Spring 2019 Purdue University

ECE 255: L12

BJT Bias Circuits

(Sedra and Smith, 7th Ed., Sec. 6.3)

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Announcements

Exam 1: Thursday, Feb. 7, 6:30 PM, LILY 1105.
(Weeks -1- 4 topics, semiconductors, diodes, **BJTs**. i.e. HW1-HW4)

Two practice exams are posted on BlackBoard

Graded HW can be picked up in EE 326B (Mary Ann Satterfield)

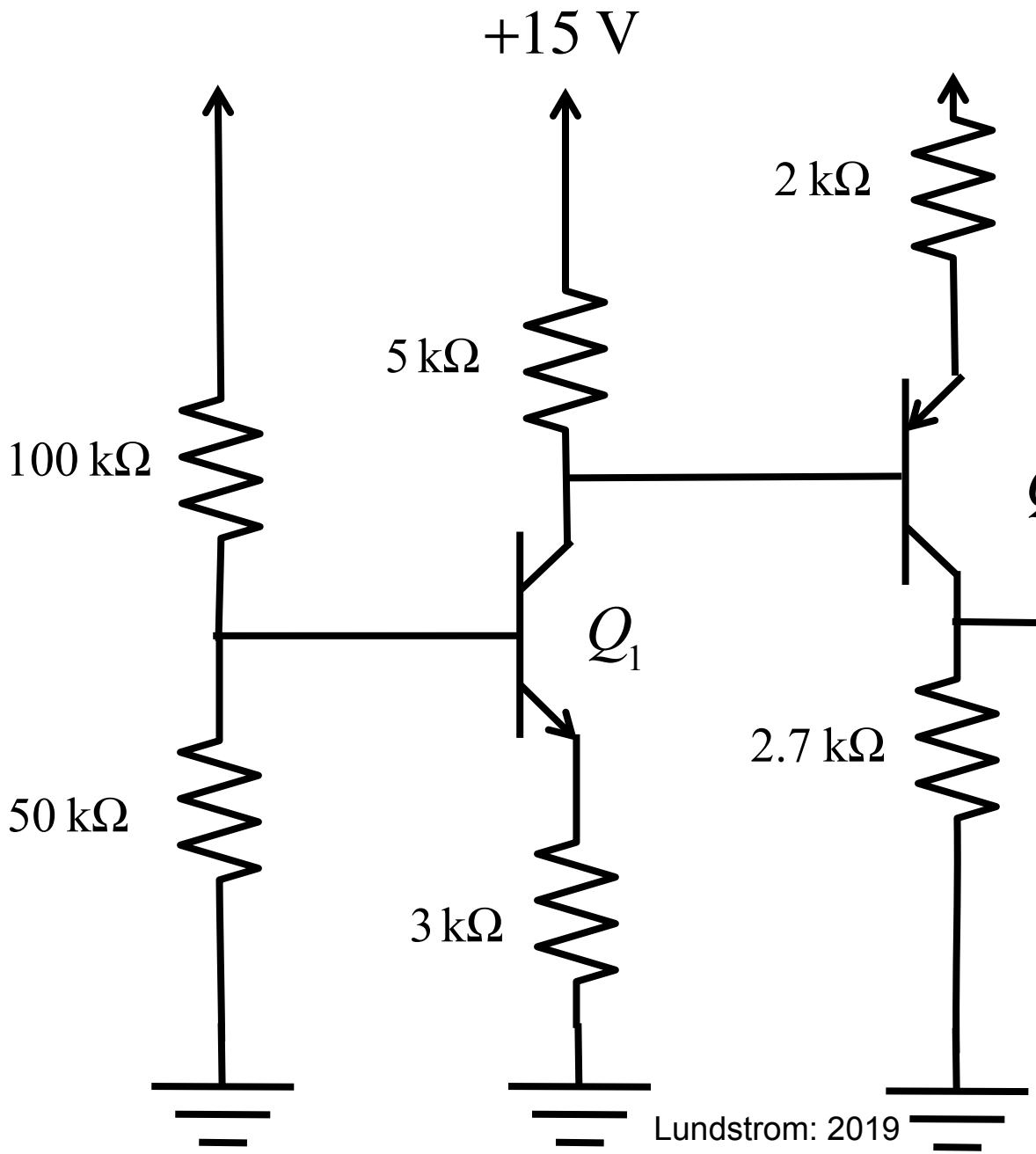
Professor Janes will conduct a help session for Exam 1 on Thursday, 2/7 at 1:30 PM in ME 1061.

Spice 1 project postponed until Monday, Feb. 11

There will be class on Friday, Feb. 8.

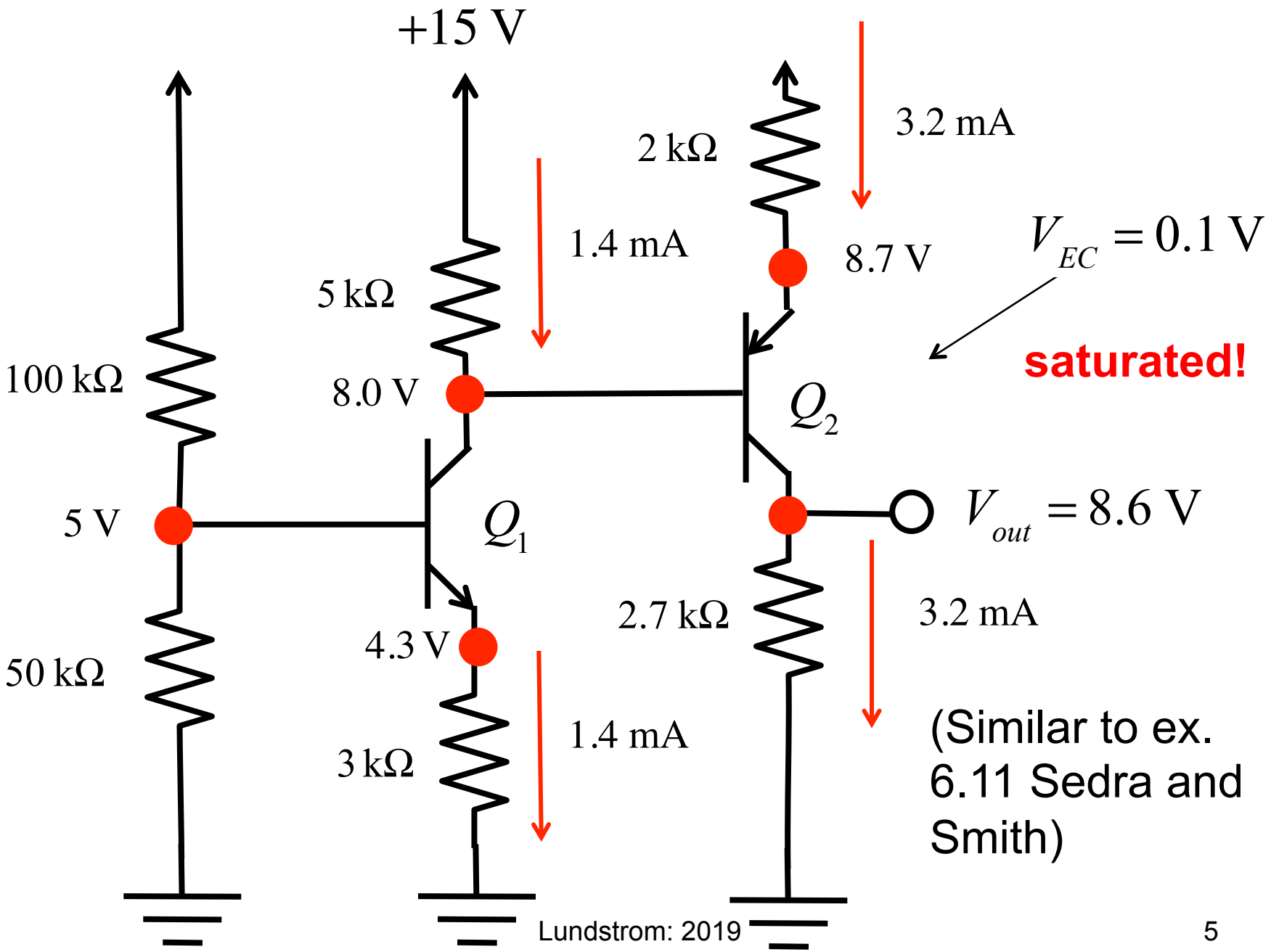
DC bias circuits

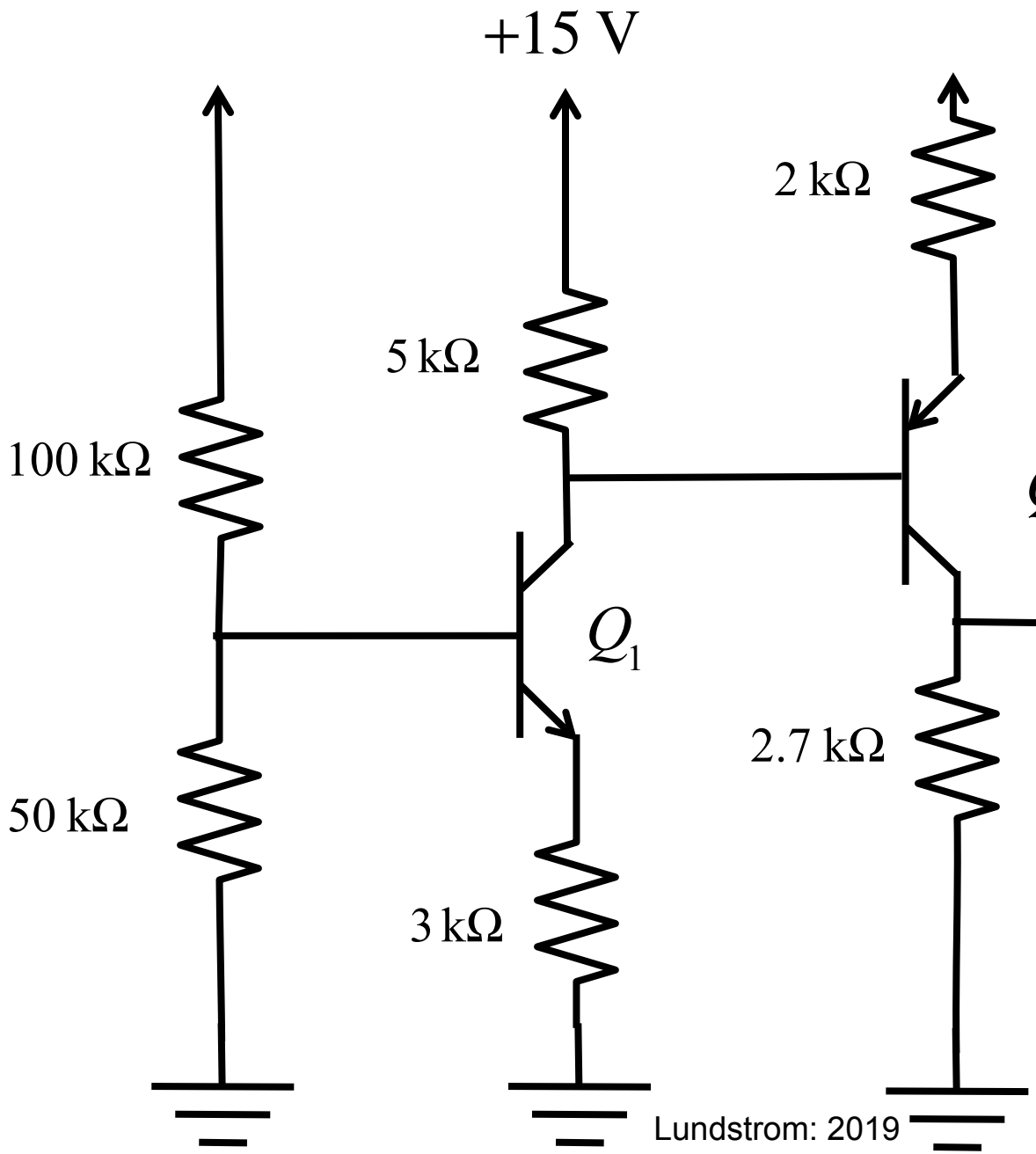
1) NPN and PNP circuits
2) Bias circuits (discrete)



Ignore base currents and compute V_{out}

(Like ex, 6.11 Sedra and Smith)


+15 V
2 kΩ
3.2 mA
1.4 mA
5 kΩ
8.7 V
$V_{EC} = 0.1$ V
saturated!
100 kΩ
8.0 V
Q_2
5 V
Q_1
$V_{out} = 8.6$ V
2.7 kΩ
3.2 mA
4.3 V
50 kΩ
1.4 mA
3 kΩ
(Similar to ex. 6.11 Sedra and Smith)



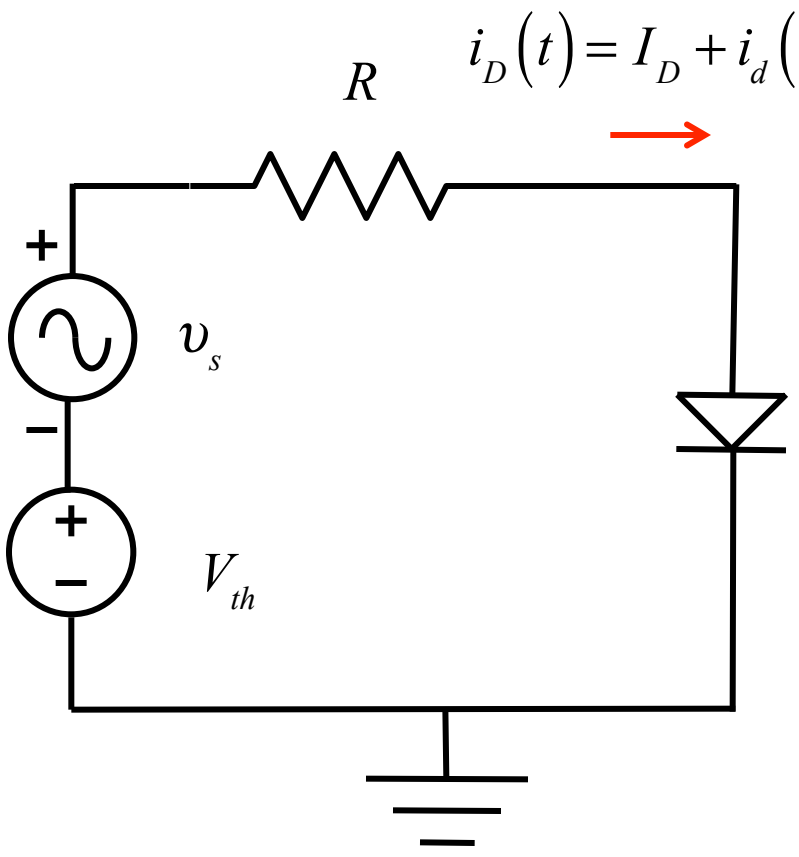
Assume beta = 100 and compute V_{out}

(Example 6.11 Sedra and Smith)

BJT bias circuits

1) NPN and PNP circuits
2) **Bias circuits (discrete)**

Diode bias circuits

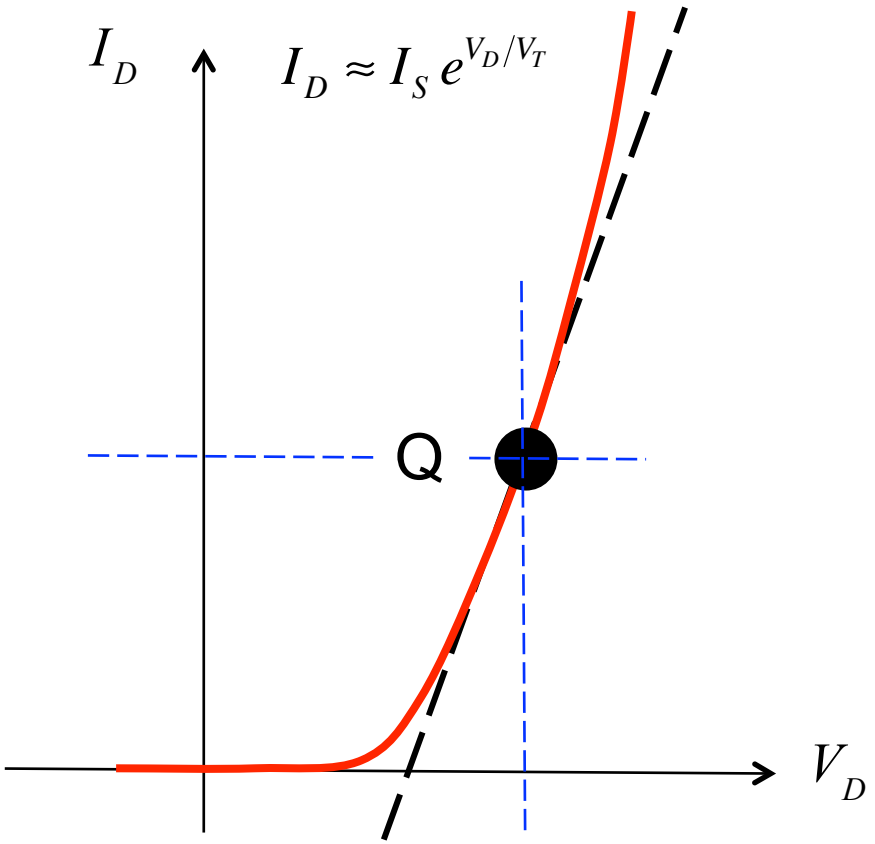


$$i_D(t) = I_D + i_d(\omega)$$

$$+$$
$$v_D(t) = V_D + v_s(\omega)$$
$$-$$

Definition: Bias: A voltage applied to a device (such as a transistor control electrode) to establish a reference level for operation.

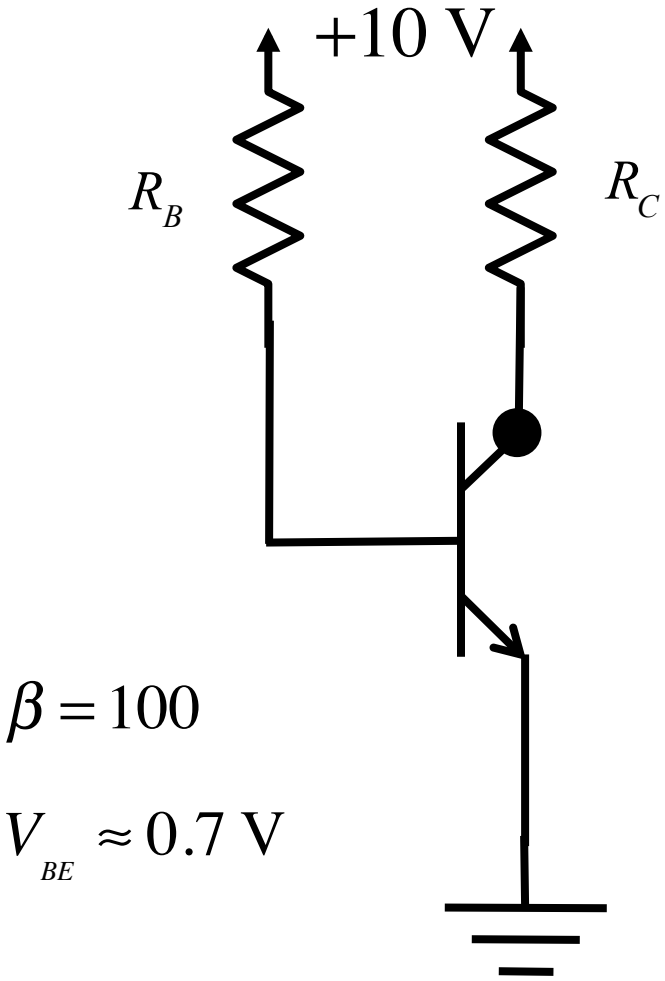
Diode bias circuits



$$g_d = \left.\frac{dI_D}{dV_D}\right|_Q = \frac{1}{r_d}$$

$$r_d = \frac{V_T}{I_D}\,\Omega$$

Transistor bias circuit **design**

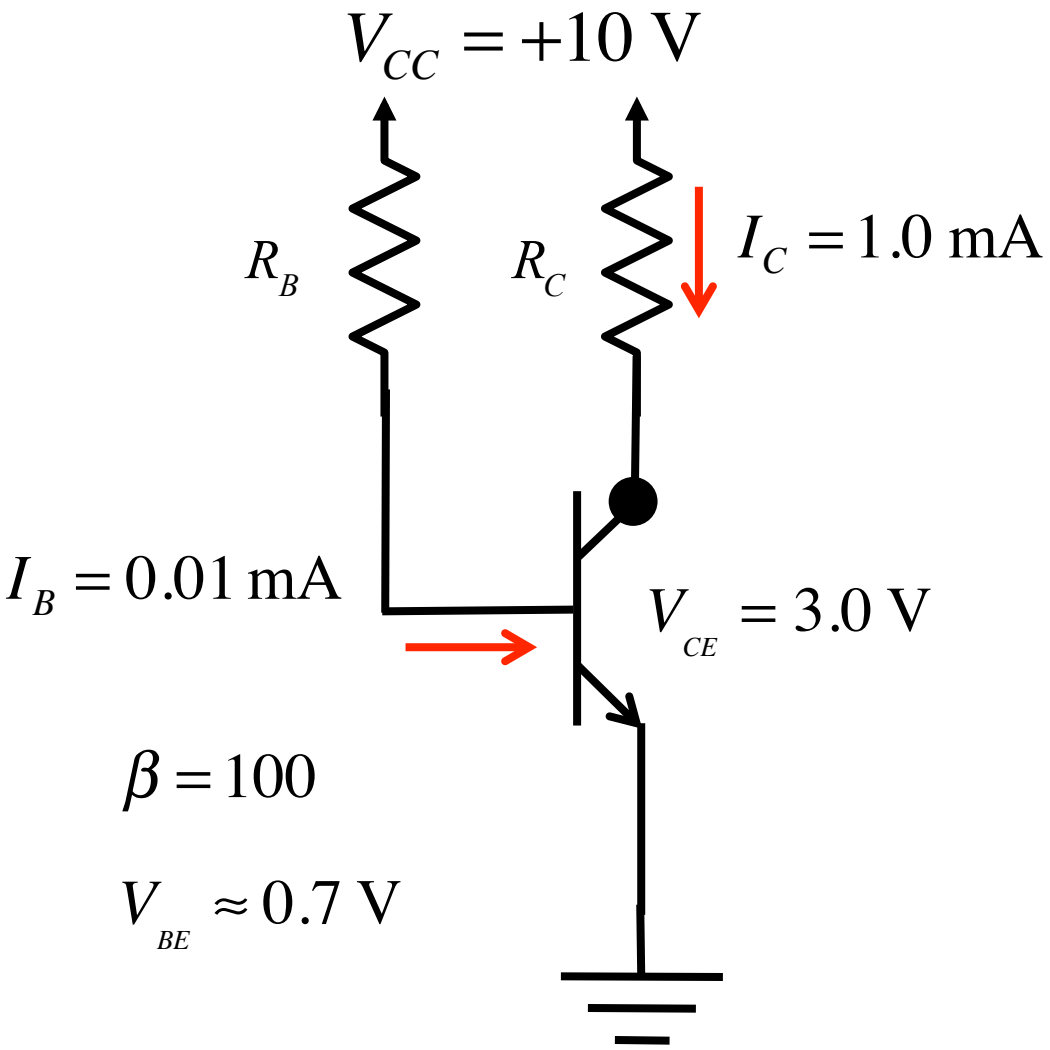


Design for

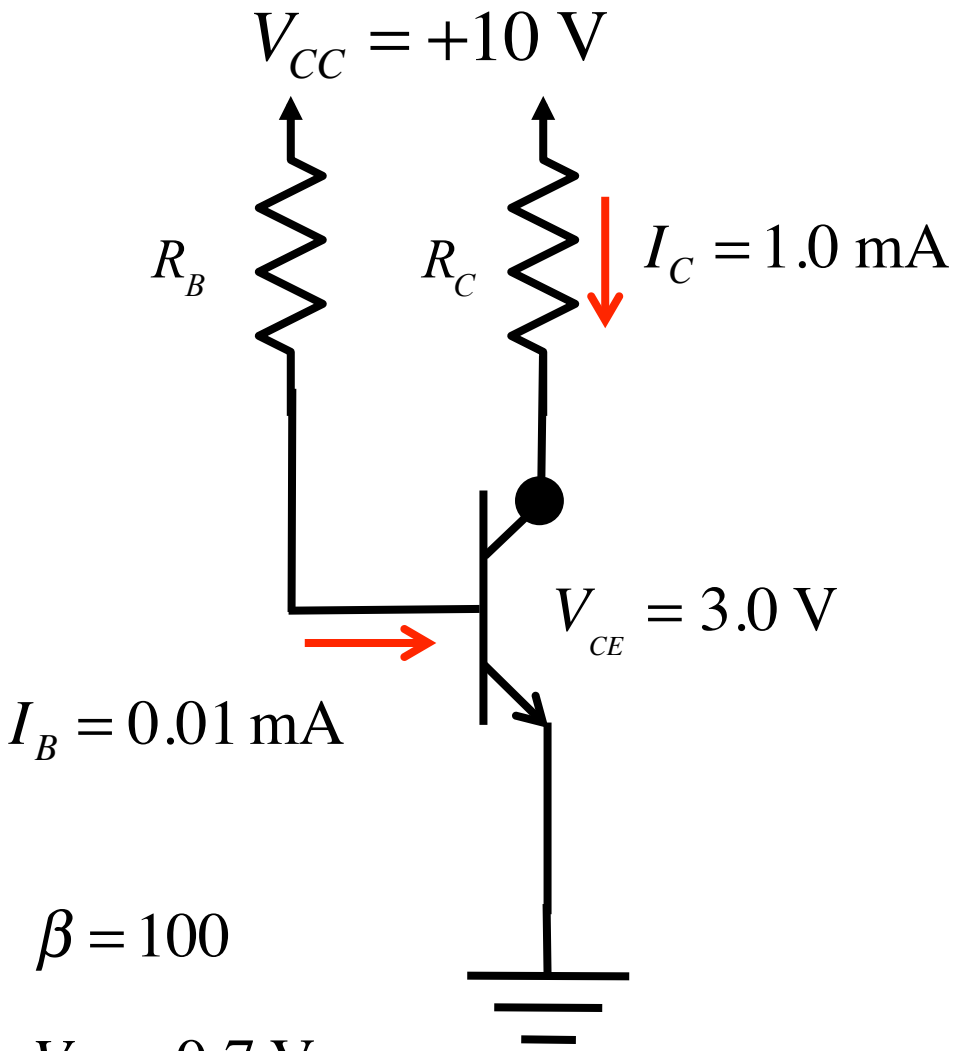
$V_{CE} = 3.0$ V

$I_C = 1.0$ mA

Bias circuit design



Bias circuit design



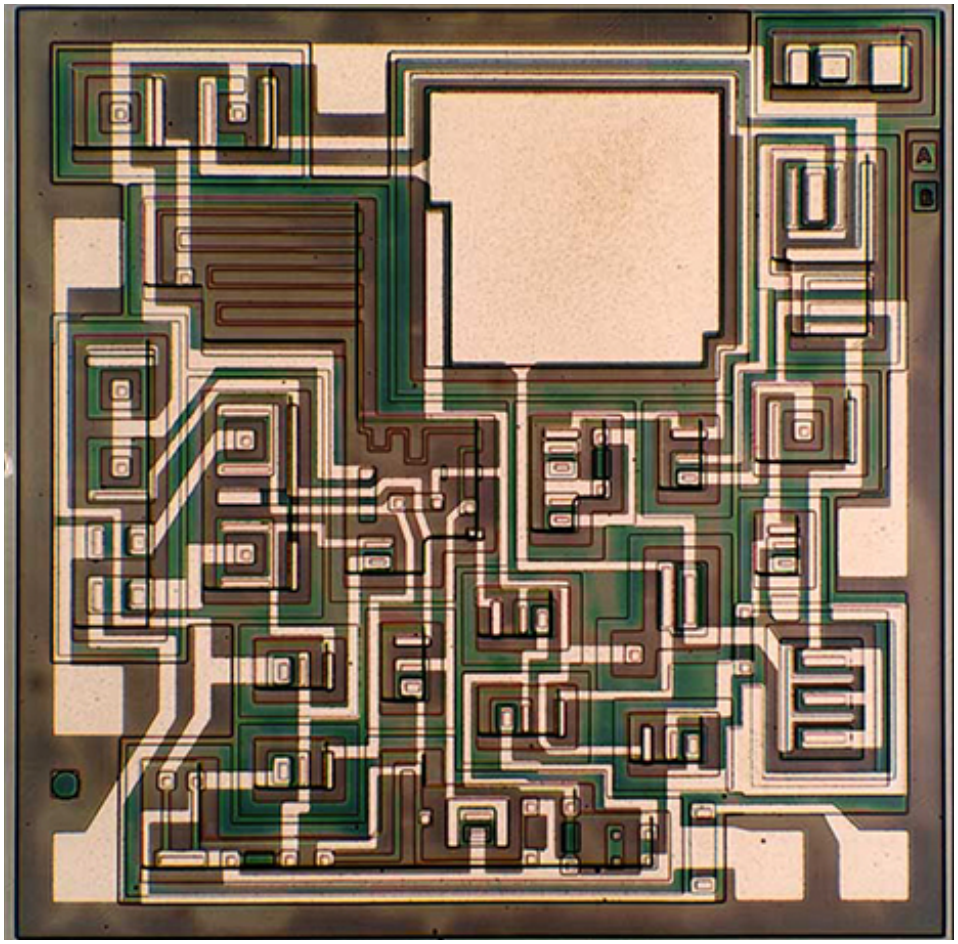
$$I_C R_C = 7\ V \rightarrow R_C = 7\ \text{k}\Omega$$

$$I_B = \frac{I_C}{\beta} = \frac{1\ \text{mA}}{100} = 0.01\ \text{mA}$$

$$I_B R_B = 9.3\ \text{V}$$

$$R_B = \frac{9.3\ \text{V}}{0.010\ \text{mA}} = 930\ \text{k}\Omega$$

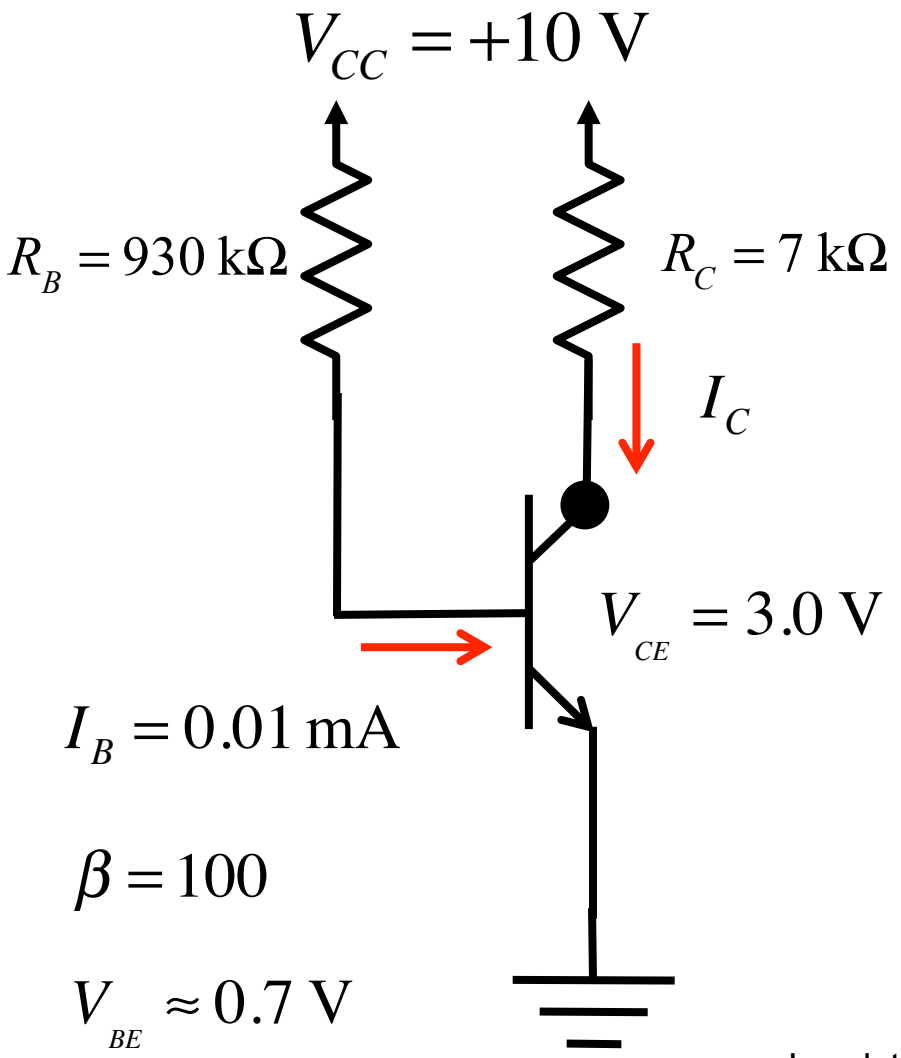
741 Op amp



David Fullagar

IEEE Spectrum, “Chip Hall of Fame: Fairchild Semiconductor μA741 Op-Amp,” June 30, 2017

Bad Bias circuit design



$$I_C = \beta I_B = \beta\left(\frac{V_{CC} - V_{BE}}{R_B}\right)$$

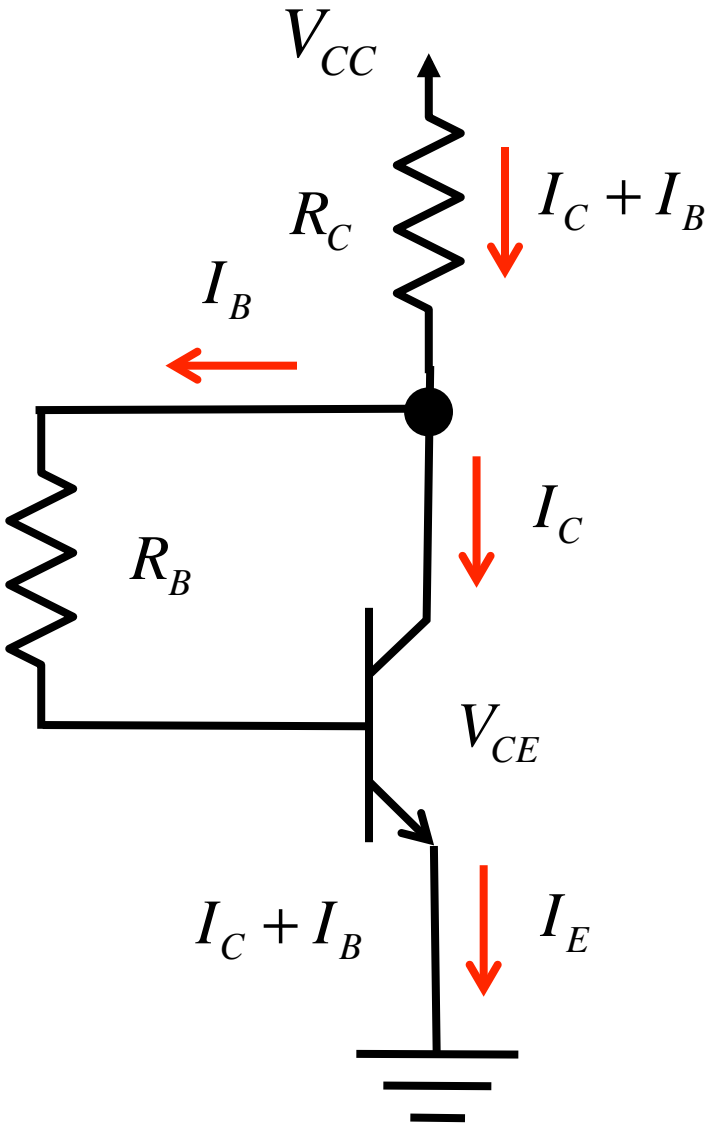
What if beta doubles?

$$I_C \rightarrow 2.0 \text{ mA}$$

$$V_C = 10\,V - I_C R_C = -4 \text{ V!}$$

Saturation!

A better bias circuit



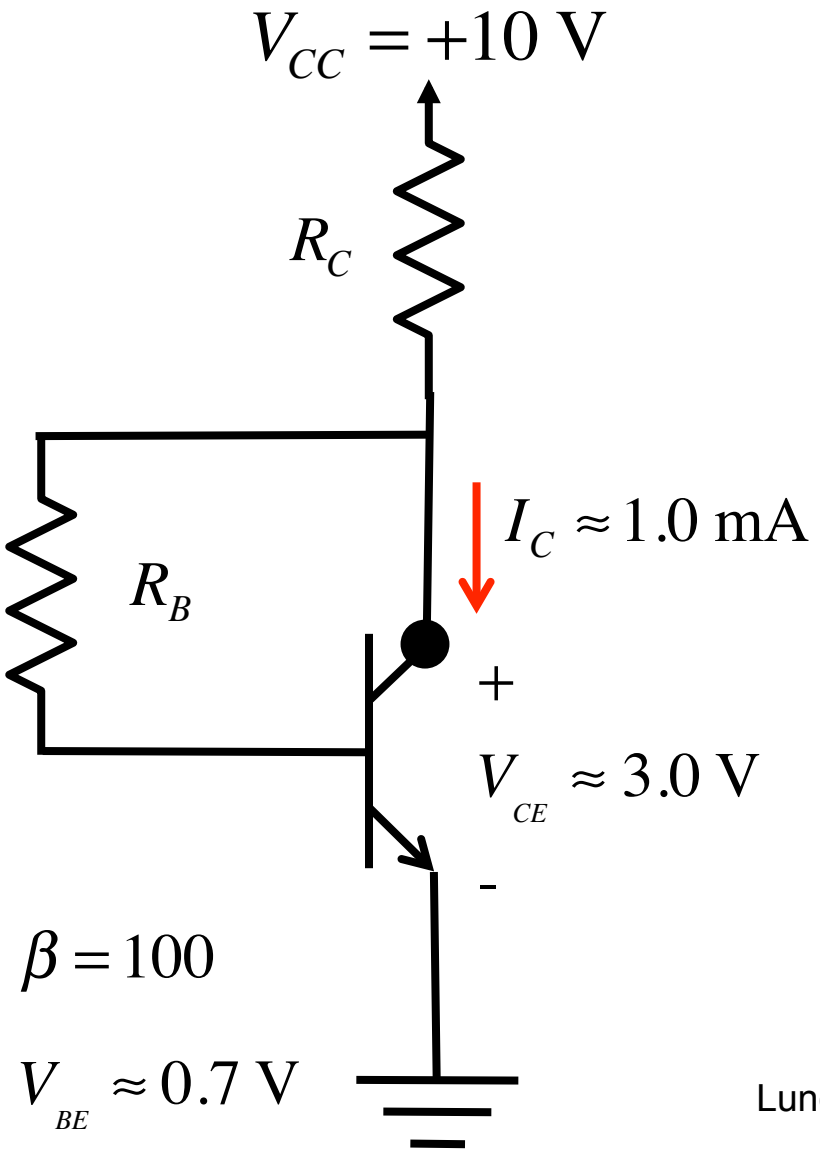
$$V_{CC} = R_C\left(I_C + I_C/\beta\right)I_C + R_B\, I_C/\beta + V_{BE}$$

$$I_C = \frac{V_{CC} - V_{BE}}{R_C\left(1 + \frac{1}{\beta}\right) + R_B\frac{1}{\beta}}$$

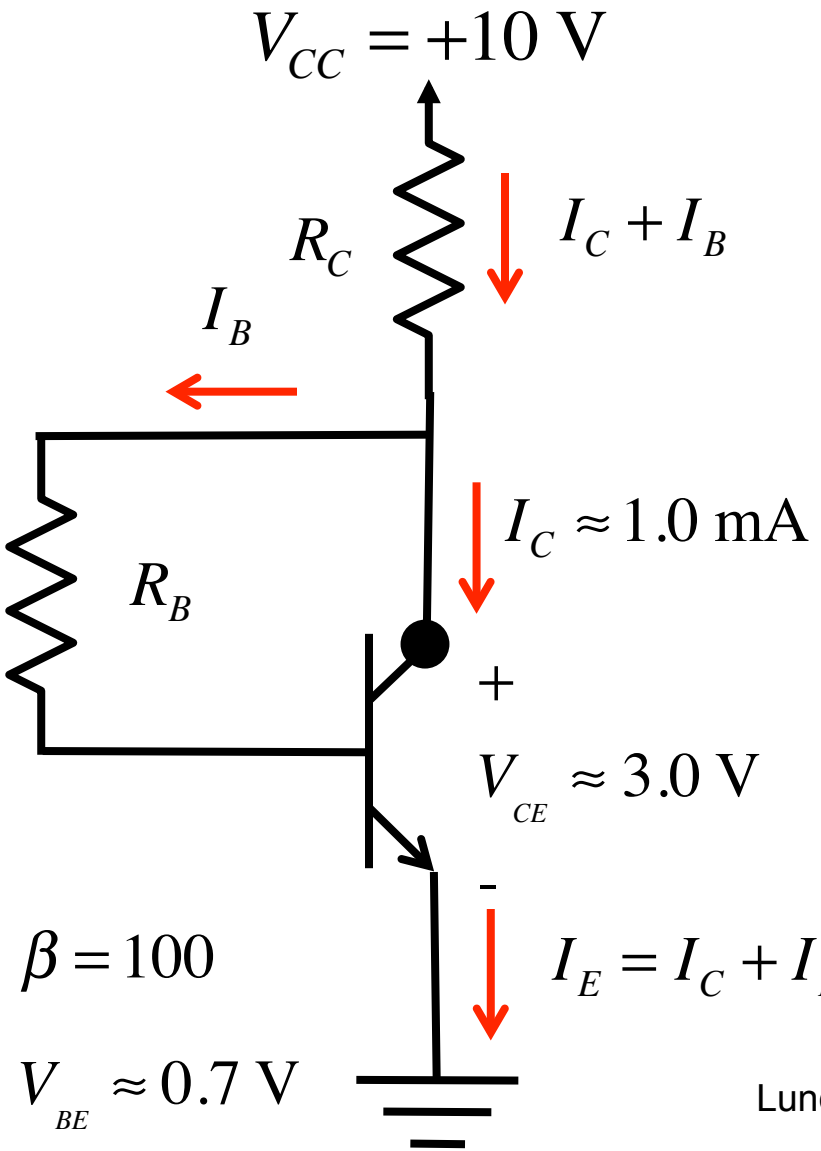
$$\beta \to \infty$$

$$I_C \to \frac{V_{CC} - V_{BE}}{R_C}$$

Design


$V_{CC} = +10$ V
R_C
R_B
$I_C \approx 1.0$ mA
+
$V_{CE} \approx 3.0$ V
-
$\beta = 100$
$V_{BE} \approx 0.7$ V

Design (Results)

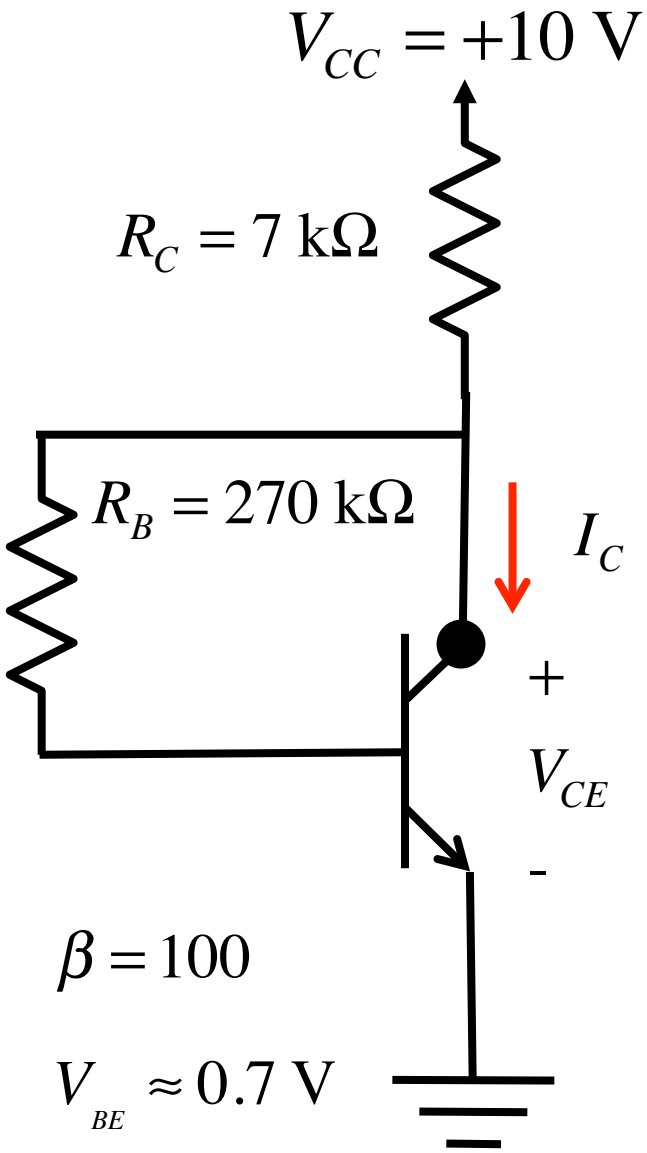


$$I_C R_C \approx 7 \text{ V} \qquad R_C = 7 \text{ k}\Omega$$

$$I_B = 0.01 \text{ mA}$$

$$R_B = \frac{V_{CE} - V_{BE}}{I_B} = \frac{2.3}{0.01} = 230 \text{ k}\Omega$$

Analysis



$$I_C = \frac{V_{CC} - V_{BE}}{R_C\left(1 + \frac{1}{\beta}\right) + R_B\frac{1}{\beta}}$$

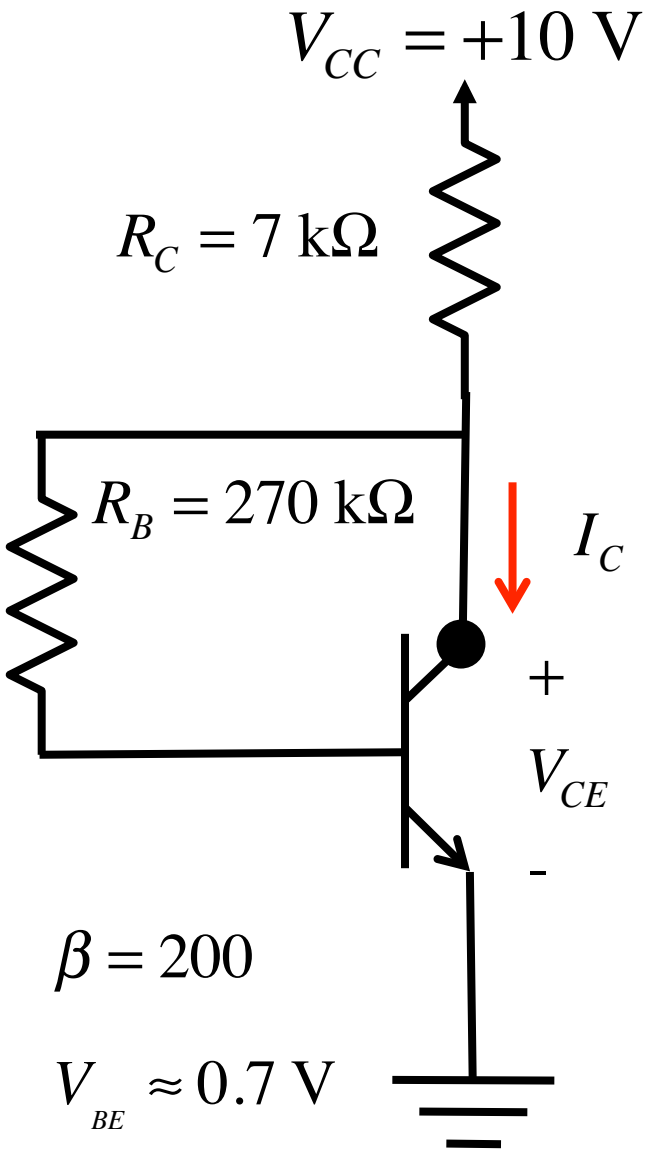
$$I_C = \frac{10 - 0.7}{7\left(1 + \frac{1}{100}\right) + \frac{230}{100}}$$

$$I_C = 1.0 \text{ mA}$$

$$V_{CE} = V_{CC} - \left(\frac{\beta + 1}{\beta}\right) I_C R_C$$

$$V_{CE} = 2.9 \text{ V} \quad \text{(close)}$$

Analysis for beta = 200



$$I_C = \frac{V_{CC} - V_{BE}}{R_C\left(1 + \frac{1}{\beta}\right) + R_B\frac{1}{\beta}}$$

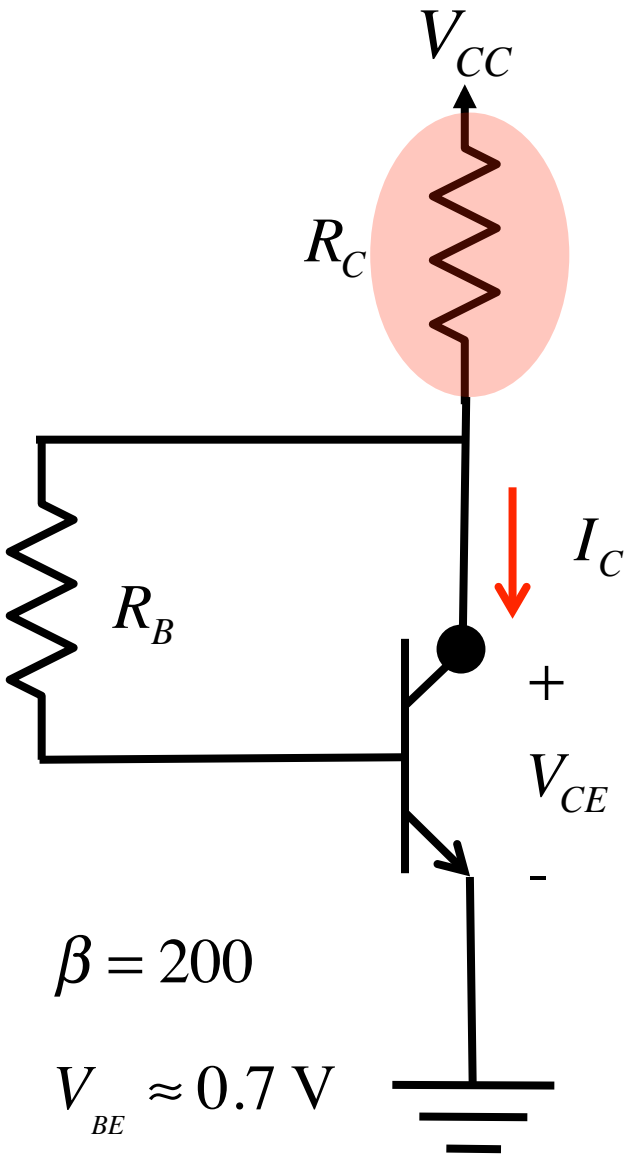
$I_C = 1.1$ mA

$(I_C = 1.0$ mA$)$

$V_{CE} = 2.3$ V

$(V_{CE} = 2.9$ V$)$

Why does it work?

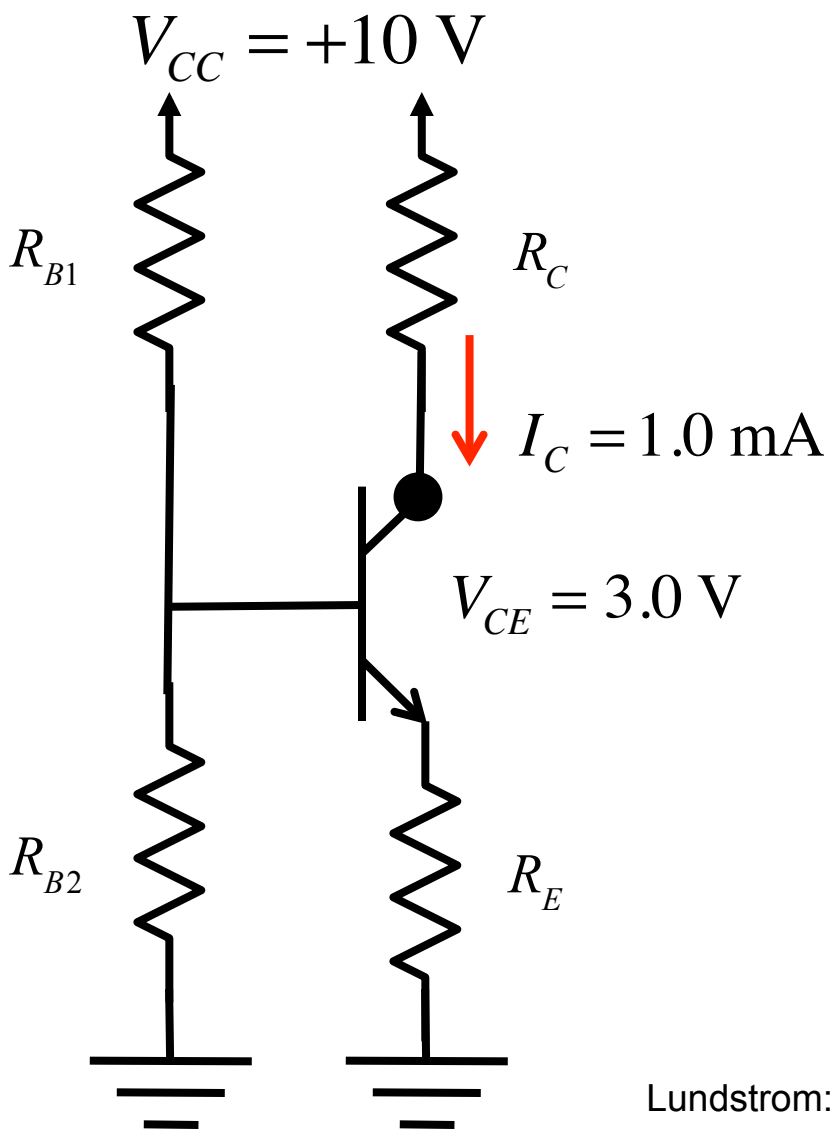


Negative feedback

$I_C \uparrow \quad V_{R_C} \uparrow \quad V_C \downarrow \quad I_B \downarrow \quad I_C \downarrow$

$I_C \downarrow \quad V_{R_C} \downarrow \quad V_C \uparrow \quad I_B \uparrow \quad I_C \uparrow$

Classic 4-resistor Bias circuit design



Design for

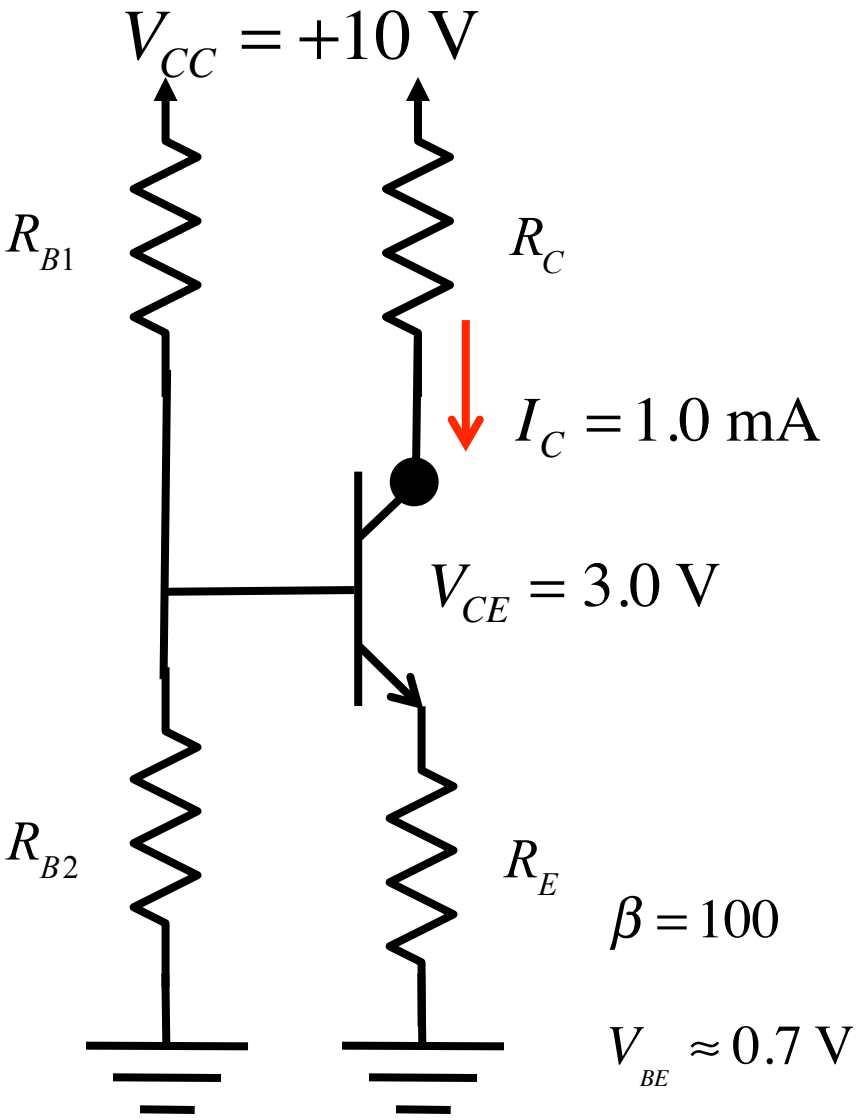
$V_{CE} = 3.0$ V

$I_C = 1.0$ mA

$\beta = 100$

$V_{BE} \approx 0.7$ V

Classic Bias circuit design



Start at the output:

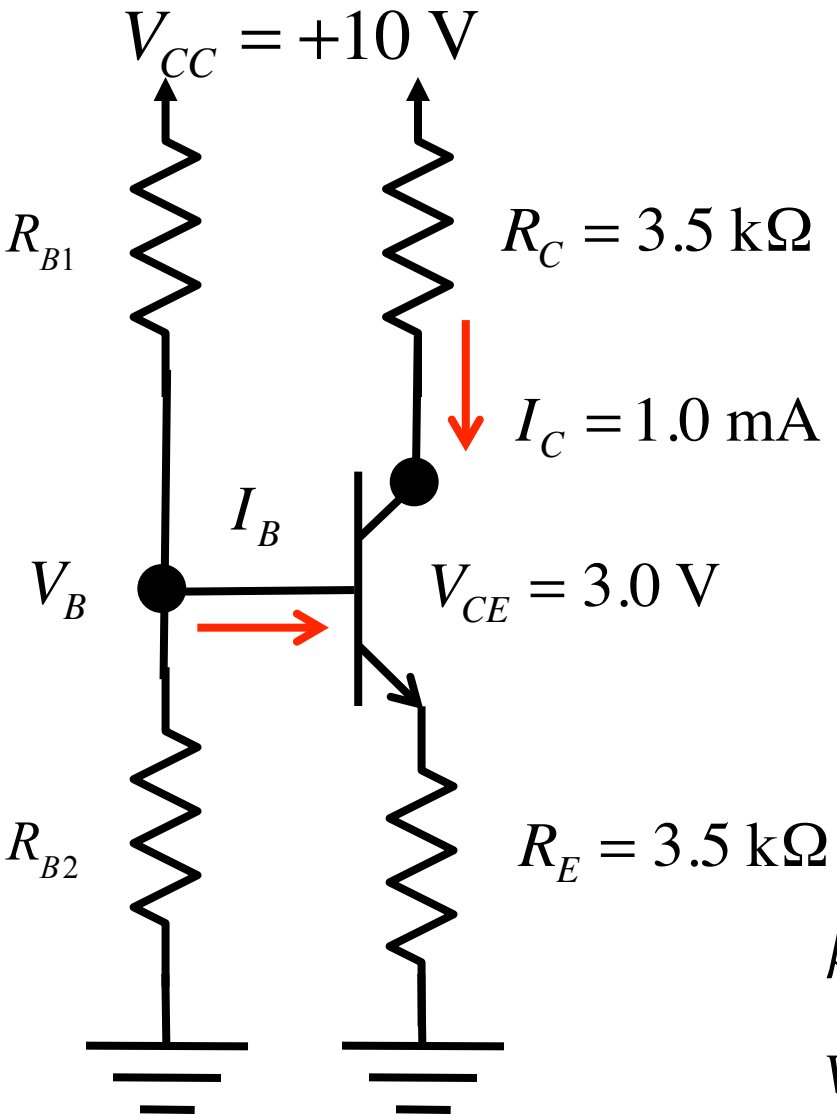
Have 7 V to split between 2 resistors.

Let: $V_{R_C} = V_{R_E} = 3.5$ V

$$R_C = \frac{3.5\text{ V}}{1.0\text{ mA}} = 3.5\text{ k}\Omega$$

$$R_E = \frac{3.5\text{ V}}{1.01\text{ mA}} \approx 3.5\text{ k}\Omega$$

Classic Bias circuit design



Now move to the input:

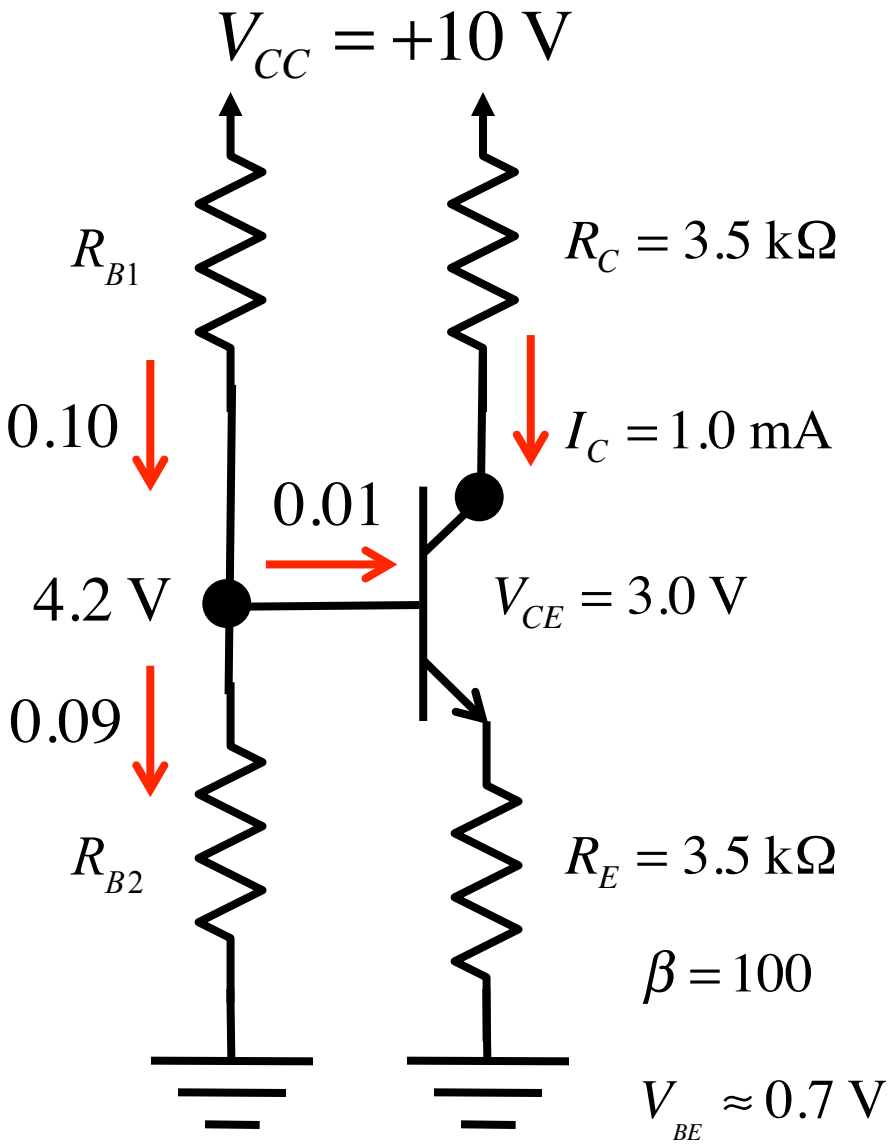
$$V_B = V_{R_E} + 0.7$$
$$= 3.5 + 0.7 = 4.2 \text{ V}$$

$$I_B = \frac{I_C}{100} = 0.01 \text{ mA}$$

$$\beta = 100$$

$$V_{BE} \approx 0.7 \text{ V}$$

Classic Bias circuit design



Choose:

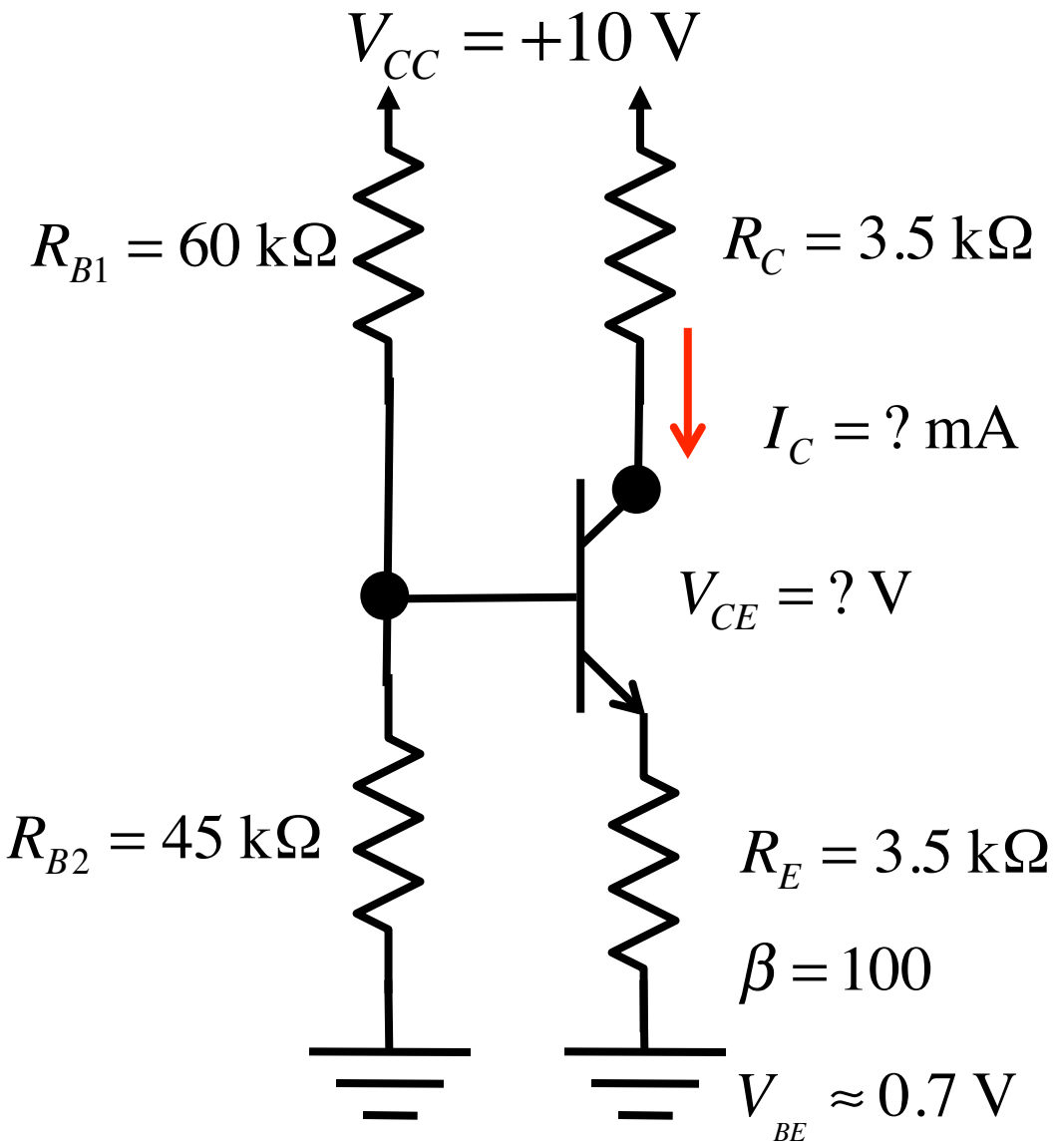
$$I_{R_{B1}} = 10 I_B = 0.1 \text{ mA}$$

$$I_{R_{B1}} = 0.1 \text{ mA} = \frac{(10 - 4.2)\text{V}}{R_{B1}} \rightarrow 58 \text{ k}\Omega$$

$$I_{R_{B2}} = I_{R_{B1}} - I_B$$
$$= 10 I_B - I_B = 0.09 \text{ mA}$$

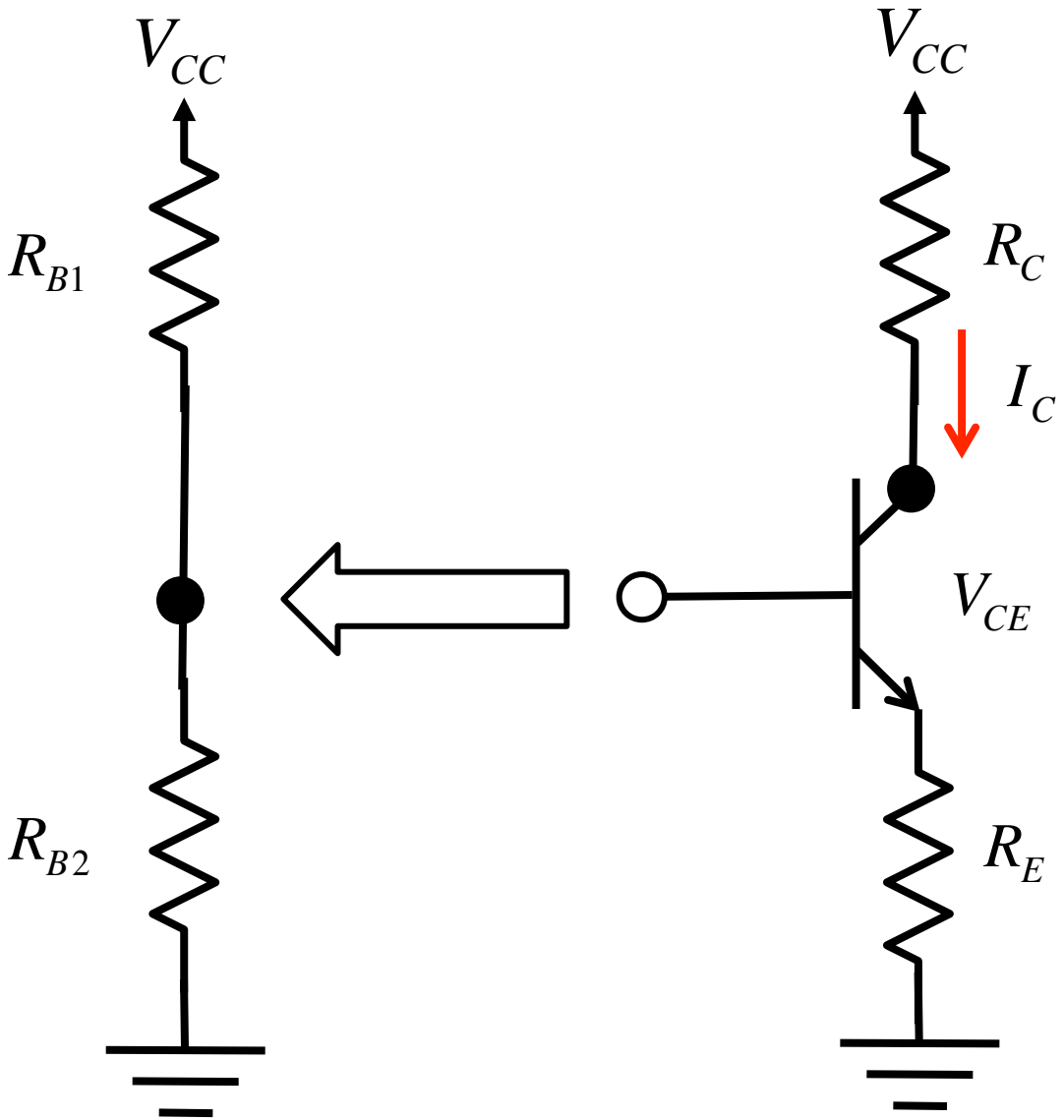
$$I_{R_{B2}} = 0.09 \text{ mA} = \frac{4.2\text{V}}{R_{B2}} \rightarrow 46.7 \text{ k}\Omega$$

Classic bias circuit **analysis**

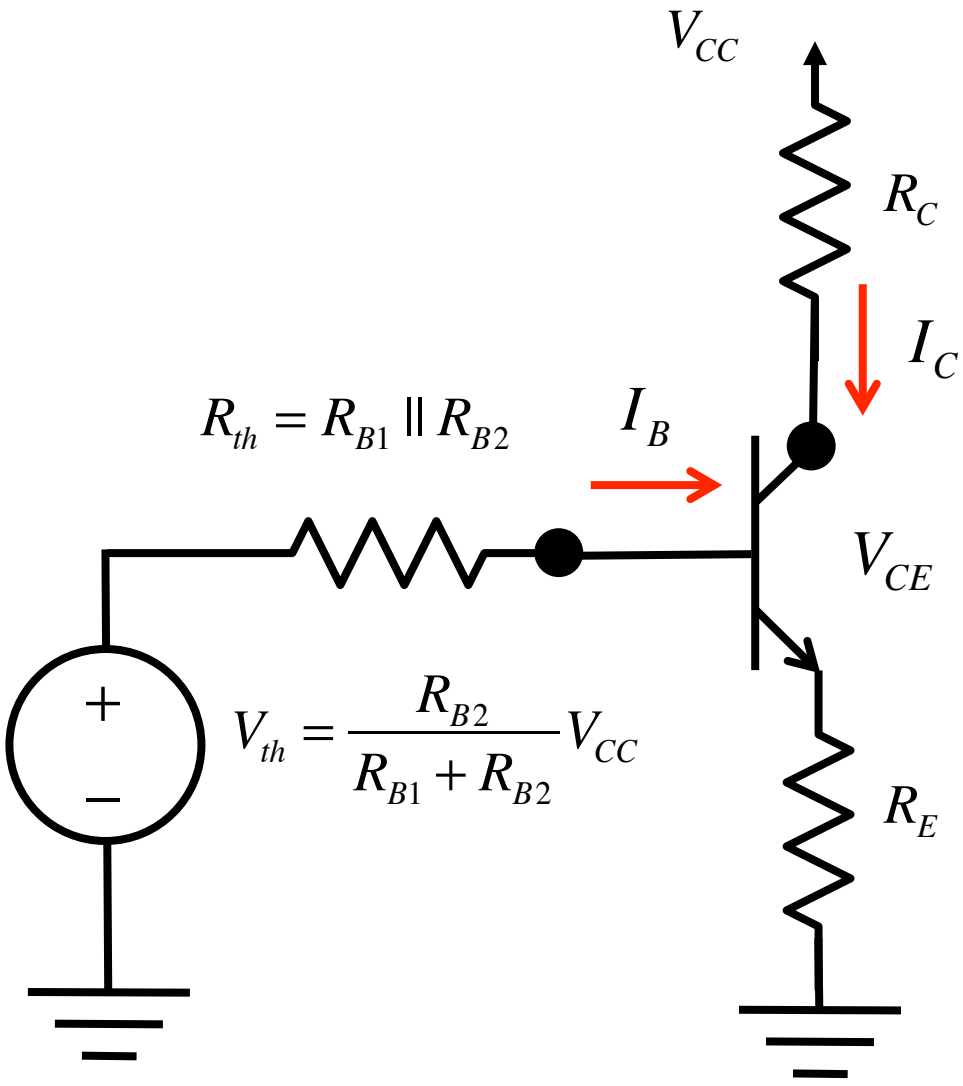


Now that everything is specified, we can **analyze** the circuit.

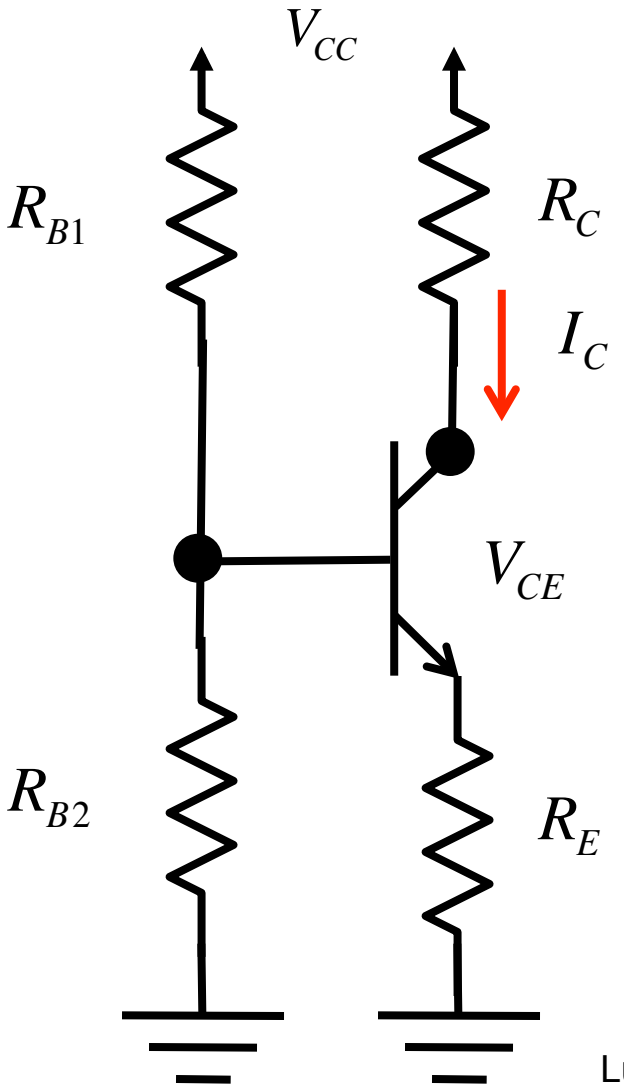
Classic Bias circuit analysis



Classic Bias circuit analysis



Classic bias circuit design

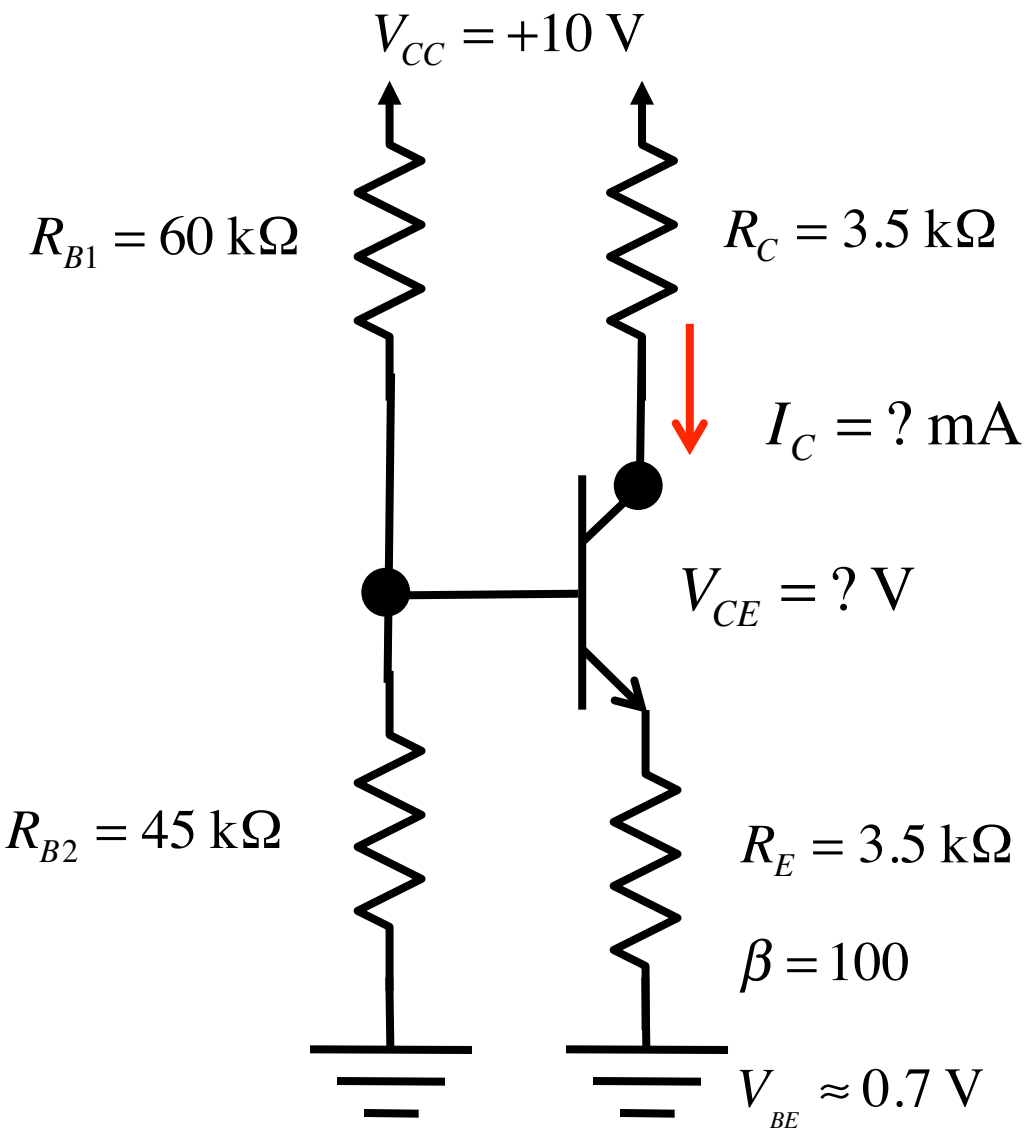


$$I_C = \beta \frac{V_{th} - V_{BE}}{R_{th} + (\beta + 1) R_E}$$

$$R_{th} = R_{B1} \parallel R_{B2}$$

$$V_{th} = V_{CC} \frac{R_{B2}}{R_{B1} + R_{B2}}$$

Classic bias circuit **analysis**

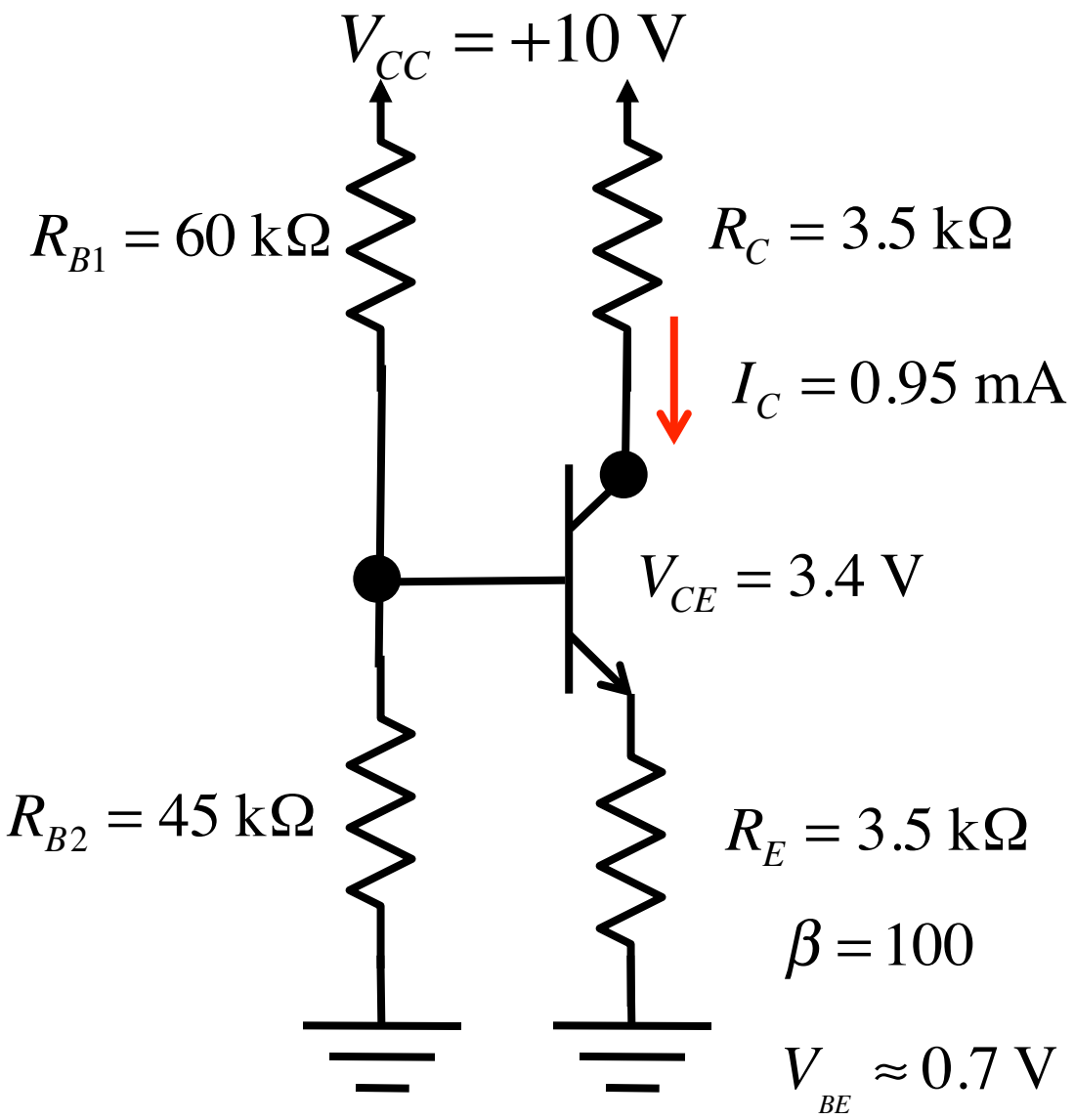


$$I_C = \beta \frac{V_{th} - V_{BE}}{R_{th} + (\beta + 1) R_E}$$

$I_C = 0.95$ mA

$V_{CE} = 3.4$ V

Classic Bias circuit design



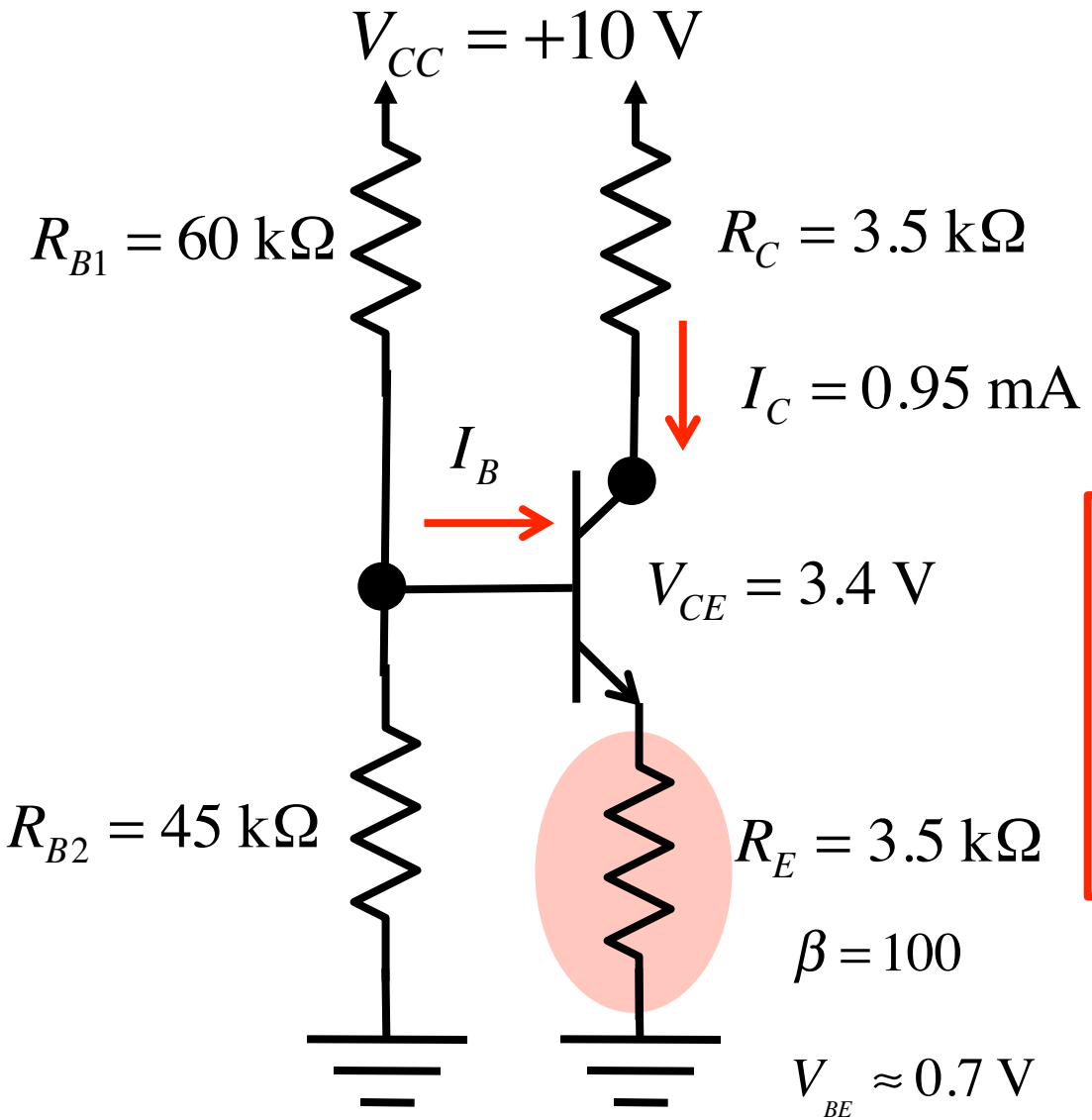
What if beta doubles?

$I_C = 0.95$ mA

$\rightarrow 1.02$ mA

Why is the circuit so good?

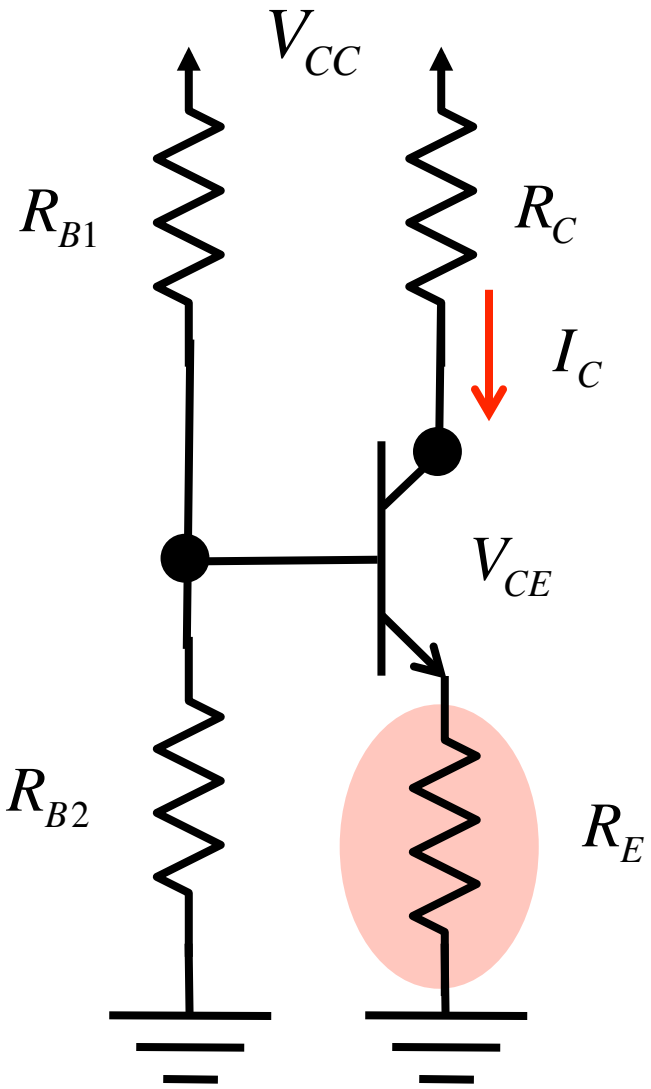
Negative feedback



$I_C \uparrow \quad V_{R_E} \uparrow \quad I_B \downarrow \quad I_C \downarrow$

$I_C \downarrow \quad V_{R_E} \downarrow \quad I_B \uparrow \quad I_C \uparrow$

From the equations



$$I_C = \beta \frac{V_{th} - V_{BE}}{R_{th} + (\beta + 1) R_E}$$

$$(\beta + 1) R_E >> R_{th}$$

$$I_C \approx \frac{\beta}{(\beta + 1)} \frac{V_{th} - V_{BE}}{R_E}$$

$$I_C \approx \frac{V_{th} - V_{BE}}{R_E}$$

Summary

Be comfortable analyzing NPN, PNP, and NPN-PNP DC circuits.

The classic 4-resistor bias circuit for discrete transistors makes use of negative feedback to deal with variations in beta.

For IC design, we don't use the 4-resistor bias circuit because high value resistors are "expensive". Instead, we make use of transistors, because they are cheap.

BJT bias circuits

1) NPN and PNP circuits
2) Bias circuits (discrete)