Universidad Carlos III de Madrid

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Session 12
Analysis of DC circuits with BJT (polarization)

Electronic Components and Circuits

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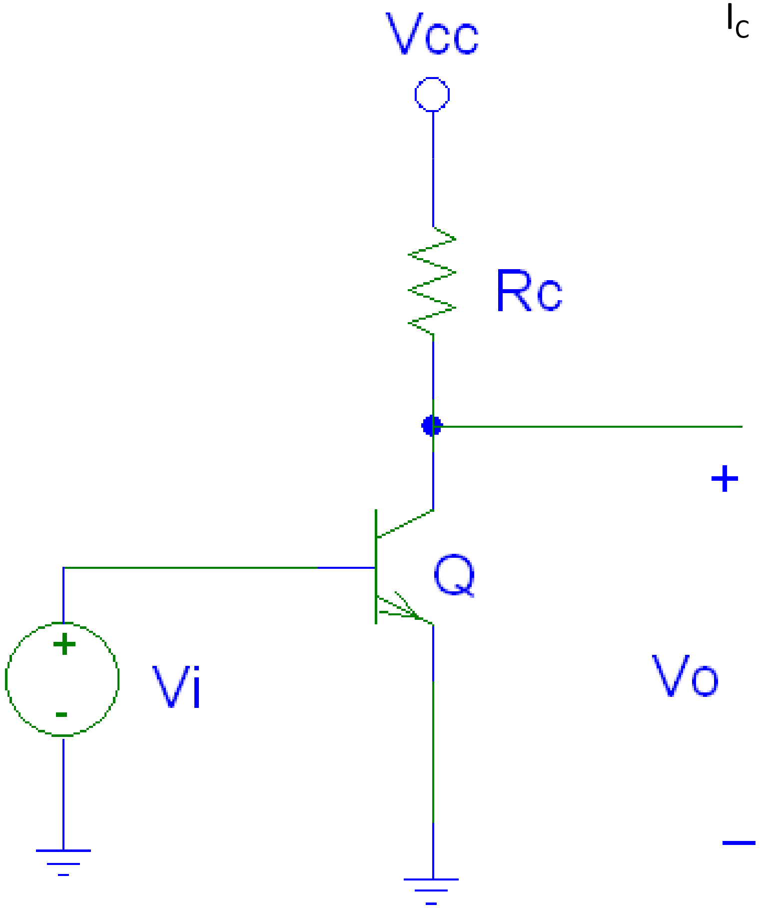
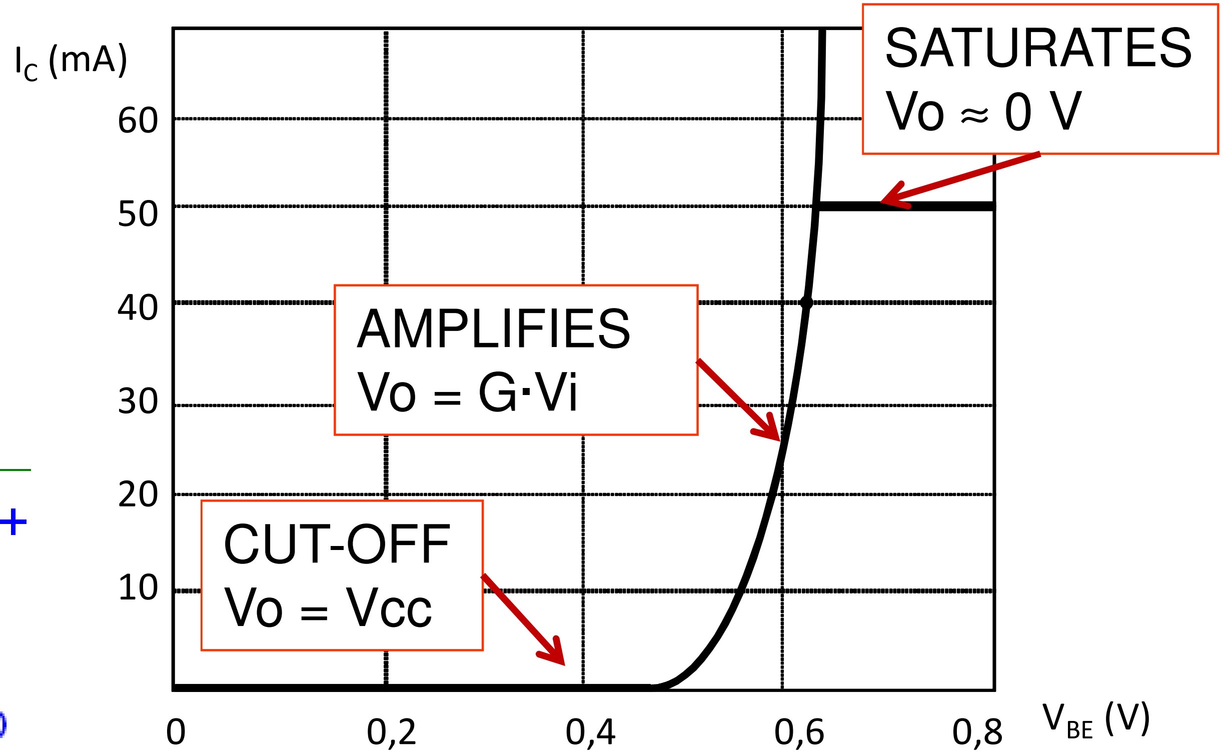
DC circuits with BJT and polarization of transistors

OBJETIVES

- Summarizing the operating regions and introducing the amplification (active)
  - Active, Cut-off, Saturation
- Analyzing basic BJT circuits in DC. Static characteristics and Load line.
- Understanding the need of polarization circuits
- Knowing and analyzing typical polarization circuits of transistors. Bias (quiescent) point.

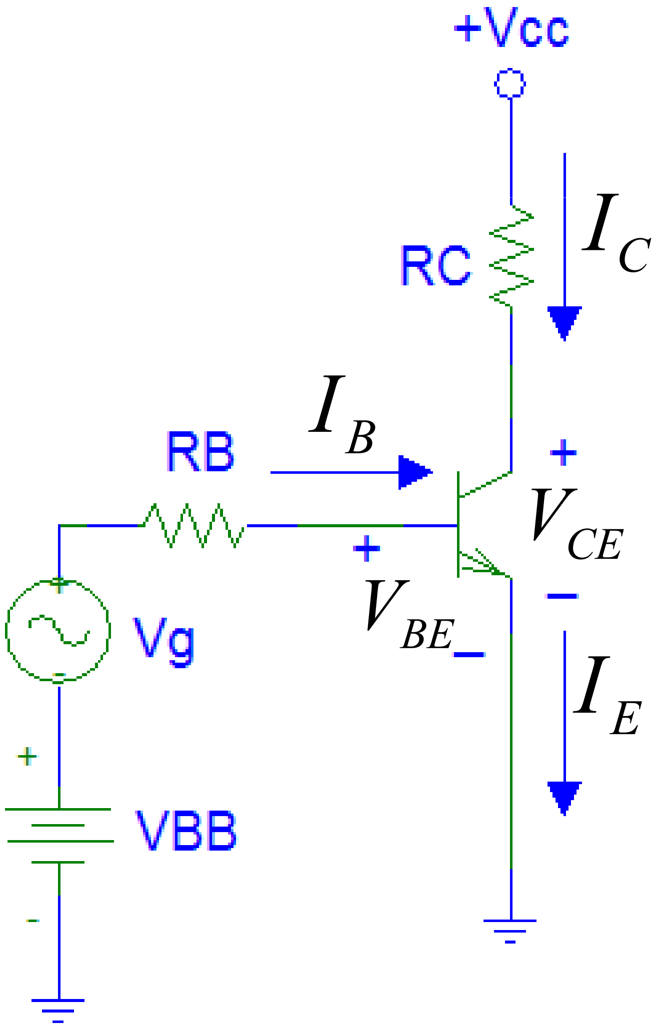
Amplification concept with BJT



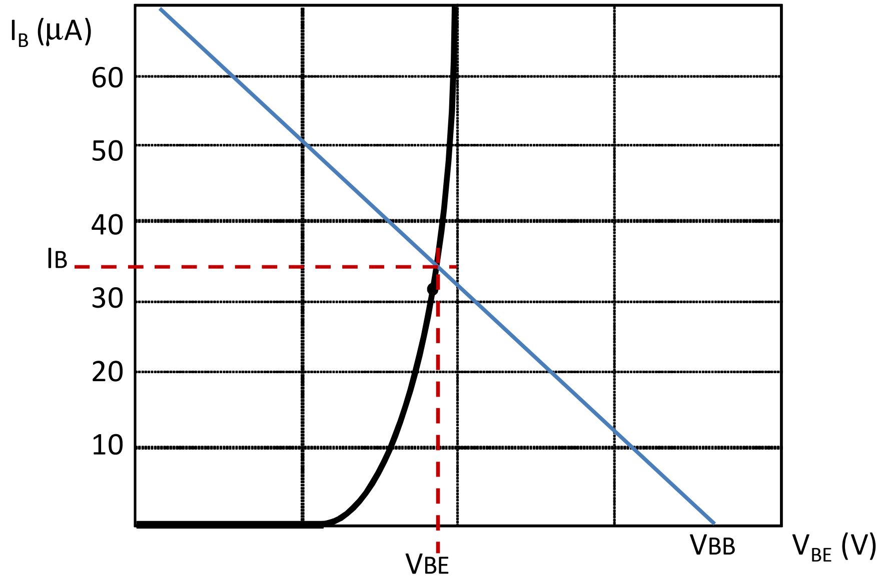


- Small changes of Vi result in greater variation of Vo, thus providing gain Vo/Vi
- It should be around a bias point or quiescent point $V_{BE\text{-}Q}$, $V_{CE\text{-}Q}$

Superposition of DC Bias and Signal



- VBB is a continuous source that provides along with RB a bias point (polarization) : $v_g = 0$



- A variable signal is introduced and it is added to VBB $V_{BB} + v_g$

Amplification focuses on Active region

- Datasheet $V_{BE(on)}$ $V_{CE(sat)}$ h_{FE} $V_{BE(sat)}$

Search BC547 in http://www.fairchildsemi.com/

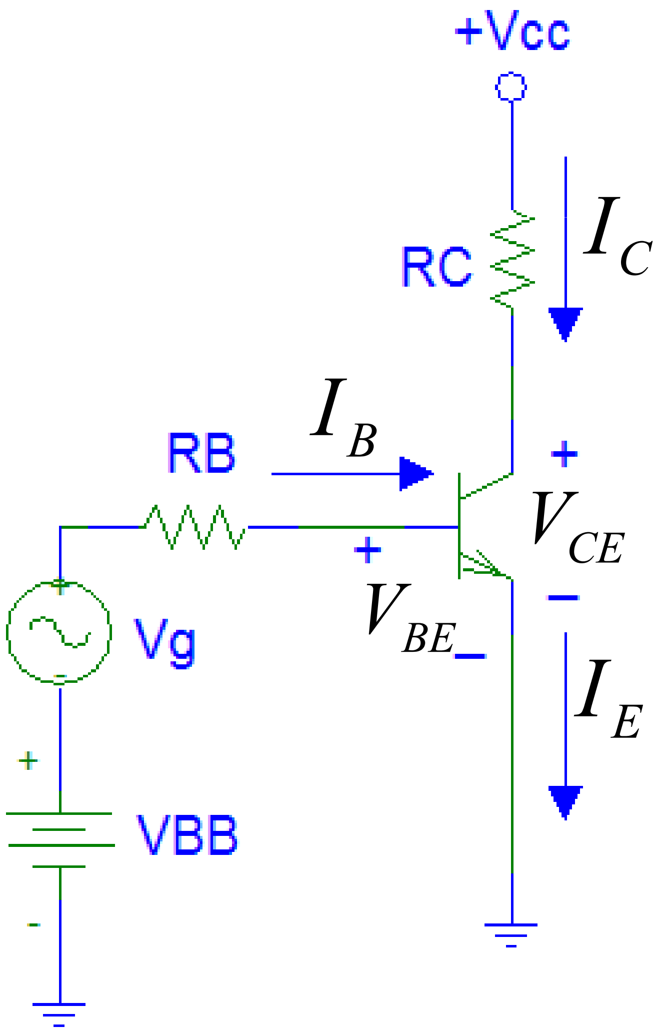
Region	Base-Emitter Junction	Base-Collector Junction
Cut-off	Reverse(OFF)	Reverse
Active	**Forward (ON)**	**Reverse (Transistor Effect)**
Saturation	Forward (ON)	Forward (Saturated)

Region	Conditions NPN	Operation NPN
Cut-off	$V_{BE} < V_{BE-ON}$ o $I_B = 0$	$I_B=0$, $I_C=I_E=0$
Active	**V_{BE-ON} y $V_{CE} > V_{CE-SAT}$**	**$I_C \approx h_{FE} \cdot I_B$ [$V_{BE}=V_{BE-ON}$]**
Saturation	V_{BE-ON} y V_{CE-SAT}	$V_{CE} = V_{CE-SAT}$ [$V_{BE}=V_{BE-SAT}$]

Graphical DC Analysis

EXAMPLE

- RC = 100 Ω
- RB = 10 kΩ
- VCC = 10 V
- VBB = 10 V
- VBE(on) = 0,7 V
- VCE(sat) = 0,2 V
- hFE = 100

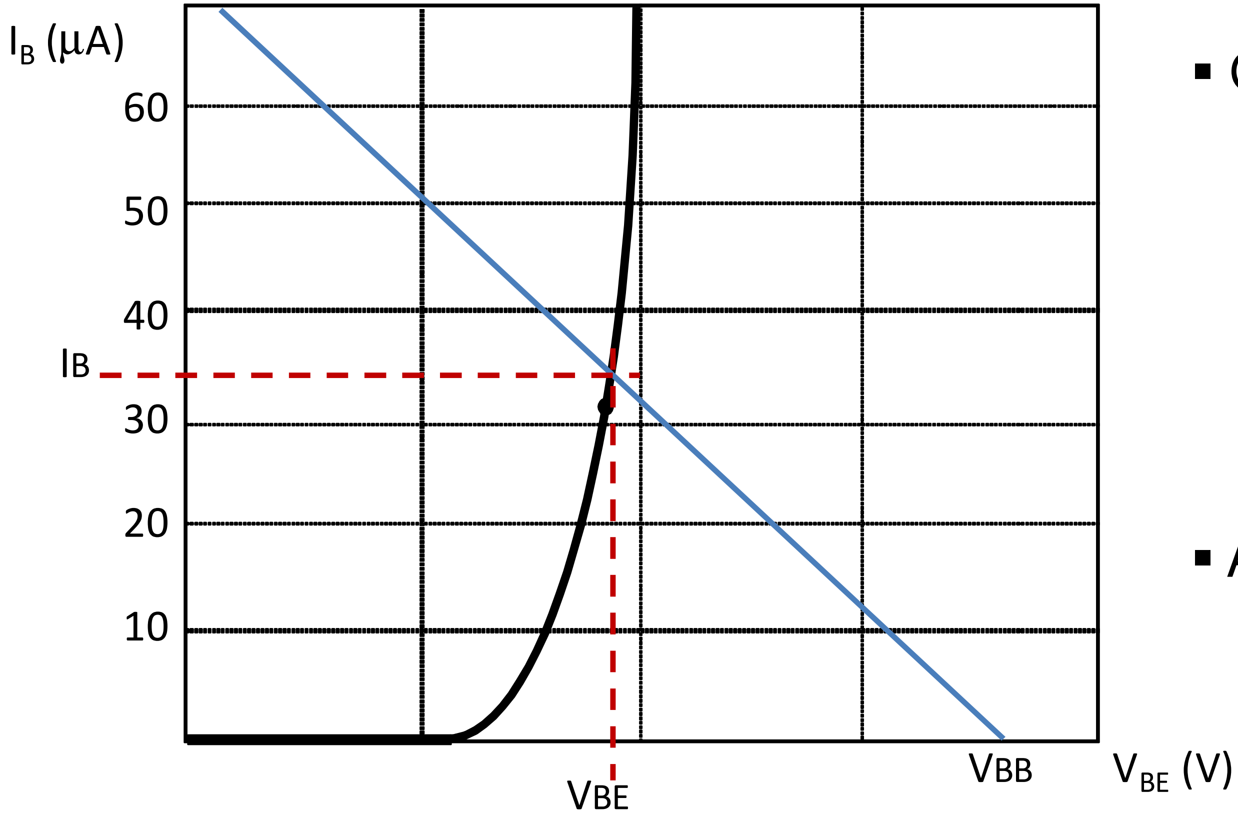


- Cancel the signal (superposition)

$$v_g = 0$$

- Analyze the input
  - Device Equation
    (Input Characteristic)
  - Circuit Equation
    (Load line)
- Analyze the output
  - Device Equation
    (Output Characteristic)
  - Circuit Equation
    (Load line)

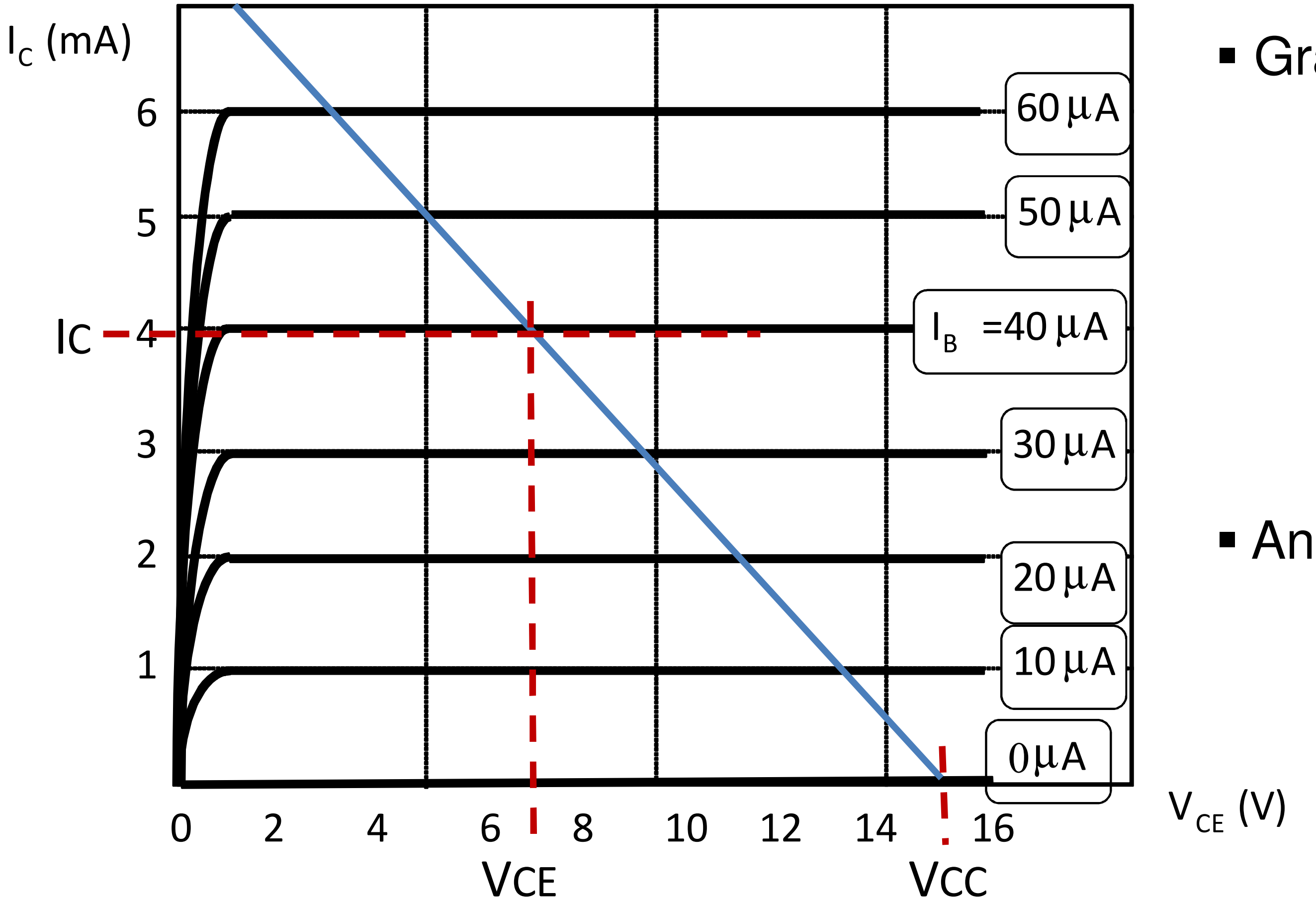
Input Characteristic and Load Line (I)



$$V_{BE} \approx V_{BE(on)} \qquad I_B = \frac{V_{BB} - V_{BE(on)}}{R_B}$$

- Graphically
  - Characteristic:
    $$i_B = i_B(v_{BE}, v_{CE})$$
  - Load line:
    $$i_B = \frac{V_{BB} - v_{BE}}{R_B}$$
- Analytically
  - VBB > VBE(on)
    $$v_{BE} = V_{BE(on)}$$
    $$V_{BB} = v_{BE} + i_B \cdot R_B$$

Output Characteristic and Load Line (II)



- Graphically
  - Characteristic:

$$i_C = i_C(v_{CE}, i_B)$$

  - Load line :

$$i_C = \frac{V_{CC} - v_{CE}}{R_C}$$

- Analytically
  - VCE > VCE(sat)

$$i_C = h_{FE} \cdot i_B$$

$$V_{CC} = v_{CE} + i_C \cdot R_C$$

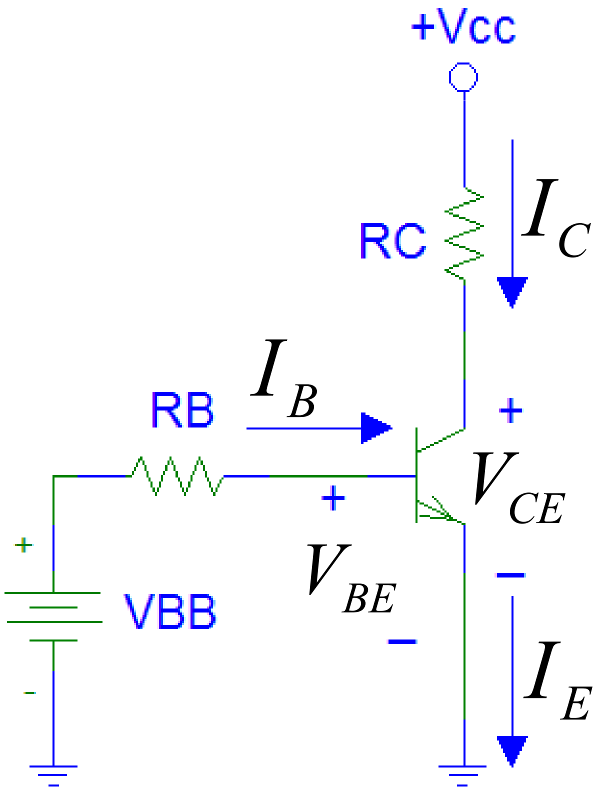
$$I_C = h_{FE} \cdot I_B \qquad V_{CE} = V_{CC} - I_C \cdot R_C$$

DC equivalent circuit: Analytically

EXAMPLE

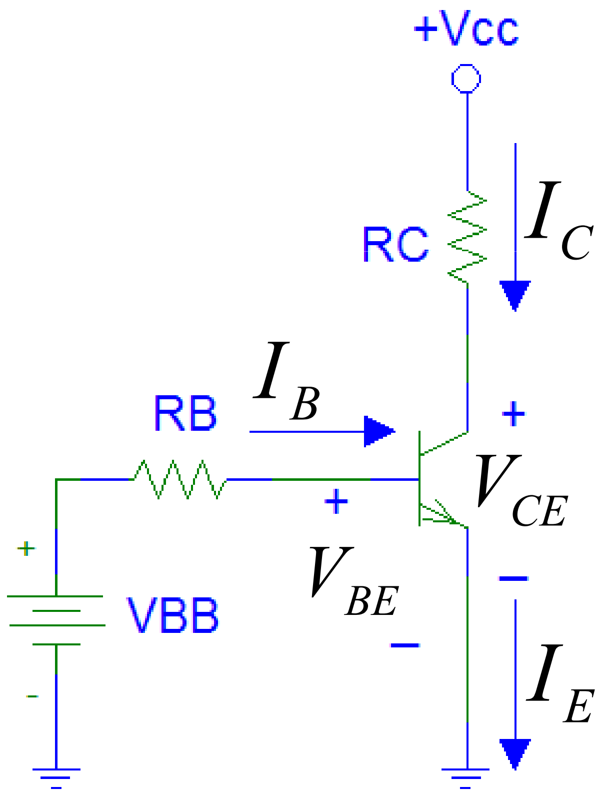
- RC = 100 Ω
- RB = …
- VCC = 10 V
- VBB = …
- VBE(on) = 0,7 V
- VCE(sat) = 0,2 V
- hFE = 100

Case 3
VBB = 10 V
RB = 10 kΩ



- Analyze the input
  - Device Equation
  - Circuit Equation
- Analyze the output
  - Device Equation
  - Circuit Equation

Solution: DC Analysis



- Analyze the input
  - VBB > VBE(on)
    - Device Equation $$v_{BE} = V_{BE(on)}$$
    - Circuit Equation $$V_{BB} = v_{BE} + i_B \cdot R_B$$
- Analyze the output
  - VCE > VCE(sat)
    - Device Equation $$i_C = h_{FE} \cdot i_B$$
    - Circuit Equation $$V_{CC} = v_{CE} + i_C \cdot R_C$$

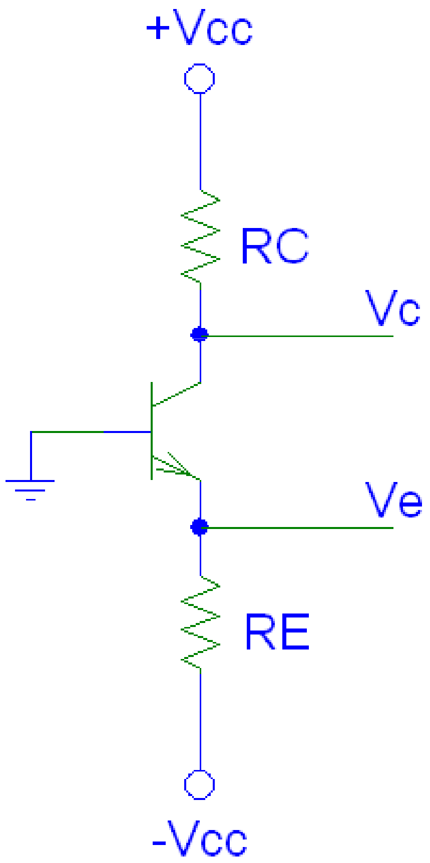
$$V_{BE} \approx V_{BE(on)}$$

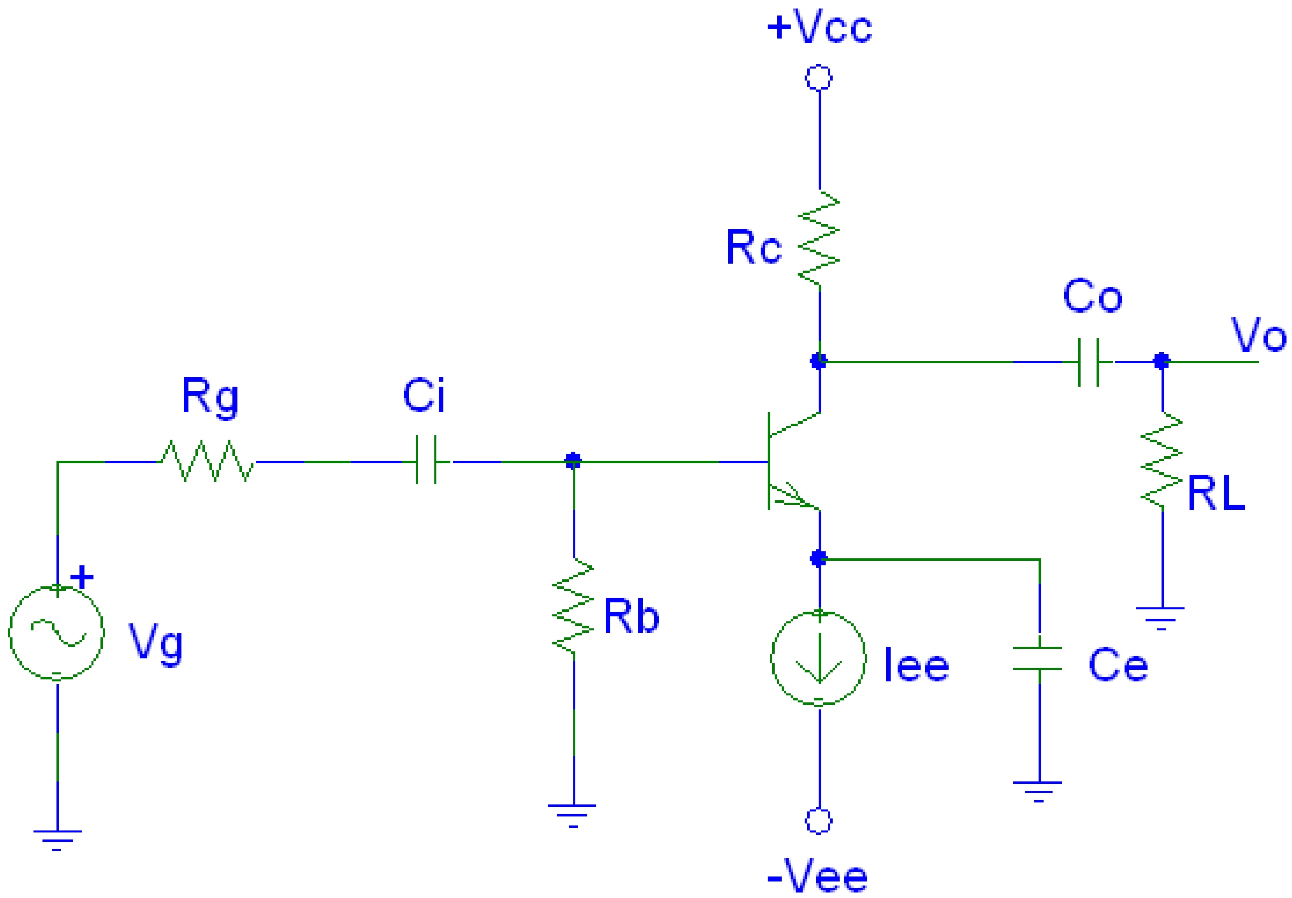
$$I_B = \frac{V_{BB} - V_{BE(on)}}{R_B}$$

$$I_C = h_{FE} \cdot I_B$$

$$V_{CE} = V_{CC} - I_C \cdot R_C$$

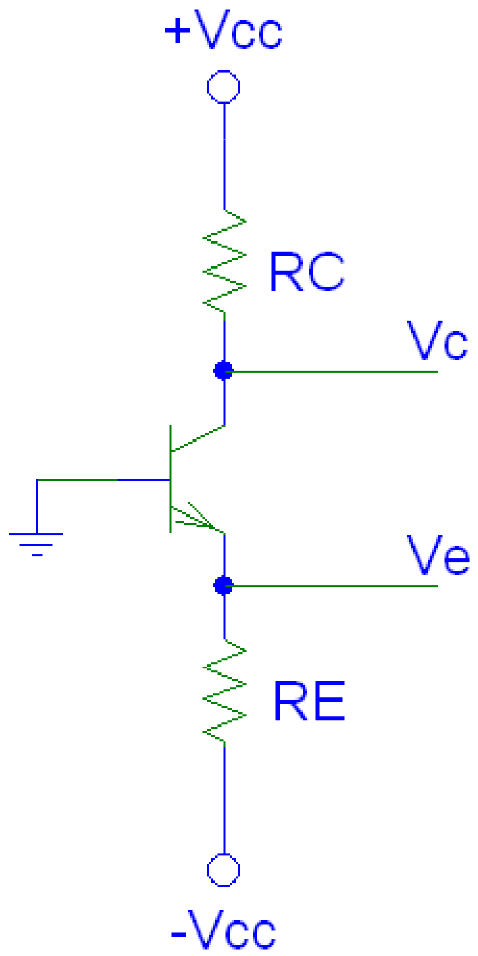
Bias circuits





- Set a stable operating point desensitized against the transistor parameters.
- Optimize the signal amplifier circuit.
- Separate bias circuit if necessary (signal AC coupling).

Example



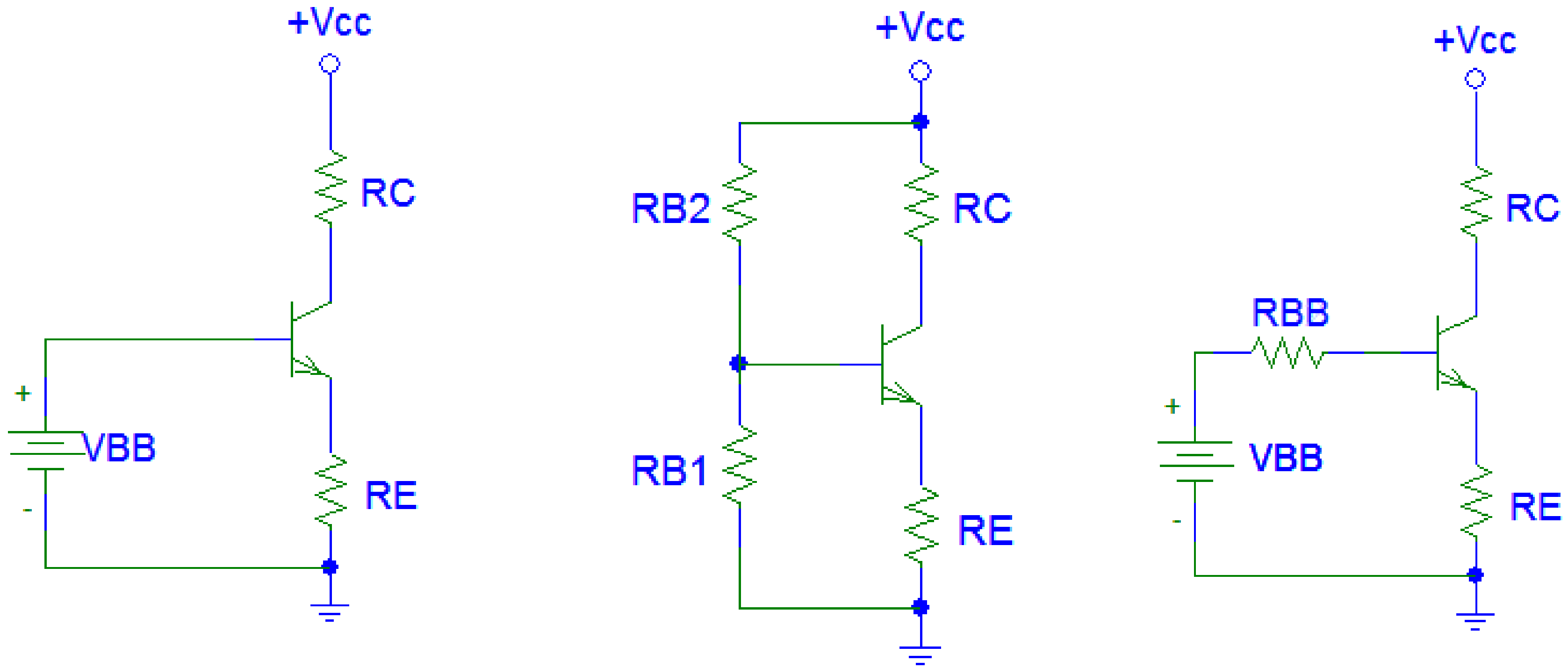
- Reasoning operating region
- Calculate the voltage V_E
- Calculate the current I_E
- Derive the relationship between I_E, I_B and I_C
- Calculate the curents I_C and I_B
- Calculate the voltage V_C

DATA

- VCC = 12 V
- RC = RE = 10 kΩ
- VBE(on) = 0,7 V
- VCE(sat) = 0,2 V
- hFE = 100

Types of polarization circuits
Biasing with RE

Practical circuit

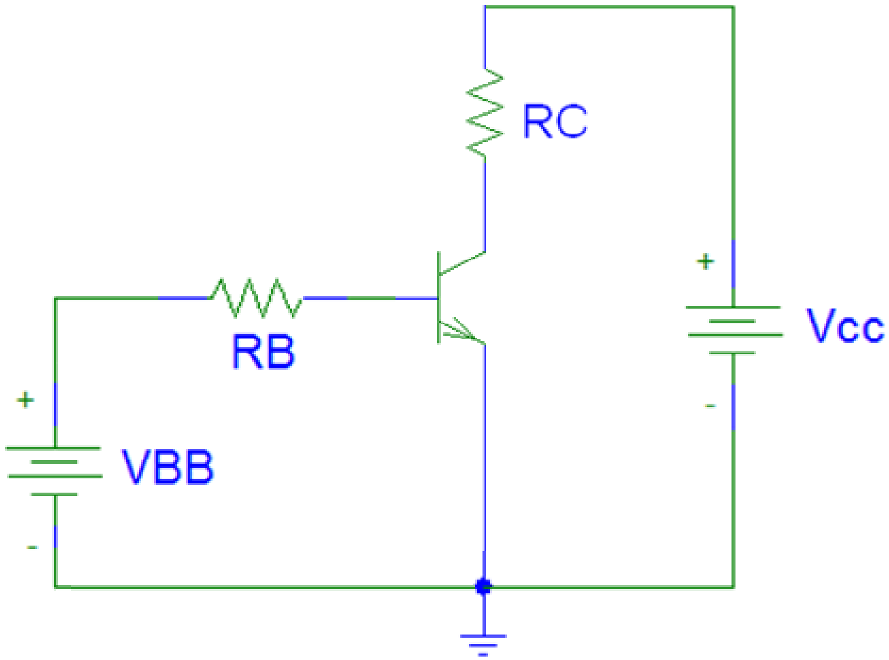


- Lower sensitivity to the transistor current gain
- Stabilizes the bias point (quiescent point) against V_{BE}, h_{FE}, etc.

Case 1: Biasing with RB

DATA:

- V_{BB} = 5 V
- V_{CC} = 10 V
- R_B = 50 kΩ
- R_C = 3 kΩ
- R_E = 2 kΩ
- $V_{BE(on)}$ = 0,7 V
- $V_{CE(sat)}$ = 0,2 V
- h_{FE} = 100

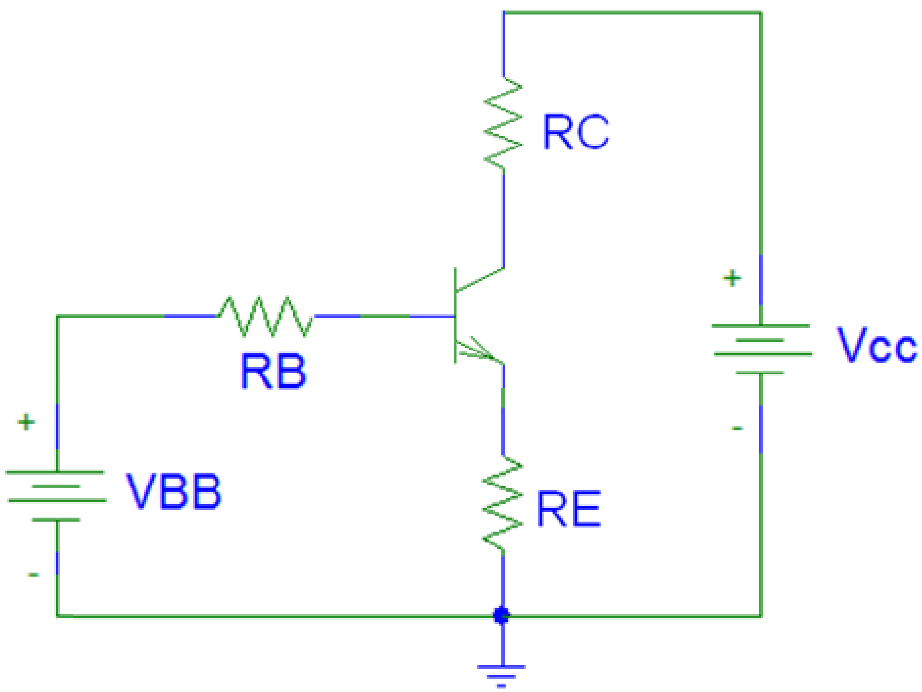


- Reasoning the operating region
- Indicate the value of V_{BE}
- Calculate the currents I_B, I_C e I_E
- Calculate the voltage V_{CE}
- Check that is in active
- Recalculate if you change h_{FE} = 200

Case 2: Biasing with RE

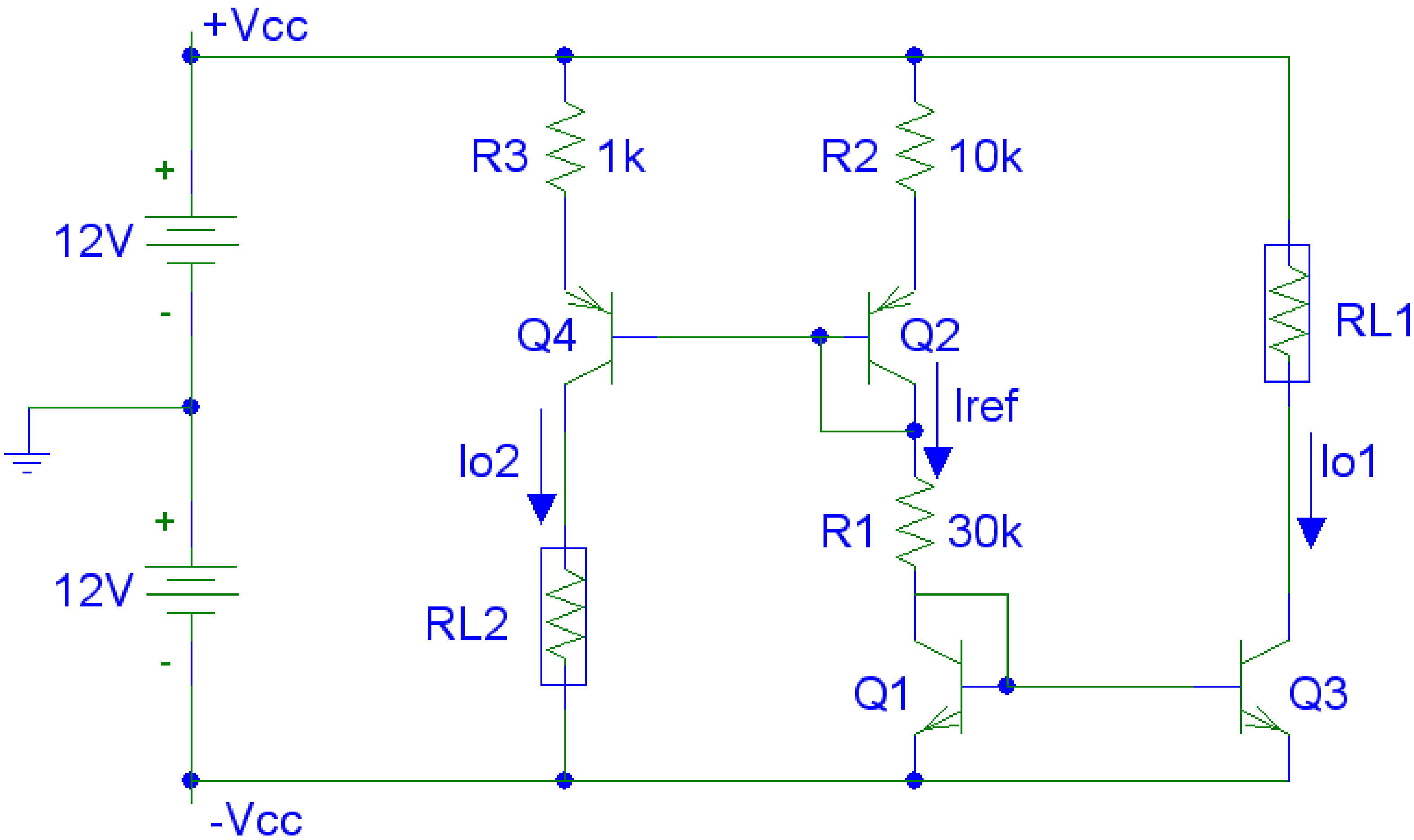
DATA:

- $V_{BB} = 5$ V
- $V_{CC} = 10$ V
- $R_B = 10$ kΩ
- $R_C = 3$ kΩ
- $R_E = 2$ kΩ
- $V_{BE(on)} = 0{,}7$ V
- $V_{CE(sat)} = 0{,}2$ V
- $h_{FE} = 100$



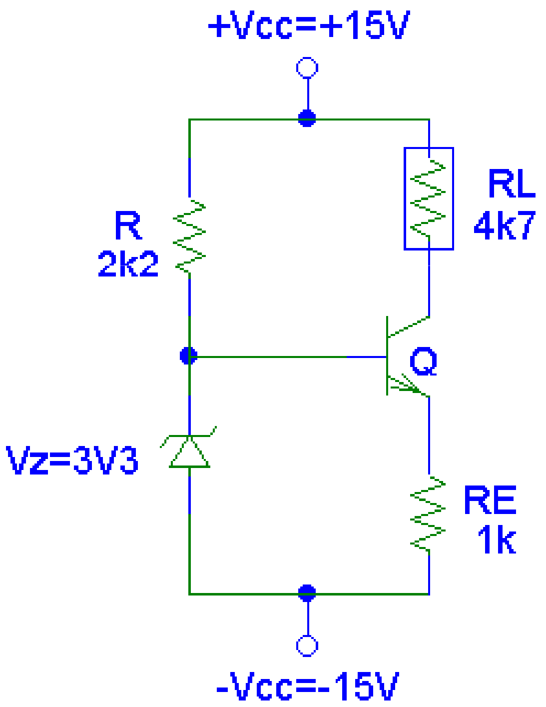
- Reasoning the operating region
- Indicate the value of V_{BE}
- Calculate the current I_E (you can neglect the base current I_B)
- Calculate the currents I_C, I_B
- Check that I_B is negligible
- Calculate the voltage V_{CE}
- Check that the BJT is in active
- Recalculate if you change $h_{FE} = 200$
- Generalize if not negligible I_B (eg if $R_B = 50$ kΩ)

Biasing with current mirrors



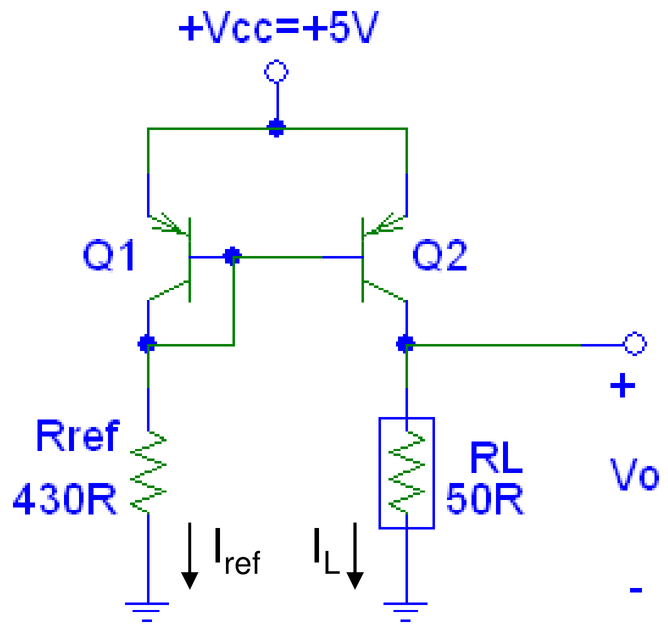
$$I_{O2} = I_{ref} \frac{R_2}{R_3} = 10 \cdot I_{ref} \qquad I_{O1} \approx I_{ref}$$

Proposed exercise: Current sources



Zener ideal:
V_Z = 3,3 V
$I_{Zmín}$ = 10 mA

Transistor:
V_{CEsat} = 0,2 V
V_{BEon} = 0,7 V
β = 270



- Calculate I_E, I_C, I_B and V_B, V_C, V_E, V_{CE}, I_Z.
- For R_L = 1 kΩ, calculate I_C y V_C
- For R_L = 22 kΩ, calculate I_C y V_C
- Plot the load lines (three cases).
- Maximum RL as a current source?.
- In the case R_L = 22 kΩ, calculate I_B, I_Z

- Obtain the ratio I_L/I_{ref}
- Reason if I_B is negligible
- Obtain I_{ref}
- There is the scale factor $I_{C2} = 2 \cdot I_{C1}$ between both transistor. Calculate Vo.