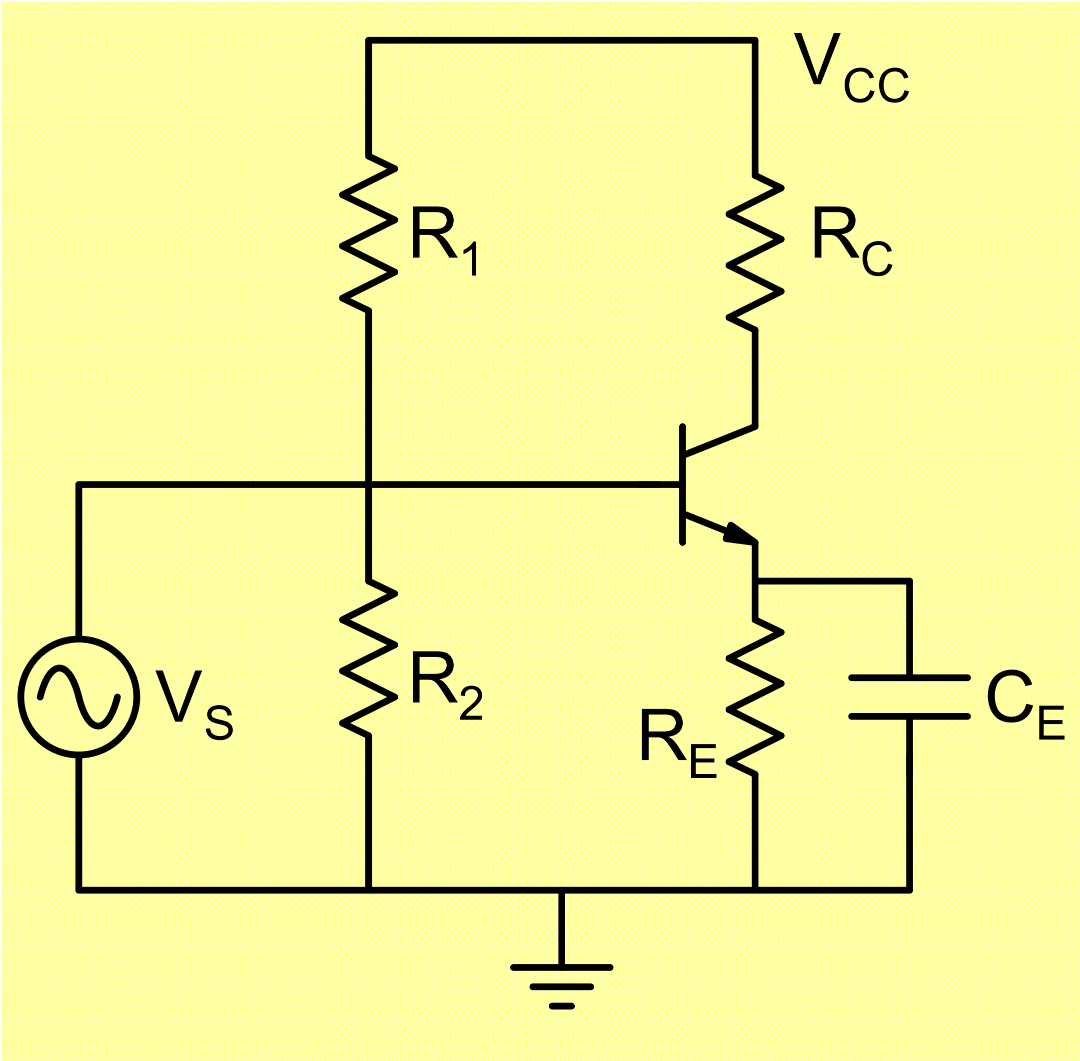
$$\text{Area} = \; 57 \; cm^2 \text{ !! for } 10\mu\text{F capacitor}$$

One can only make capacitors of the order of a few Picofarads on chip

This would lead to an unacceptably large lower cutoff frequency

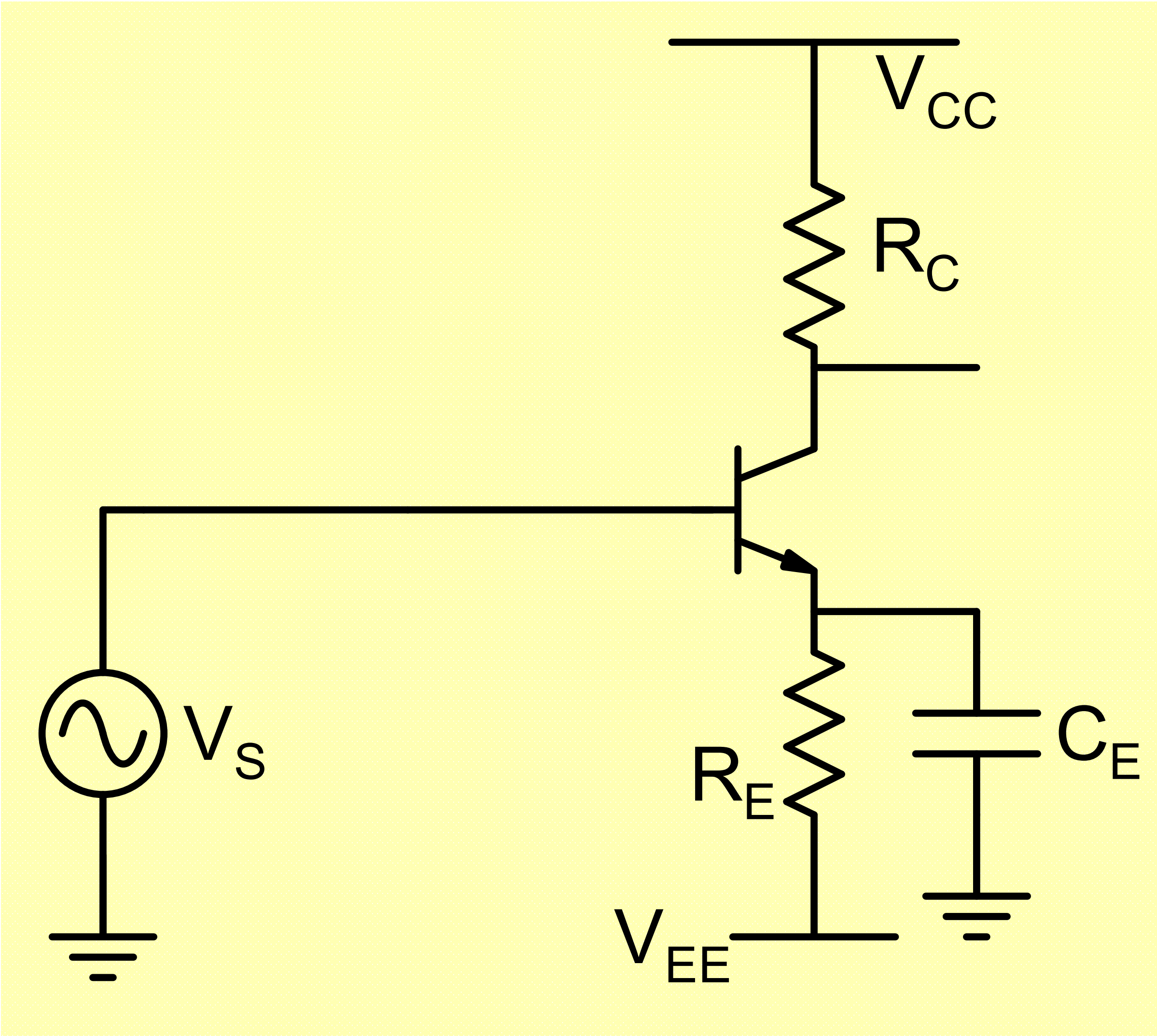


Cannot simply remove C_B !



V_{BE} = 0 so that BJT is in Cutoff Mode

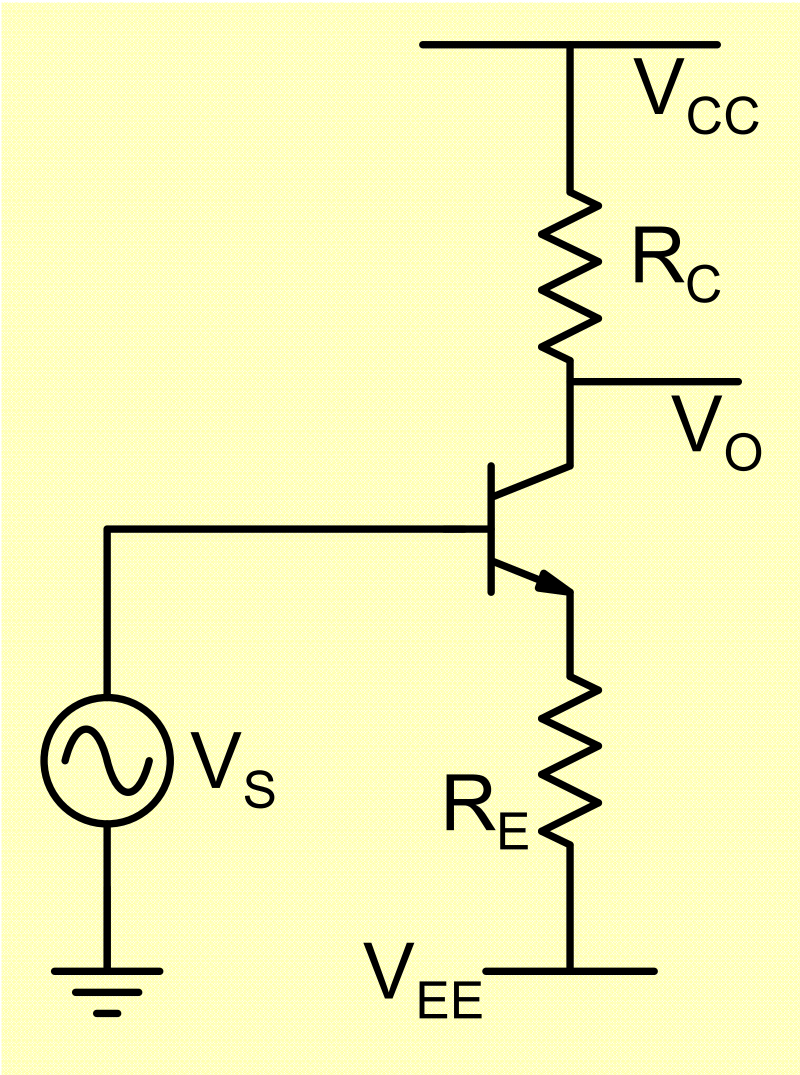
dc coupled input with use of negative power supply



$$I_{CQ} = \frac{-0.7 - V_{EE}}{R_E}$$

Good bias point stability against variations in β

Without C_E , voltage gain is too low !



$$A_V \cong -\frac{R_C}{R_E}$$

$$I_{CQ} = \frac{-0.7 - V_{EE}}{R_E}$$

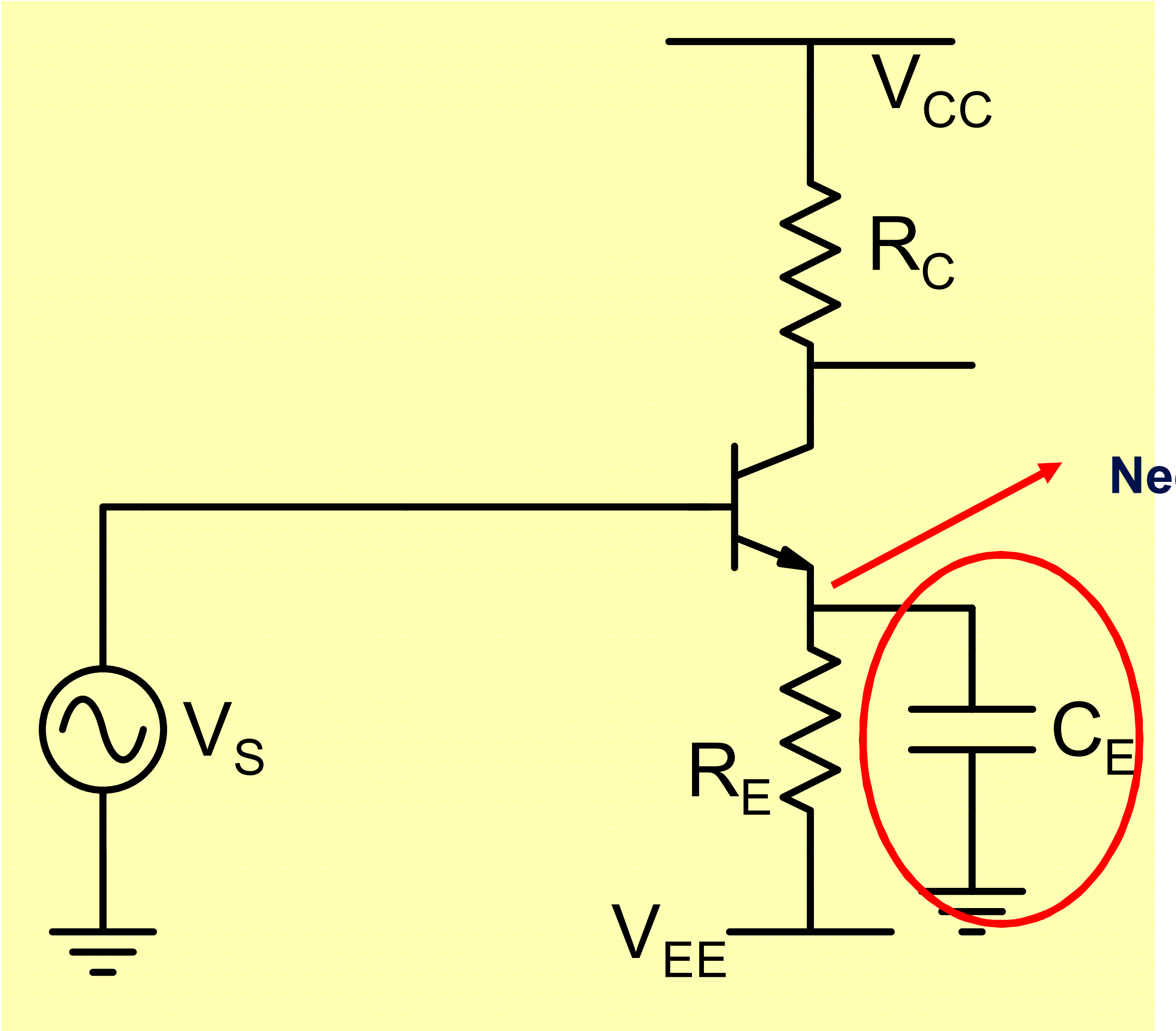
$$I_{CQ} = \frac{V_{CC} - V_{CQ}}{R_C}$$

$$|A_V| \cong \frac{V_{CC} - V_{CQ}}{-0.7 - V_{EE}}$$

$$< \frac{V_{CC}}{-0.7 - V_{EE}} = \frac{12}{11.3}$$

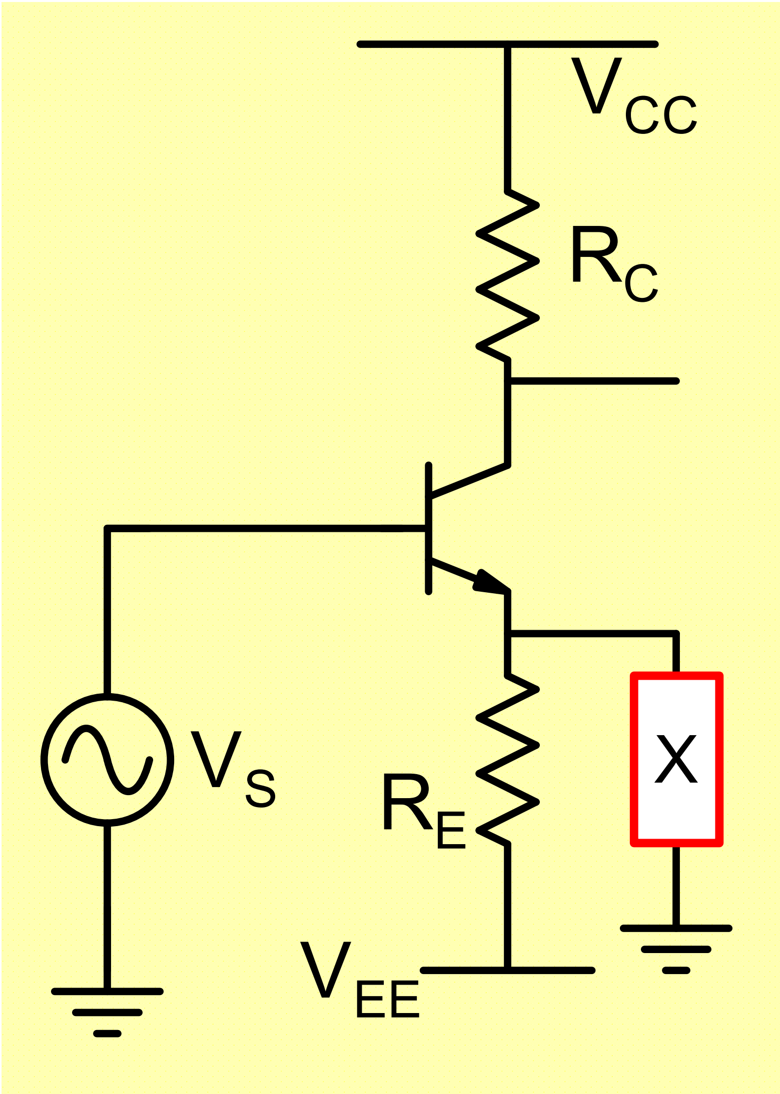
Have to keep R_E for proper biasing

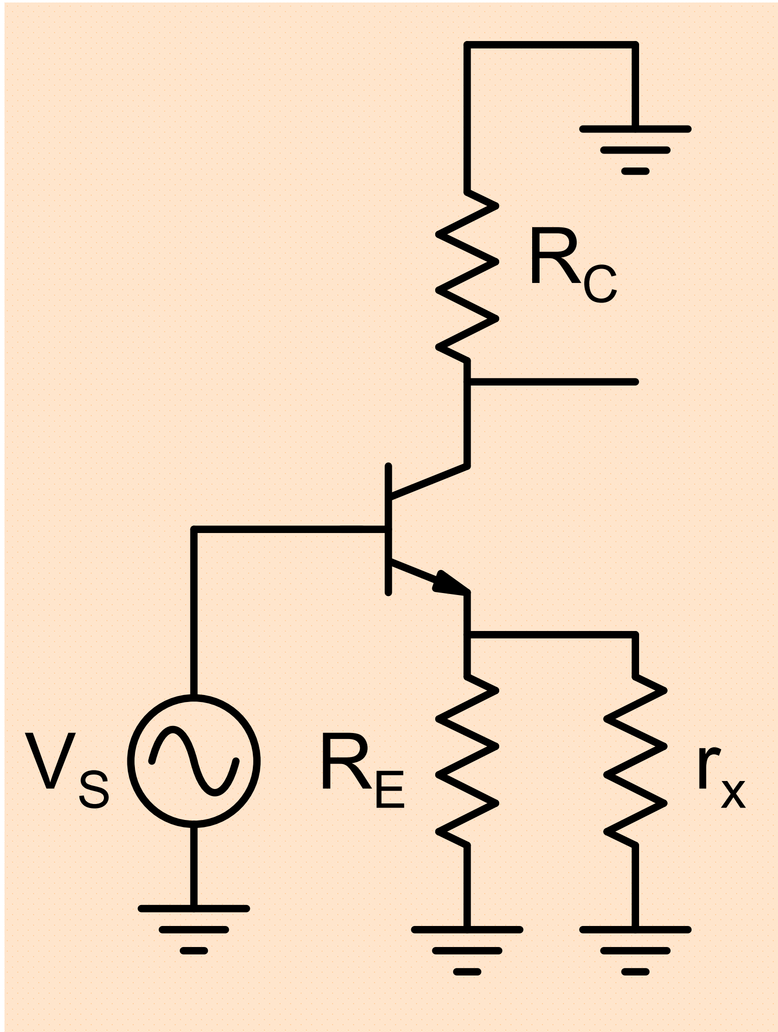
Key Problem: How do we get rid of C_E ?



Need Small signal ground

Want an element with very low small-signal resistance

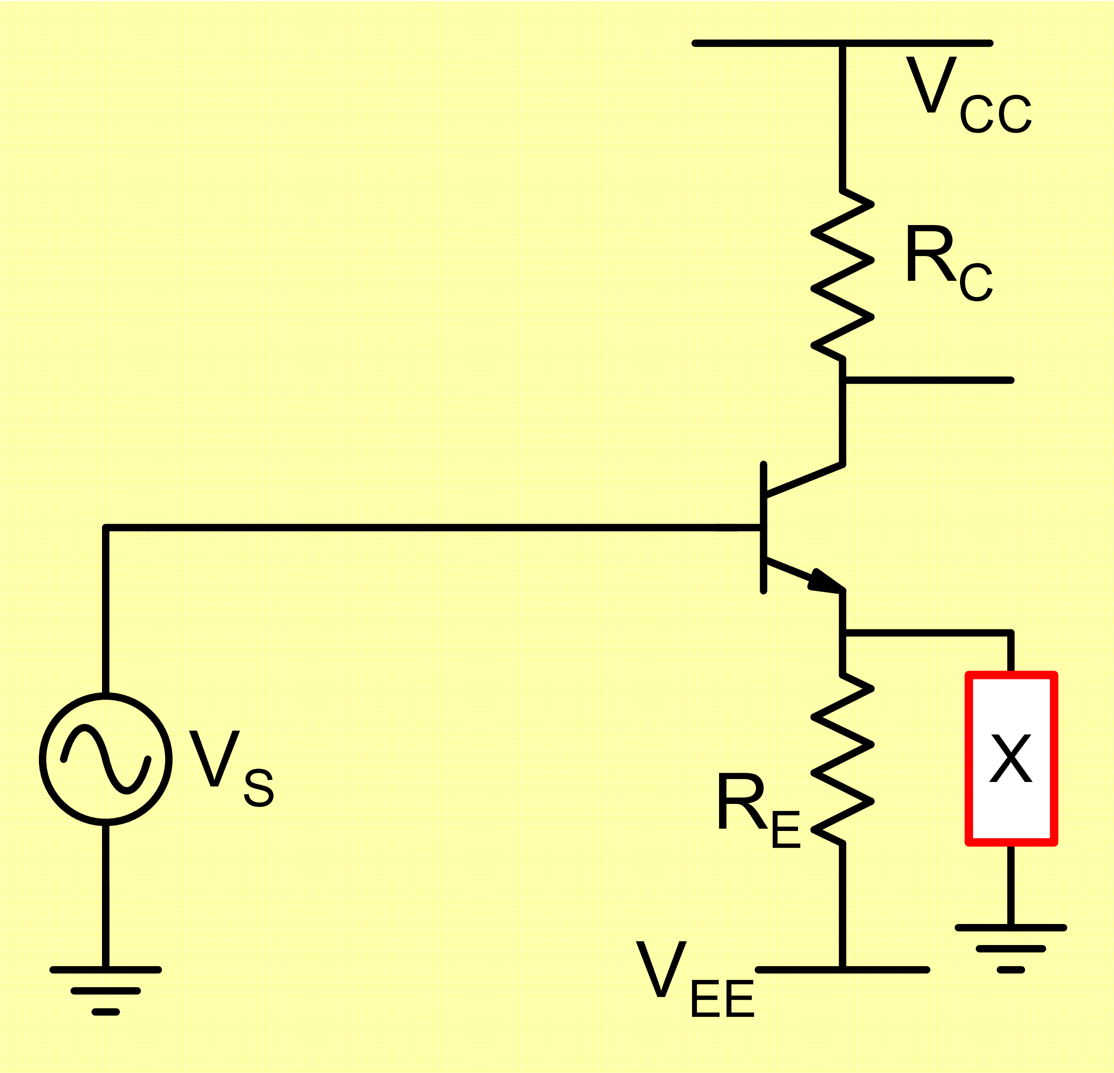


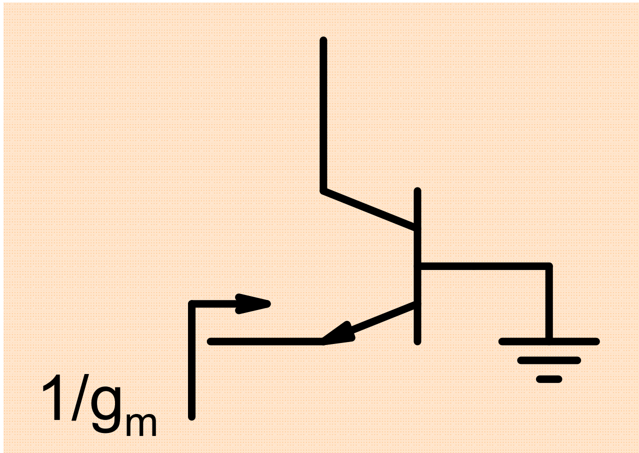


$$r_x << R_E, R_C$$

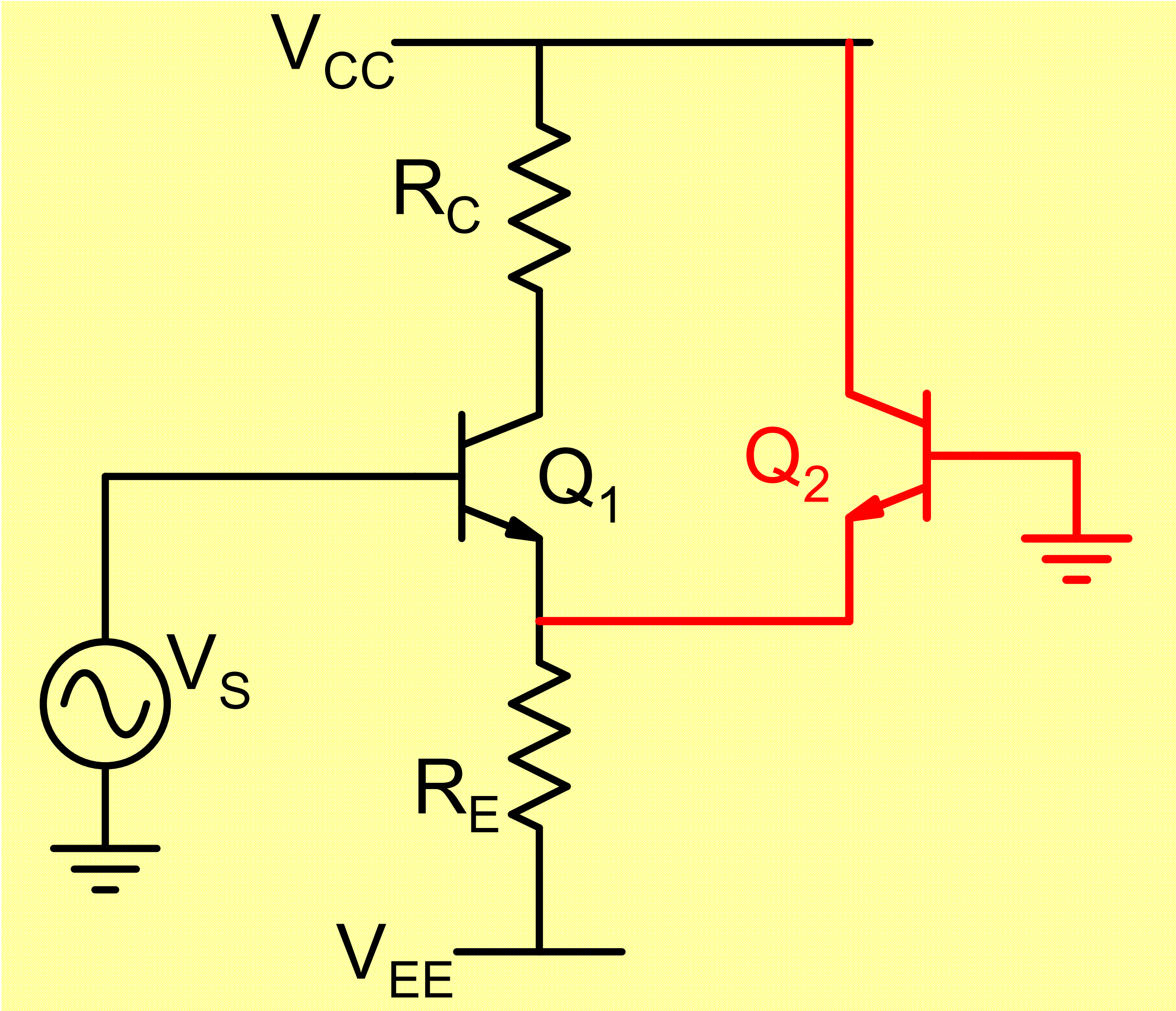
G-Number

Want an element with very low small-signal resistance

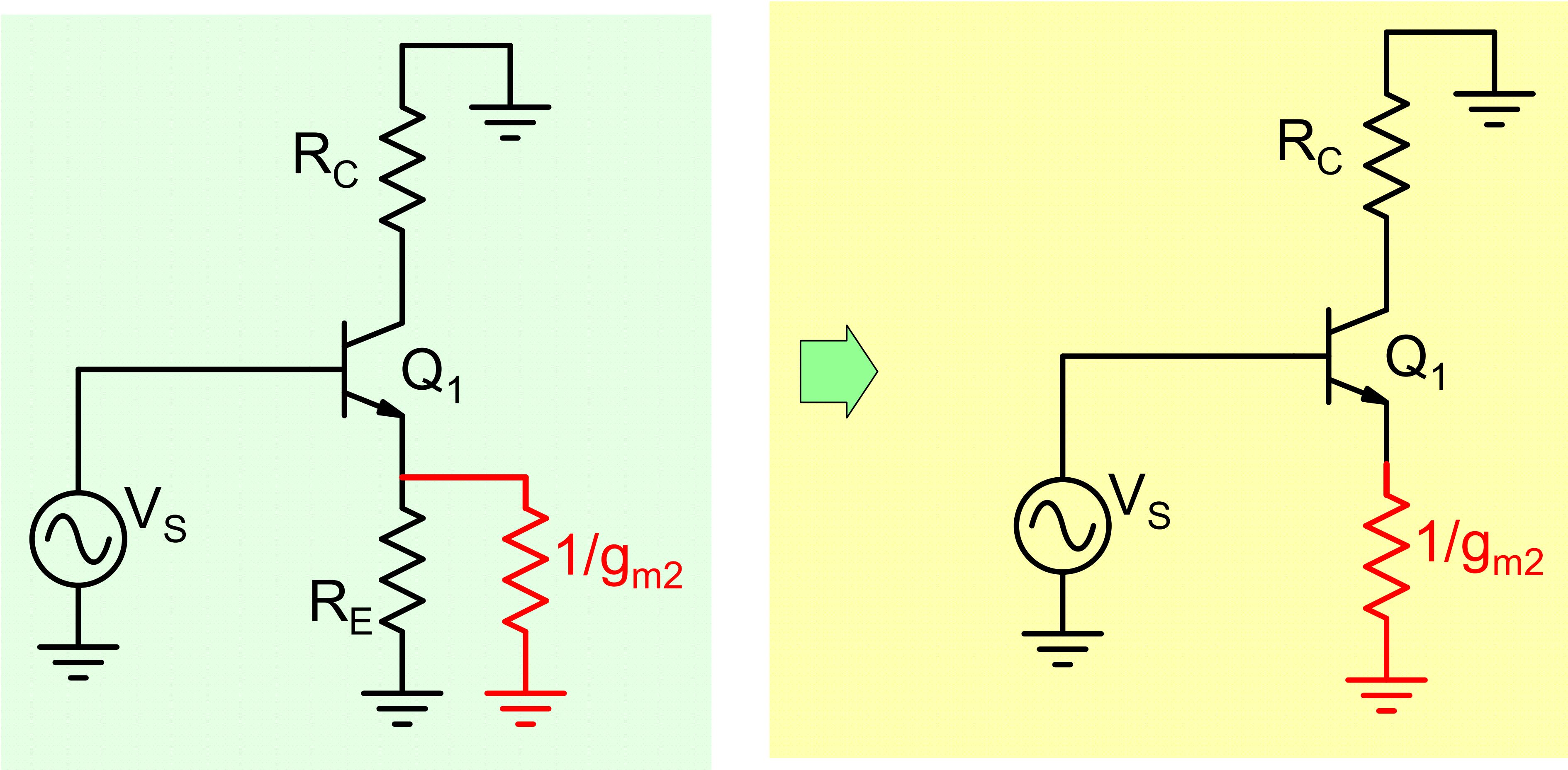




Possible Solution



Small Signal Gain



$$A_V \cong -\frac{g_{m1}}{1 + g_{m1}/g_{m2}} R_C = -0.5 g_m R_C$$

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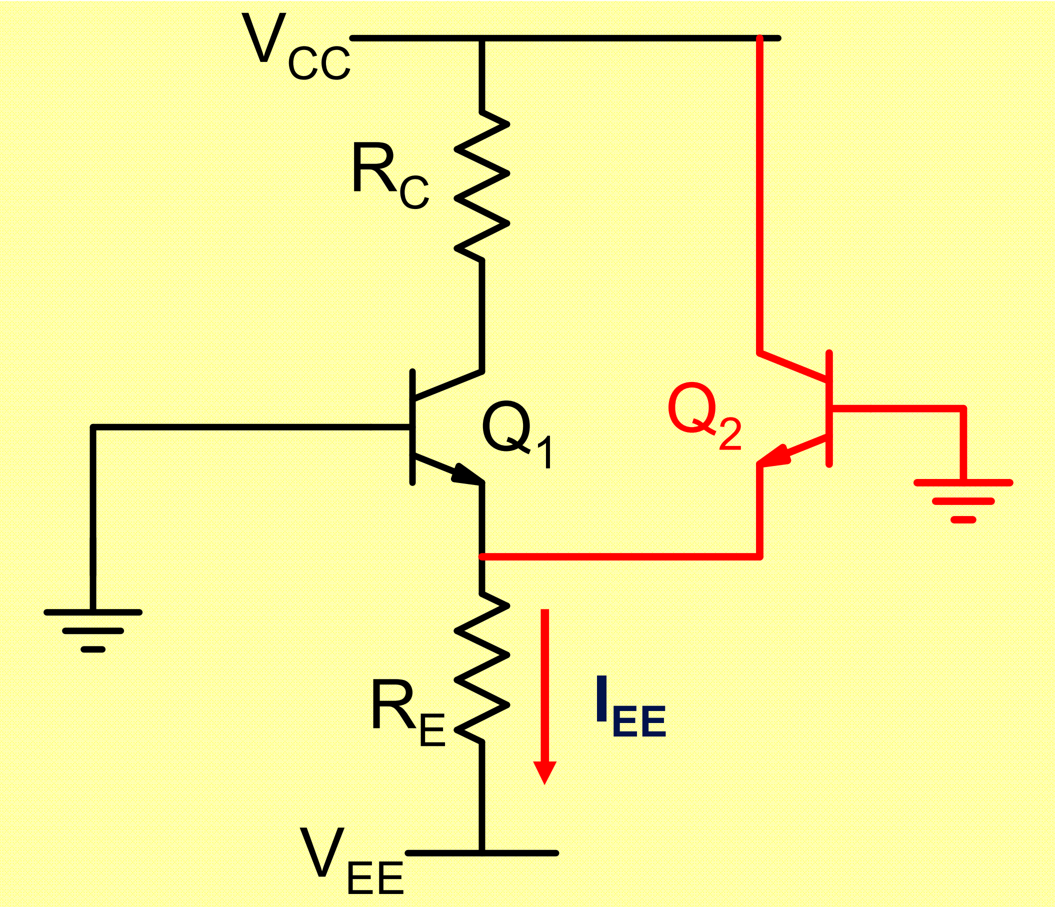
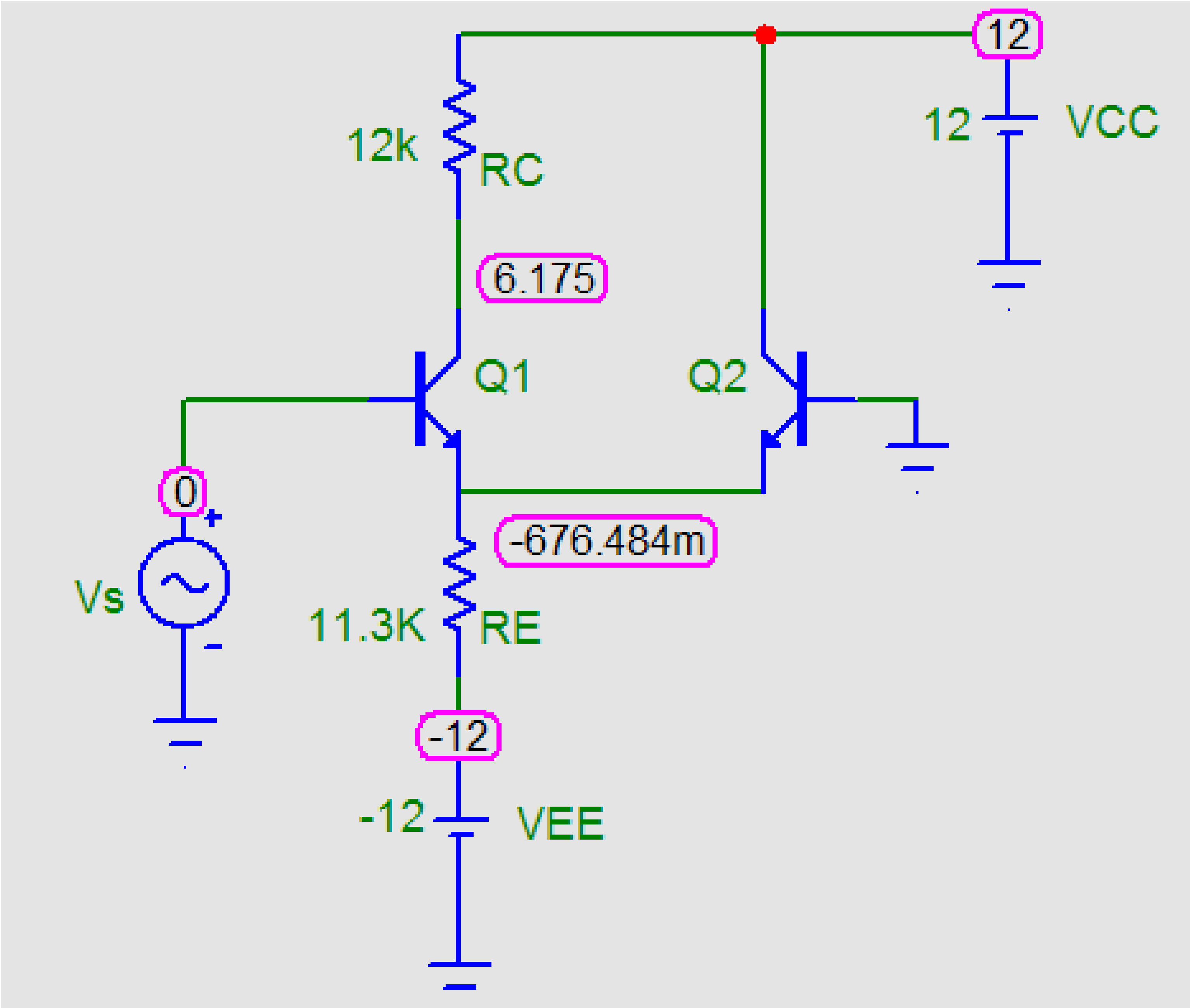
What about bias point?

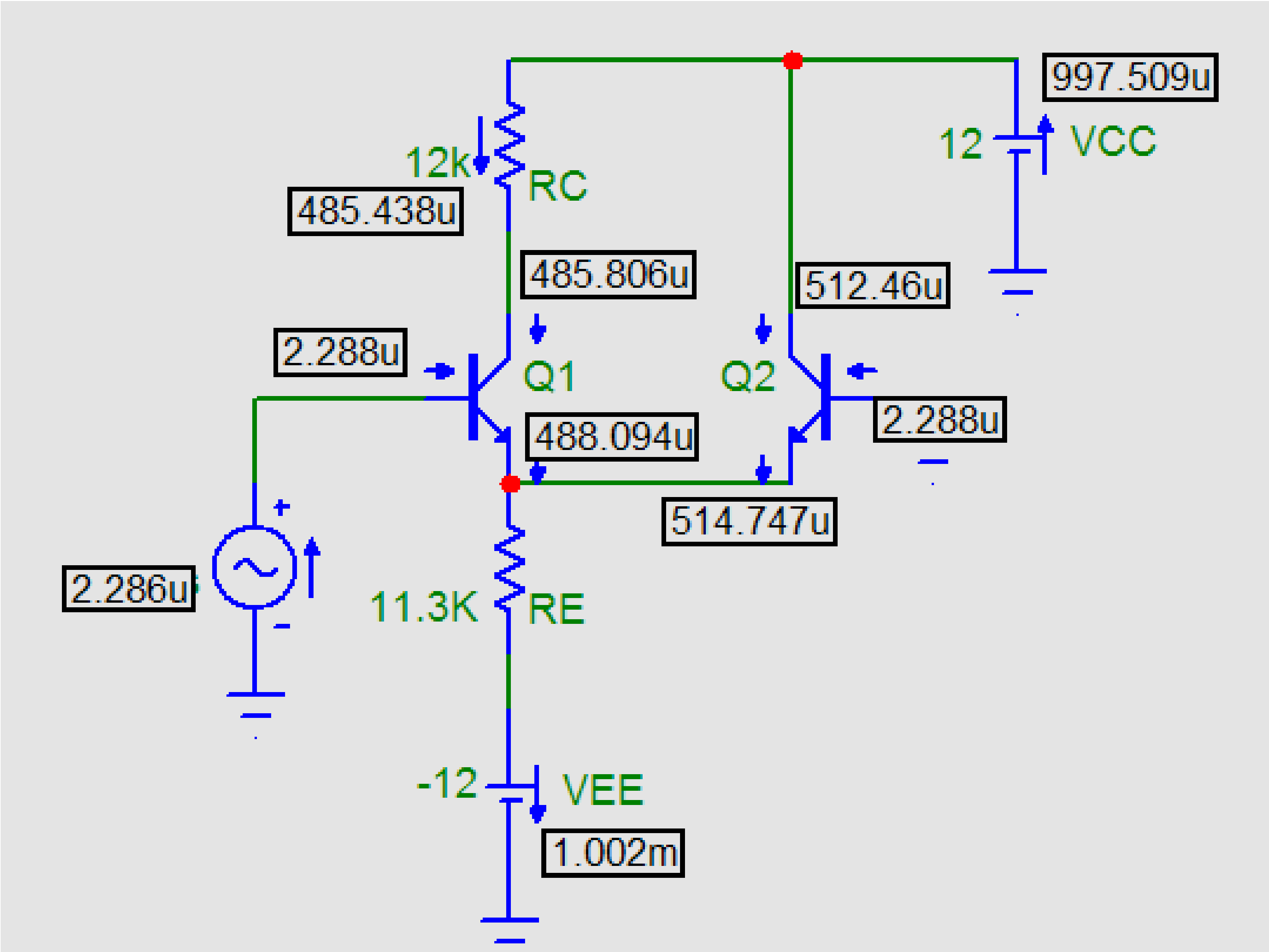


$$I_{EE} = \frac{-0.7 - V_{EE}}{R_E}$$

$$I_{CQ1} = I_{CQ2} = 0.5 I_{EE}$$

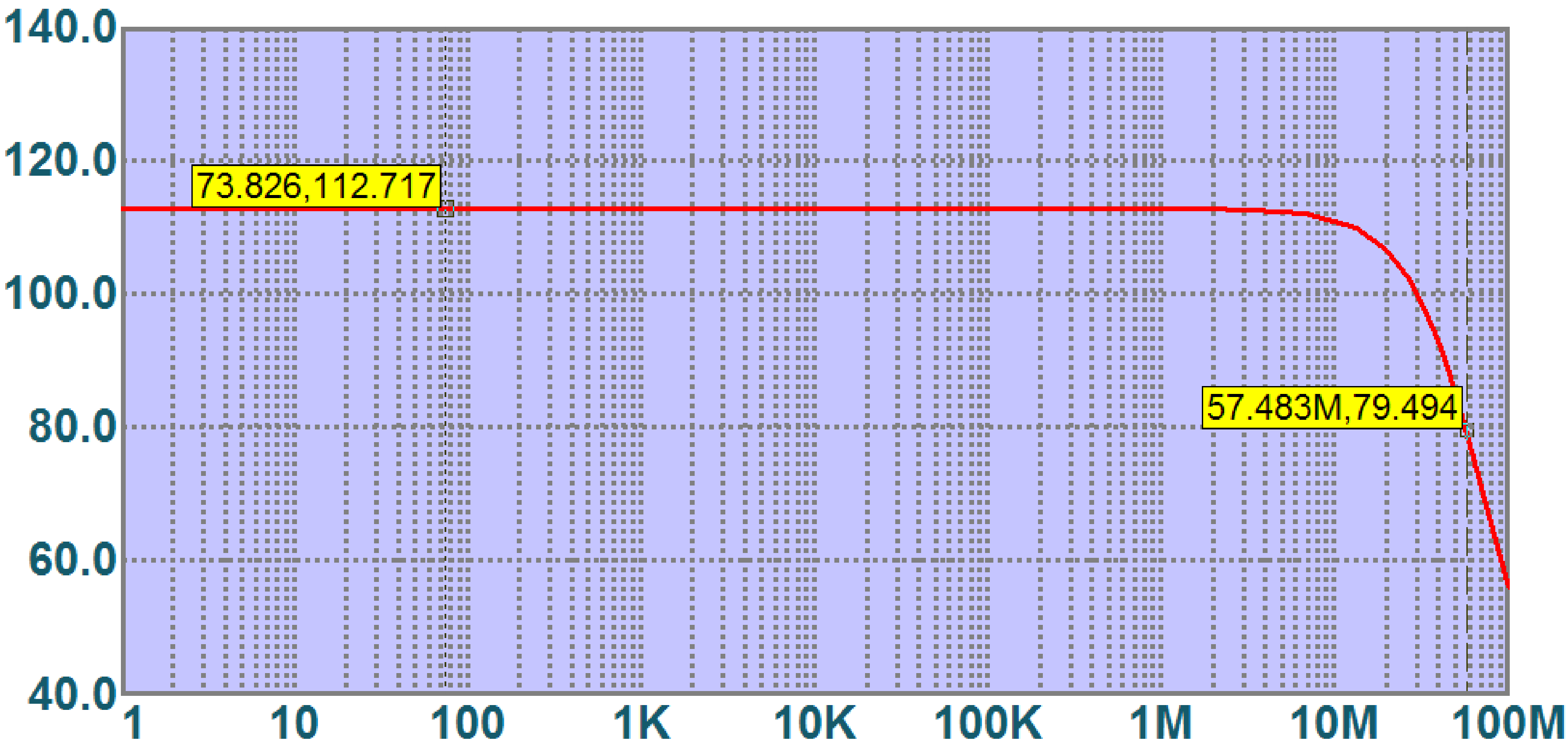
Example





997.509u
12
VCC
12k
RC
485.438u
485.806u
512.46u
2.288u
Q1
Q2
2.288u
488.094u
514.747u
2.286u
11.3K
RE
-12
VEE
1.002m

dc amplifier



$$A_V \cong 0.5 g_m R_C = 115.4$$

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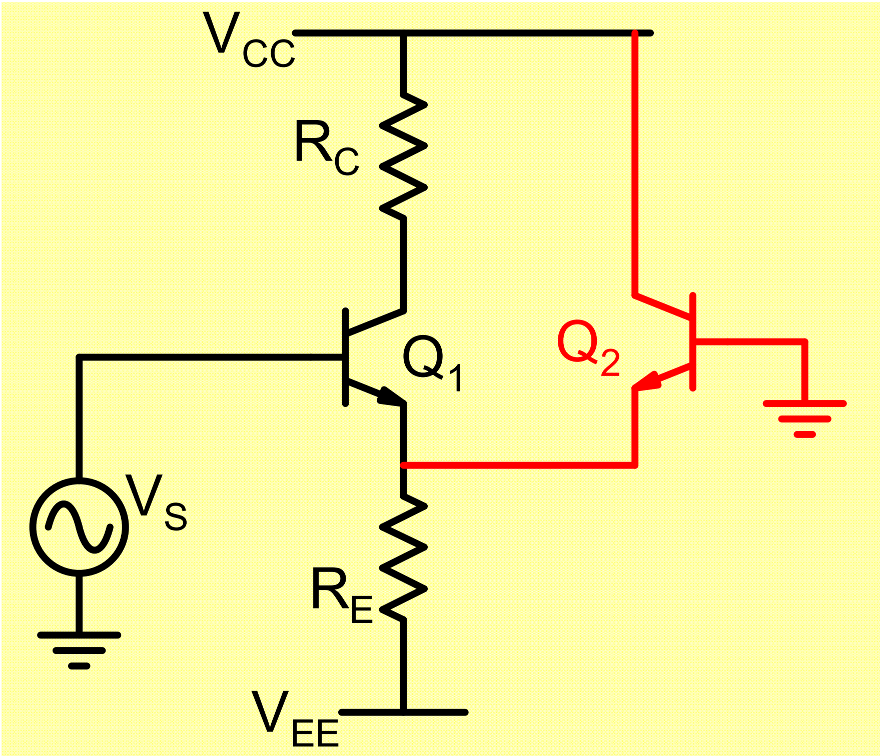
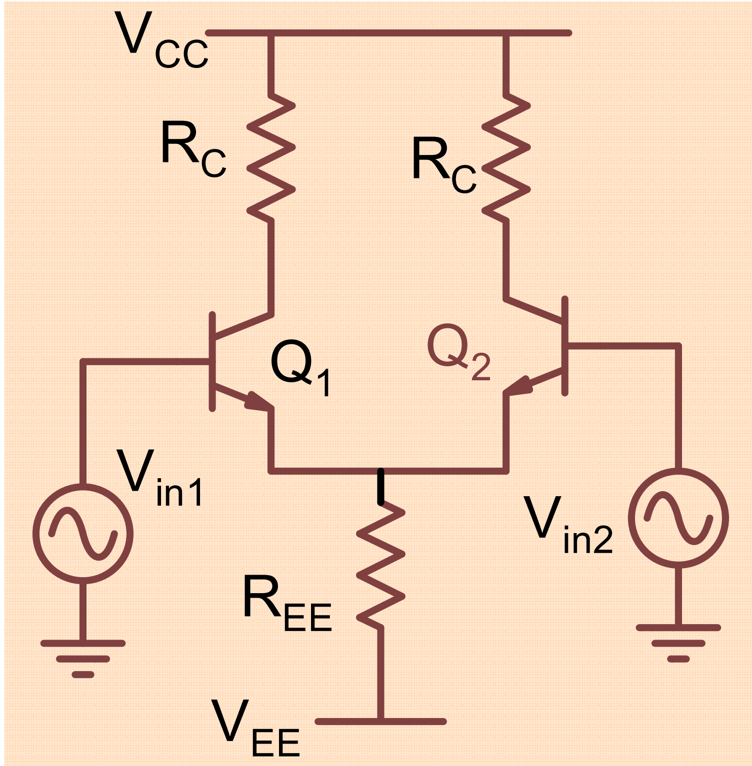
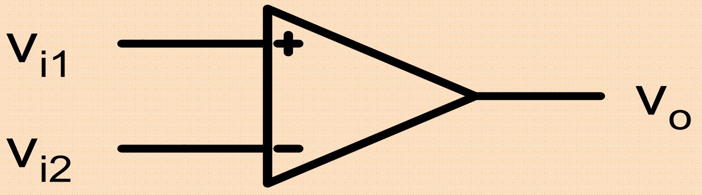
Can make the circuit more useful by making it symmetrical



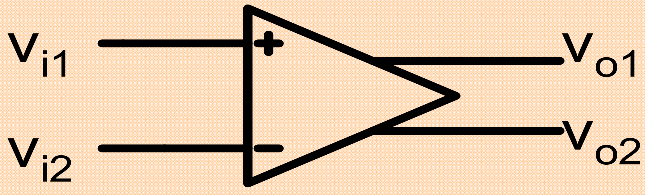


Differential Amplifier

-An amplifier that is sensitive to difference in input voltages and insensitive to what is common.



Differential input
Single-ended Output



Differential input
Differential Output

$$v_{id} = v_{in1} - v_{in2}$$

$$v_{ic} = \frac{v_{in1} + v_{in2}}{2}$$

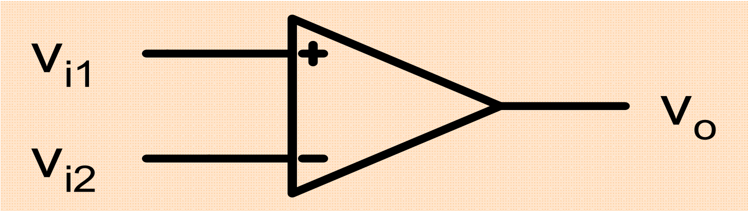
$$v_o = A_d v_{id} + A_{cm} v_{ic}$$

A_d : Differential mode gain

A_{cm} : Common mode gain

$$A_d >> A_{cm}$$

$$\text{Common Mode Rejection Ratio} : CMRR = \frac{A_d}{A_{cm}}$$



$$A_d = 100; \quad A_{cm} = 0.01$$

$$v_{i1} = 1V + 5mV \times Sin(\omega t)\ ; \ v_{i2} = 1V - 5mV \times Sin(\omega t)$$

$$v_{id} = v_{in1} - v_{in2} = 10mV \times Sin(\omega t)$$

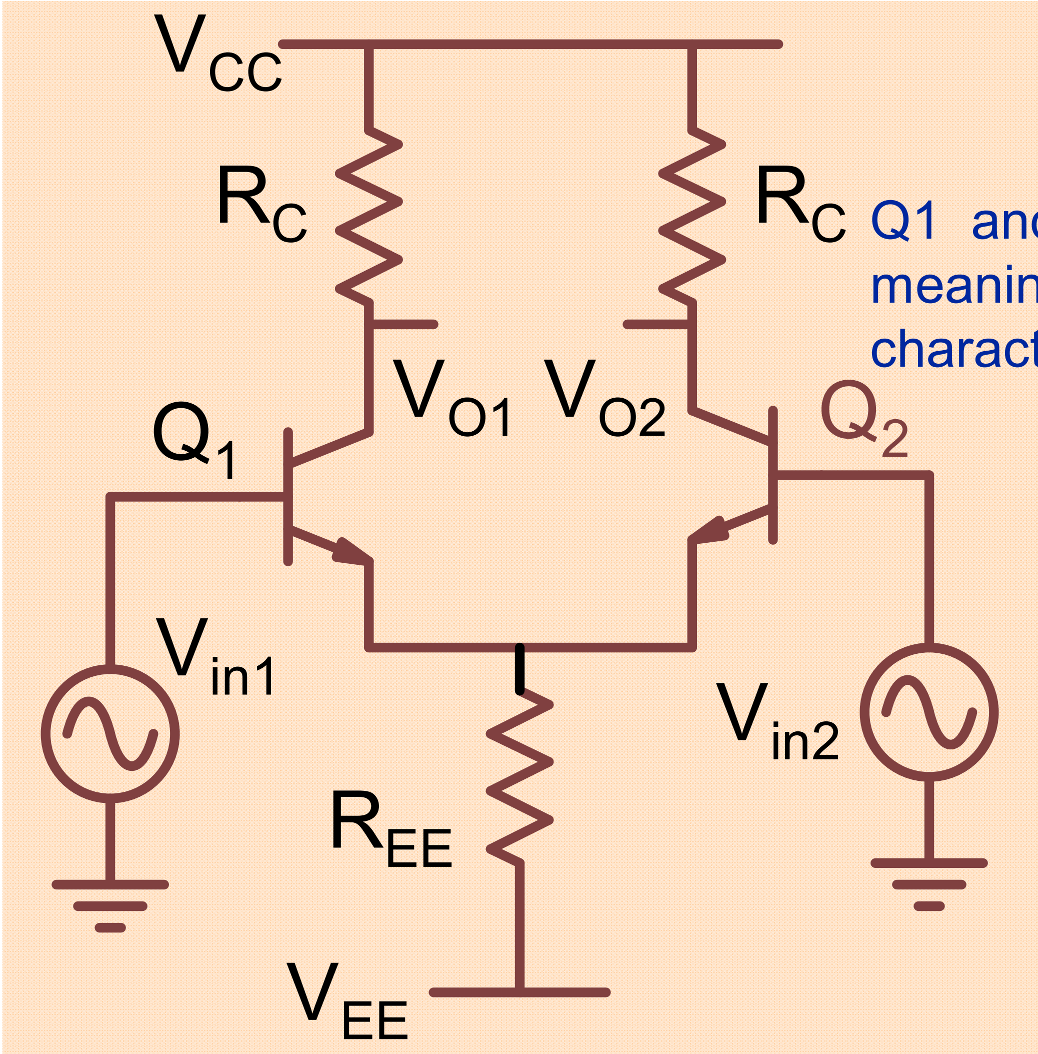
$$v_{ic} = \frac{v_{in1} + v_{in2}}{2} = 1V$$

$$v_o = A_d v_{id} + A_{cm} v_{ic}$$
$$= 1V \times Sin(\omega t) + 10mV$$

Whatever is common is rejected and whatever is different is amplified !

Applications ?

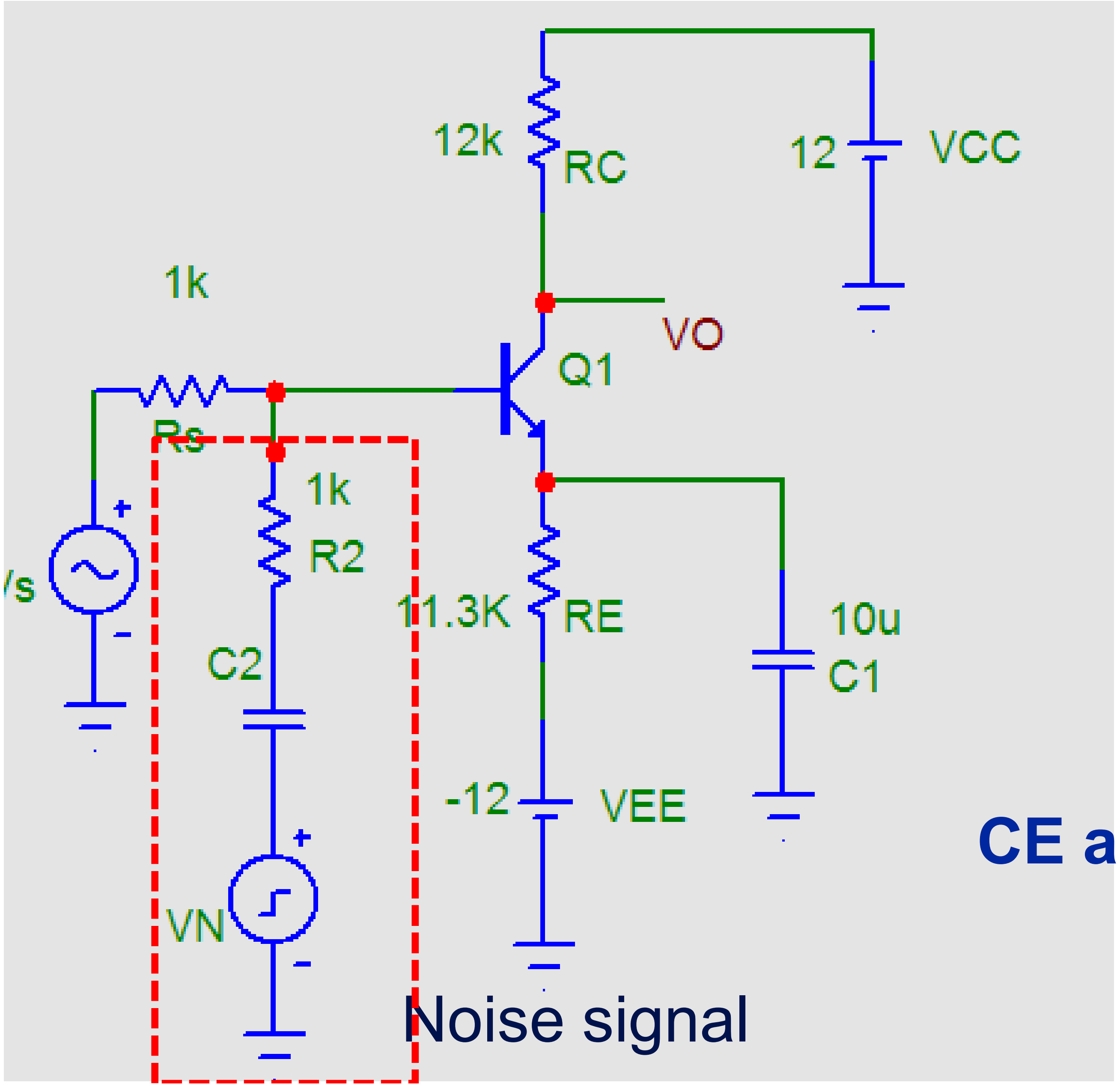
Differential Pair



Q1 and Q2 are matched meaning identical characteristics

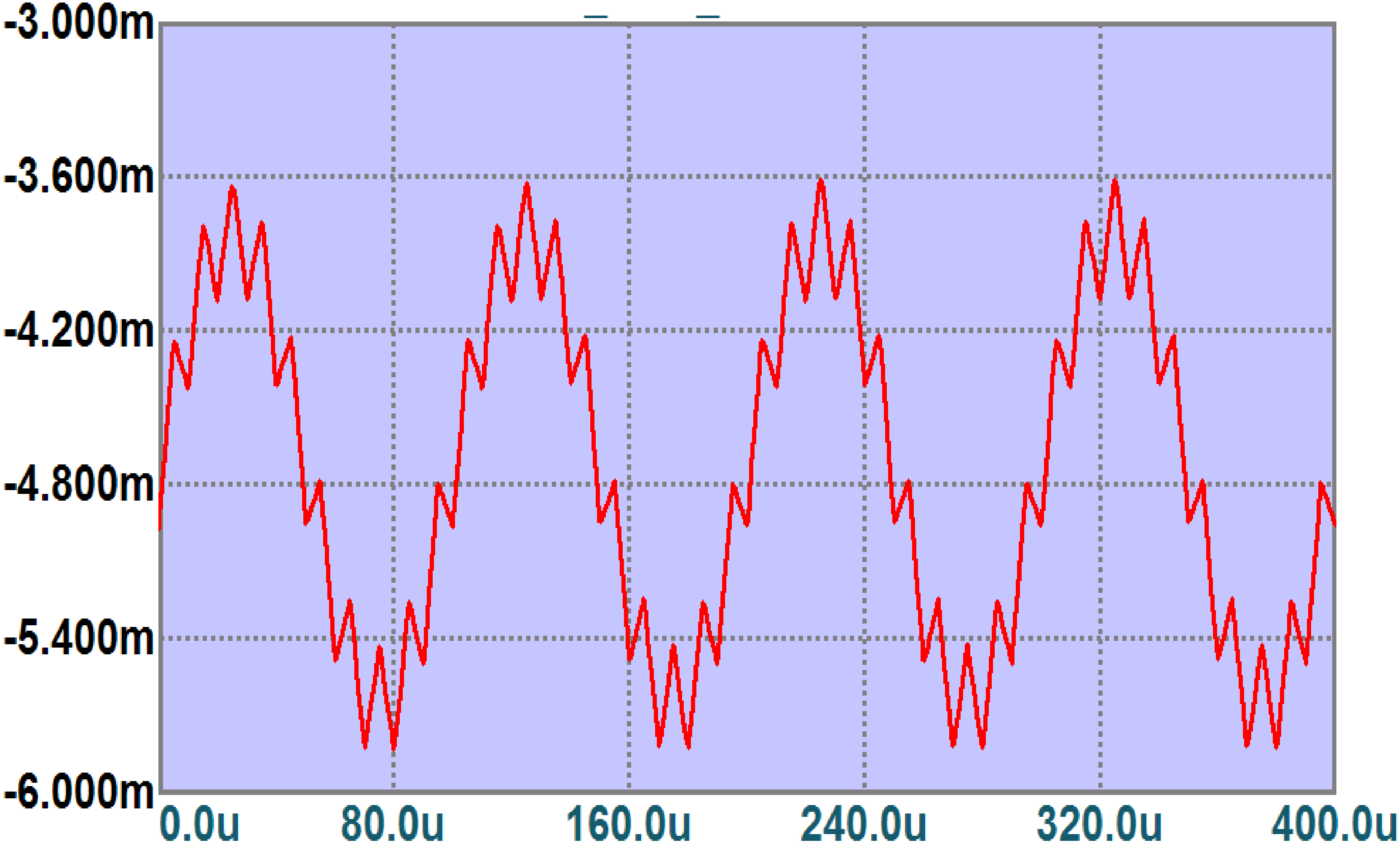
Both outputs sensitive to only difference of input voltages

Advantages: Unwanted signal rejection



CE amplifier

Noisy input



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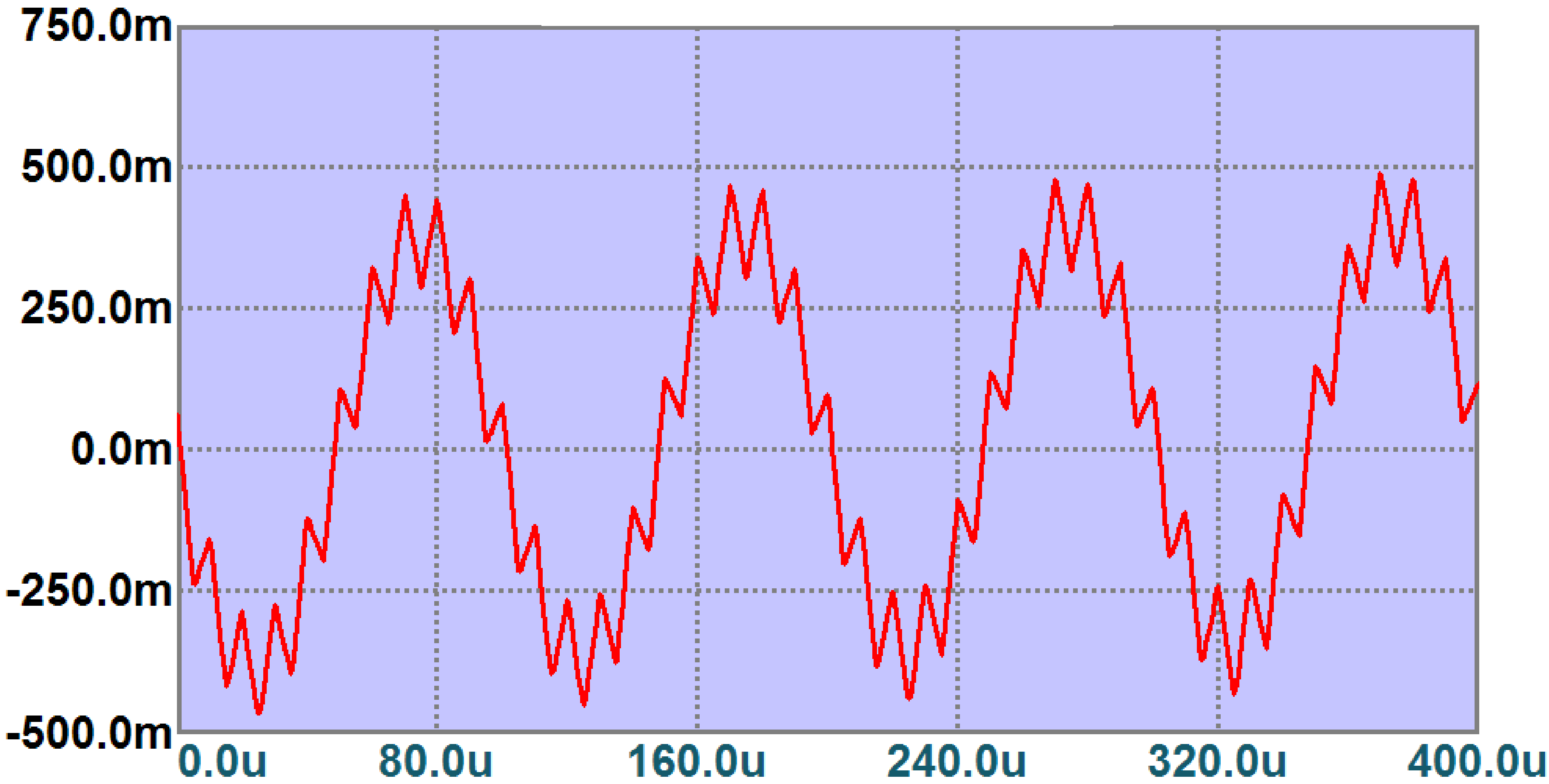
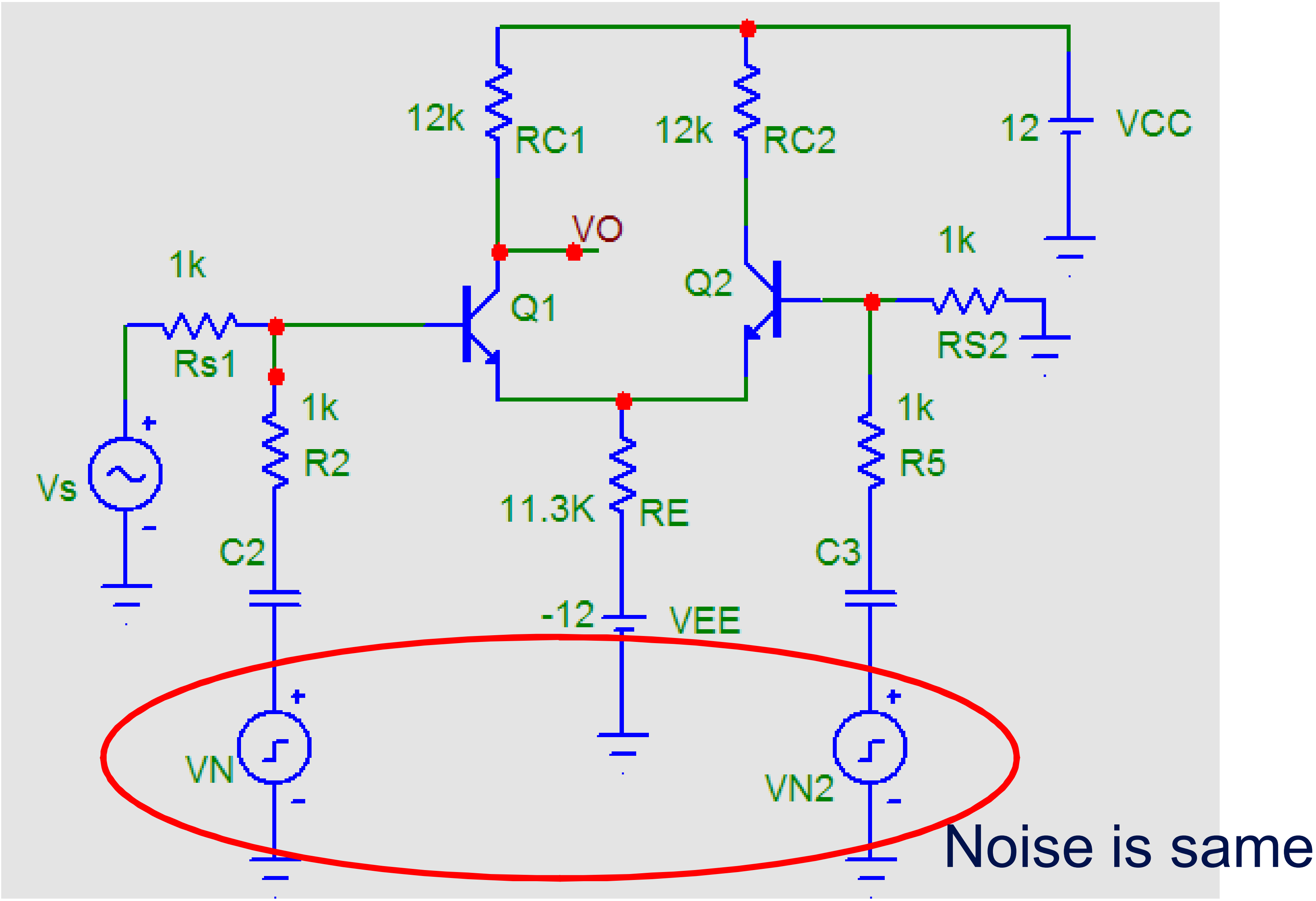
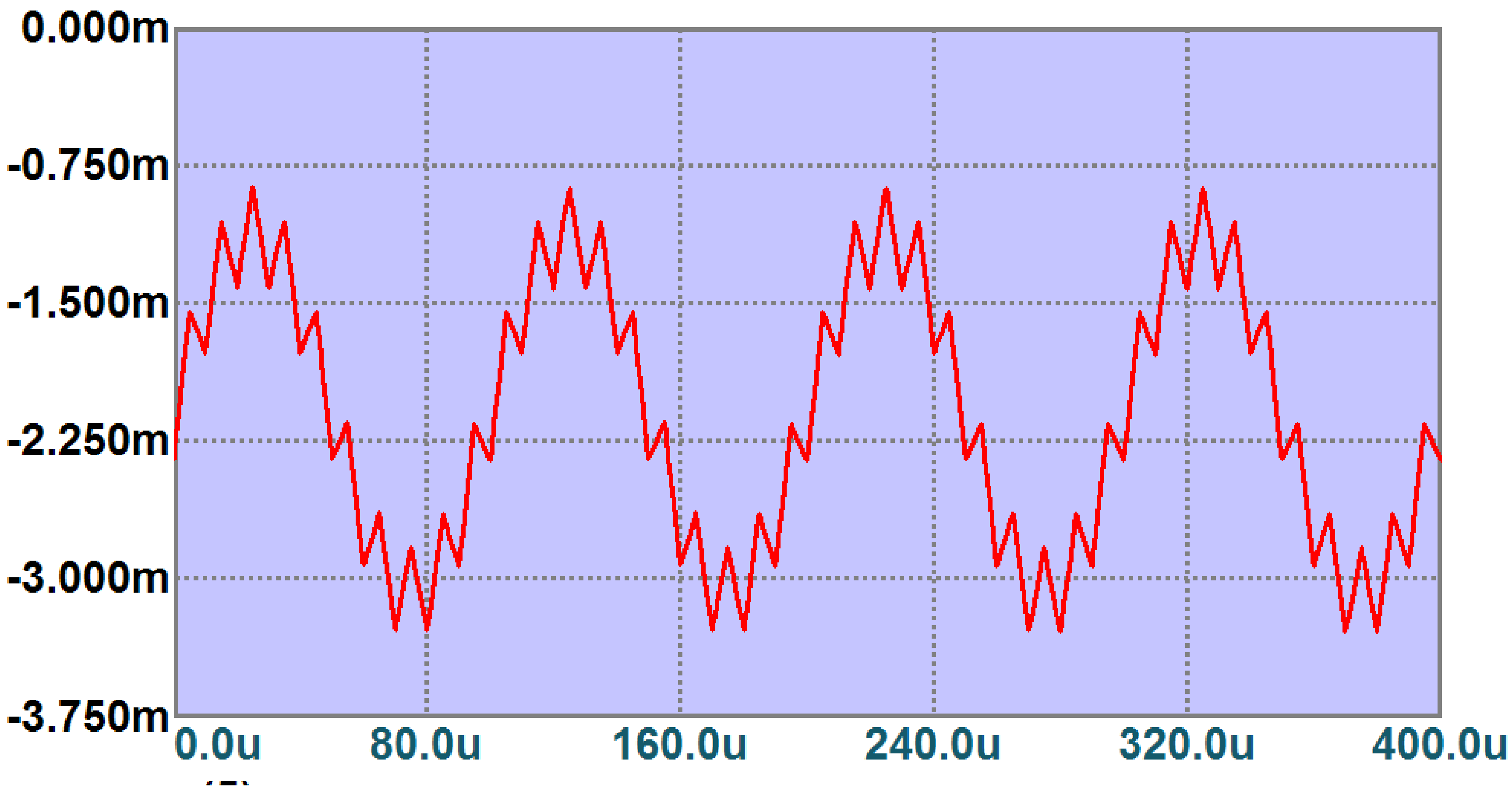
CE amplifier: Output is noisy as well



Differential Amplifier



Noisy input



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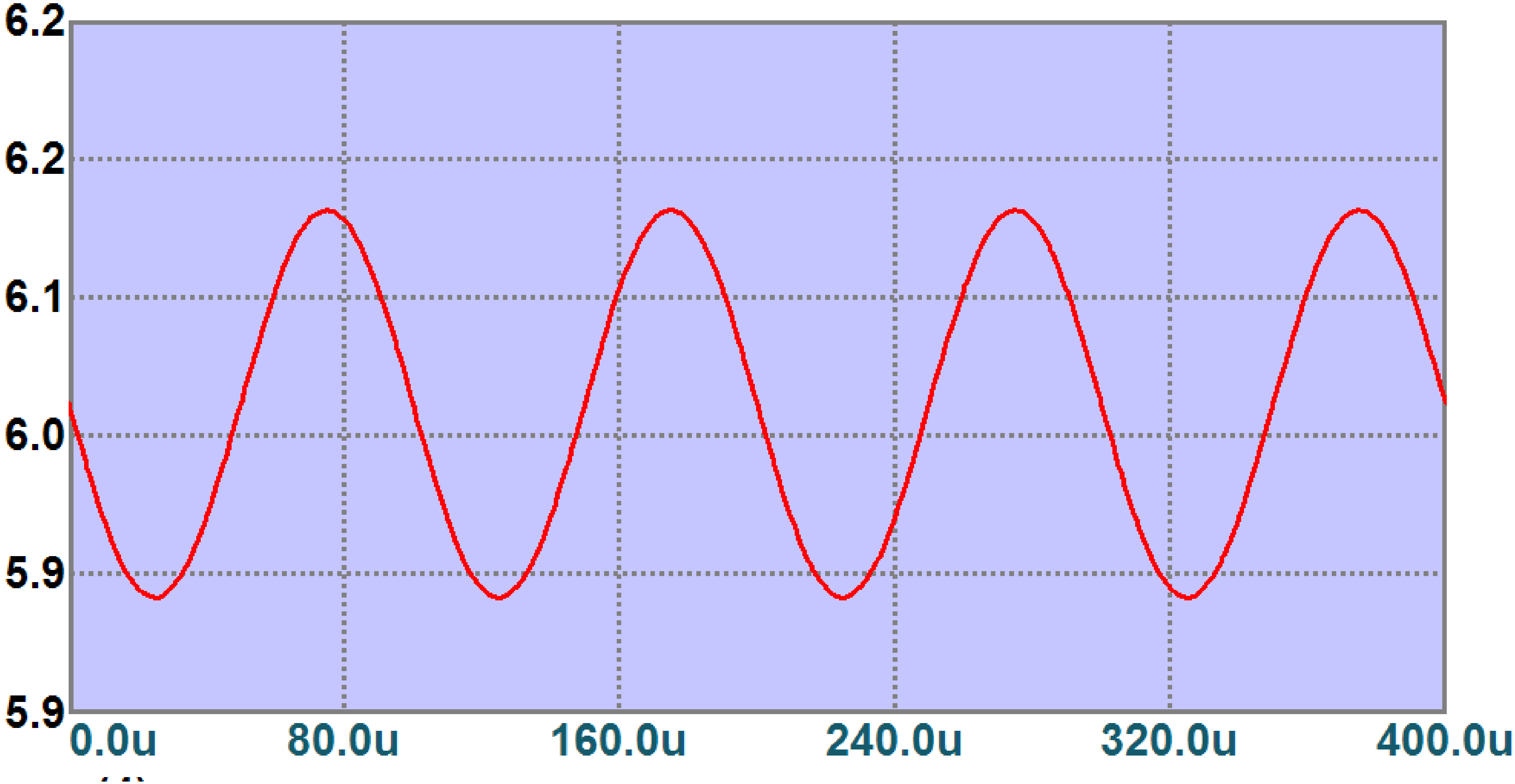
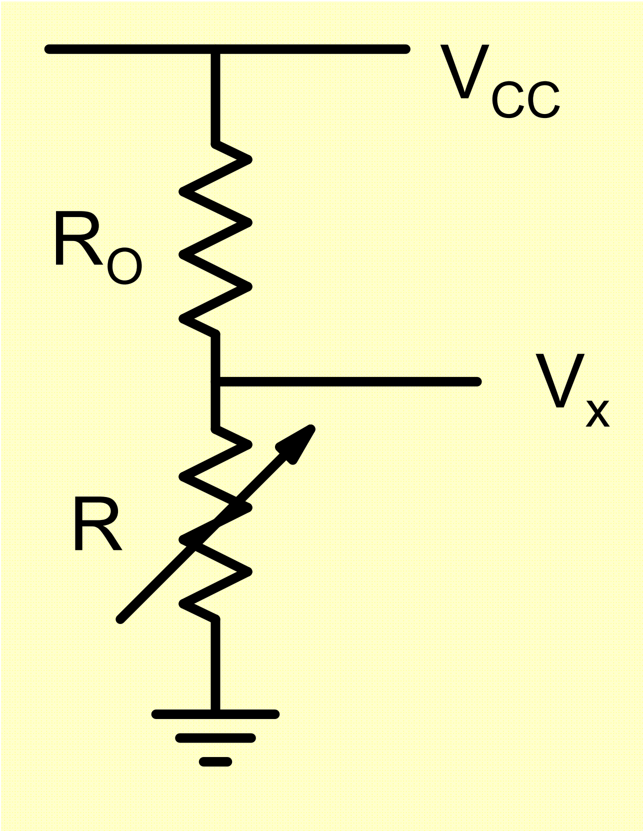


Output: Noise Free

G-Number

Amplifying small signal immersed in a large signal



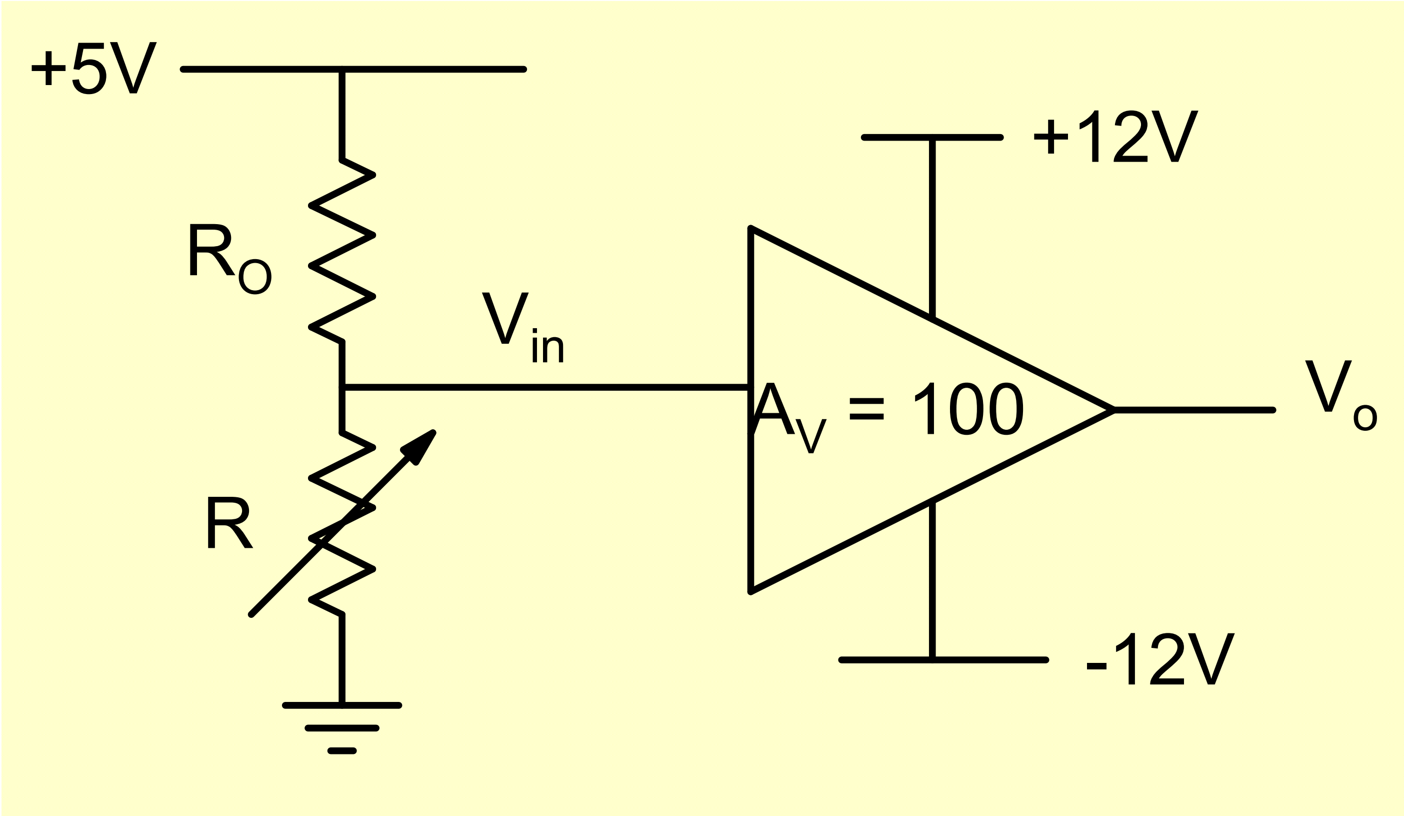
$$V_x \cong 0.5V_{CC} + 0.5V_{CC} \times \frac{\Delta R}{R_O}$$

$$V_{CC} = 5V\,;\; \frac{\Delta R}{R_O} = 1\%$$

$$V_x \cong 2.5V + 25mV$$

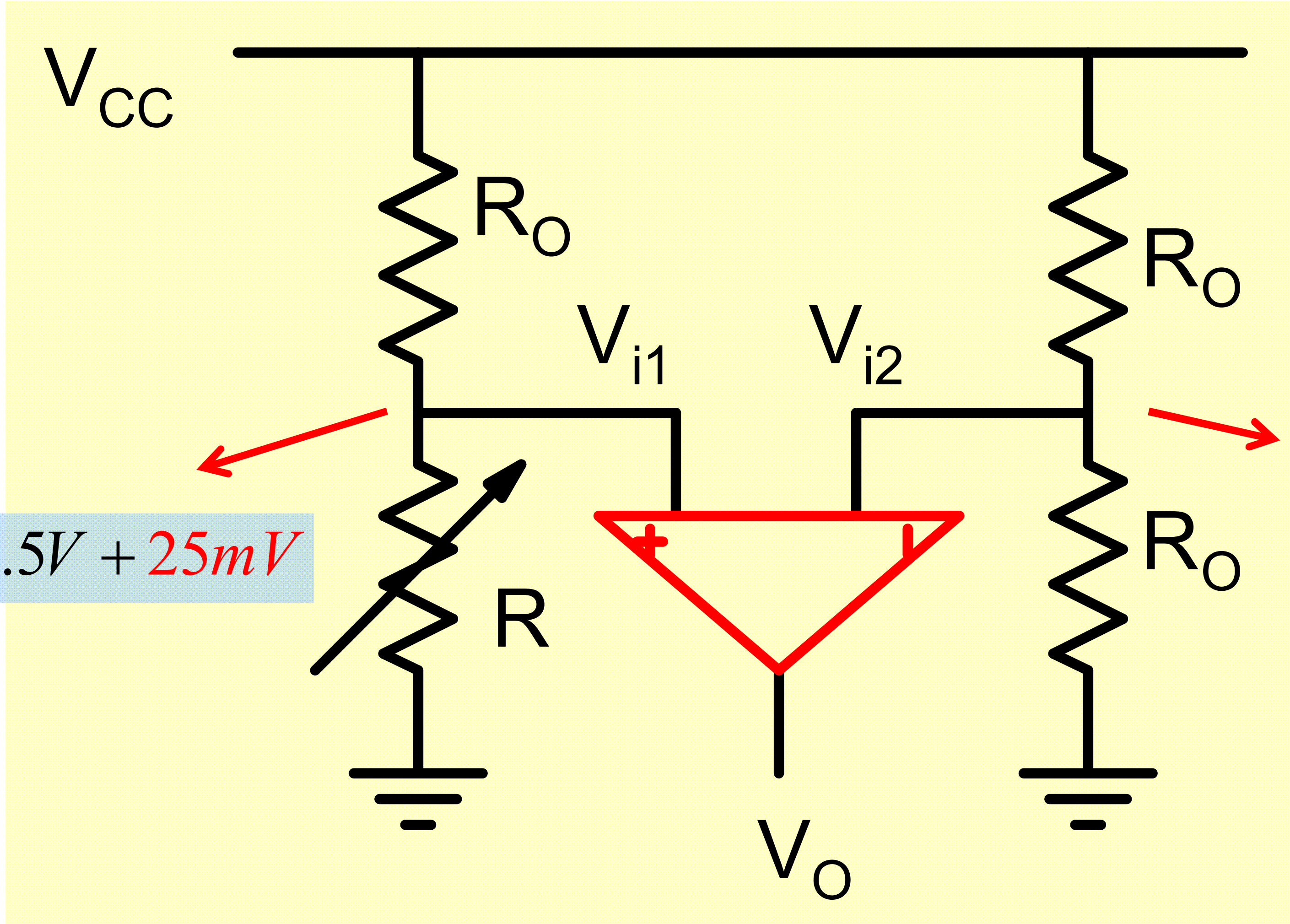
How do we detect the small signal ?

Amplifier with single ended input won't work !



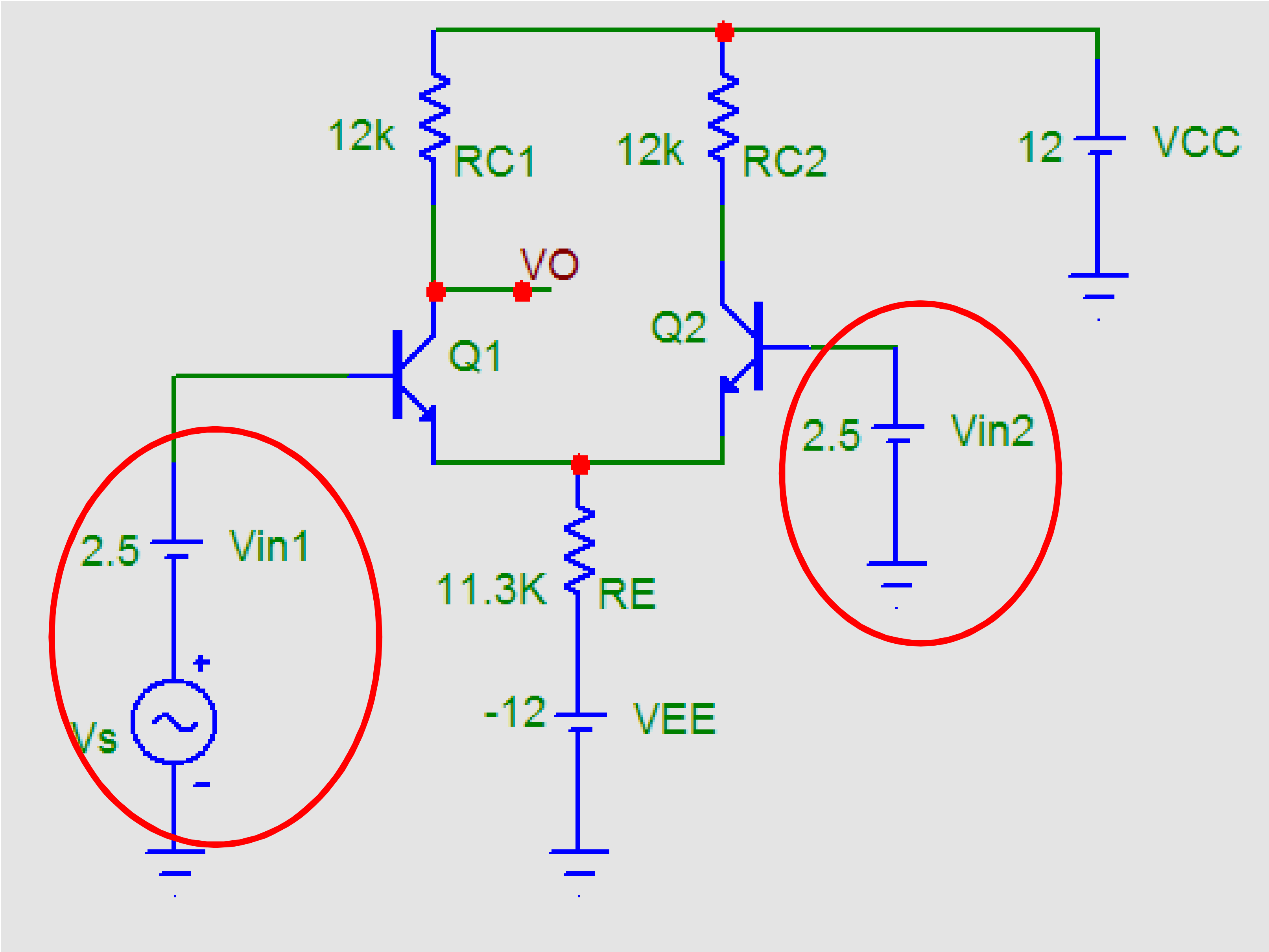
$$V_{in} \cong 2.5V + 25mV$$

Differential amplifier is a natural solution

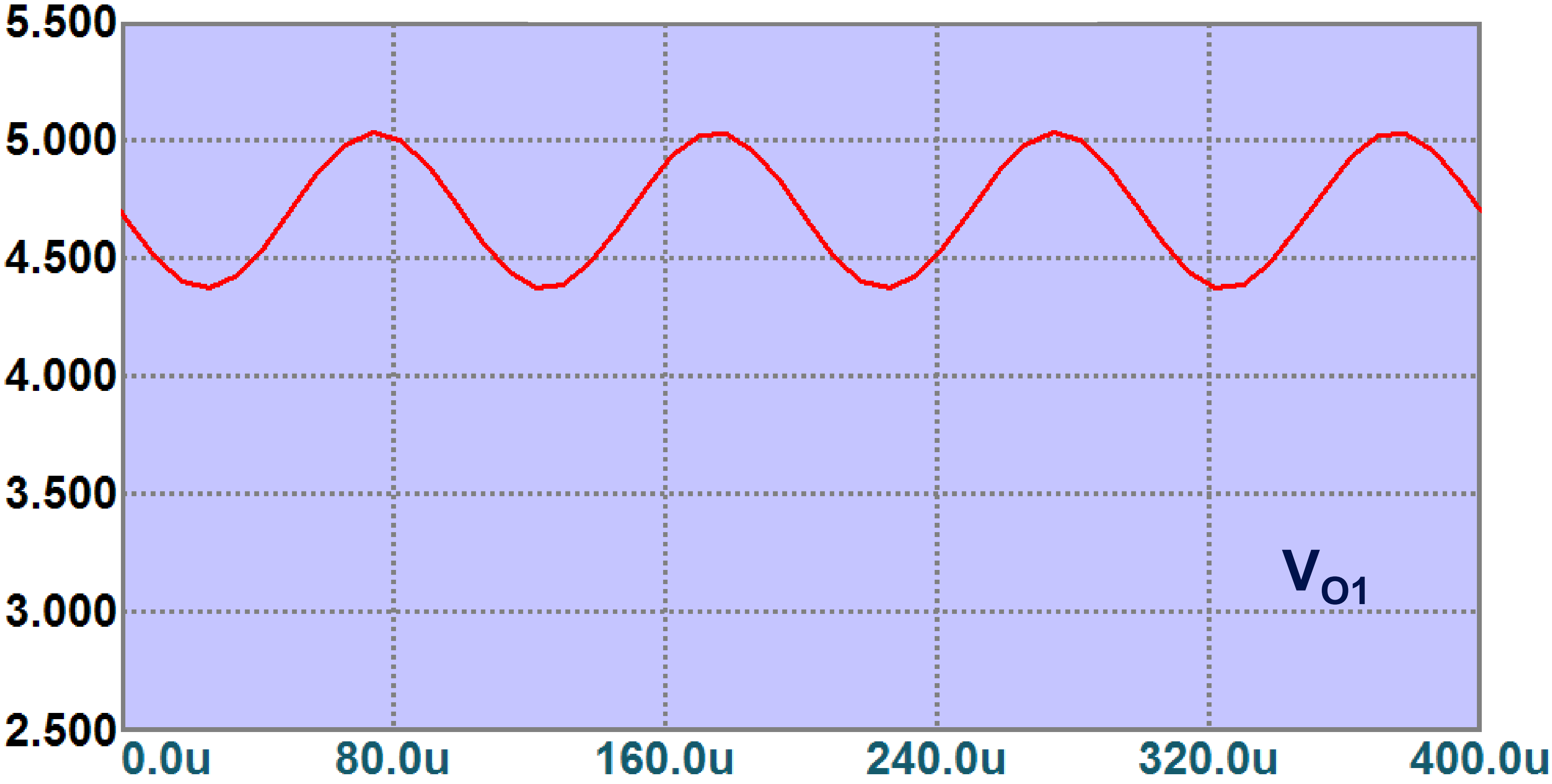


$V_{i1} = 2.5V + 25mV$

$V_{i2} = 2.5V$

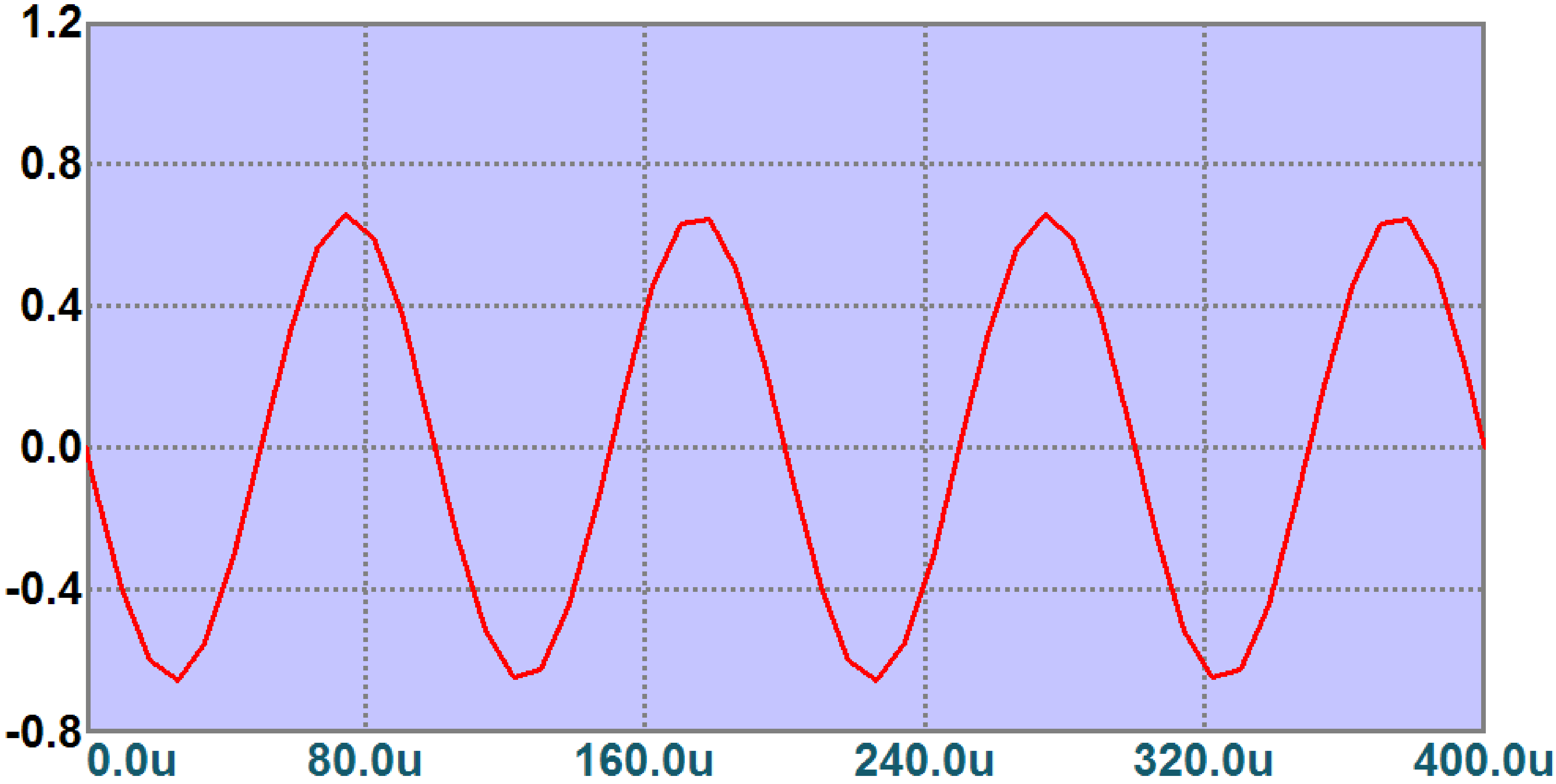


G-Number

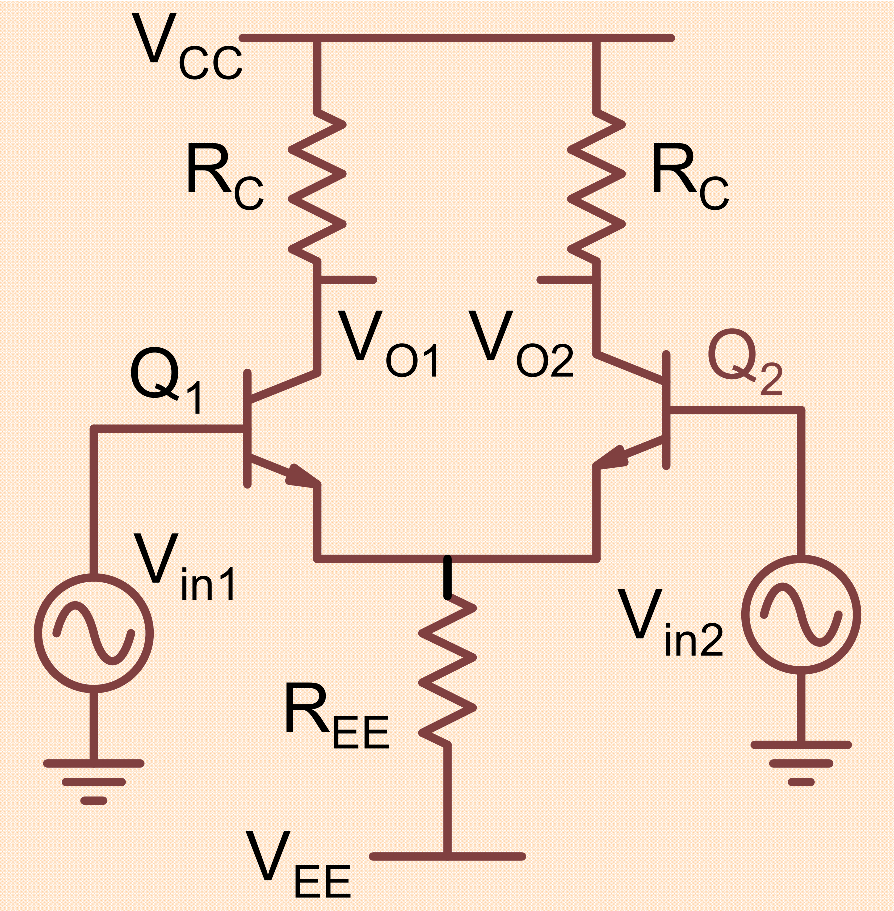


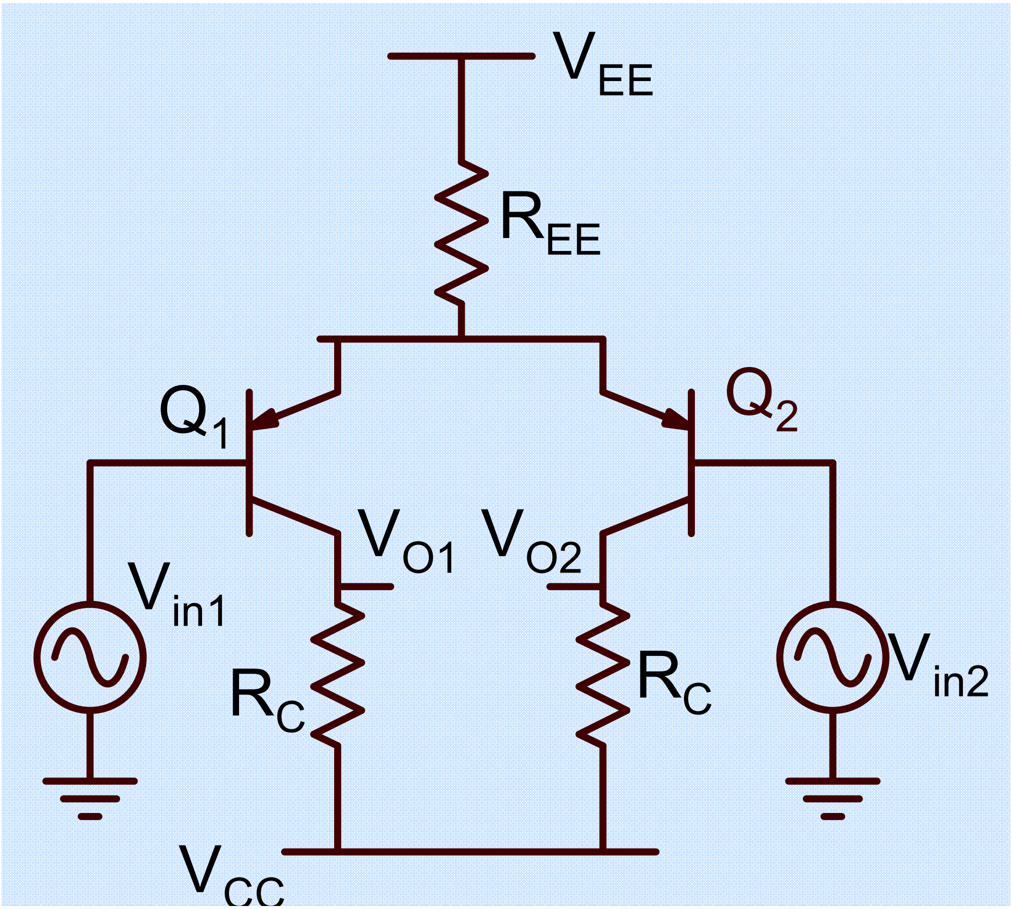
One can detect and amplify the desired input signal

Differential output signal is even better !



Differential pairs





Transistors are matched