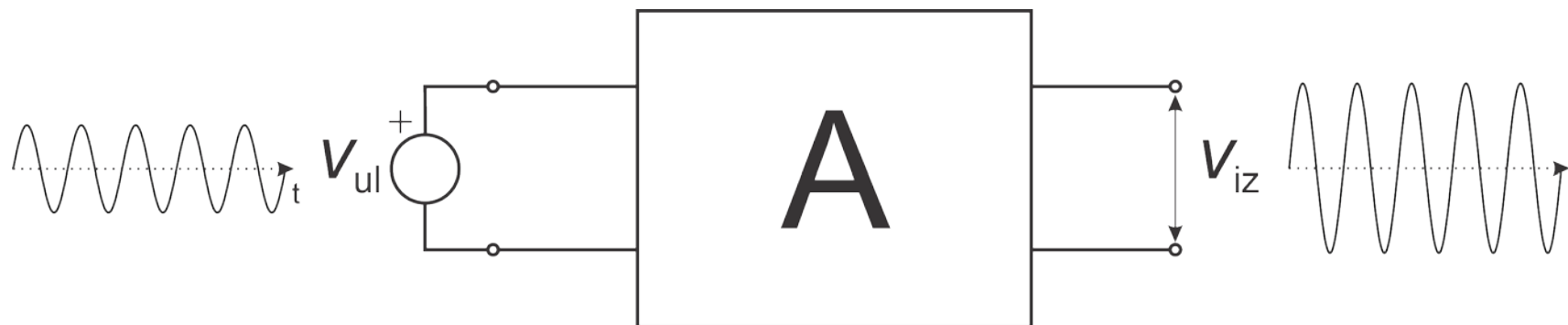


# **Bipolarni tranzistor**

# Koncept pojačavača

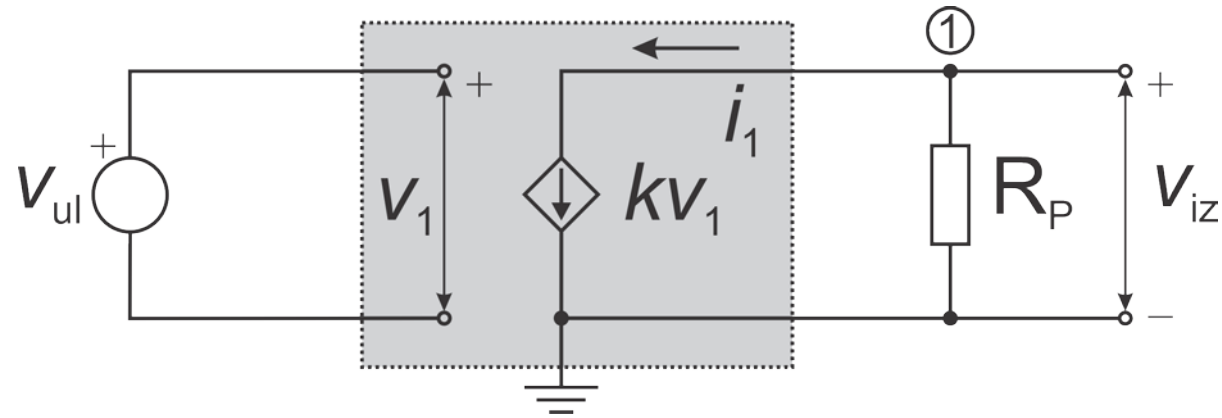
- Pojačavač je četvoropol koji pojačava snagu signala (napon, struju).



$$v_{iz}(t) = A \cdot v_{ul}(t)$$

# Koncept pojačavača

- Pojačavač se može realizovati pomoću kontrolisanog izvora.



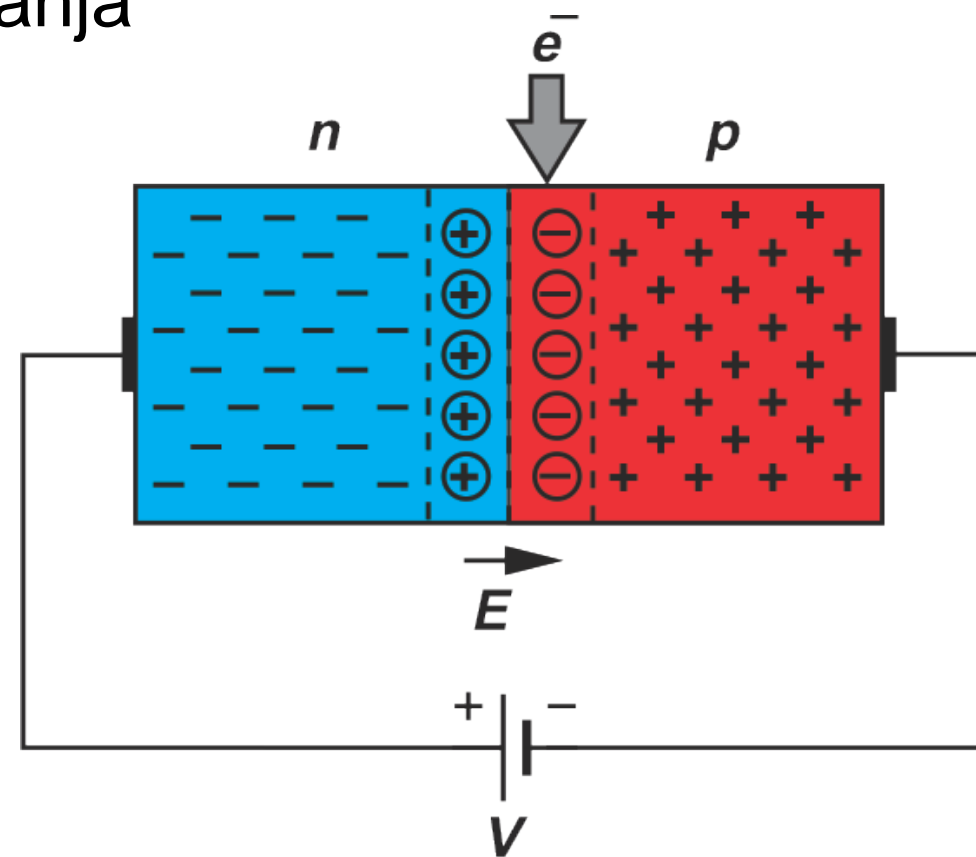
$$\frac{v_{iz}}{R_P} + kv_1 = 0, \quad v_1 = v_{ul}$$

$$v_{iz} = -k \cdot v_{ul} \cdot R_P$$

# Bipolarni tranzistor - principi

## 1. Ubacivanje slobodnih naelektrisanja

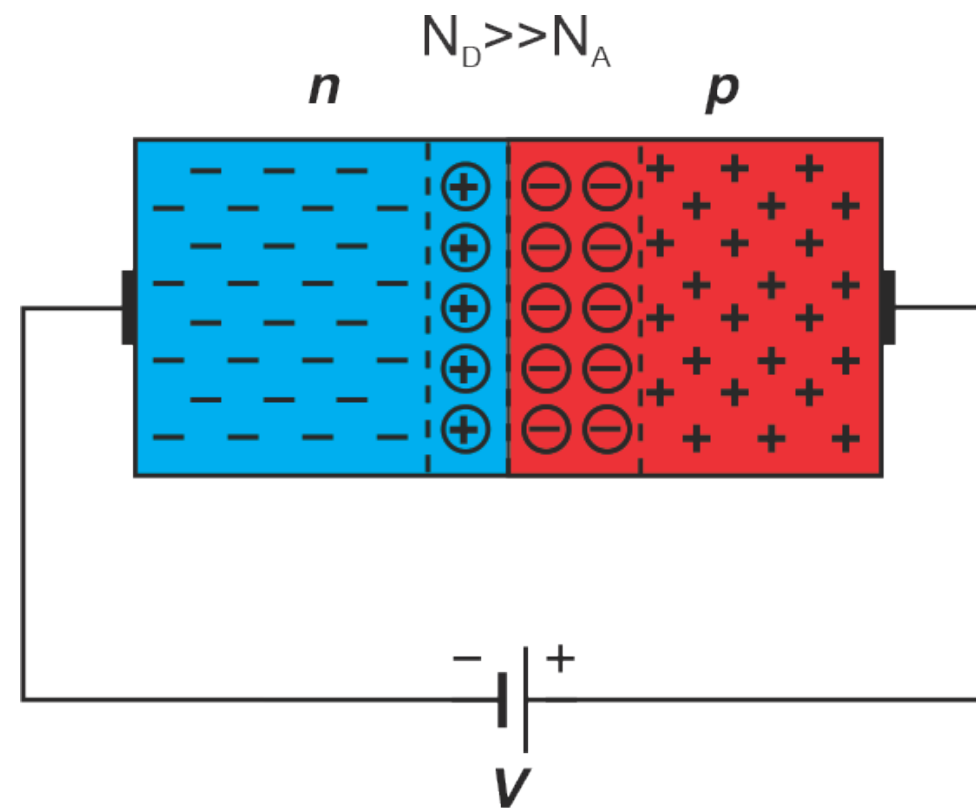
- Inverzno polarisani PN spoj
- Slobodna naelektrisanja koja su ubačena u osiromašenu oblast se kreću pod uticajem električnog polja
- Kondukciona struja



# Bipolarni tranzistor - principi

## 2. Asimetrično dopiranje

- Direktno polarisani PN spoj
- Koncentracija donora veća od koncentracije akceptora
- Struju čine elektroni



# Bipolarni tranzistor

- Tranzistor je poluprovodnička komponenta koja može da radi u nekoliko režima, koji se mogu kontrolisati naponima između njegovih priključaka. U zavisnosti od režima rada, tranzistor može **pojačavati** signal ili se ponašati kao prekidač.
- Bipolarni tranzistor je tip tranzistora kod koga električnu struju čine oba nosioca naelektrisanja – elektroni i šupljine.
- Bipolarni tranzistor su 1947. konstruisali, John Bardeen, Walter Brattain i William Shockley iz Bell laboratorije.
- Otkriće tranzistora je omogućilo složenije elektronske uređaje i trasirao put ka razvoju integrisanih kola.

# Bipolarni tranzistor - istorija

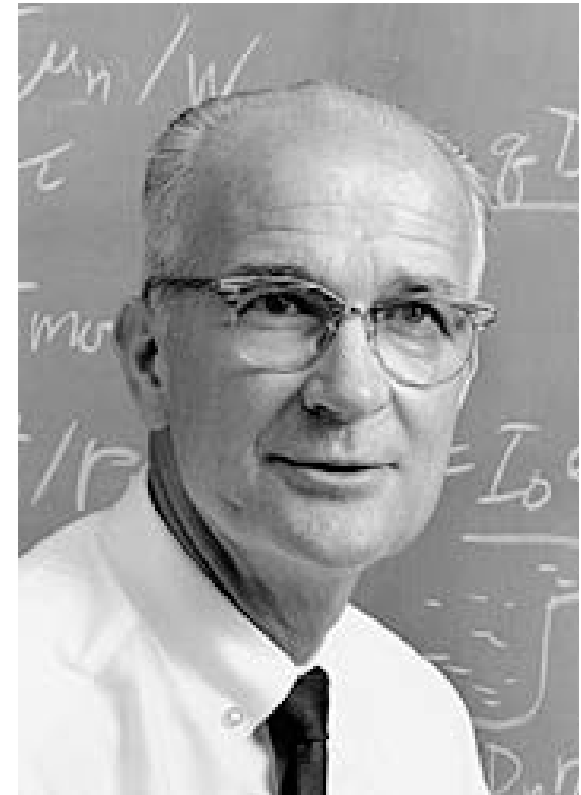
- Nobelova nagrada za fiziku 1956. godine



John Bardeen

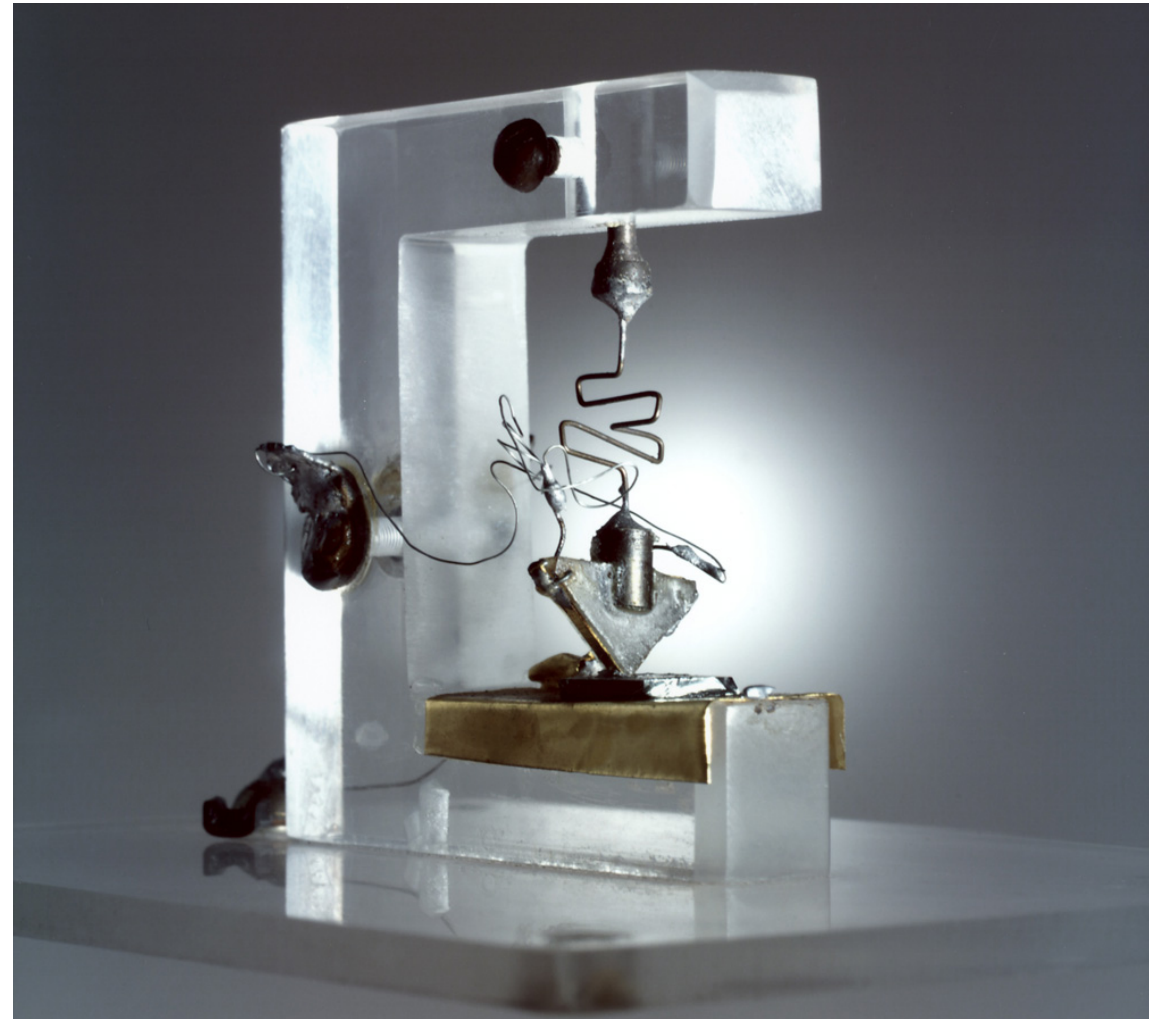
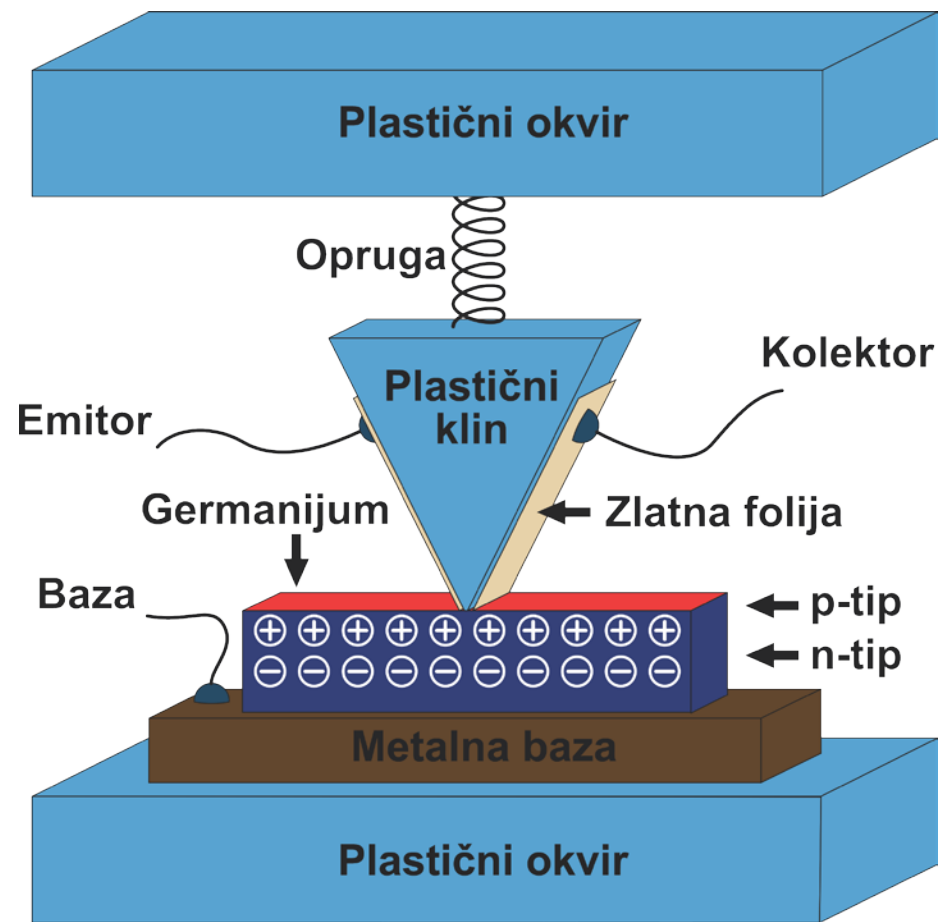


Walter Brattain



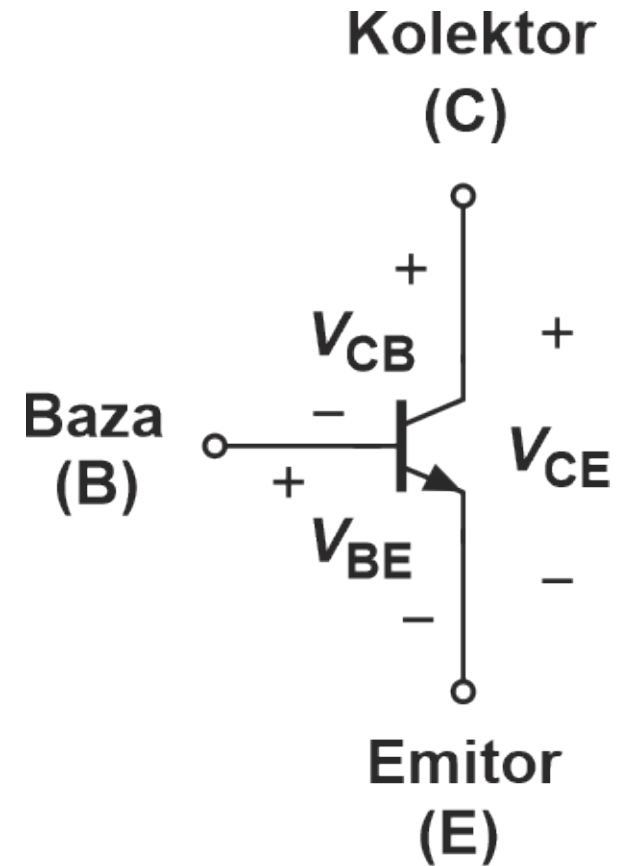
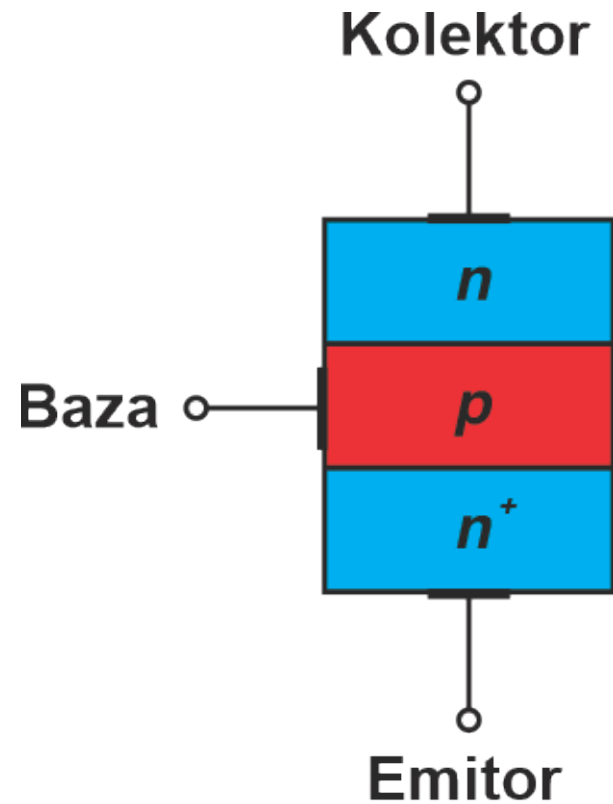
William Shockley

# Bipolarni tranzistor - istorija

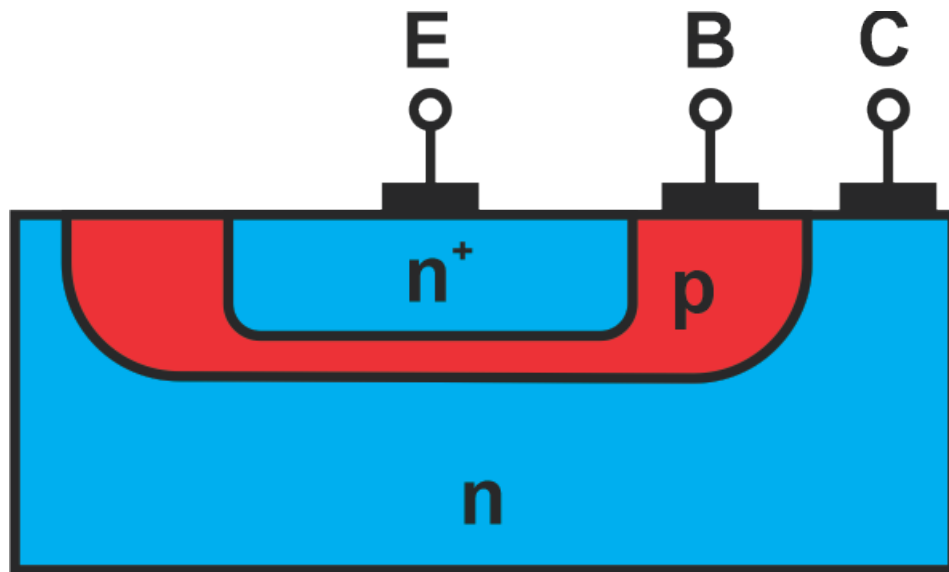




# Struktura bipolarnog tranzistora (NPN)



# Struktura bipolarnog tranzistora



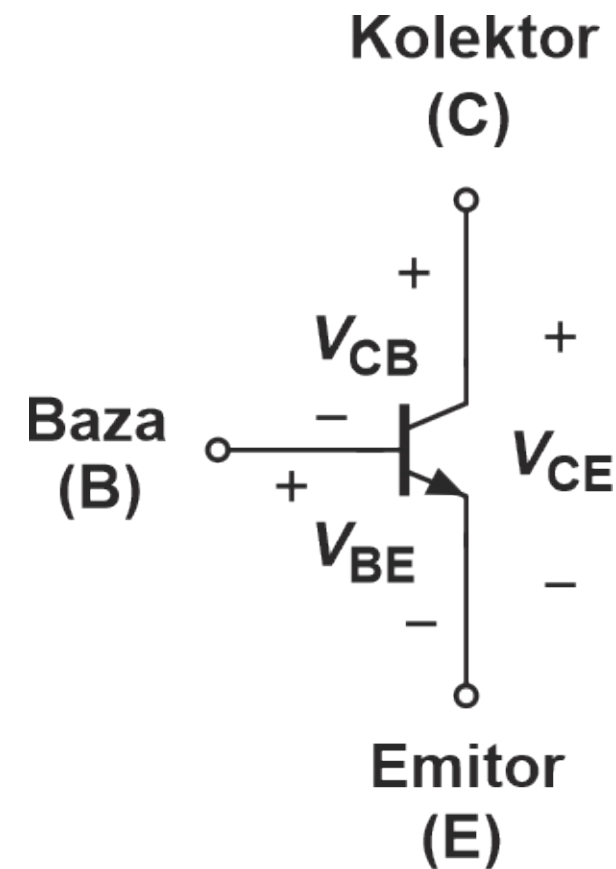
Poprečni presek



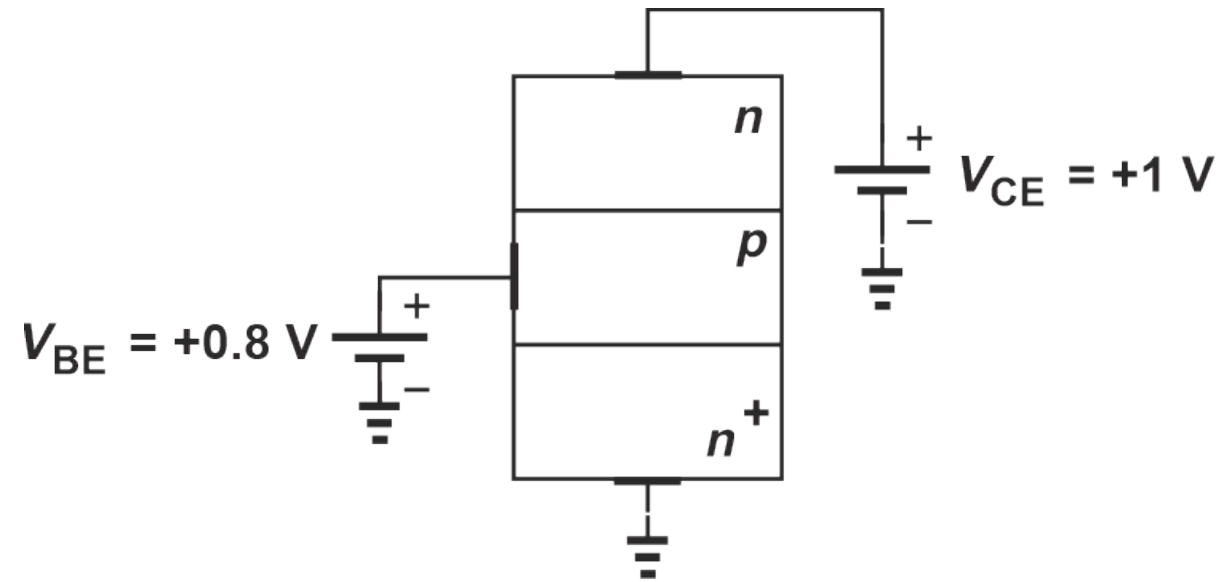
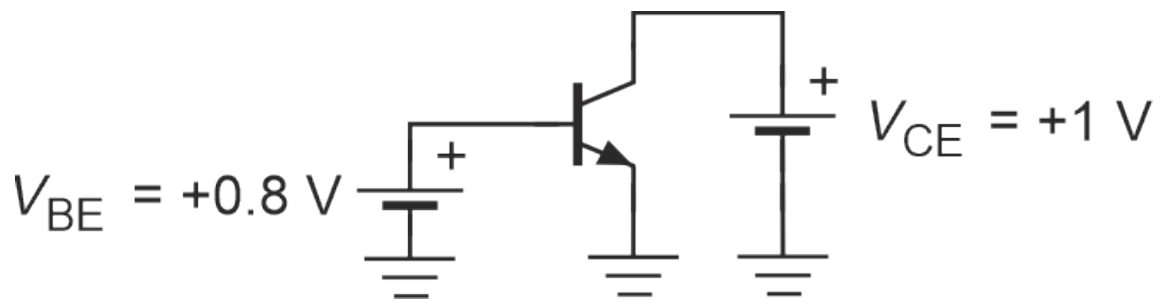
BC107

# Režimi rada

Naponi	Emitorski	Kolektorski	Režim
$V_{BE} > 0, V_{CB} > 0$	direktno	inverzno	aktivna oblast
$V_{BE} > 0, V_{CB} < 0$	direktno	direktno	zasićenje
$V_{BE} < 0, V_{CB} > 0$	inverzno	inverzno	zakočenje
$V_{BE} < 0, V_{CB} < 0$	inverzno	direktno	inverzna aktivna o.

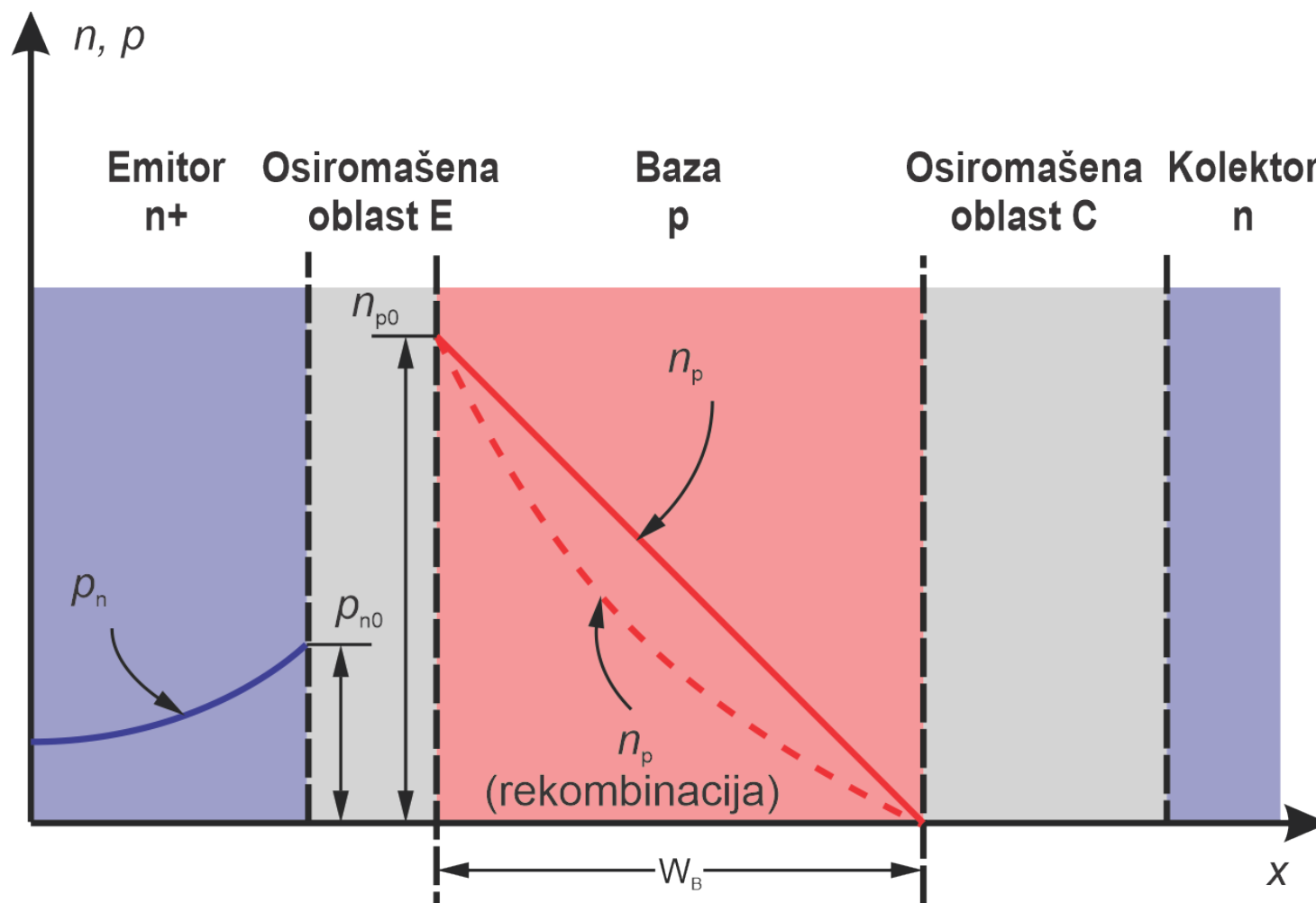


# Tranzistorski efekat – aktivan režim

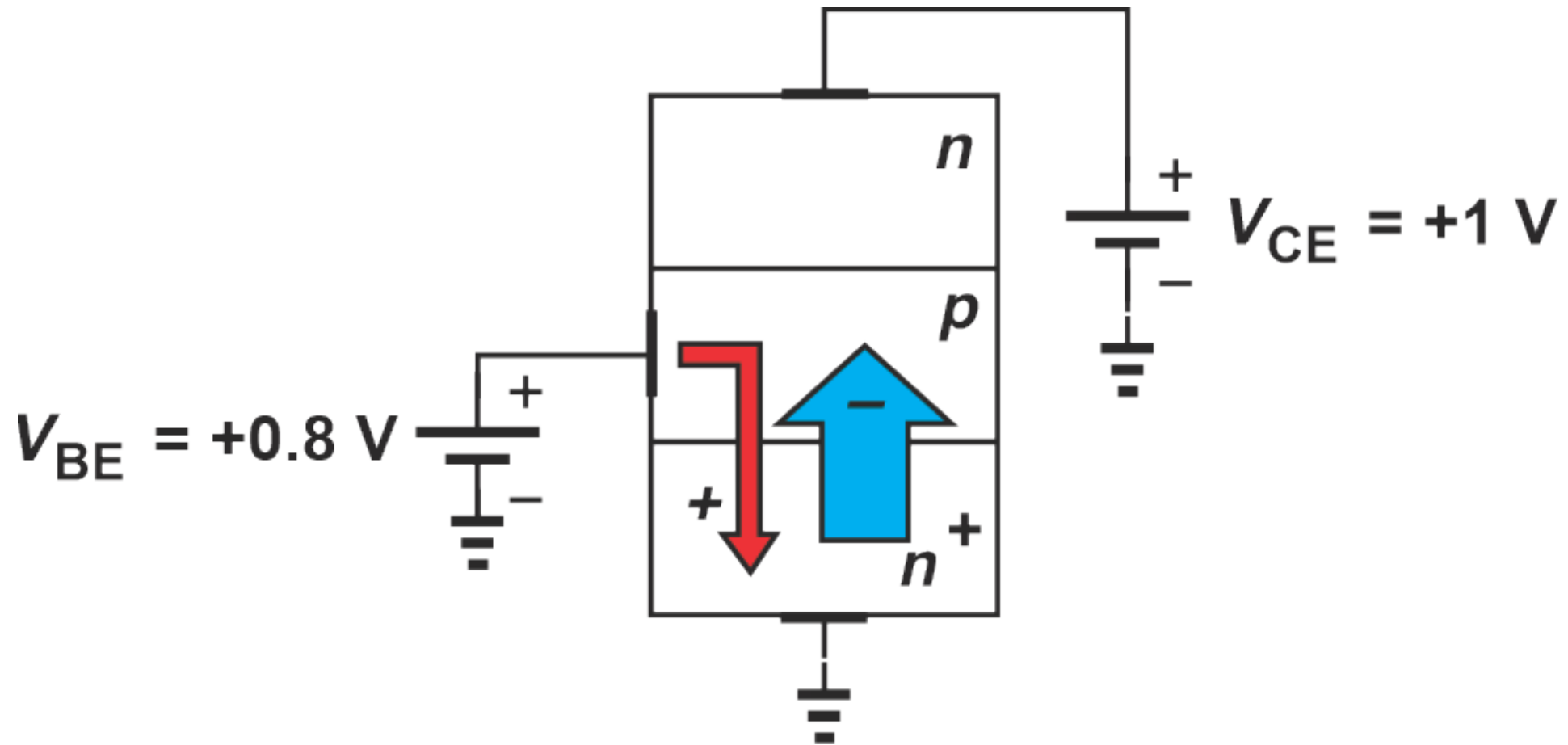


$$V_{CB} = V_{CE} - V_{BE} \geq 0$$

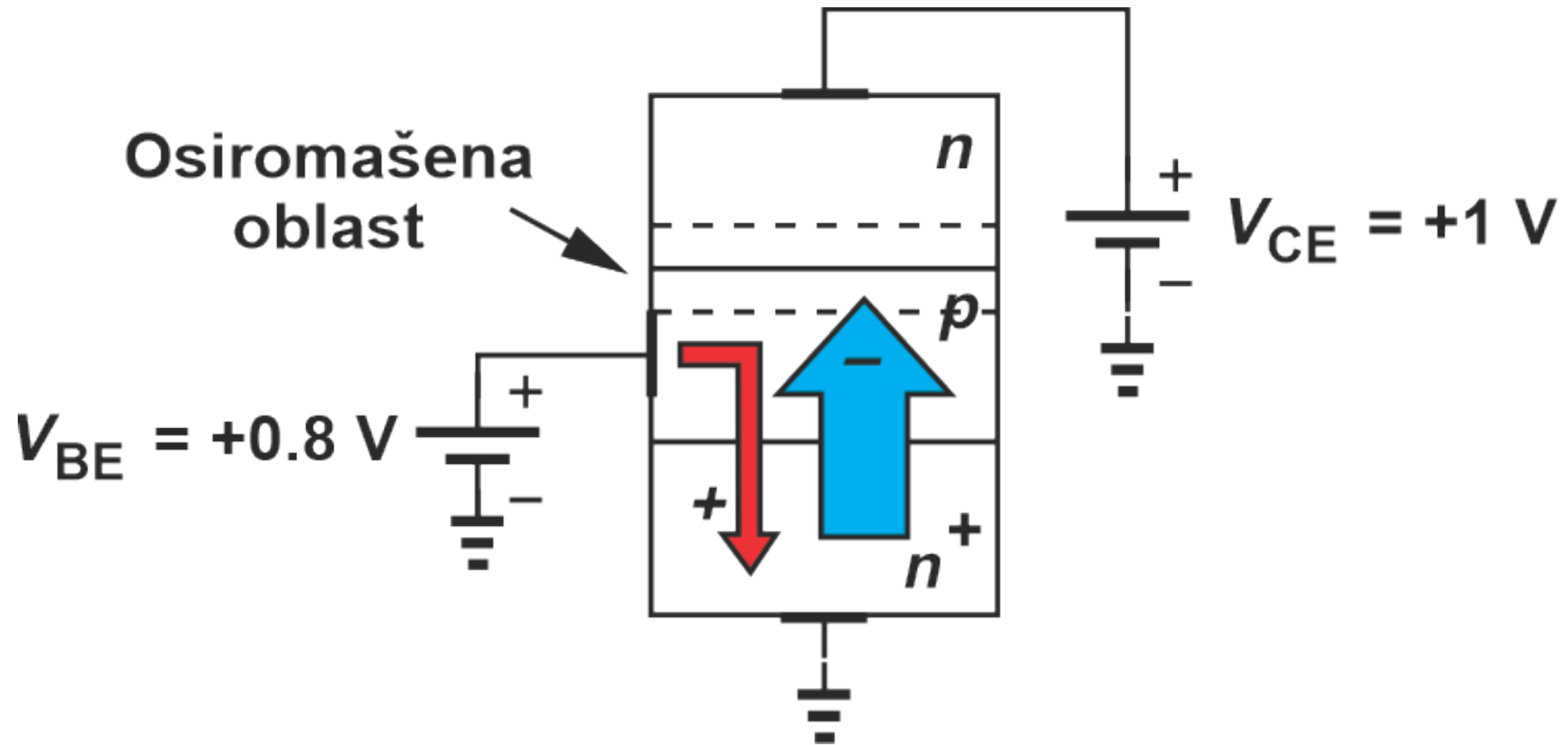
# Tranzistorski efekat – koncentracija nosilaca



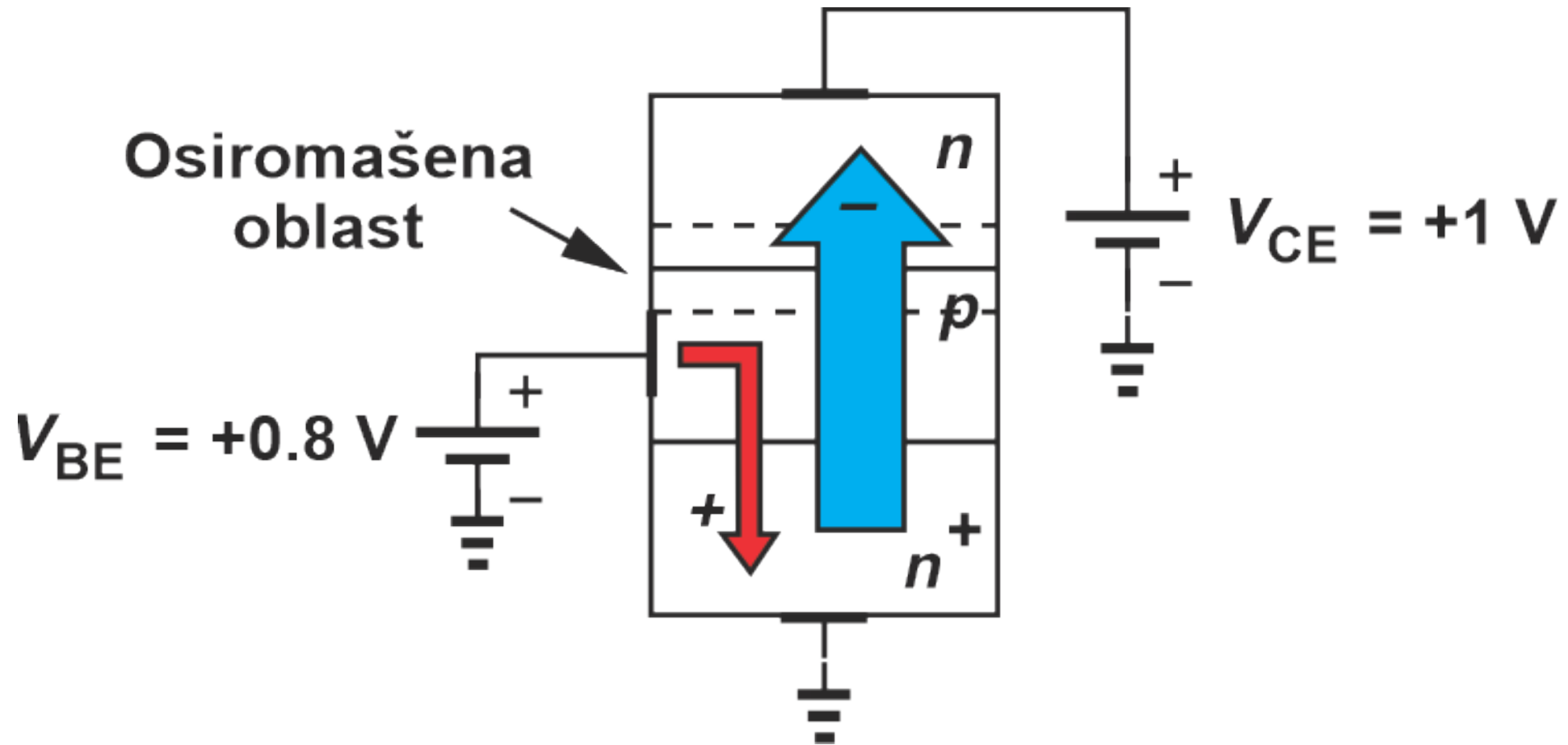
# Tranzistorski efekat – aktivan režim



# Tranzistorski efekat – aktivan režim



# Tranzistorski efekat – aktivan režim





# Kolektorska struja

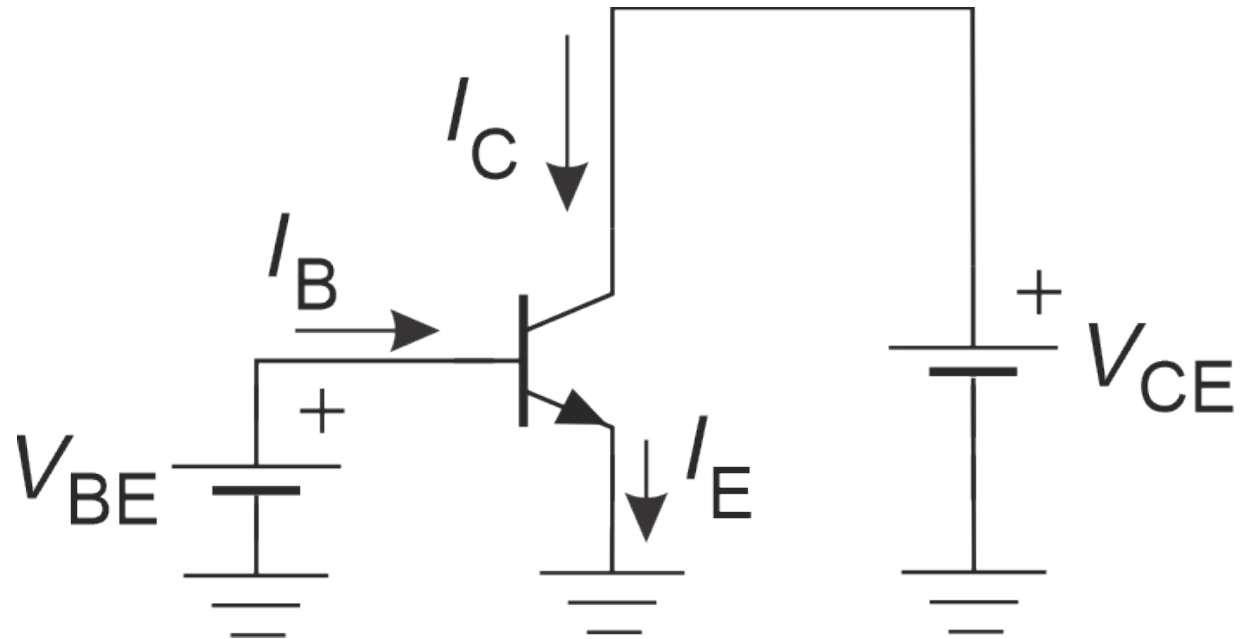
$$I_C = I_S \left( \exp\left(\frac{V_{BE}}{V_T}\right) - 1 \right) \approx I_S \cdot \exp\left(\frac{V_{BE}}{V_T}\right)$$

$$I_S = \frac{A_E \cdot q_e \cdot n_i^2 \cdot D_n}{W_B \cdot N_B}$$

$A_E$  – površina emitorskog spoja

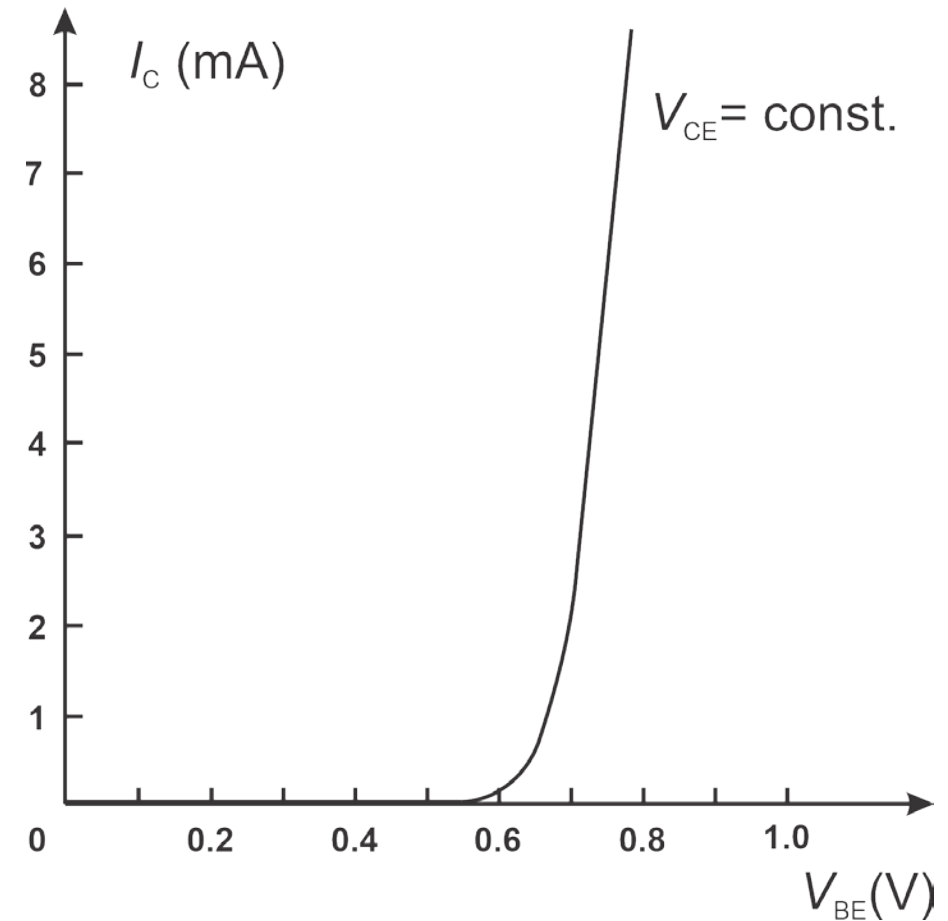
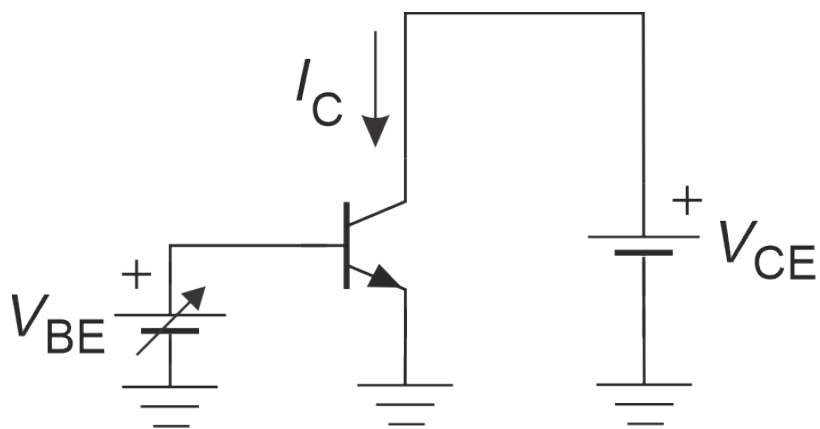
$W_B$  – širina oblasti baze

$N_B$  – koncentracija akceptora u bazi



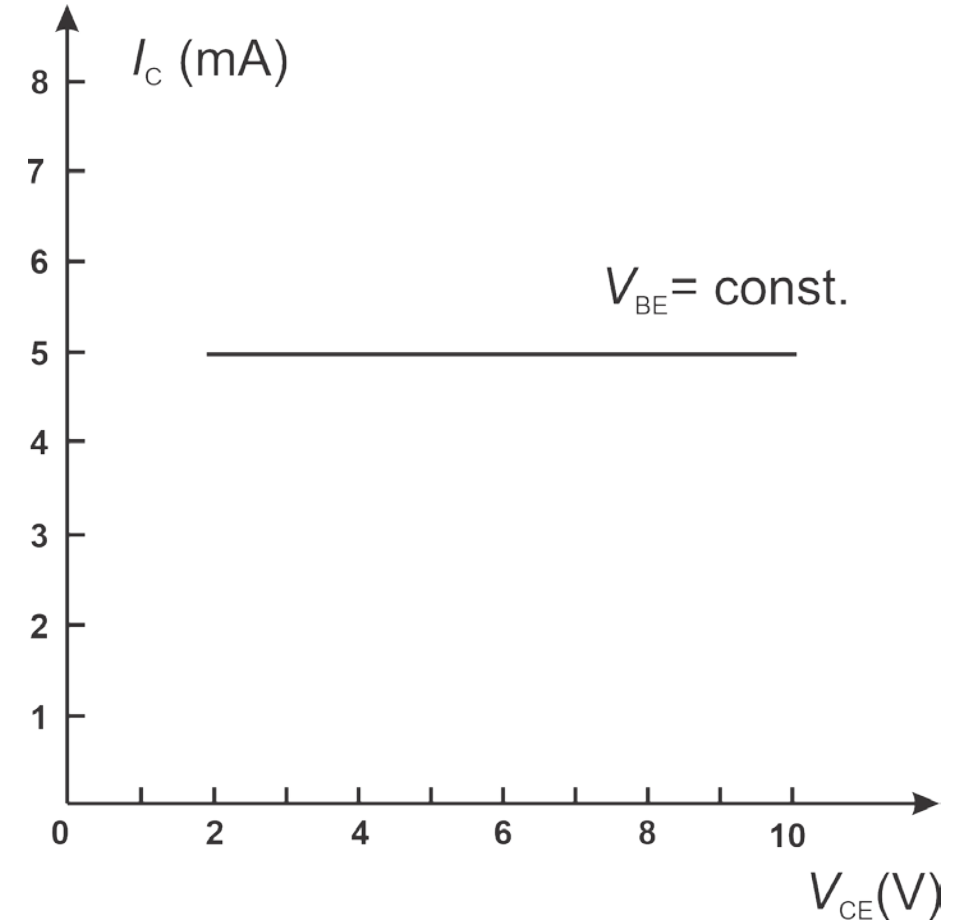
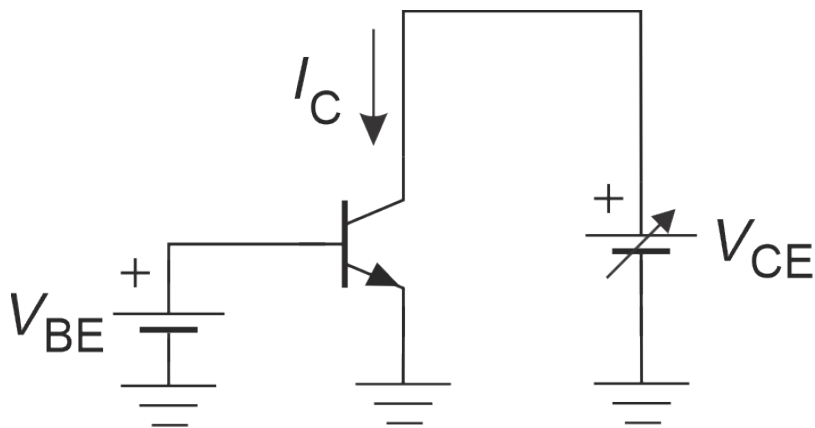
# Zavisnost struje kolektora od napona $V_{BE}$

- Prenosna karakteristika
- $V_{CE}$  konstantno
- Familija karakteristika za različite vrednosti  $V_{CE}$

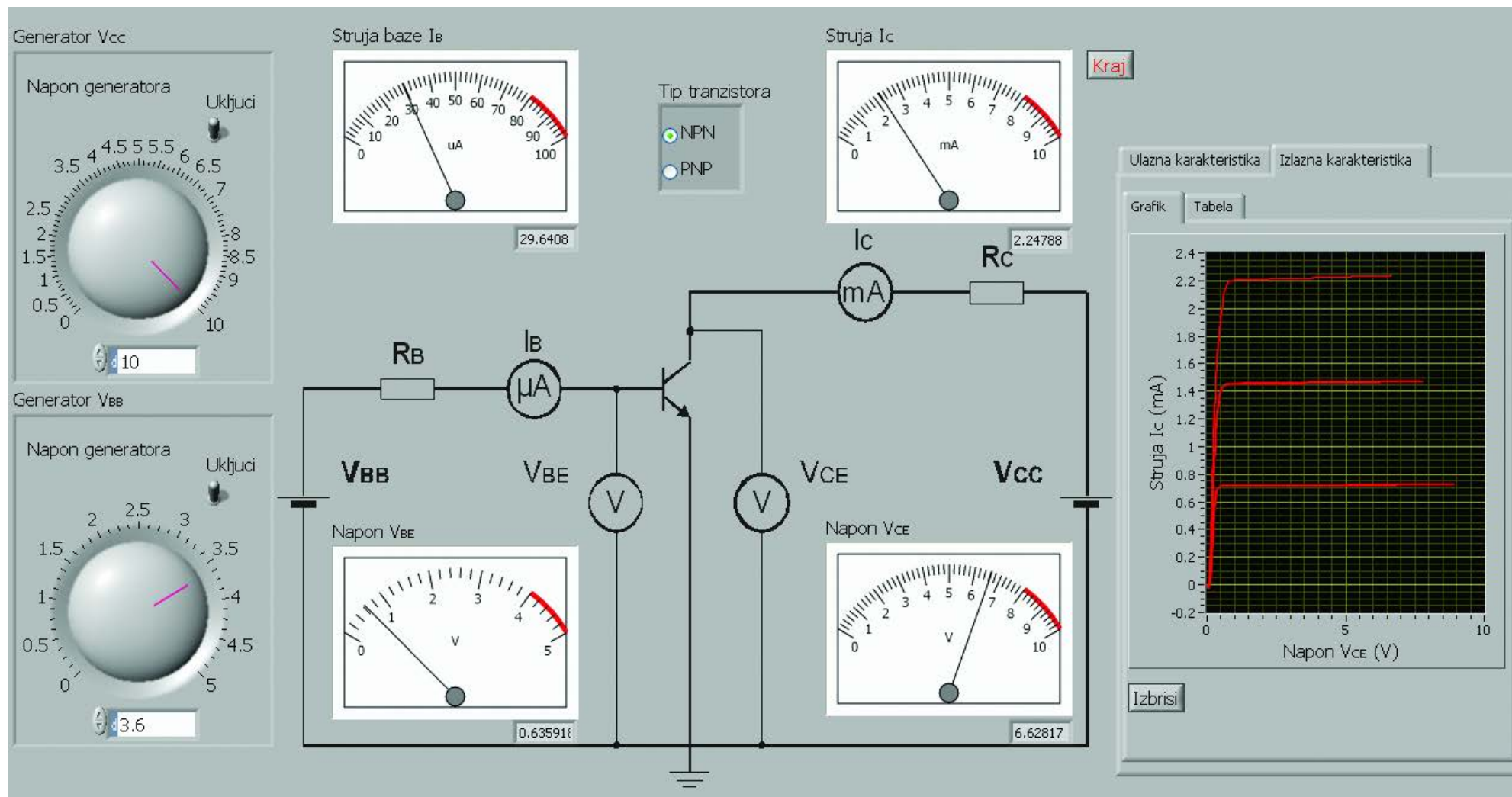


# Zavisnost struje kolektora od napona $V_{CE}$

- Izlazna karakteristika
- $V_{BE}$  konstantno
- Familija karakteristika za različite vrednosti  $V_{BE}$



# Merene karakteristike



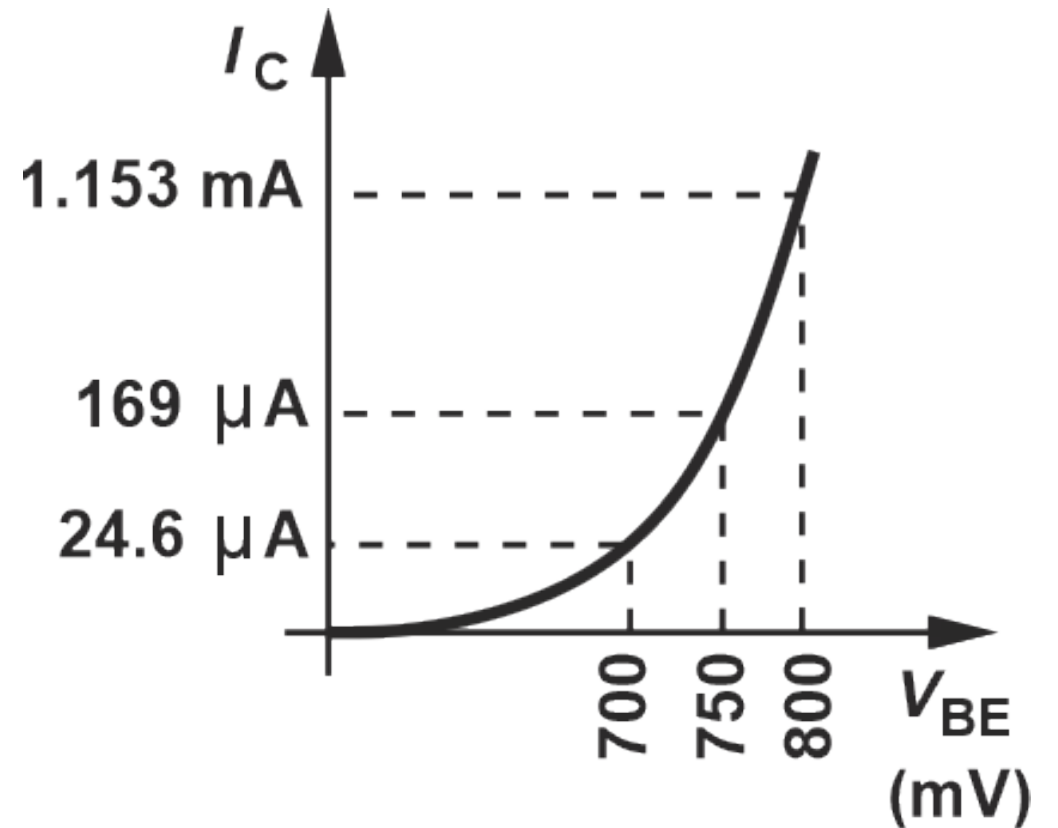
# Primer

Parametri tranzistora:  $I_S=5 \cdot 10^{-17} \text{A}$ ,  $\beta=100$ :

$$V_{BE1} = 700 \text{ mV} \Rightarrow I_{c1} = 24.6 \mu\text{A}$$

$$V_{BE2} = 750 \text{ mV} \Rightarrow I_{c2} = 169 \mu\text{A}$$

$$V_{BE3} = 800 \text{ mV} \Rightarrow I_{c3} = 1.153 \text{ mA}$$



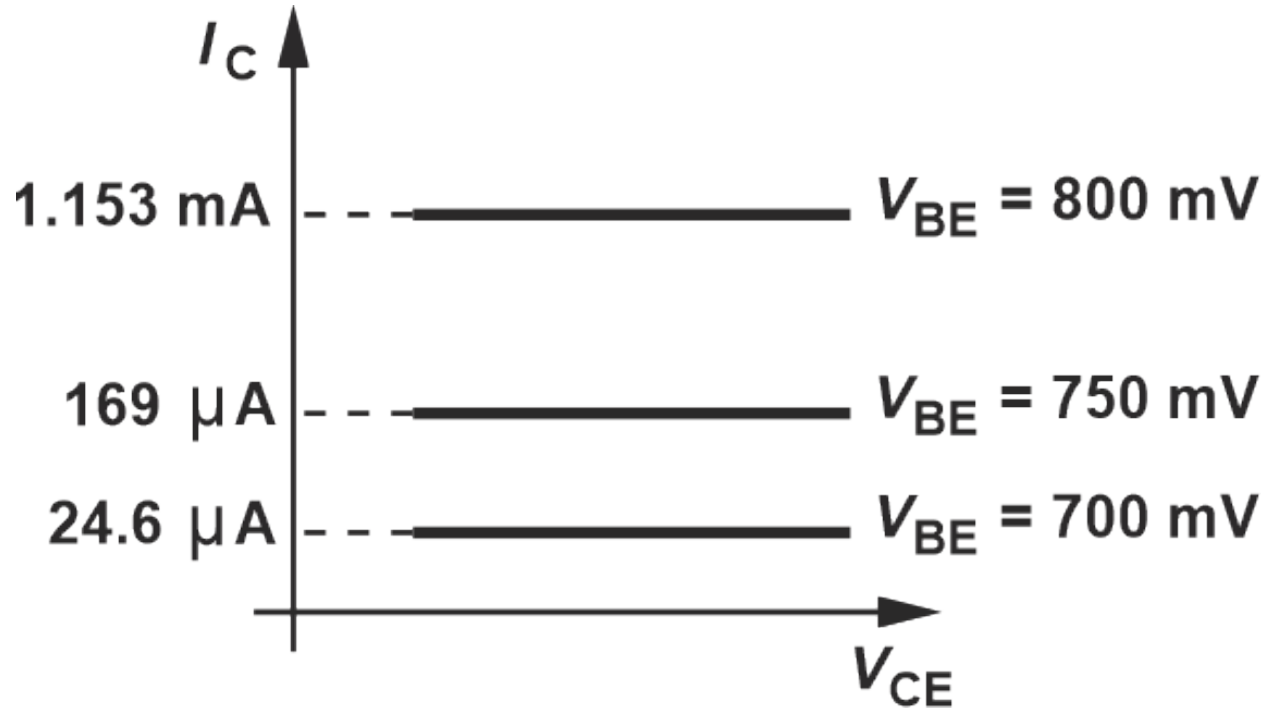
# Primer

Parametri tranzistora:  $I_S = 5 \cdot 10^{-17} \text{ A}$ ,  $\beta = 100$ :

$$V_{BE1} = 700 \text{ mV} \Rightarrow I_{c1} = 24.6 \mu\text{A}$$

$$V_{BE2} = 750 \text{ mV} \Rightarrow I_{c2} = 169 \mu\text{A}$$

$$V_{BE3} = 800 \text{ mV} \Rightarrow I_{c3} = 1.153 \text{ mA}$$



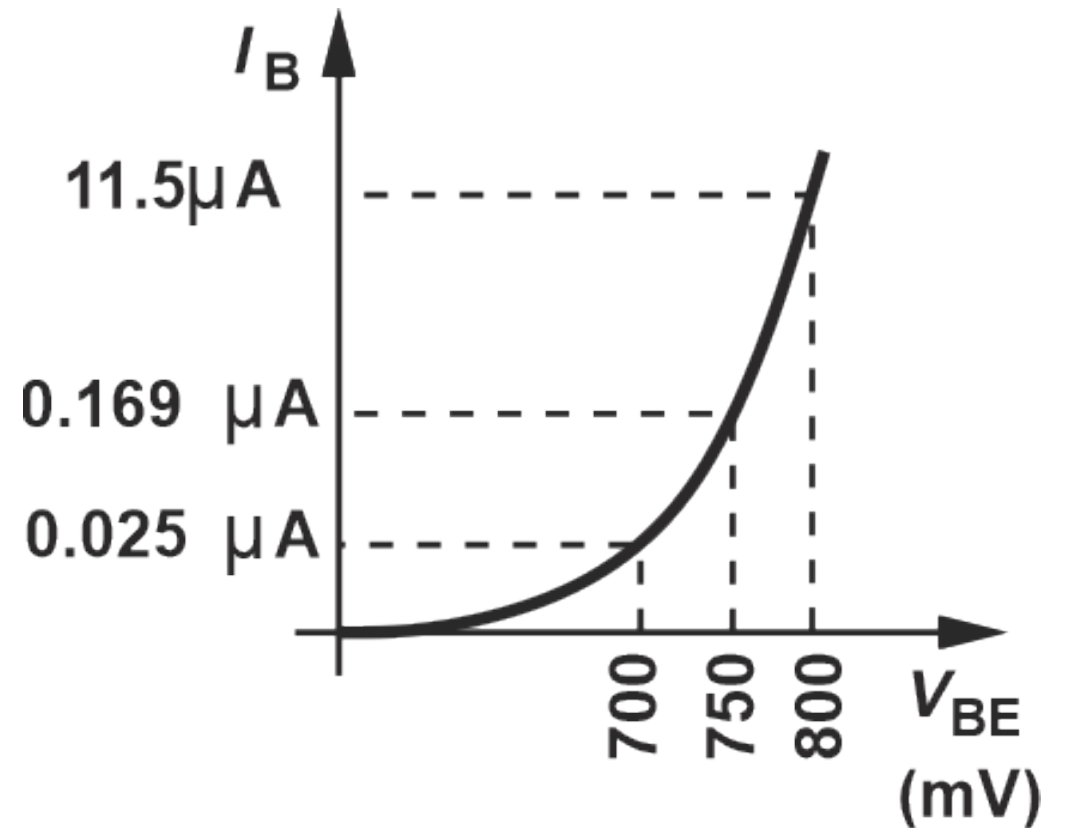
# Primer

Parametri tranzistora:  $I_S=5 \cdot 10^{-17} \text{A}$ ,  $\beta=100$ :

$$V_{BE1} = 700 \text{ mV} \Rightarrow I_{c1} = 24.6 \mu\text{A}$$

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$$V_{BE3} = 800 \text{ mV} \Rightarrow I_{c3} = 1.153 \text{ mA}$$



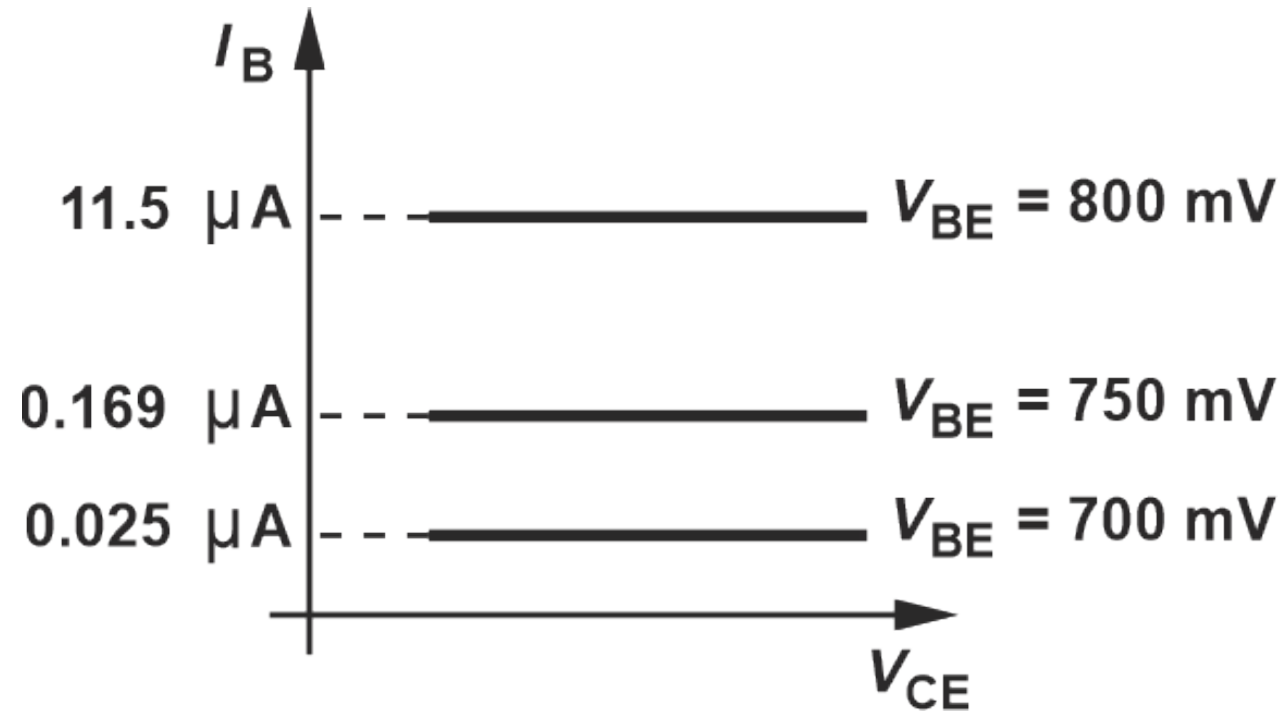
# Primer

Parametri tranzistora:  $I_S=5 \cdot 10^{-17} \text{ A}$ ,  $\beta=100$ :

$$V_{BE1} = 700 \text{ mV} \Rightarrow I_{c1} = 24.6 \mu\text{A}$$

$$V_{BE2} = 750 \text{ mV} \Rightarrow I_{c2} = 169 \mu\text{A}$$

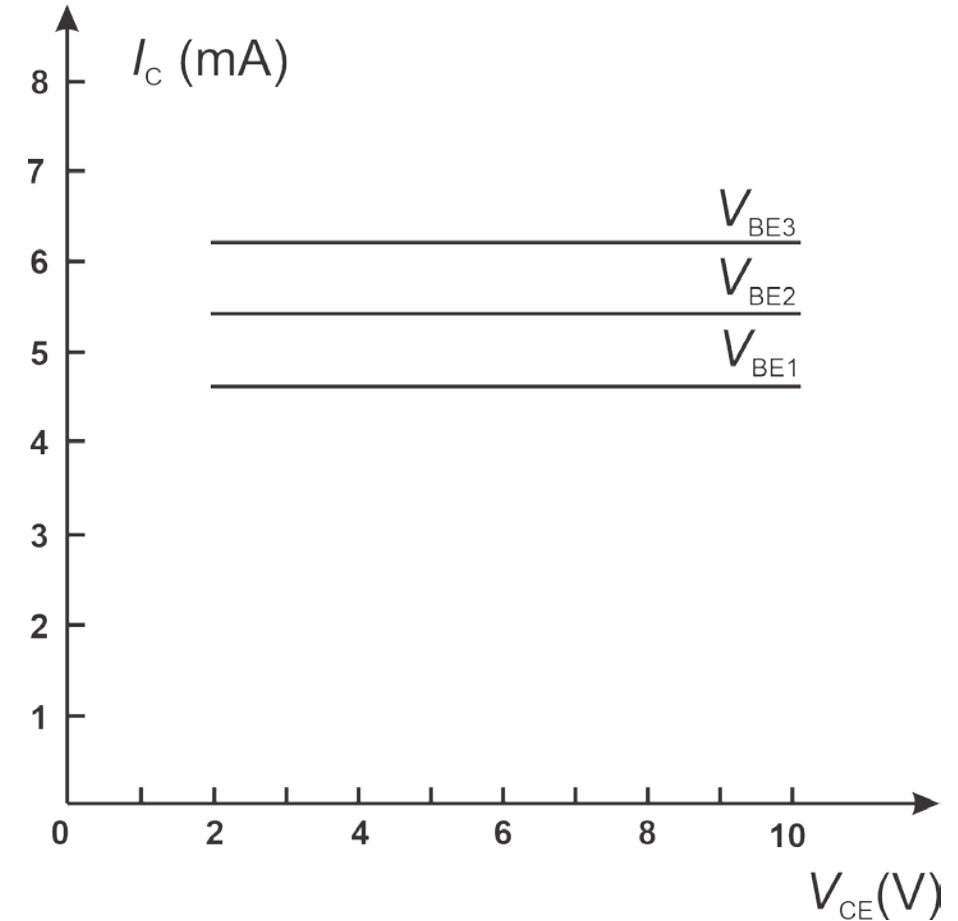
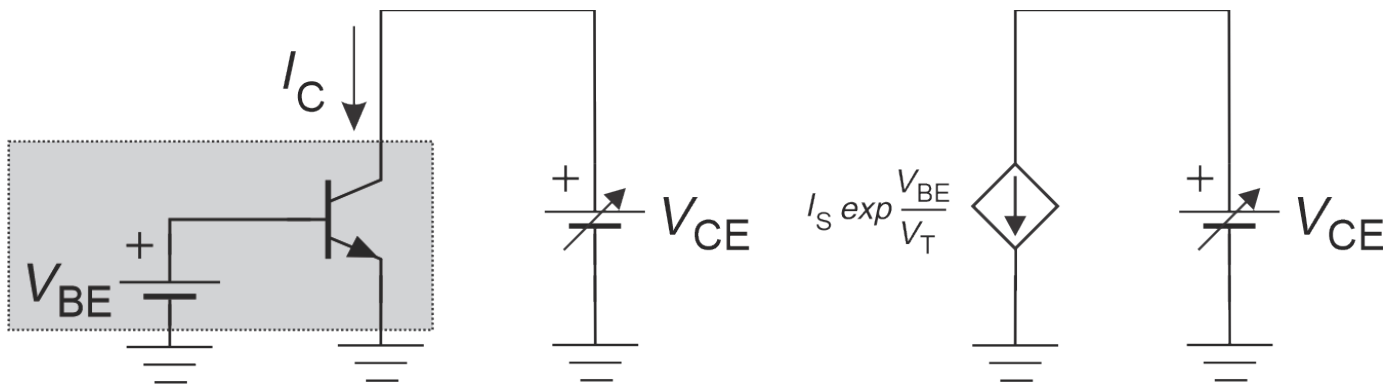
$$V_{BE3} = 800 \text{ mV} \Rightarrow I_{c3} = 1.153 \text{ mA}$$



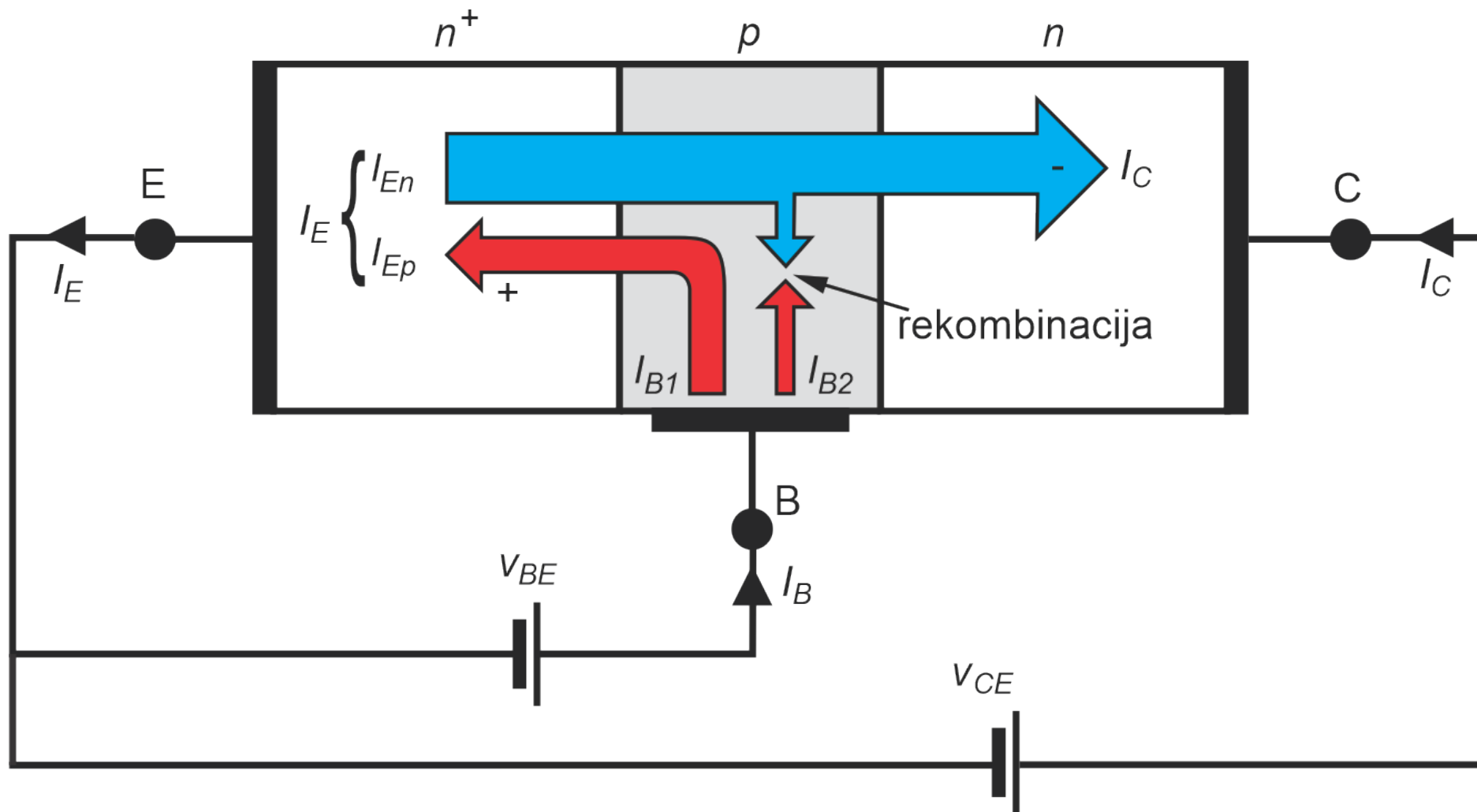


# Zavisnost struje kolektora od napona $V_{CE}$

- Strujni izvor kontrolisan naponom  $V_{BE}$
- Pojačavač!



# Struje



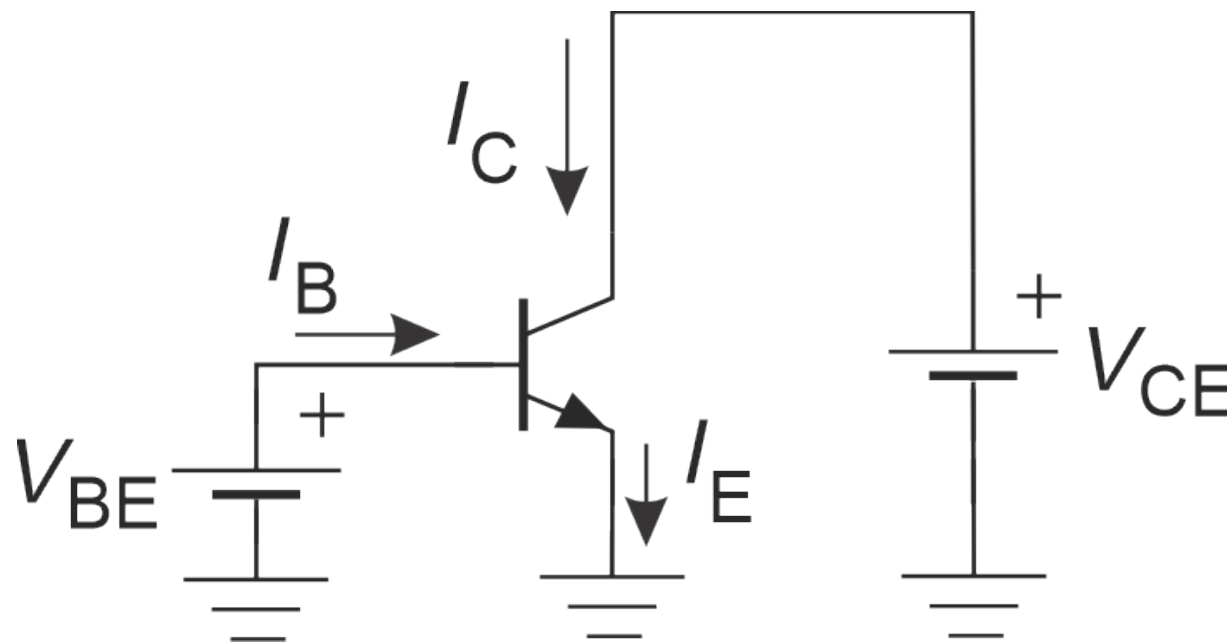
# Struje

- Struja koju čine šupljine (struja baze) je proporcionalna struji koju čine elektroni (struji kolektora):

$$I_C = \beta \cdot I_B$$

- $\beta$  je strujno pojačanje, zavisi od tipa tranzistora (50-200).

$$I_E = I_B + I_C = (\beta + 1) \cdot I_B$$



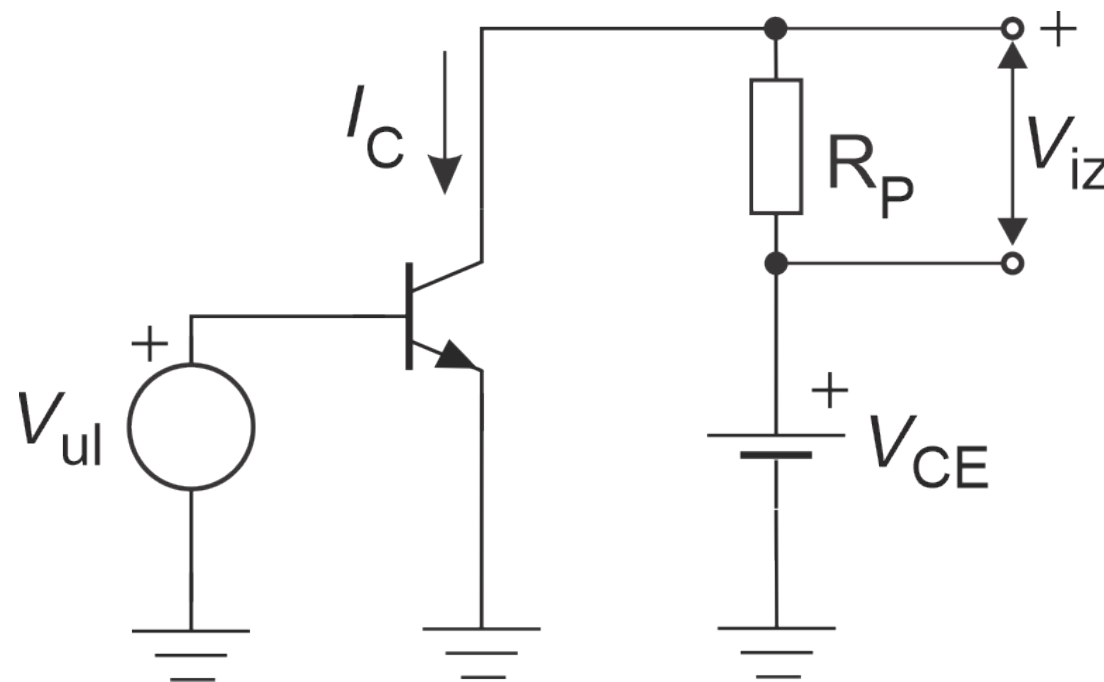
# Polarizacija

- Parametri tranzistora:  $I_S = 5 \cdot 10^{-16} \text{ A}$
- $\Delta V_{ul} = 10 \text{ mV}$

$$\Delta I_C = I_S \cdot \left( \exp\left(\frac{\Delta V_{ul}}{V_T}\right) - 1 \right)$$

$$\Delta V_{iz} = -R_P \cdot \Delta I_C = -R_P \cdot I_S \cdot \left( \exp\left(\frac{\Delta V_{ul}}{V_T}\right) - 1 \right)$$

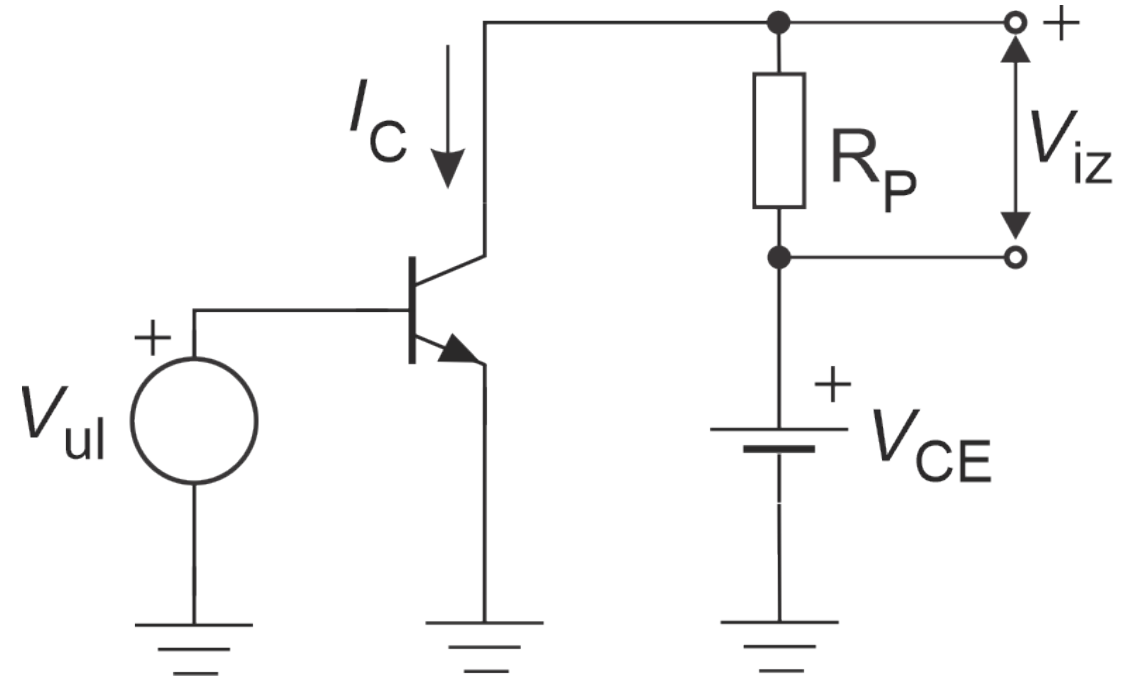
$$\Delta V_{iz} = -R_P \cdot \Delta I_C = -R_P \cdot 2.34 \times 10^{-16} \text{ A}$$



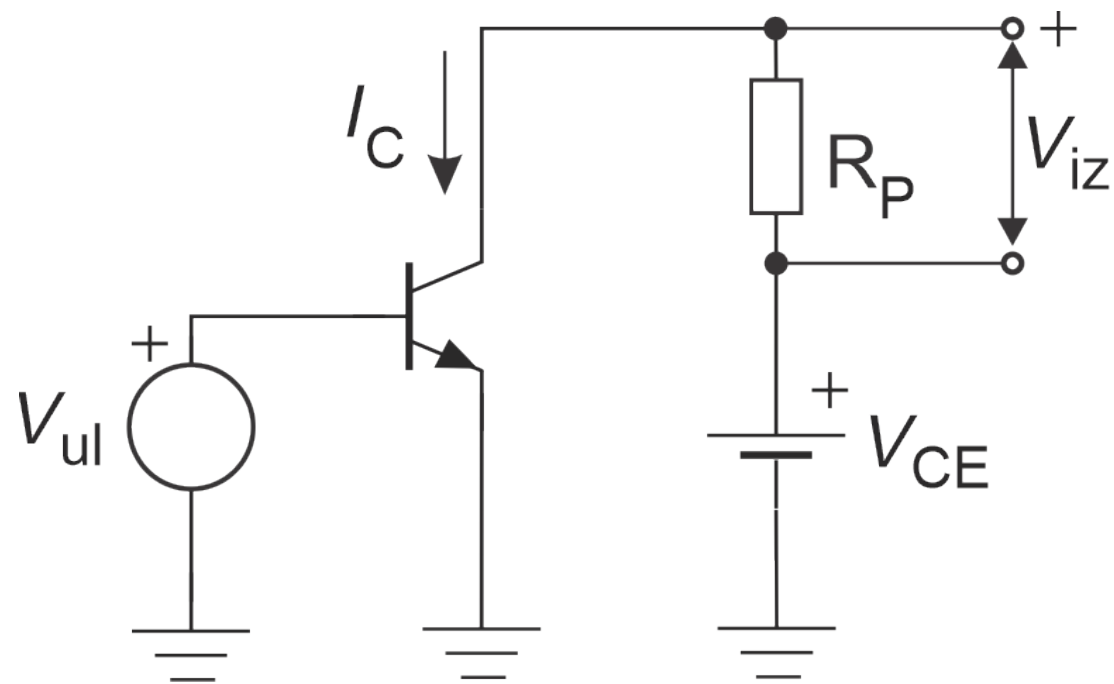
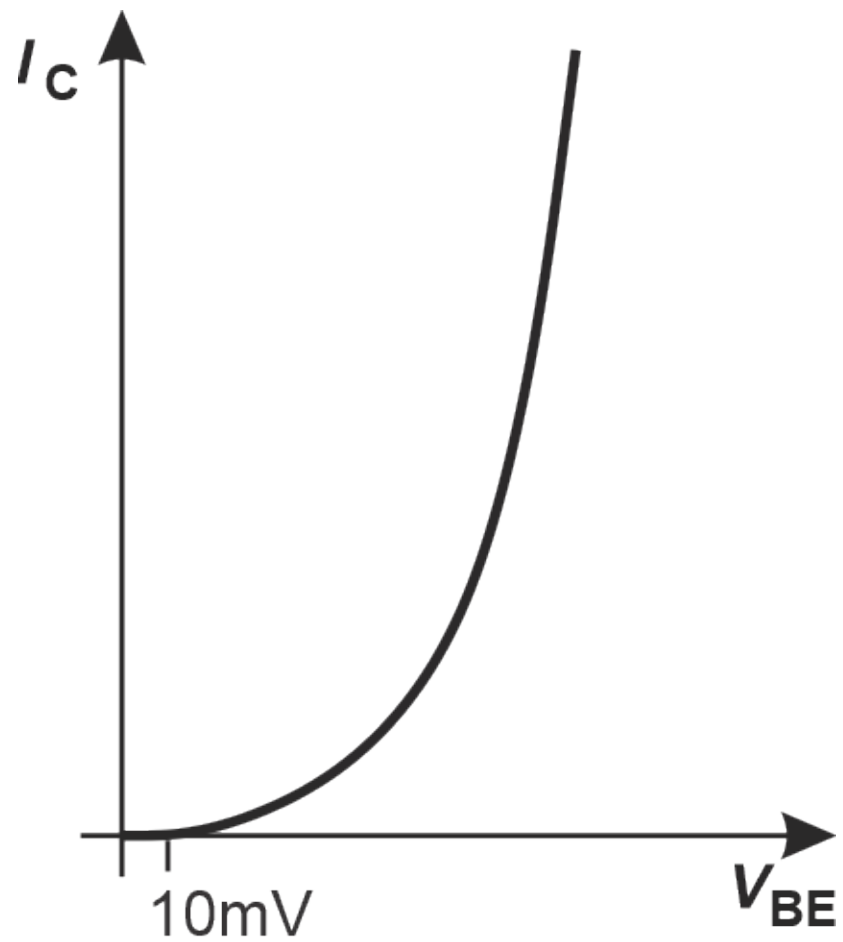
# Polarizacija

- Za pojačanje 10, izlazni napon je  $V_{iz}=100\text{mV}$ , dobija se:

$$R_P = \frac{\Delta V_{iz}}{\Delta I_C} = 4,25 \times 10^{16} \Omega$$



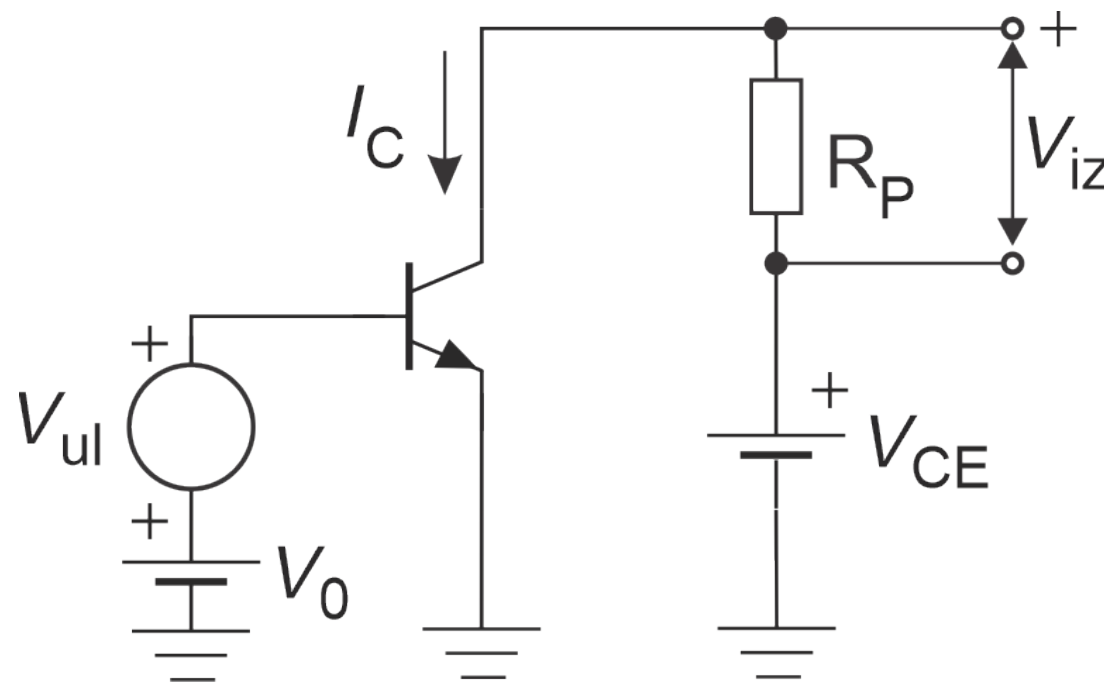
# Polarizacija



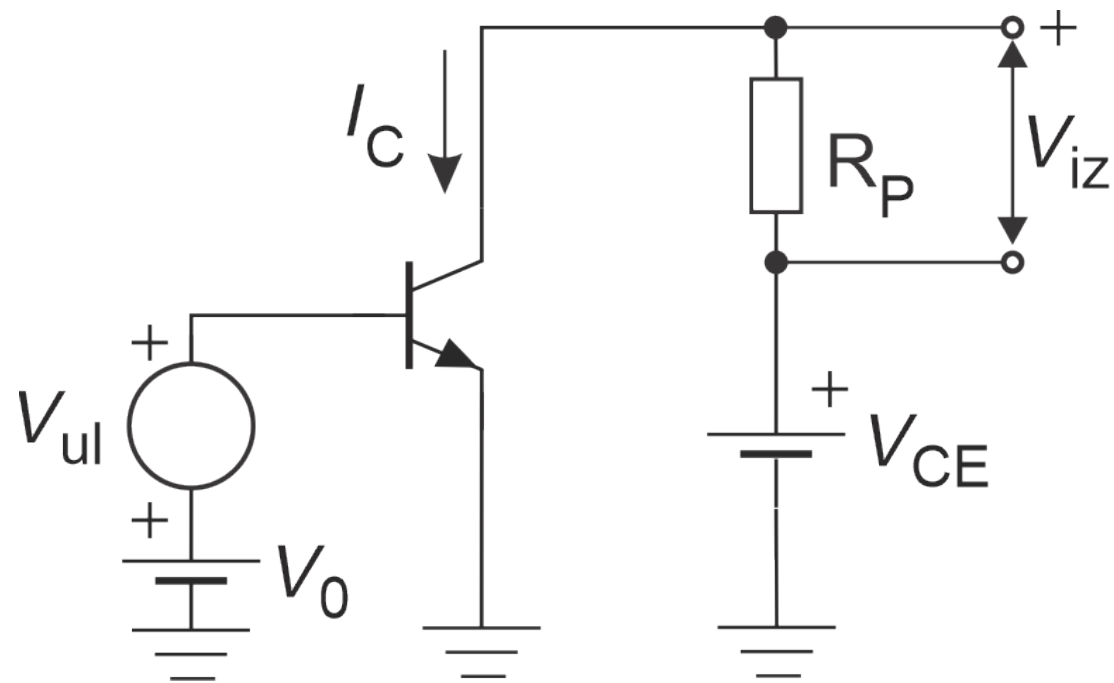
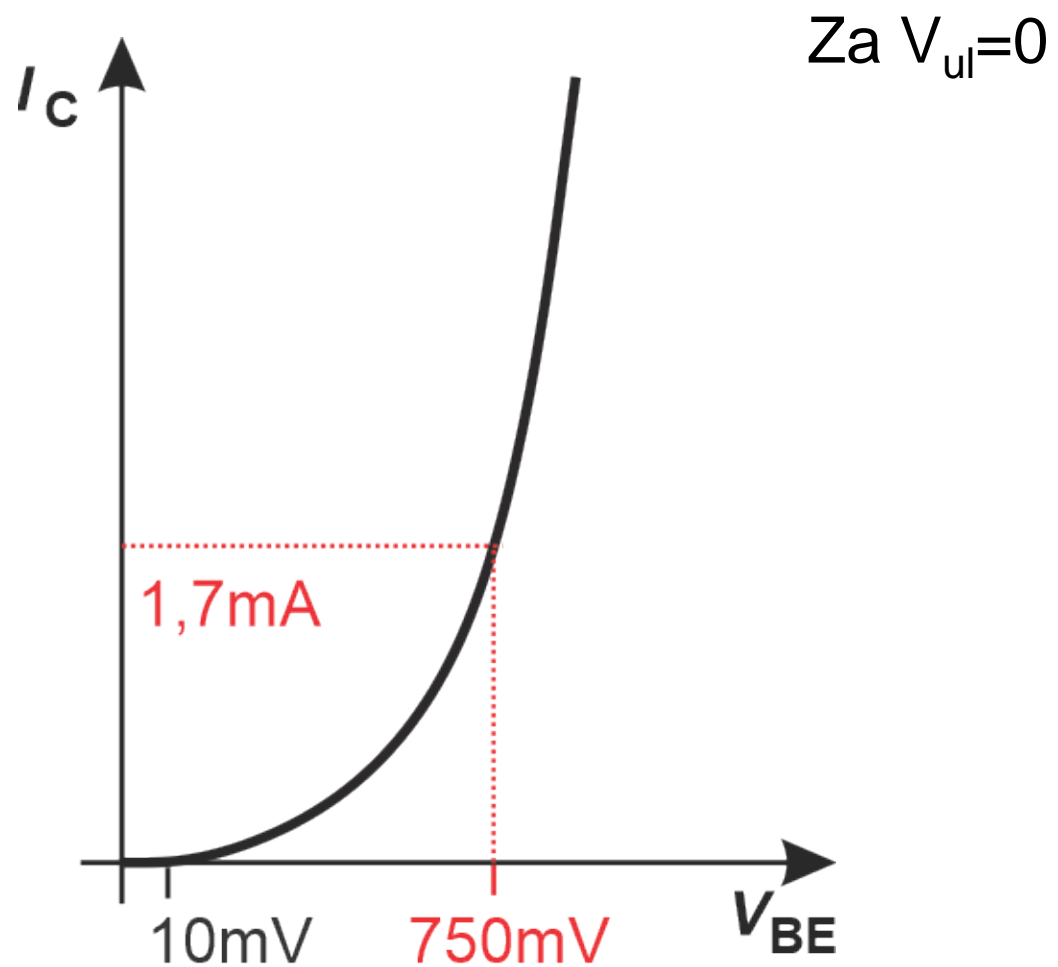
# Polarizacija

- Parametri tranzistora:  $I_S = 5 \cdot 10^{-16} \text{ A}$
- $\Delta V_{ul} = 10 \text{ mV}$ ,  $V_{BE} = 750 \text{ mV}$ .

$$I_C = I_S \cdot \left( \exp\left(\frac{V_{ul} + V_0}{V_T}\right) - 1 \right)$$

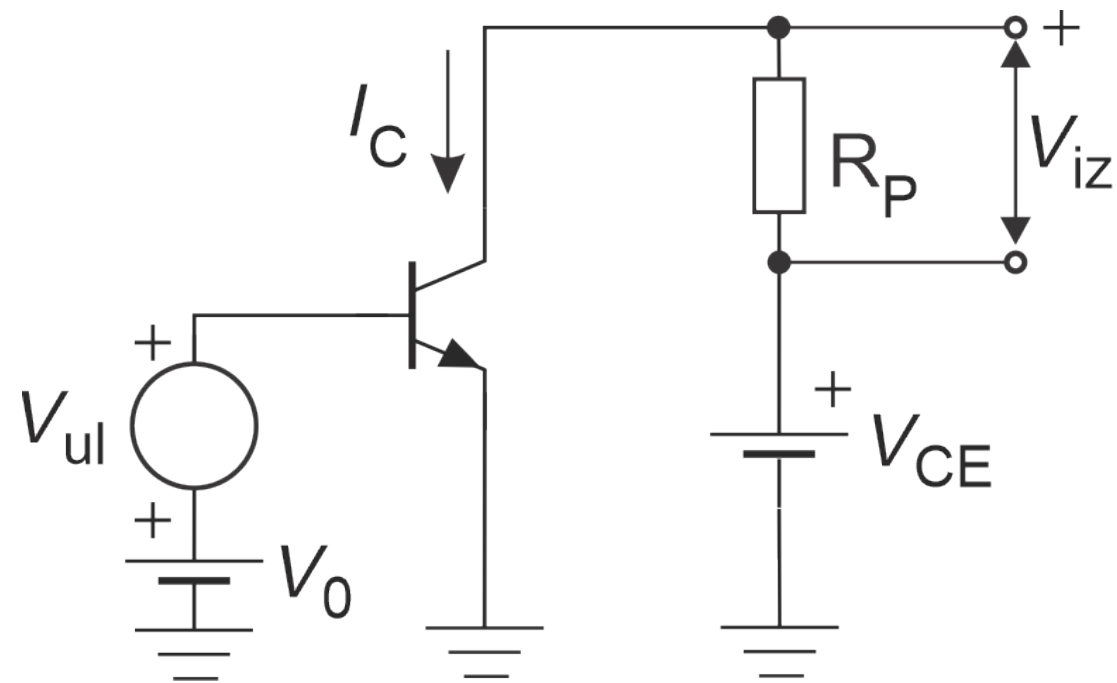
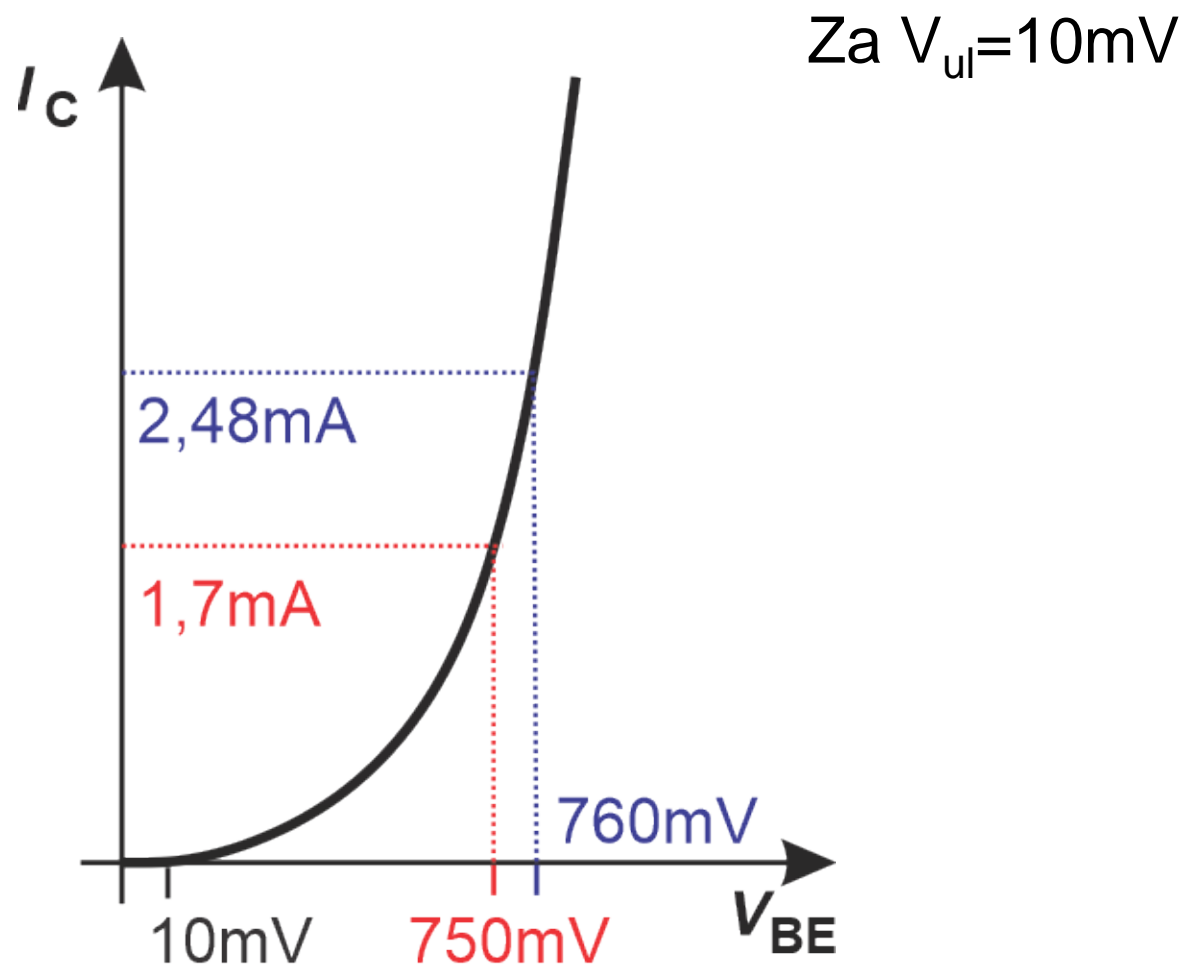


# Polarizacija

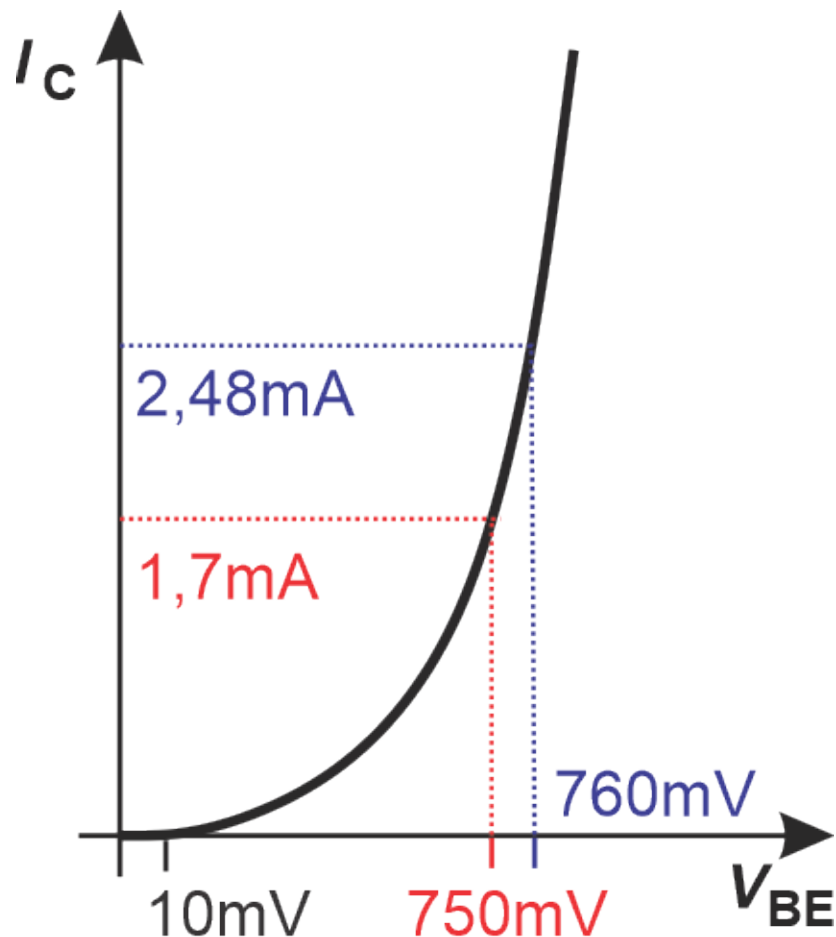




# Polarizacija



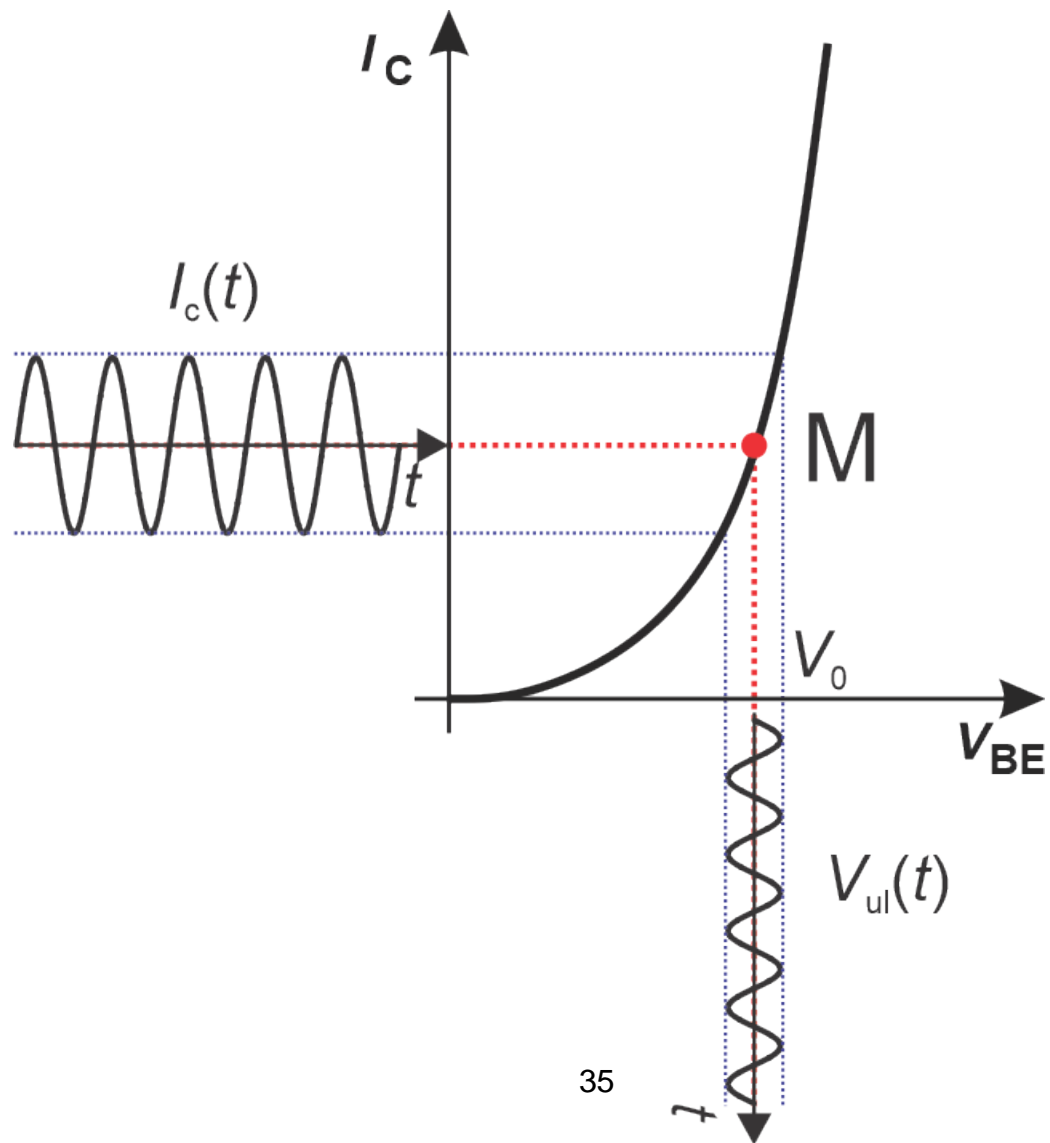
# Polarizacija i radna tačka



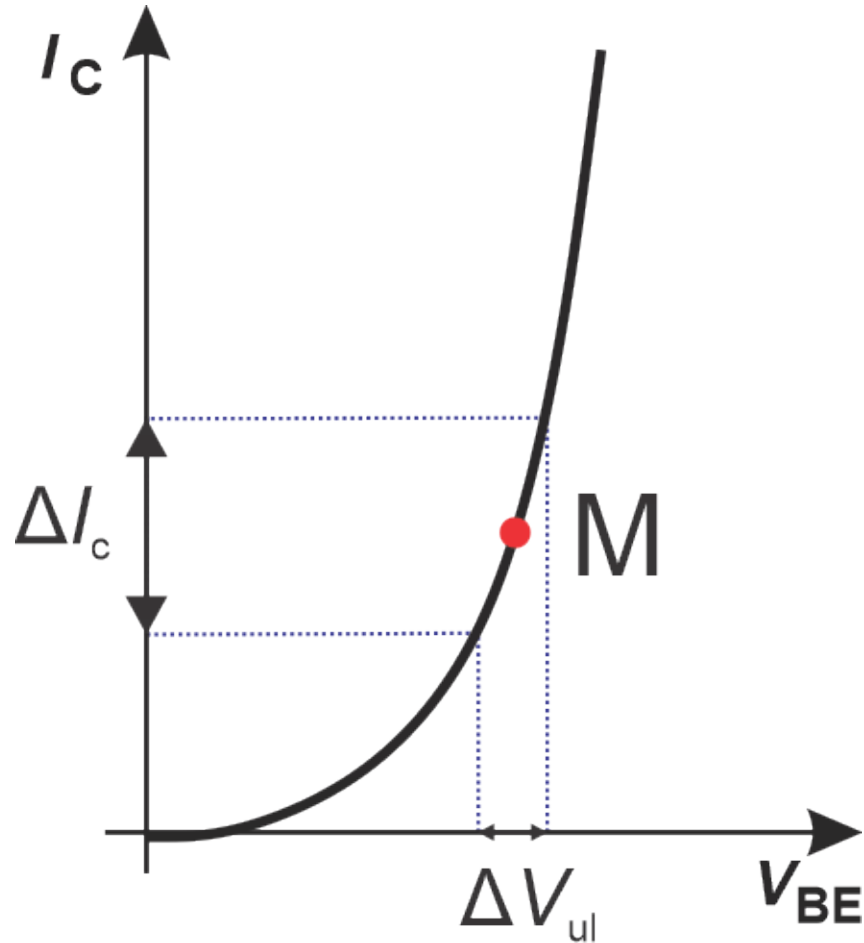
- Bez polarizacije ( $V_0=0$ ) promena napona  $V_{ul}$  od 10mV izaziva promenu kolektorske struje reda veličine  $10^{-16}\text{A}$ .
- Sa polarizacijom naponom  $V_0=750\text{mV}$ , promena napona  $V_{ul}$  od 10mV izaziva promenu kolektorske struje od 0,78mA.
- Radna tačka tranzistora određena je naponima polarizacije  $V_{BE}$ ,  $I_C$ ,  $V_{CE}$ .

$$R_P = \frac{\Delta V_{iz}}{\Delta I_C} = 128\Omega$$

# Polarizacija i radna tačka



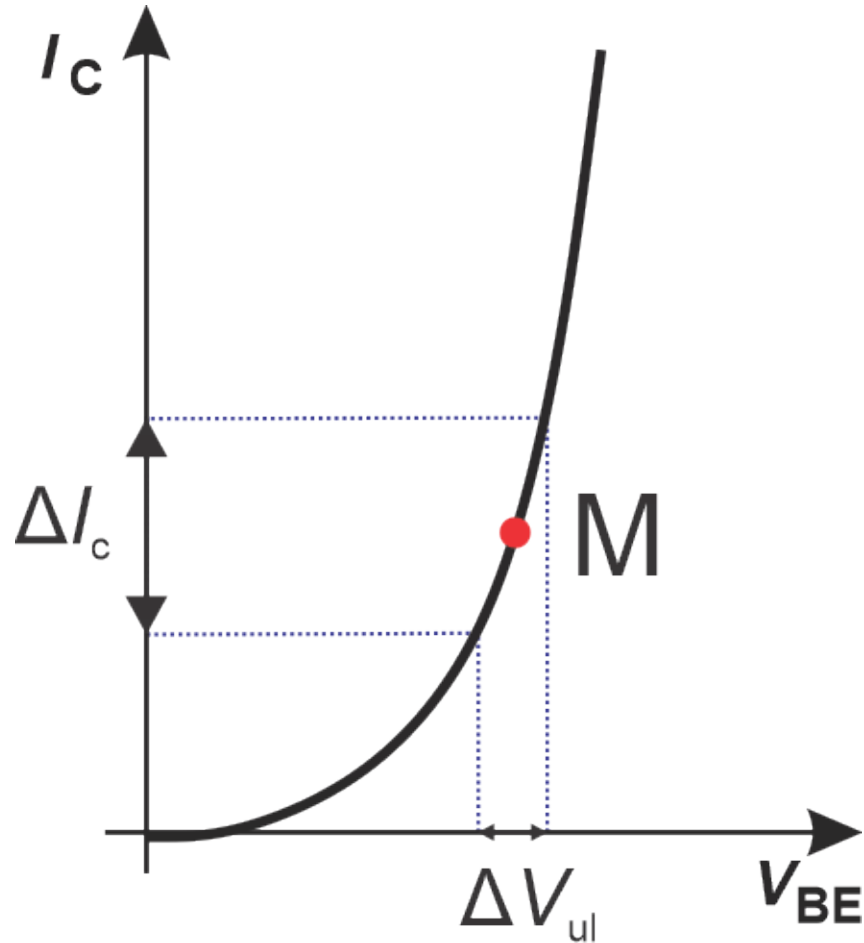
# Transkonduktansa



- Transkonduktansa predstavlja količnik promene struje kolektora i promene napona između baze i emitora:

$$g_m = \frac{dI_C}{dV_{BE}}$$

# Transkonduktansa

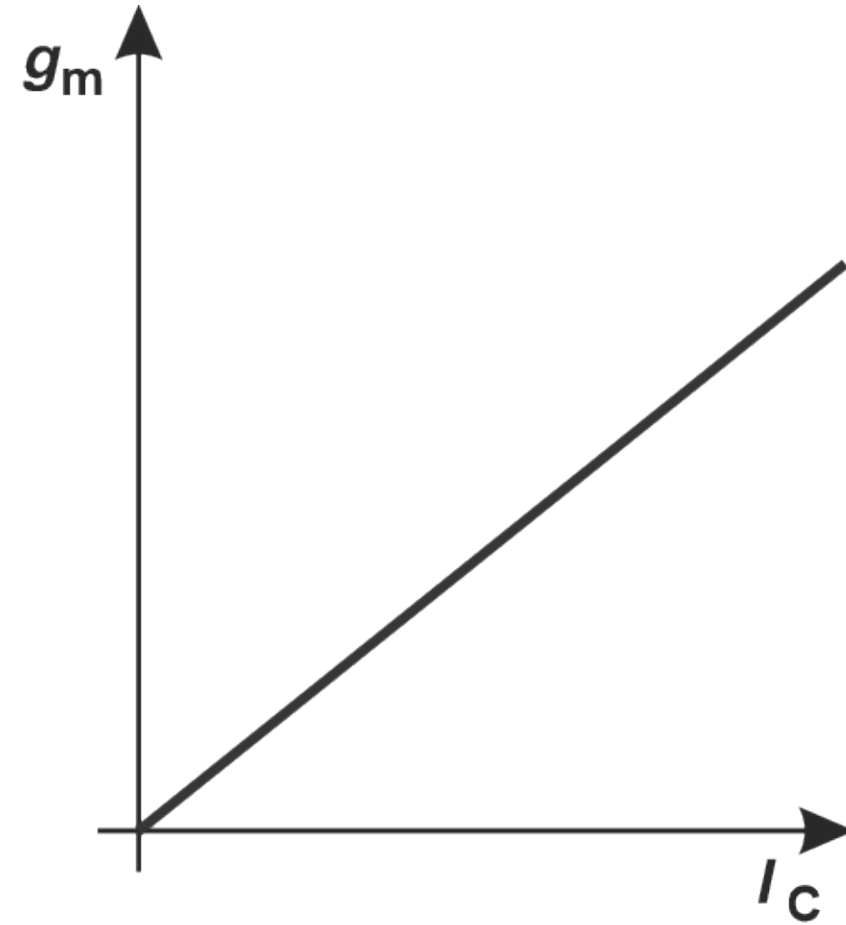
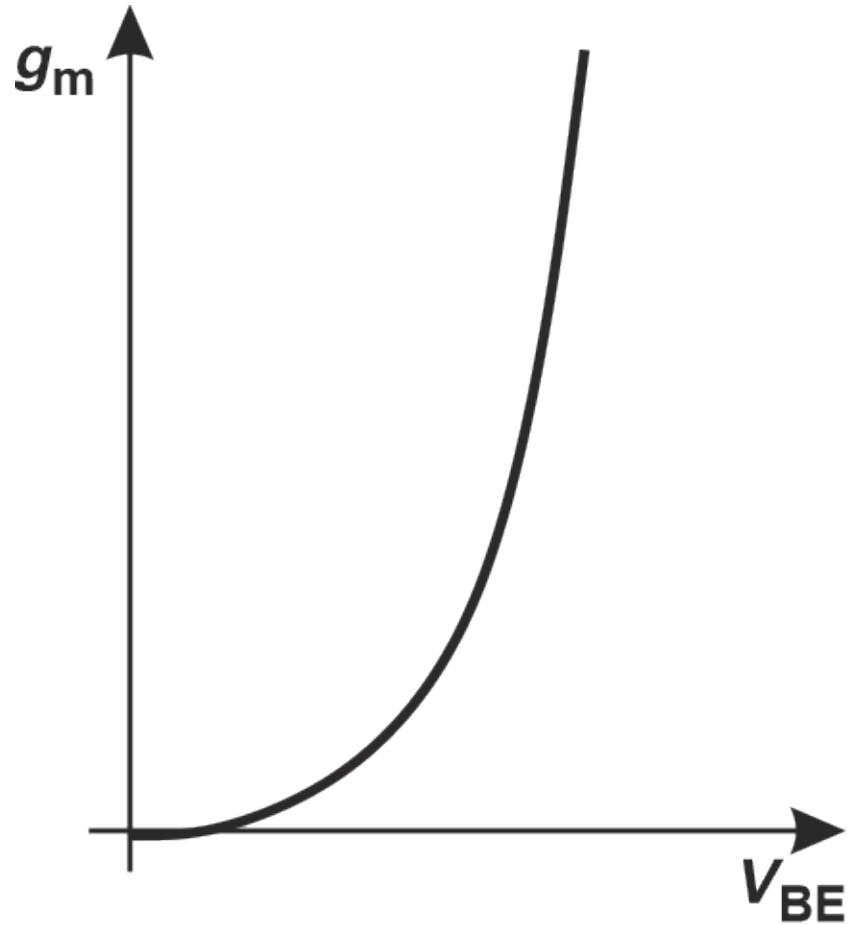


$$I_C = I_S \cdot \left( \exp\left(\frac{V_{BE}}{V_T}\right) - 1 \right)$$

$$g_m = \frac{dI_C}{dV_{BE}}$$

$$g_m = \frac{I_S}{V_T} \cdot \exp\left(\frac{V_{BE}}{V_T}\right) = \frac{I_C}{V_T}$$

# Transkonduktansa



# Transkonduktansa

- Transkonduktansa zavisi od radne tačke tranzistora.
- Pojačanje je proporcionalno transkonduktansi.
- Transkonduktansa je proporcionalna struji kolektora, veća transkonduktansa (samim tim i pojačanje) zahteva veću snagu generatora koji napaja kolo.