Freie Universität Berlin

Kapitel 4:
Halbleiter und Bipolare Transistoren

- pn-Übergang
- Diode
- Gleichrichtung
- Zenerdiode
- npn- und pnp-Übergang
- Arbeitsweise eines Transistors
- Kennlinienfeld eines Transistors
- Transistor als Schalter
- Transistor als Verstärker

Halbleiter

Halbleiter sind Stoffe, deren elektrische Leitfähigkeit geringer als von Leitern und größer als von Nichtleitern ist.

Halbleiter wie Silizium und Germanium verfügen über eine Kristallstruktur.

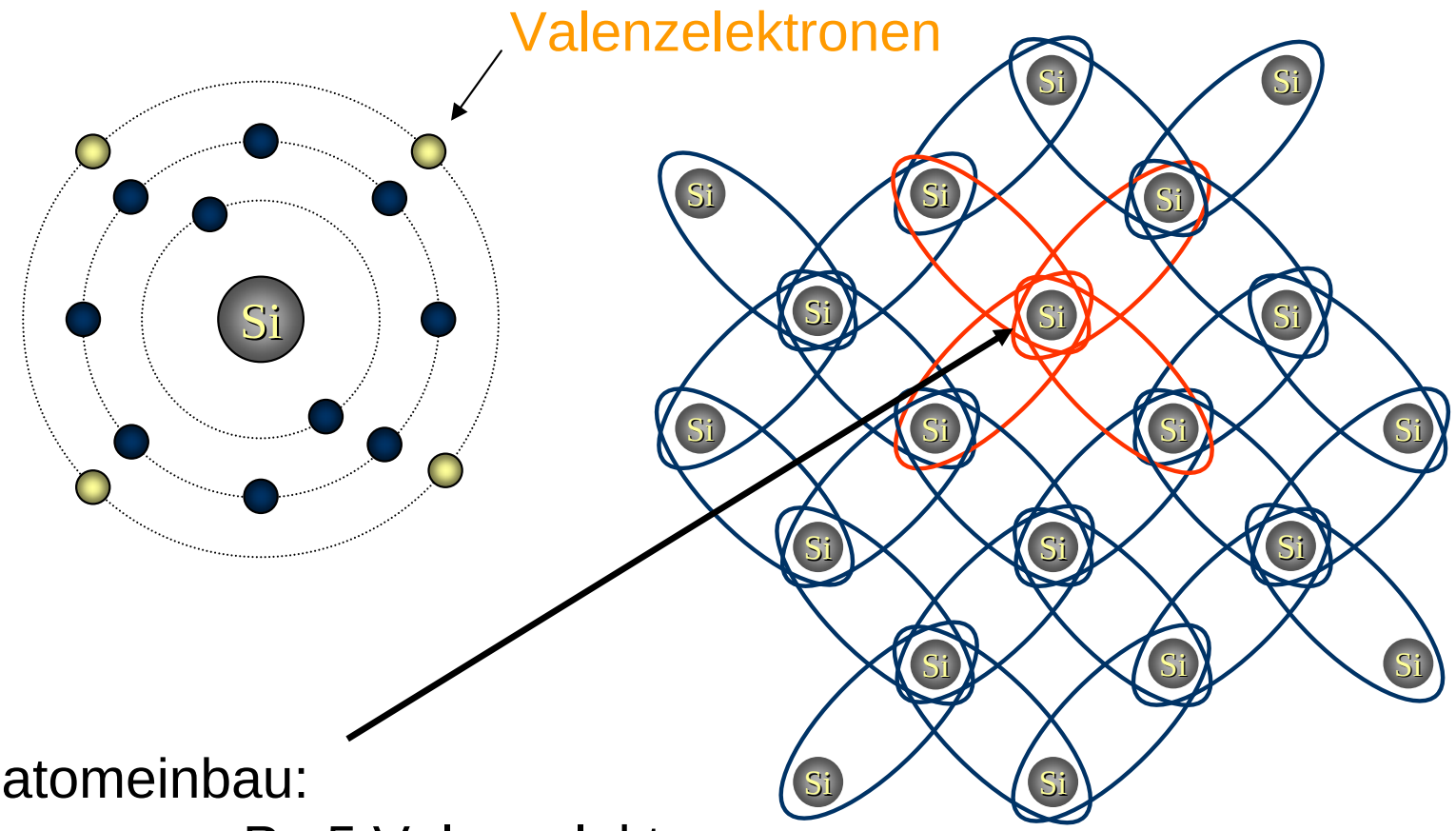
Die Kristallstruktur wird mit hoher Reinheit hergestellt.

Auf ca. 10^{10} Atome kommt ein Fremdatom.

Die Eigenleitfähigkeit von Halbleitern basiert auf:

- Verunreinigung
- Aufbrechen von Kristallbindungen
- Oberflächen-Leitfähigkeit

Silizium Halbleiterkristall

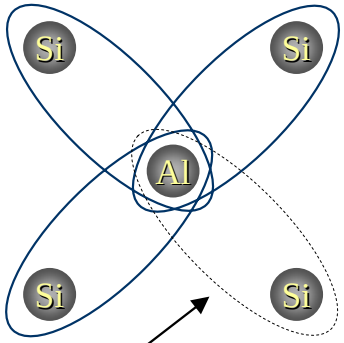


Fremdatomeinbau:

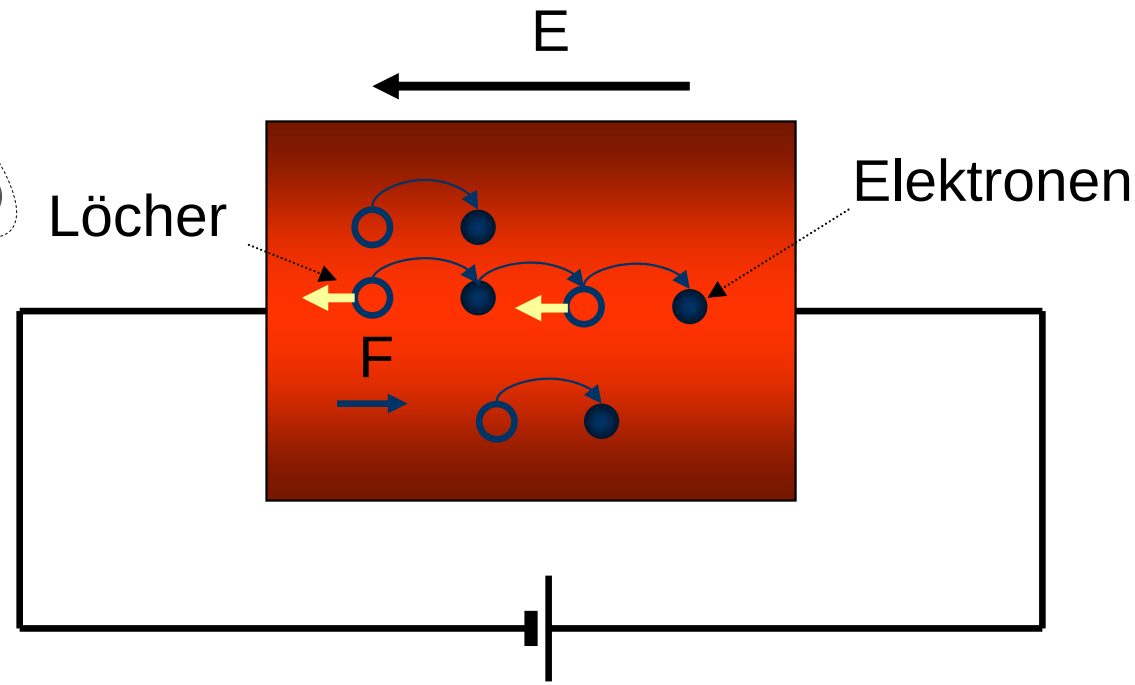
Donator	P	5 Valenzelektronen
Akzeptor	Al	3 Valenzelektronen

p–Silizium

- Akzeptoratom verursacht ein offene Bindung (Loch).
- Je höher die Dotierung, desto mehr Löcher.
- p-Silizium ist elektrisch nicht geladen.
- Löcher wandern zum negativen Pol.

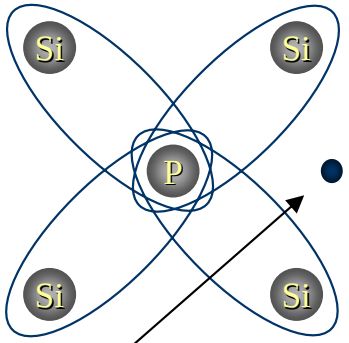


offene Bindung
ein Elektron fehlt.

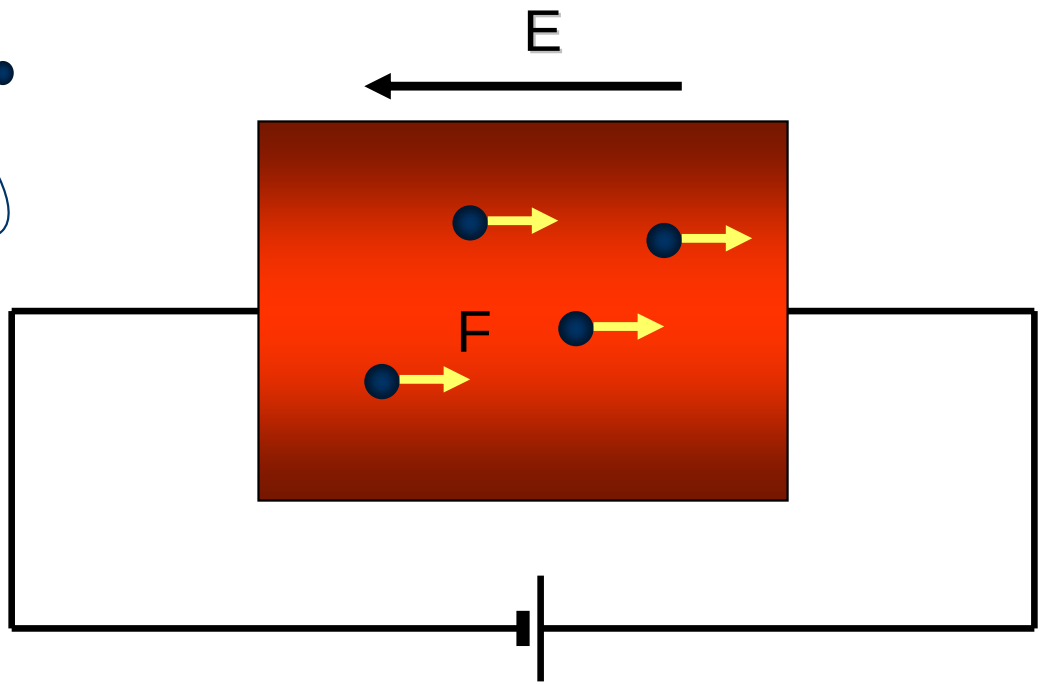


n-Silizium

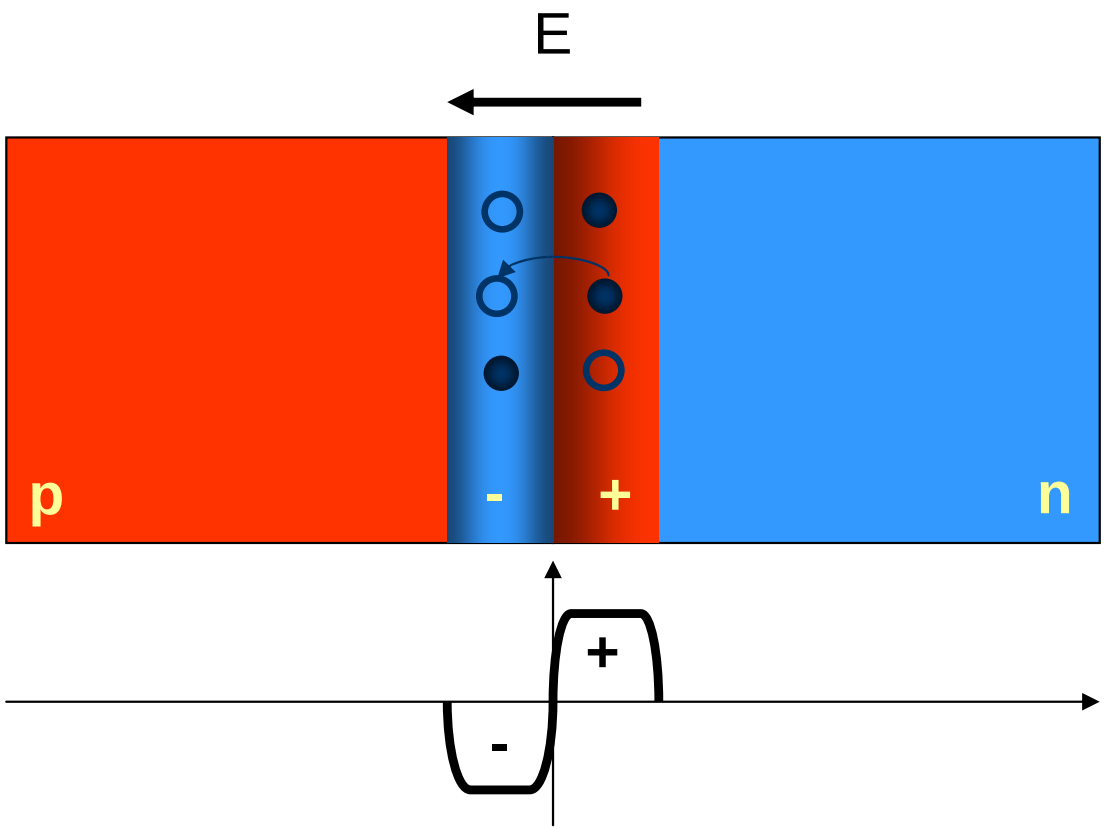
- Donatoratom verursacht ein freies Elektron.
- Je höher die Dotierung, desto mehr freie Elektronen.
- n-Silizium ist elektrisch nicht geladen.
- Es fließt ein Elektronenstrom wie in Metallen.



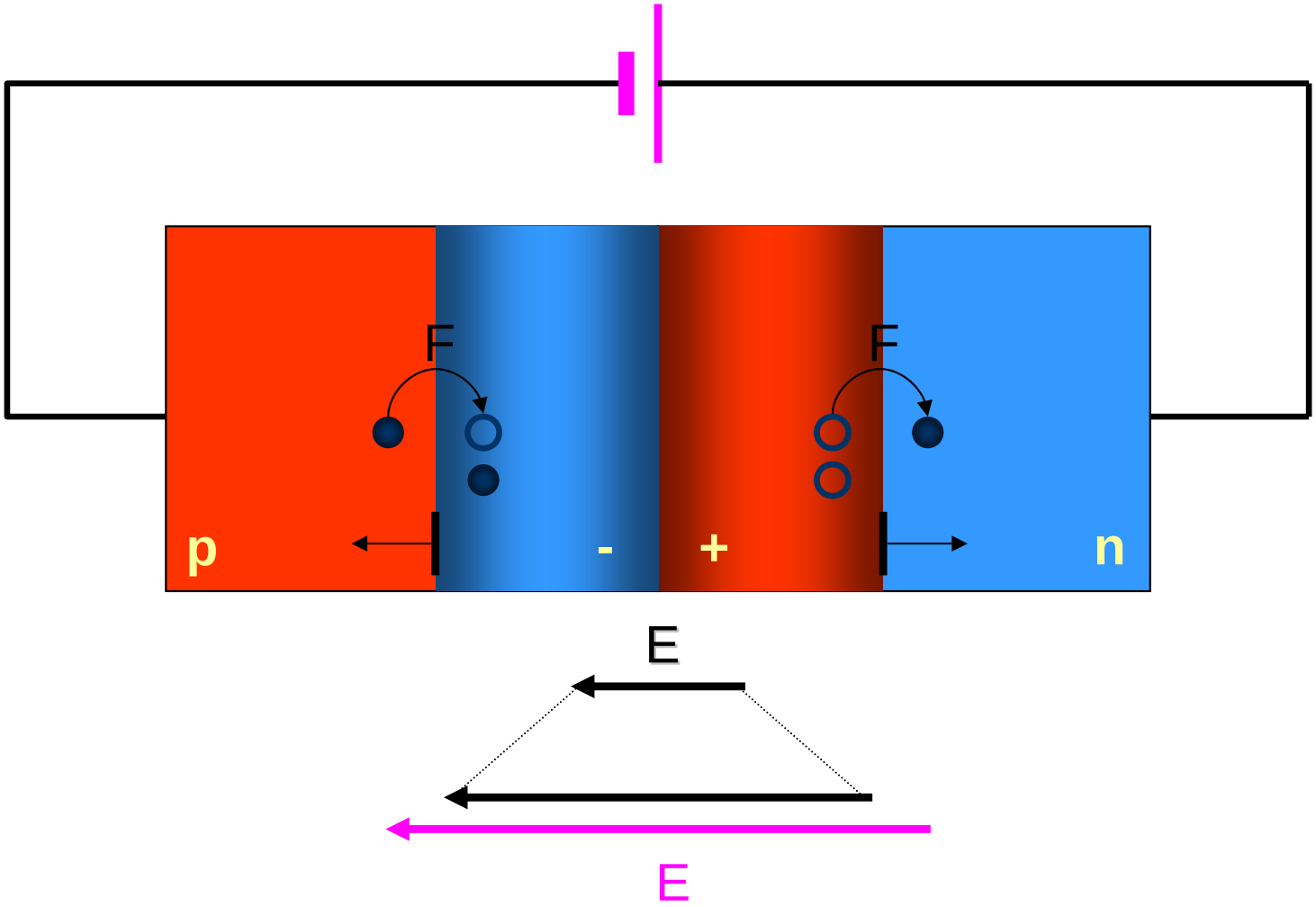
Ein Elektron Überschuss.



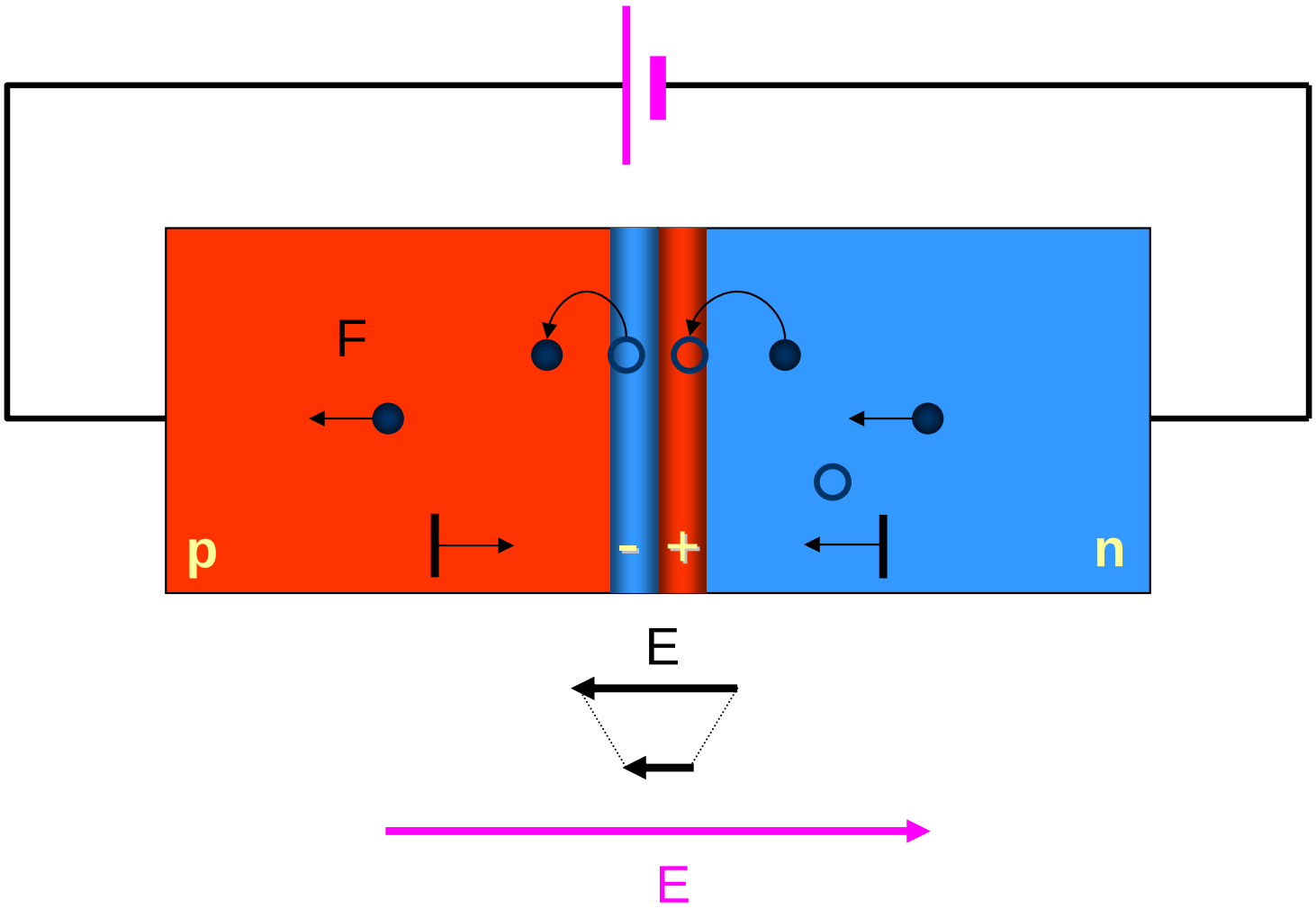
pn–Übergang



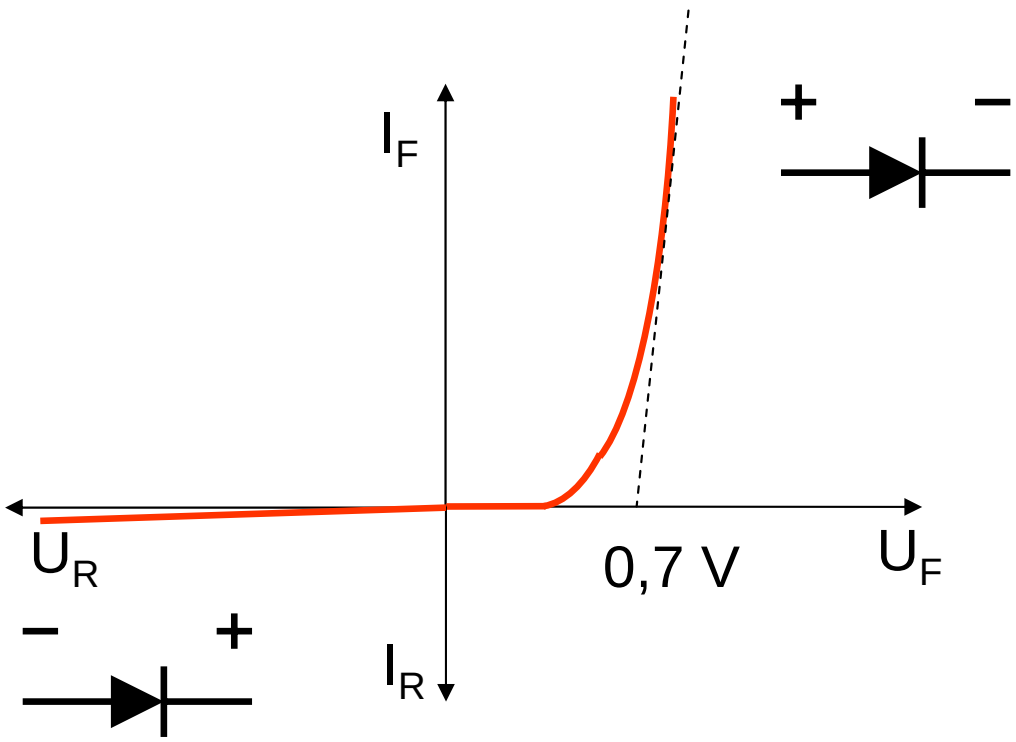
pn-Übergang in Sperrichtung



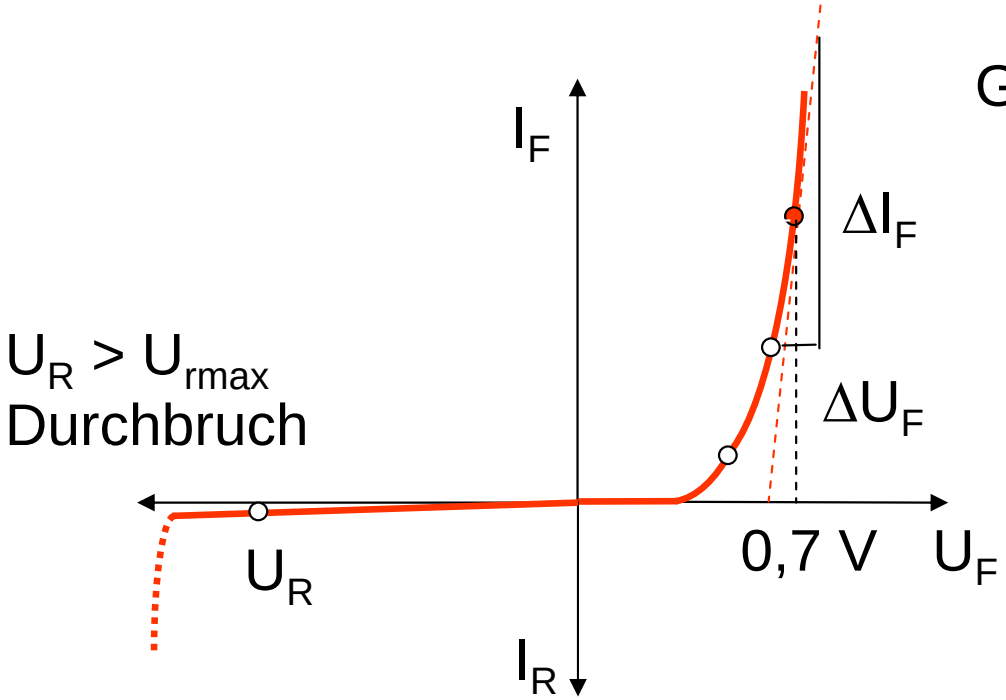
pn-Übergang in Durchlaßrichtung



Diodenkennlinie



Kennlinie einer Si-Diode



Gleichstromwiderstand am AP

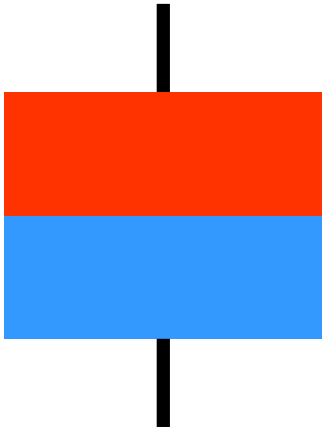
$$R_F = \frac{U_F}{I_F}$$

differentieller Widerstand
(an jedem Punkt anders)

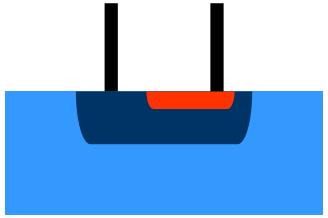
$$r_F = \frac{\Delta U_F}{\Delta I_F}$$

Schwellspannung	U_F	0,7V
Durchlasswiderstand	R_F	2-50Ω
Sperrwiderstand	R_R	1-3000MΩ
Sperrspannung	U_{rmax}	<3kV

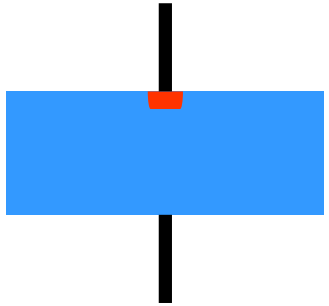
Aufbau unterschiedlicher Dioden



Flächendiode

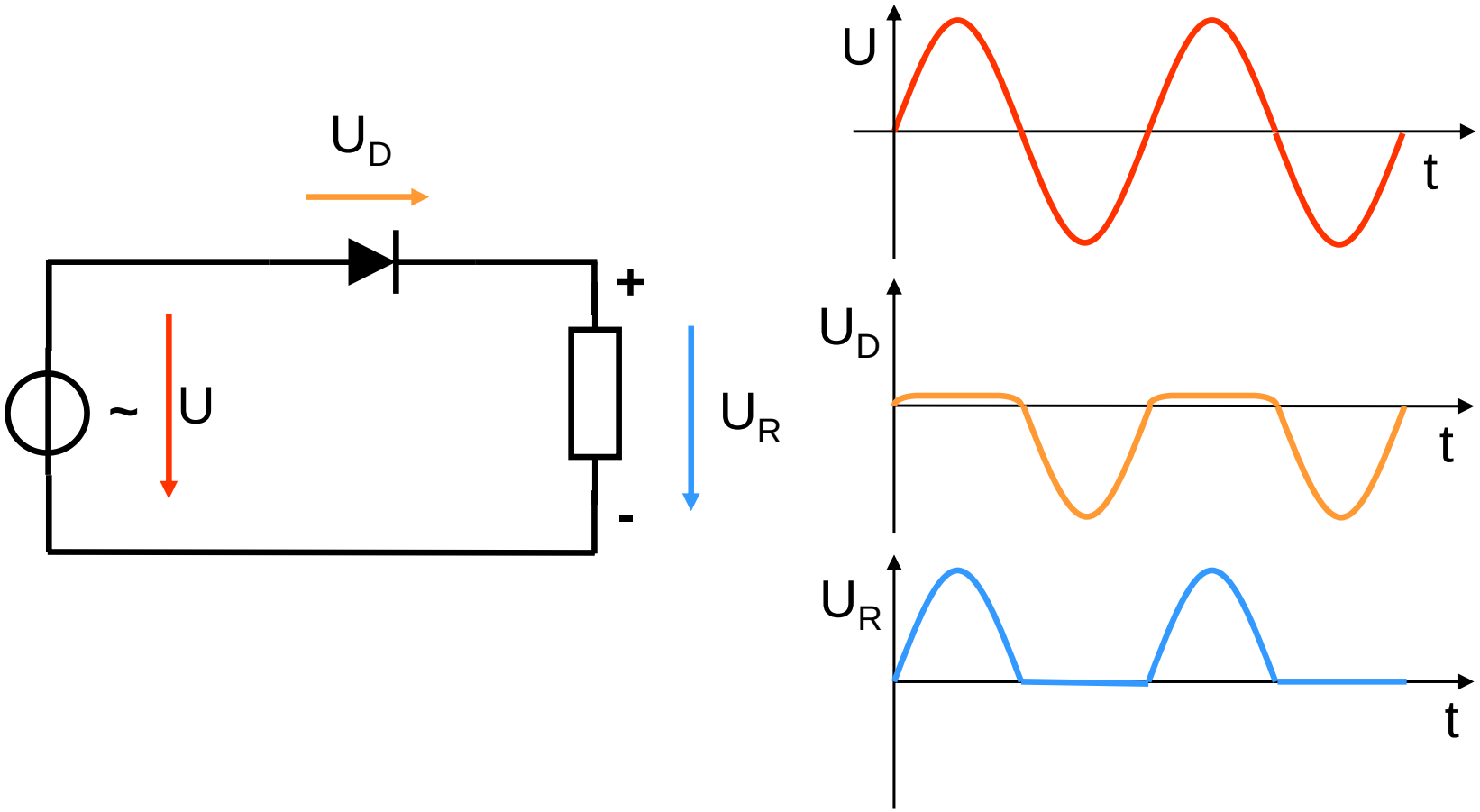


Planardiode

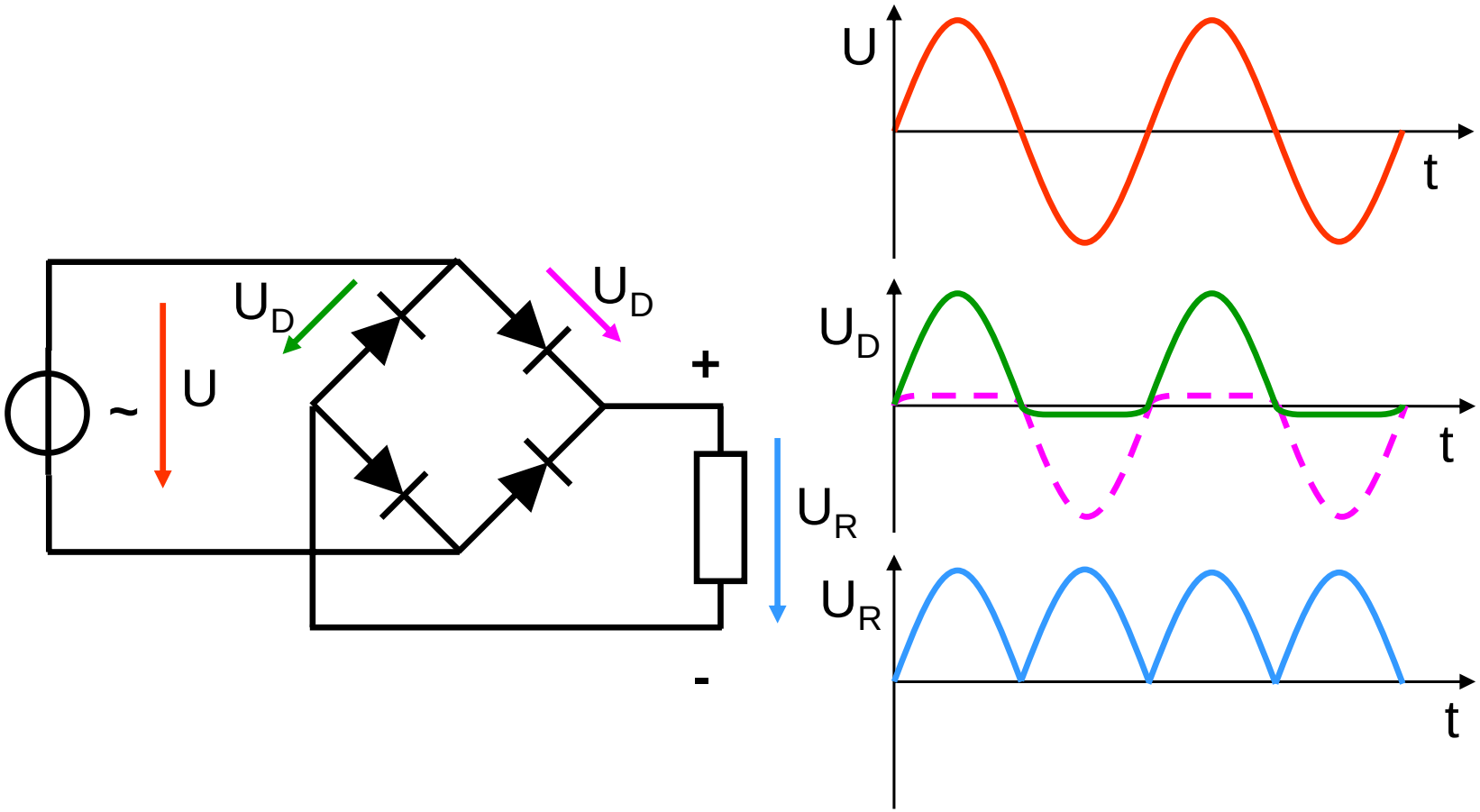


Spitzendiode

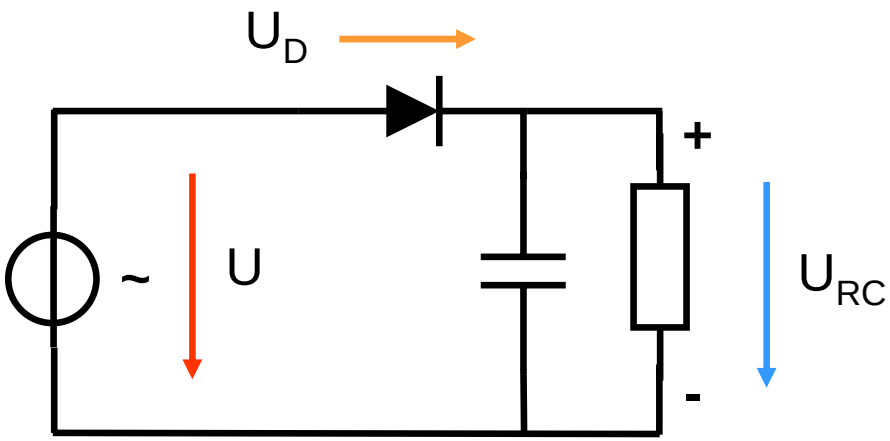
Einweggleichrichtung

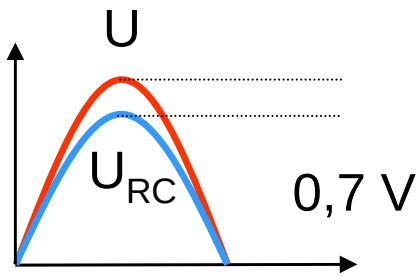


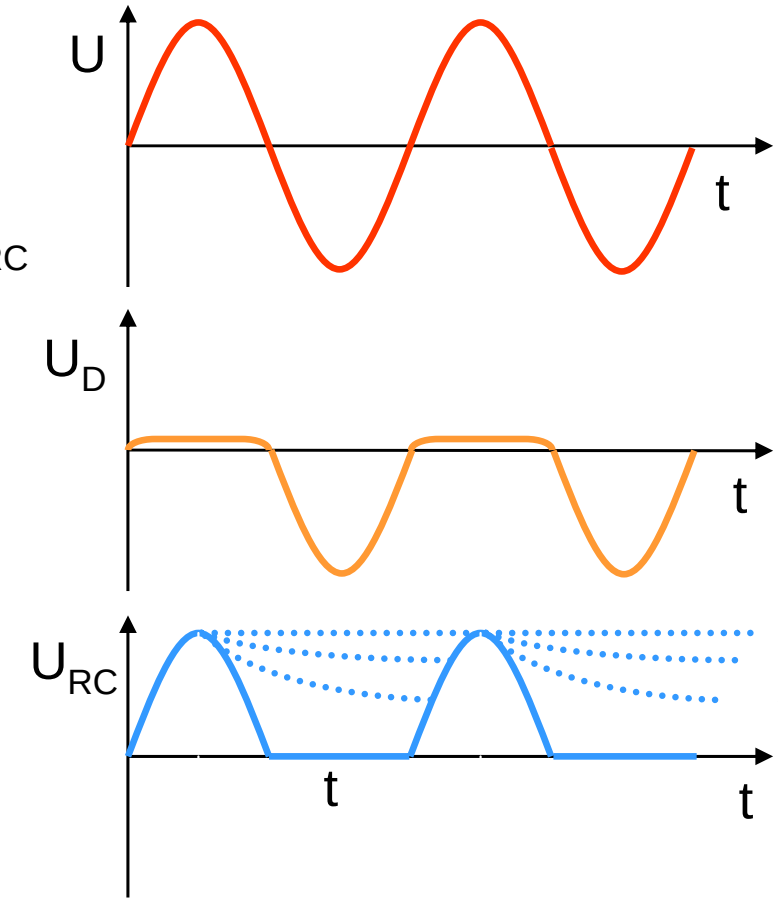
Zweiweggleichrichtung



Gleichspannungsglättung

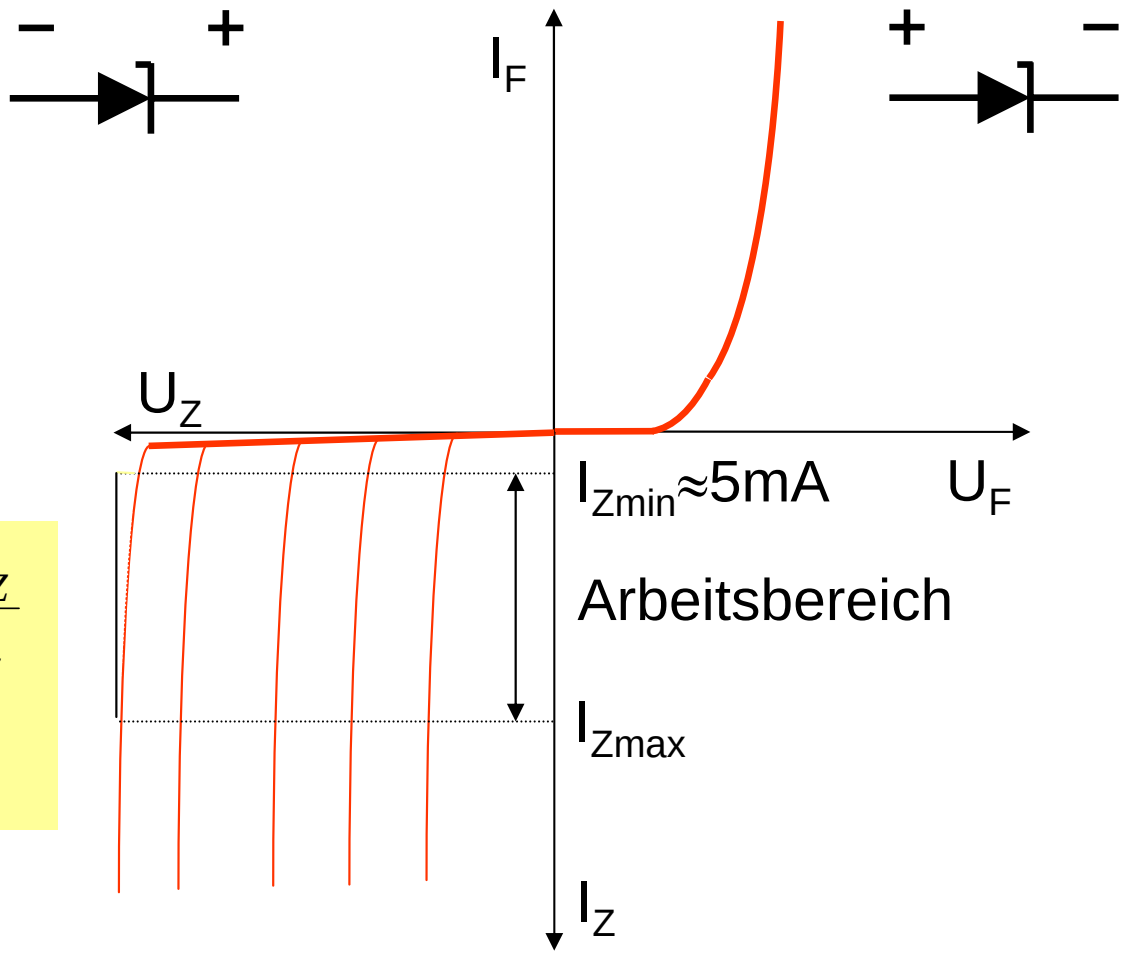






$$\tau = R \cdot C$$

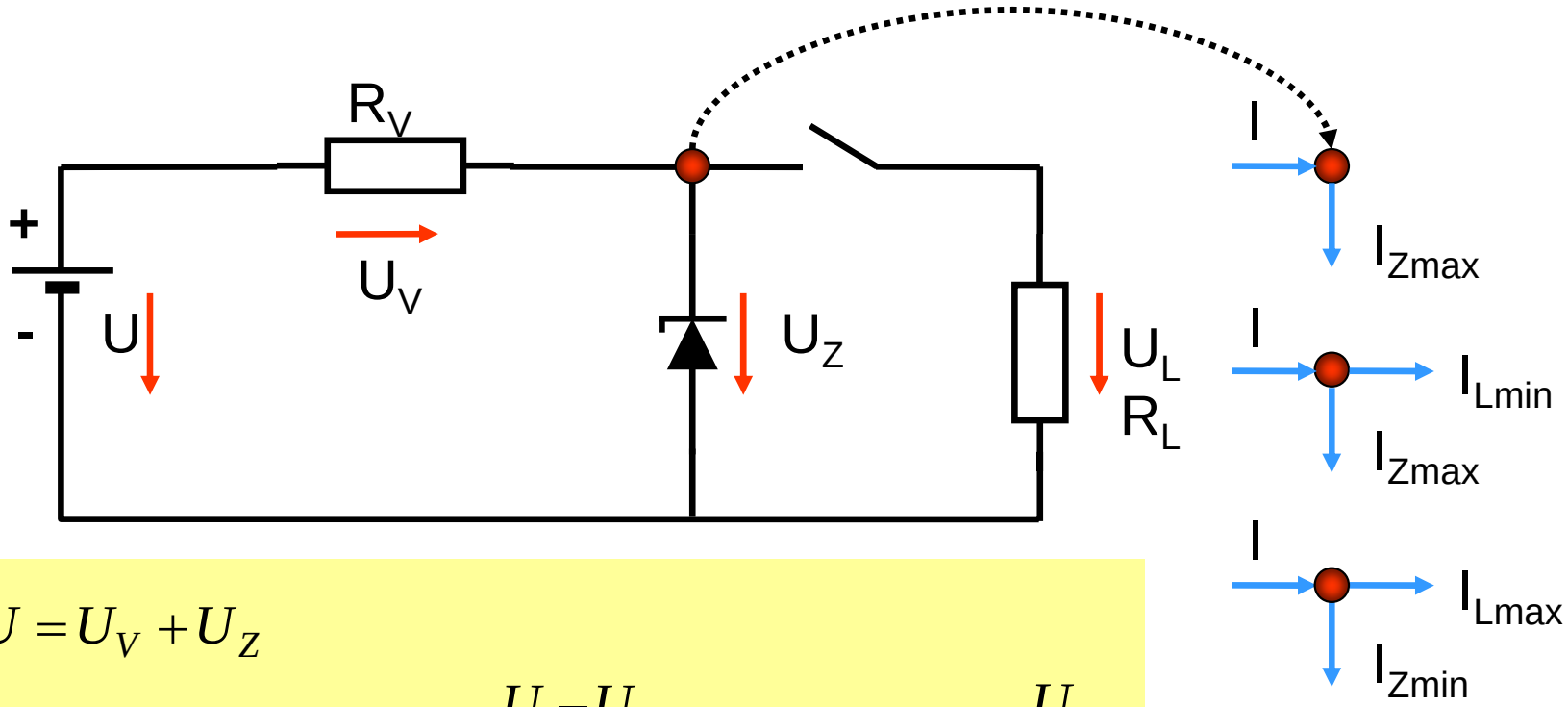
Zenerdiode



$$r_Z = \frac{\Delta U_Z}{\Delta I_Z}$$

ca. 1-100Ω

Spannungsstabilisierung



$$U = U_V + U_Z$$

$$I = I_Z + I_L \qquad R_V = \frac{U - U_Z}{I_Z + I_L} \qquad R_{L\min} = \frac{U_Z}{I_{L\max}}$$

$$I_{\max} = \frac{U - U_Z}{R_V} \qquad R_V = \frac{U - U_Z}{I_{Z\min} + I_{L\max}} \qquad R_{L\max} = \frac{U_Z}{I_{L\min}}$$

Transistoren

Transistor – Transfer Resistor

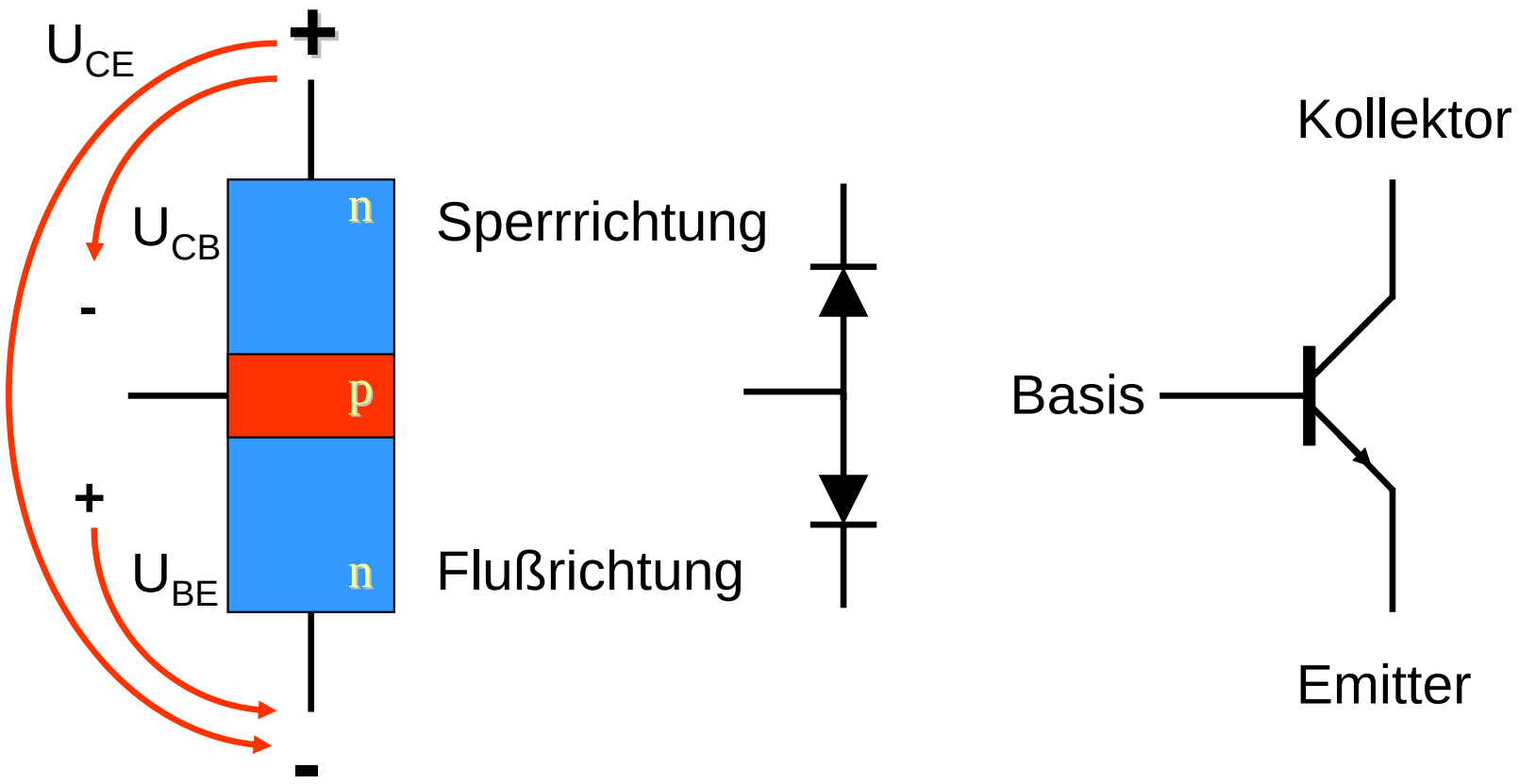
Bipolare Transistoren

npn-Transistor
pnp-Transistor

Unipolare Transistoren

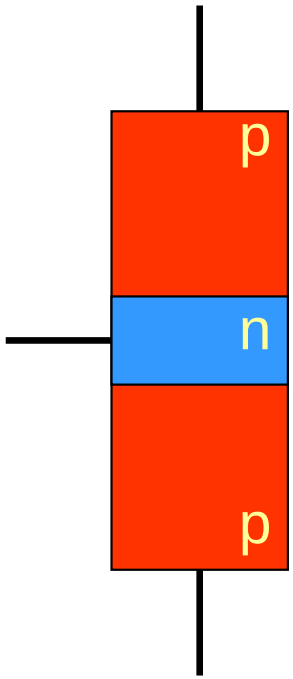
J-FET
MOS-FET

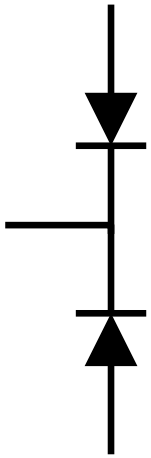
Bipolare Transistoren

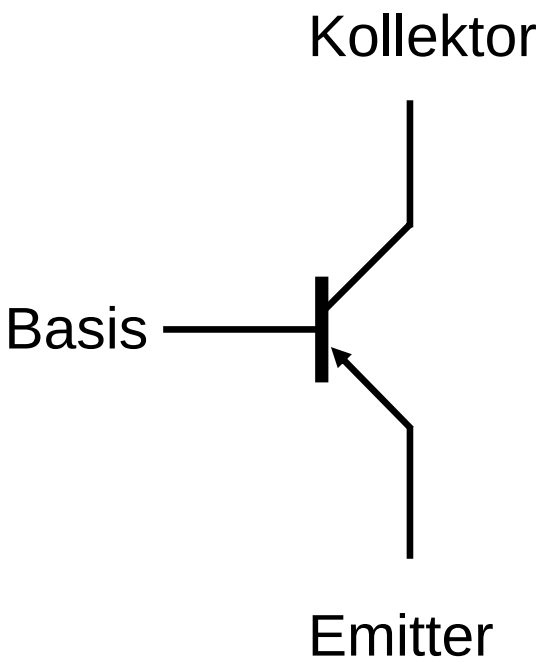


Bei Bipolaren Transistoren befindet sich ein pn-Übergang in Sperrichtung und der andere in Flußrichtung. Die pn-Übergänge werden bipolar genutzt. Es existieren npn- und pnp-Transistoren.

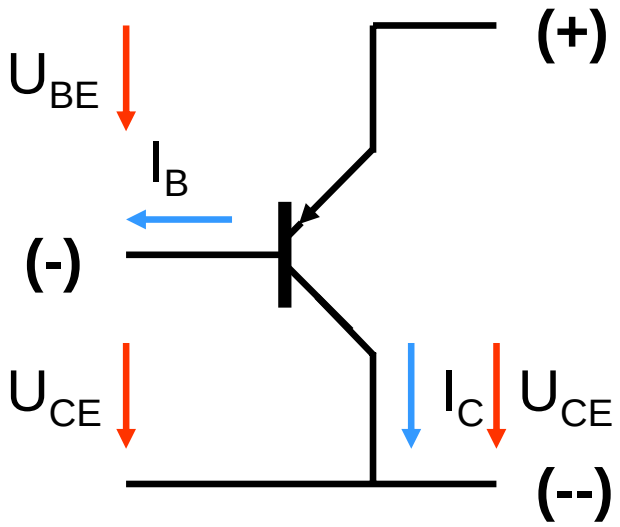
pnp-Übergang





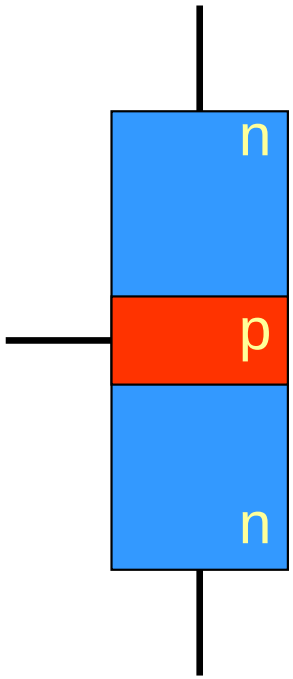


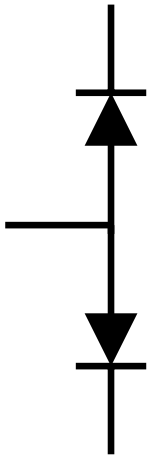
pnp-Transistor
Ströme und Spannungen

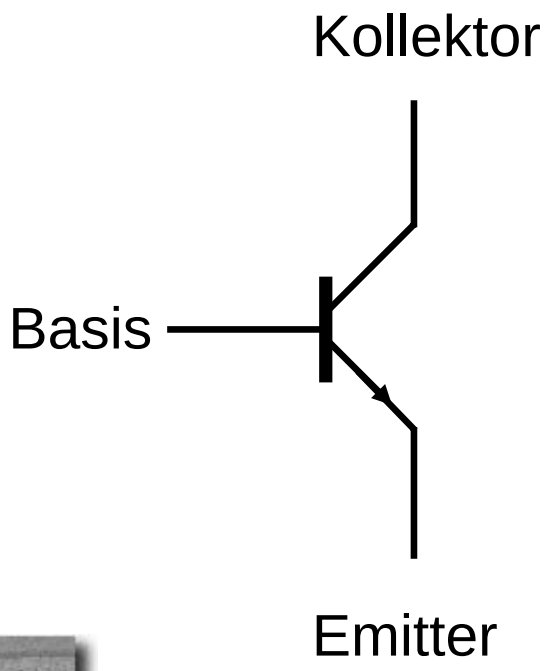


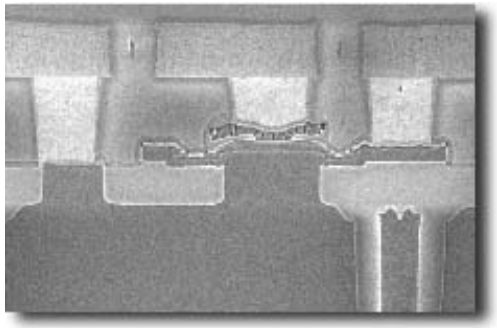
$$U_{CE} = U_{BE} + U_{CB} \qquad I_E = I_B + I_C$$

npn-Übergang



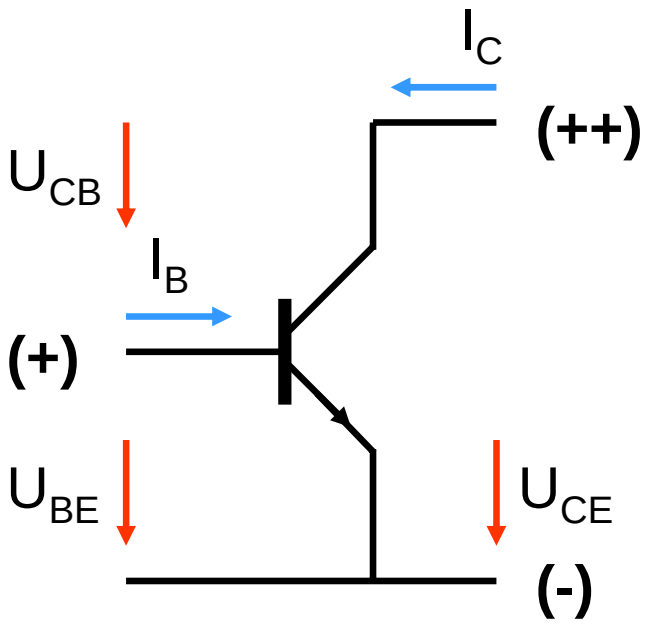






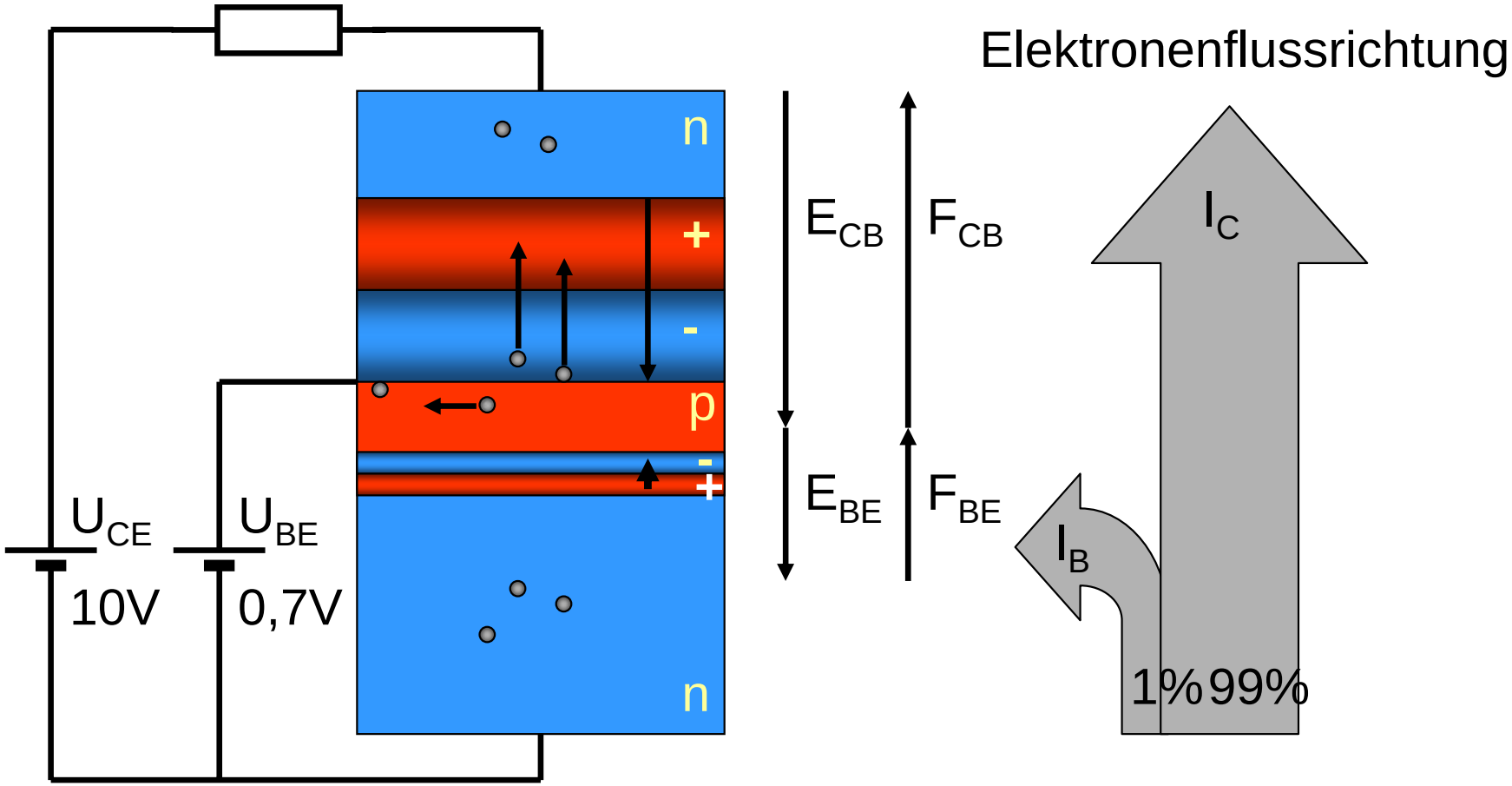
Schliffbild eines npn -Transistors

npn-Transistor
Ströme und Spannungen

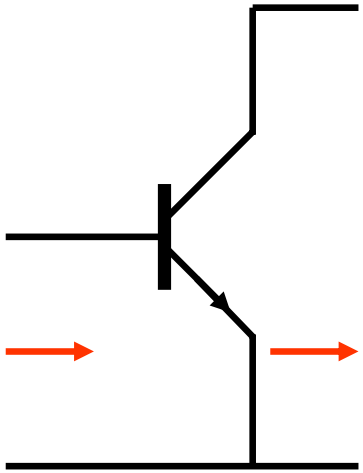


$$U_{CE} = U_{BE} + U_{CB} \qquad I_E = I_B + I_C$$

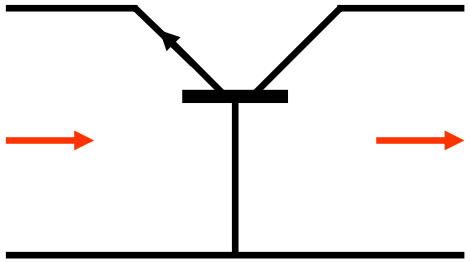
Arbeitsweise eines npn-Transistors



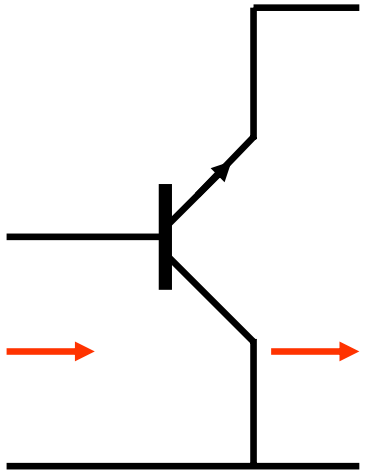
Grundschaltungen



Emitterschaltung

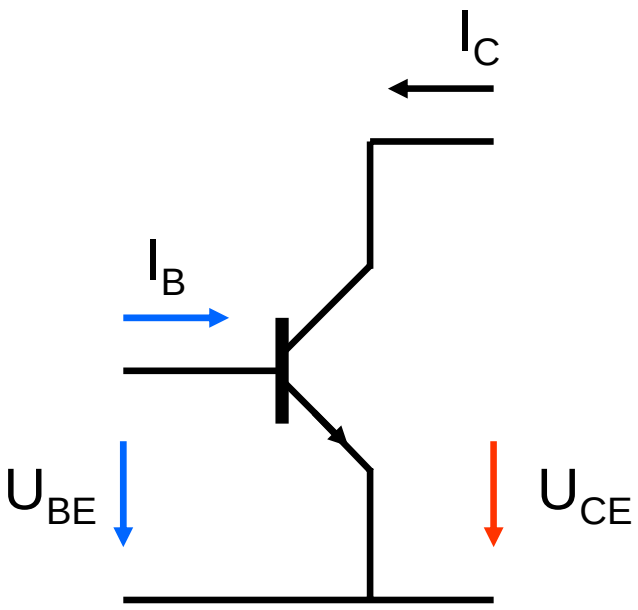


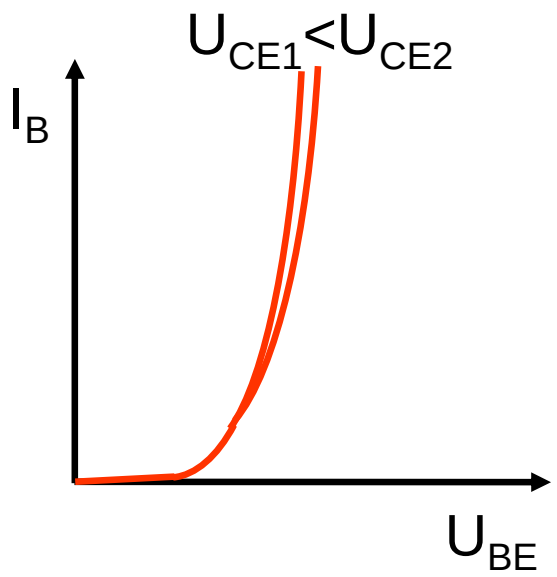
Basisschaltung



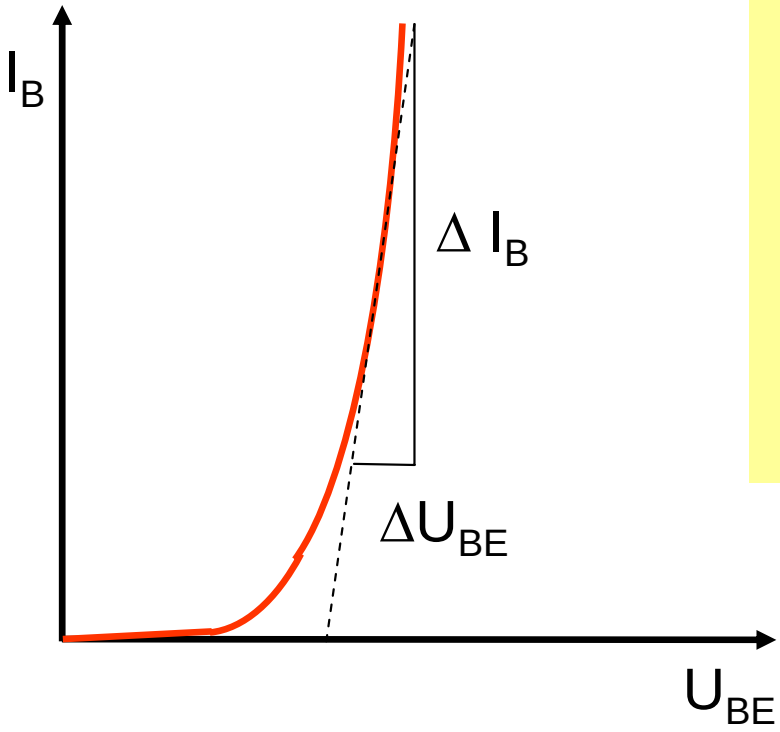
Kollektorschaltung

Kennlinienfeld
Eingangskennlinie





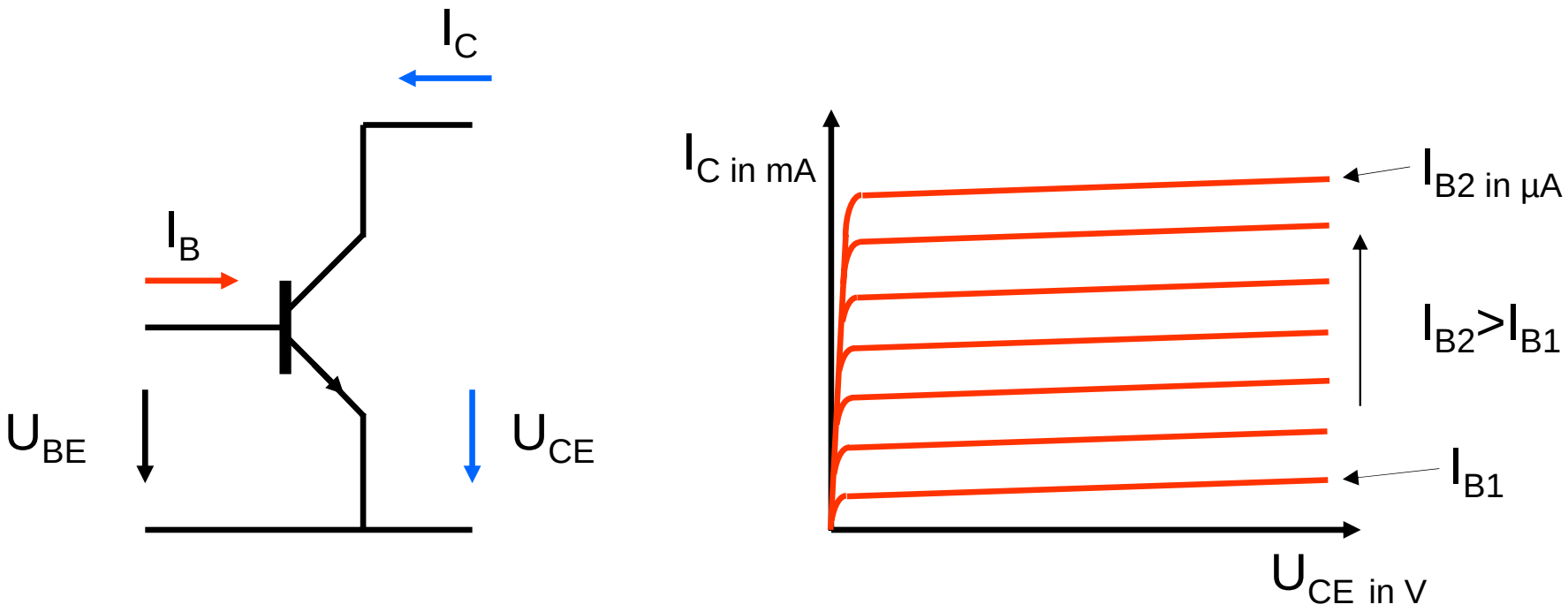
Kennlinienfeld
Eingangskennlinie



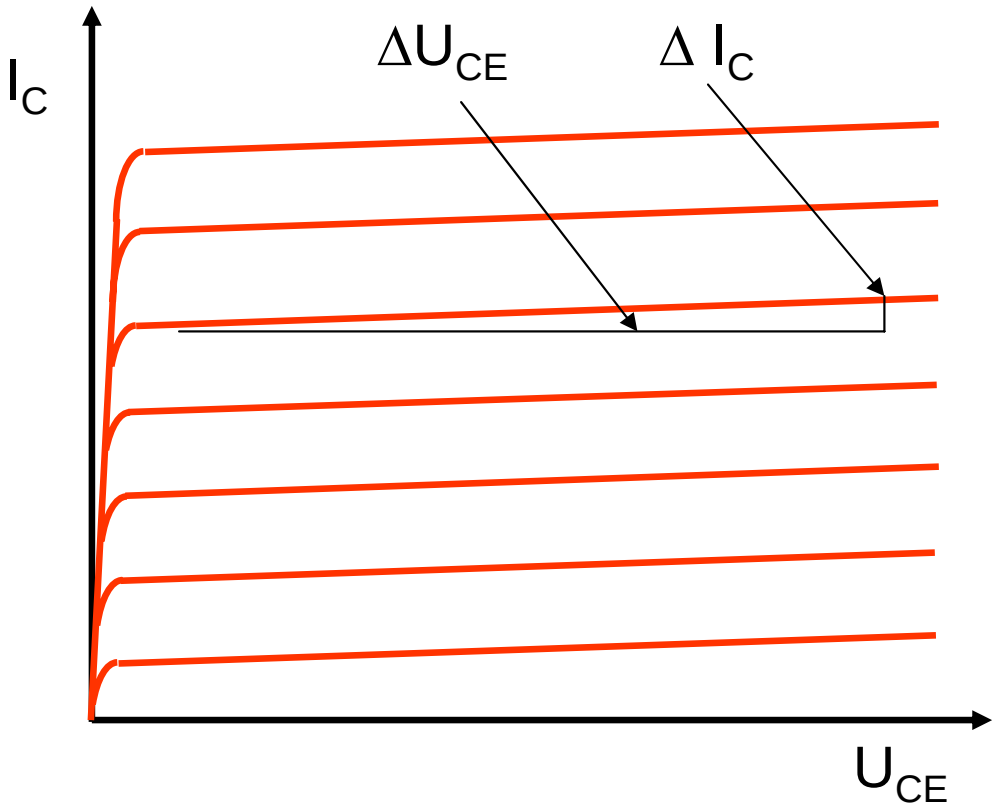
Differentieller Transistoreingangswiderstand

$$r_{BE} = \frac{\Delta U_{BE}}{\Delta I_B}$$

Kennlinienfeld
Ausgangskennlinie



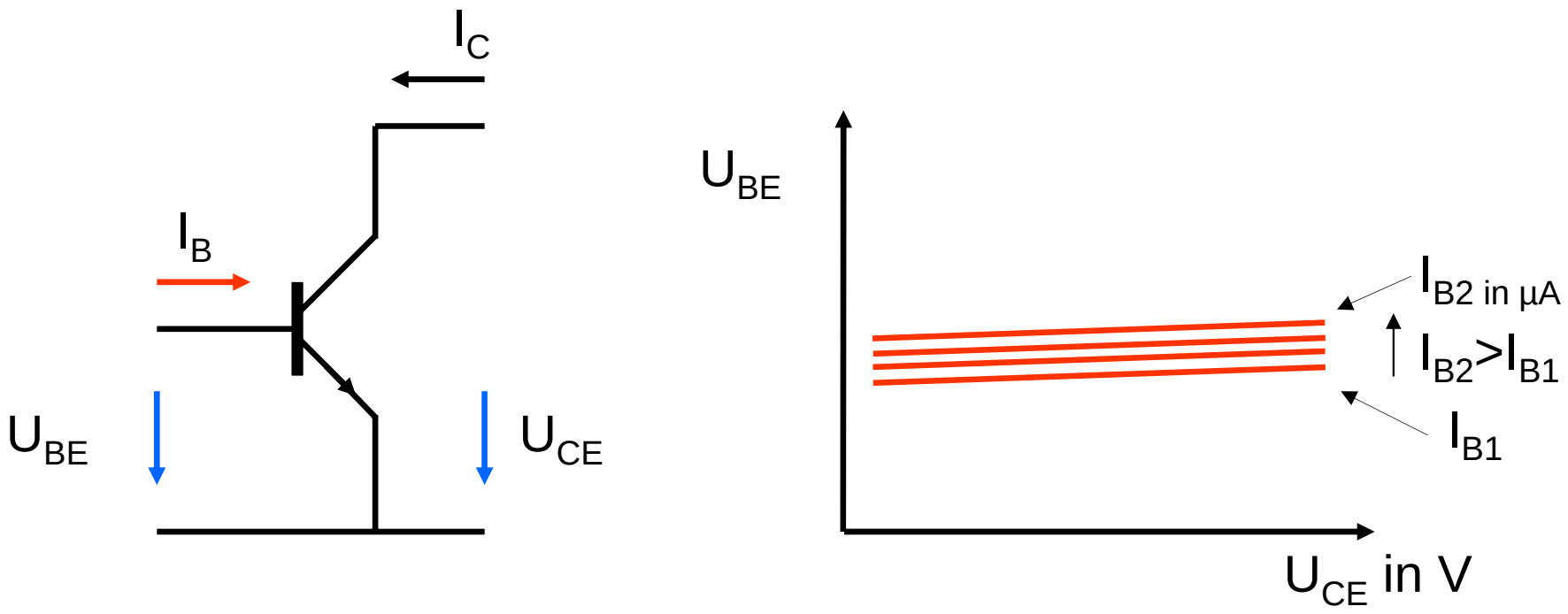
Kennlinienfeld
Ausgangskennlinie



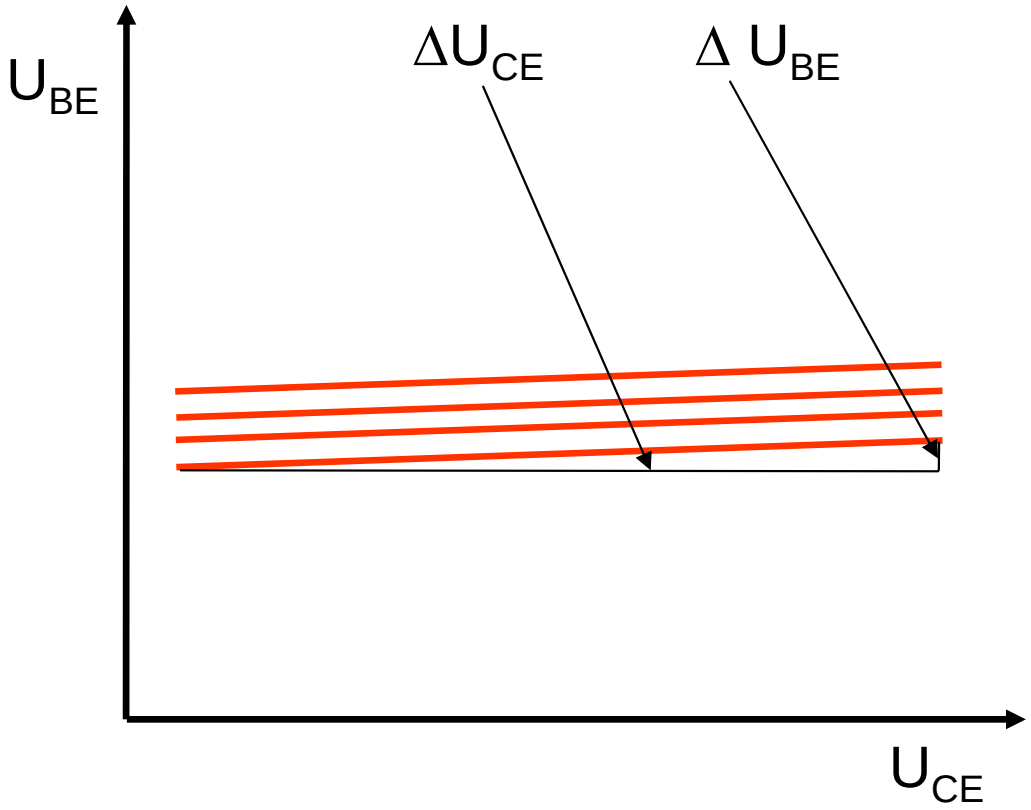
Differentieller Ausgangswiderstand

$$r_{CE} = \frac{\Delta U_{CE}}{\Delta I_C}$$

Kennlinienfeld
Rückwirkungskennlinie



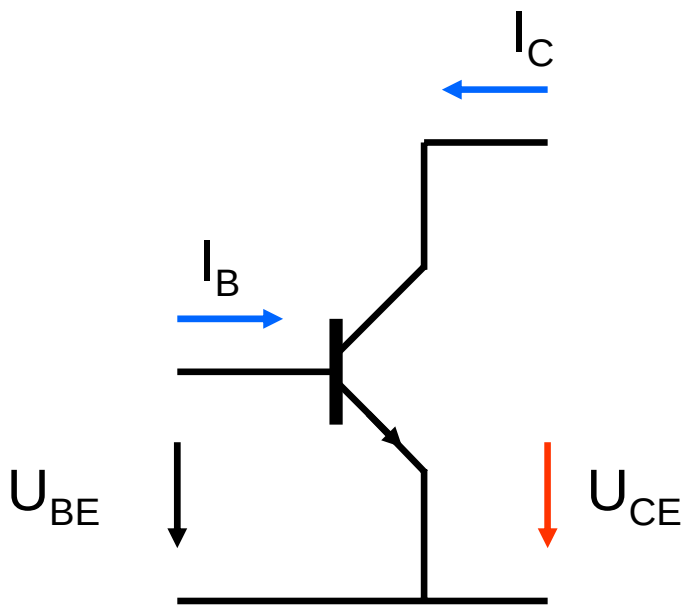
Kennlinienfeld
Ausgangskennlinie

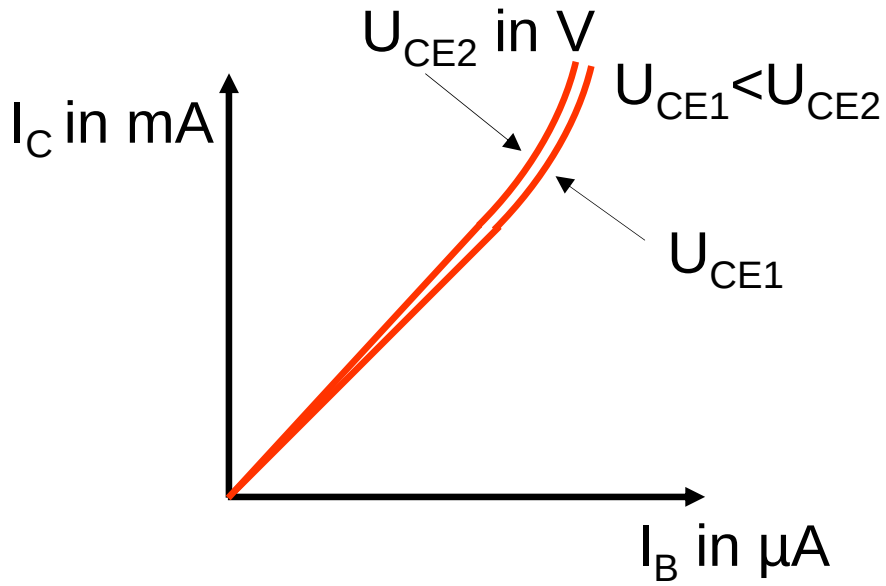


Differentieller Rückwirkungsfaktor

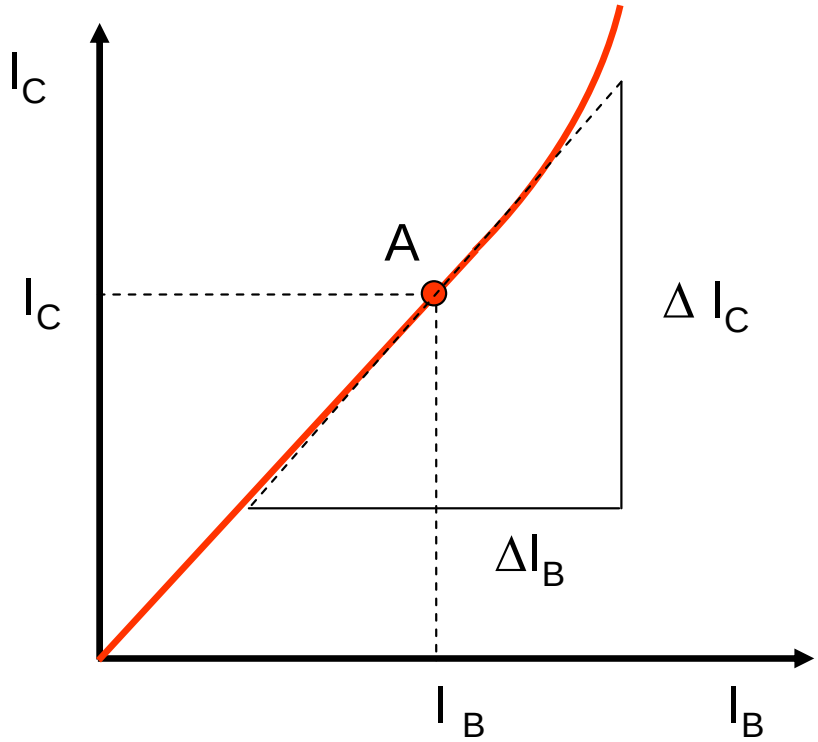
$$D = \frac{\Delta U_{BE}}{\Delta U_{CE}}$$

Kennlinienfeld
Stromsteuerungskennlinie





Kennlinienfeld
Stromsteuerungskennlinie



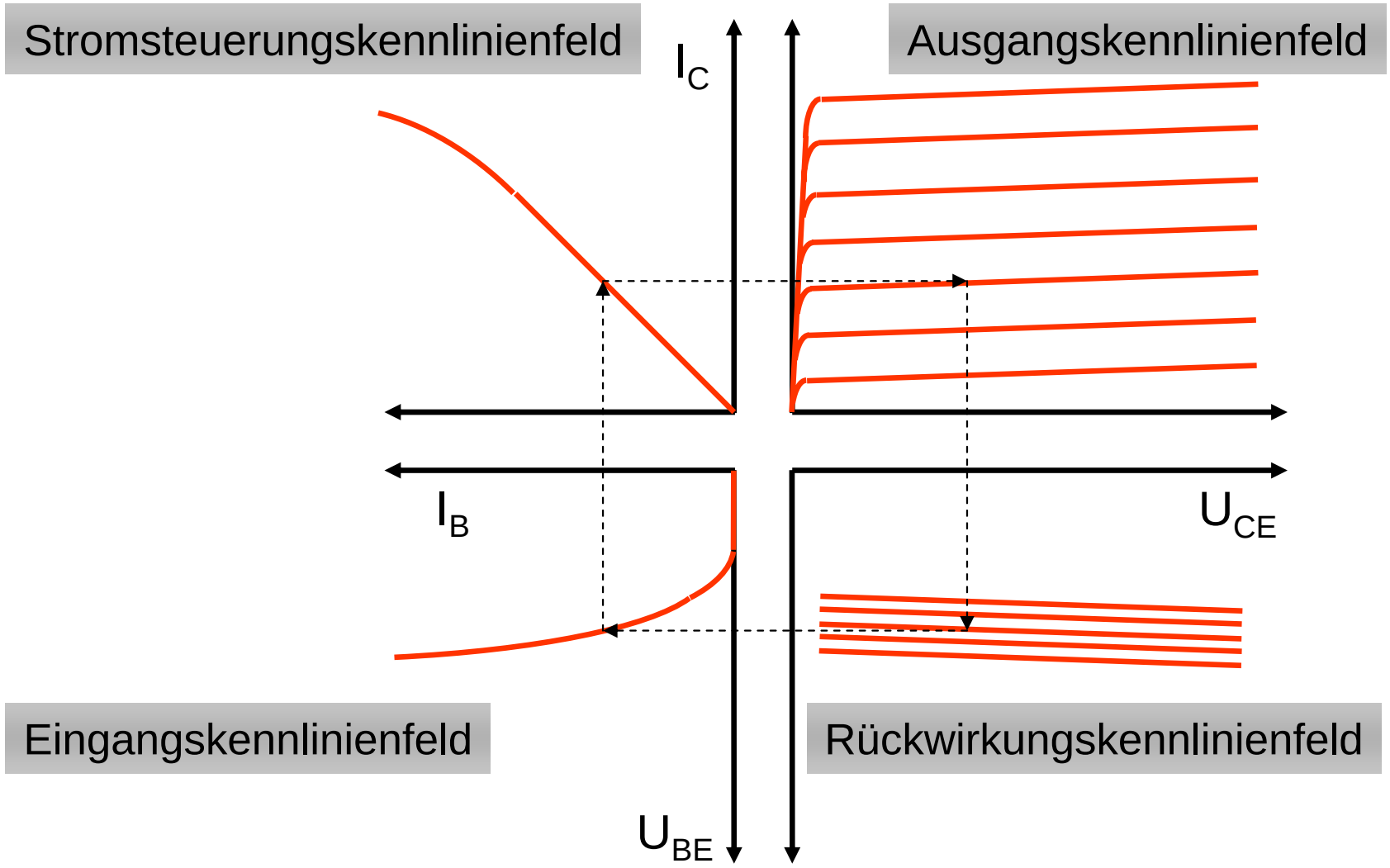
Gleichstromverstärkung

$$B = \frac{I_C}{I_B}$$

Differentielle Gleichstromverstärkung

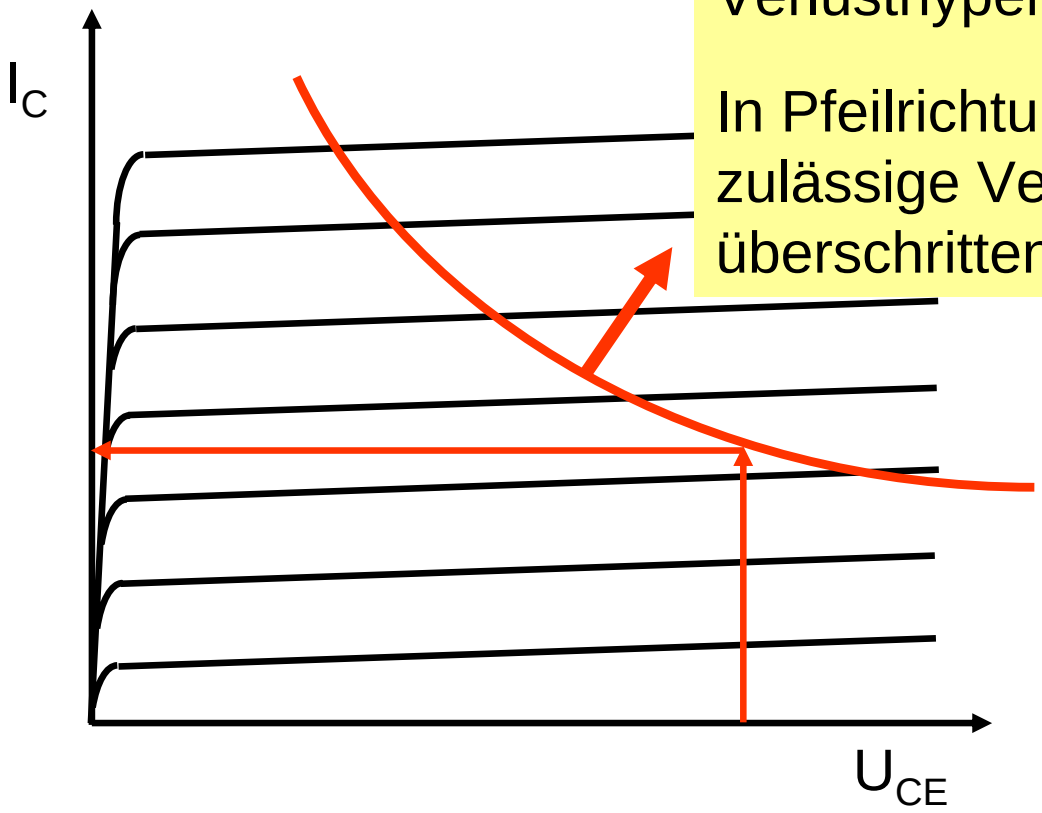
$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

Kennlinienfeld
des bipolaren Transistors



Kennlinienfeld

Verlustleistung des bipolaren Transistors



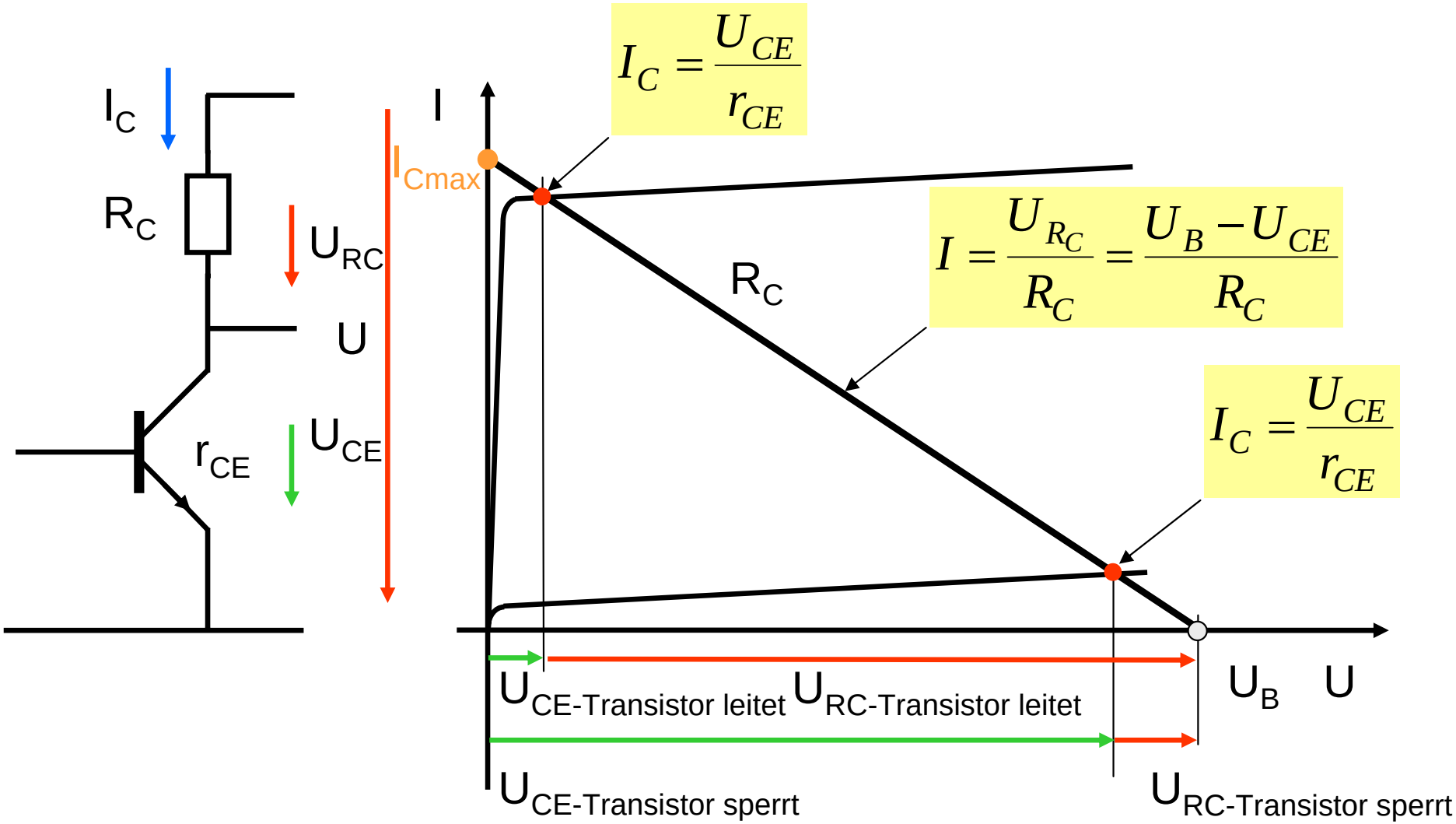
Verlusthyperbel P_{tot}

In Pfeilrichtung wird die zulässige Verlustleistung überschritten

$$P_{tot} = U_{CE} \cdot I_{C\max}$$

$$I_{C_{\max}} = \frac{P_{tot}}{U_{CE}}$$

Transistor
als Schalter



Transistor
als Verstärker

Spannungsverstärkung

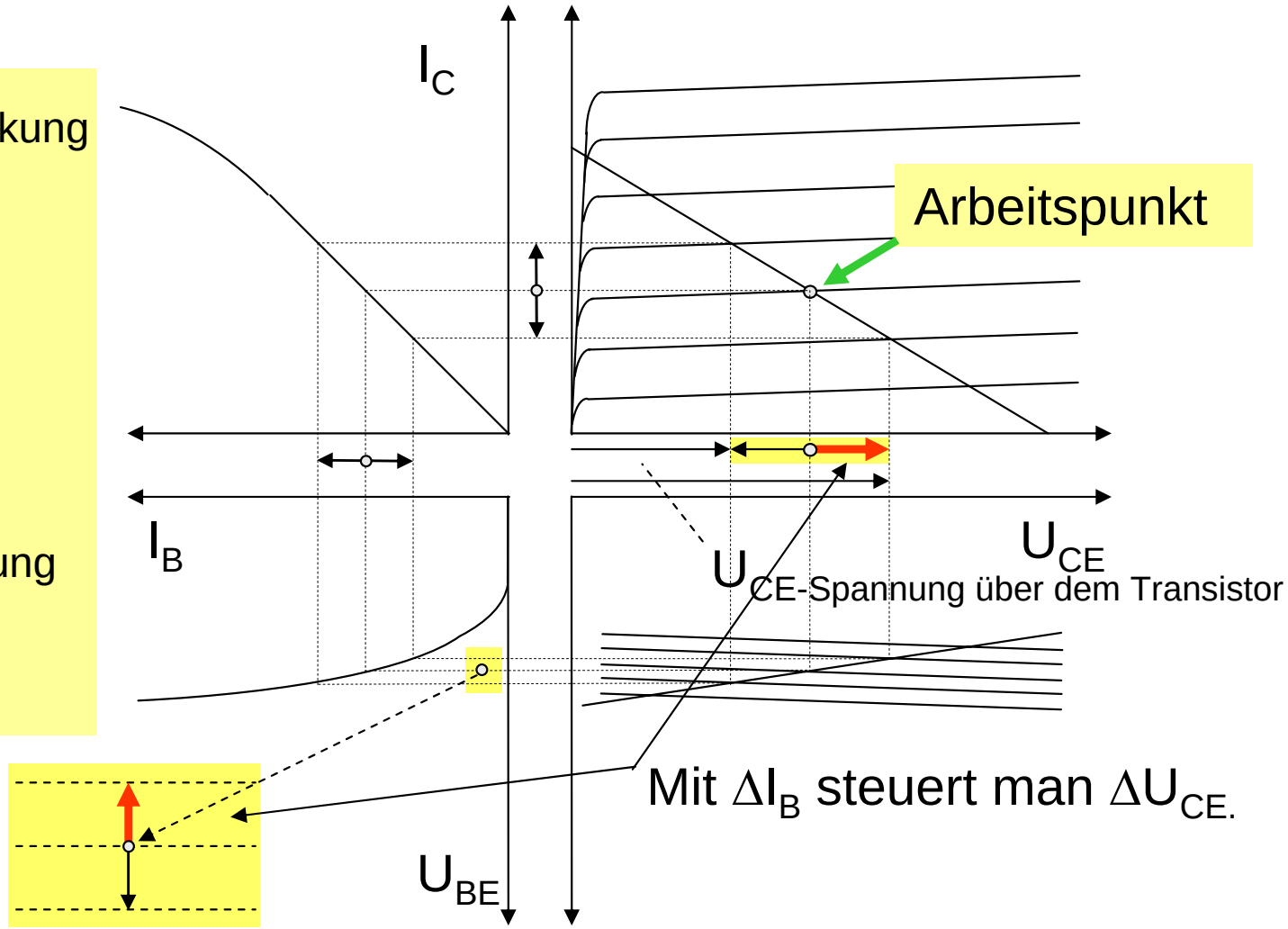
$$V_u = \frac{\hat{u}_{CE}}{\hat{u}_{BE}}$$

Stromverstärkung

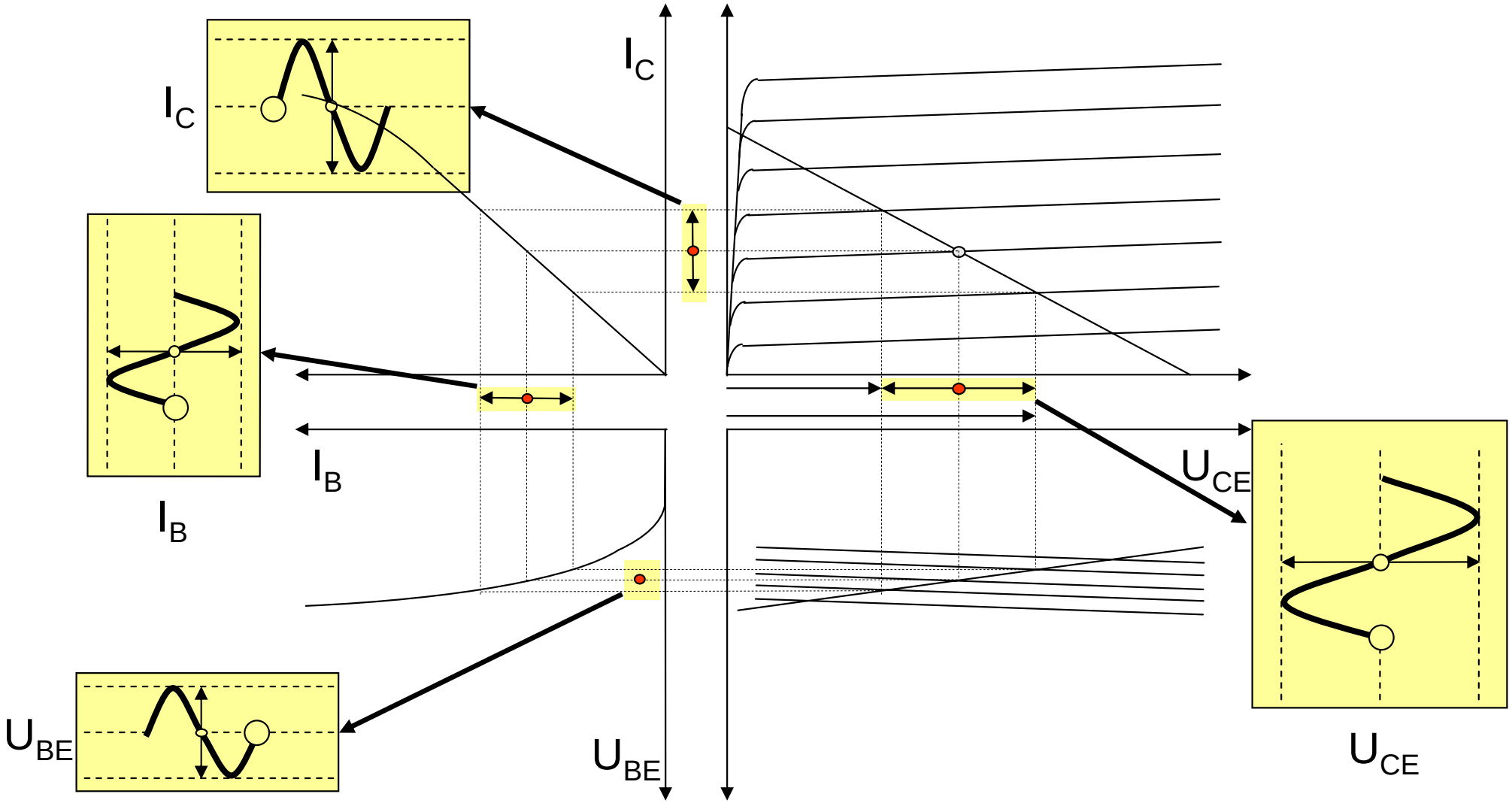
$$V_i = \frac{\hat{i}_C}{\hat{i}_B}$$

Leistungsverstärkung

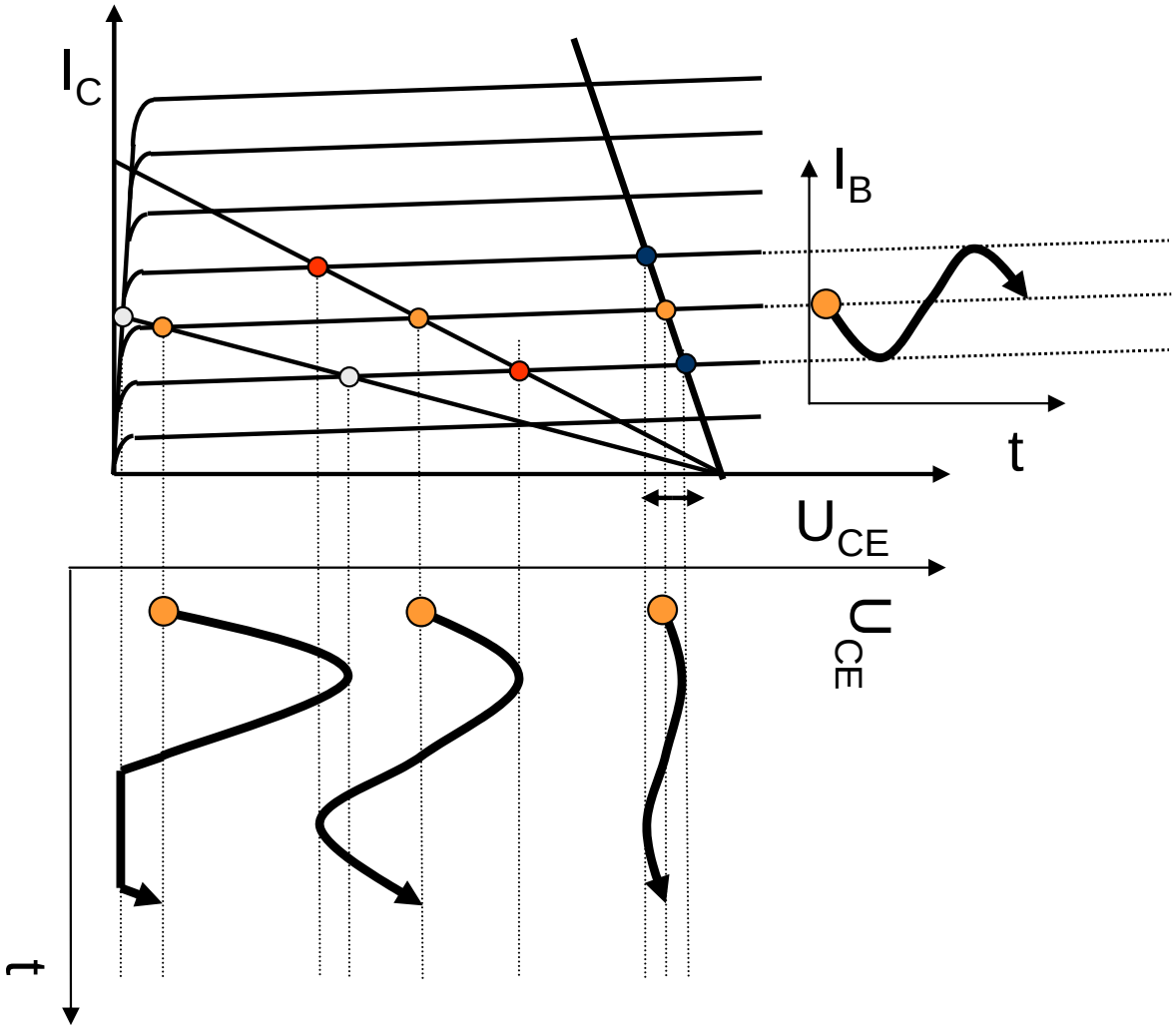
$$V_p = V_u \cdot V_i$$



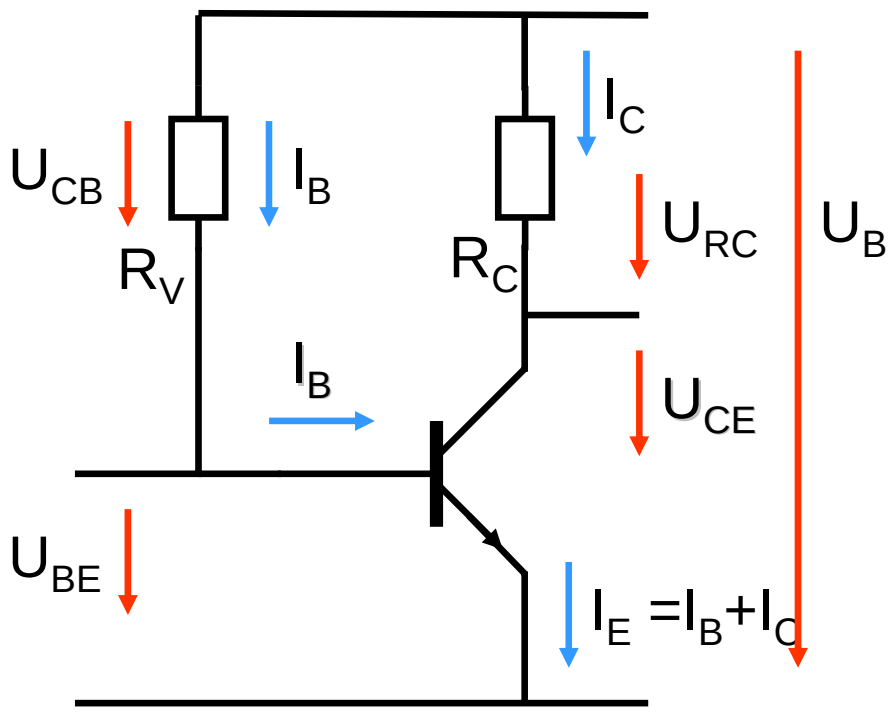
Transistor
als Verstärker



Transistor
als Verstärker mit veränderlichem R_C

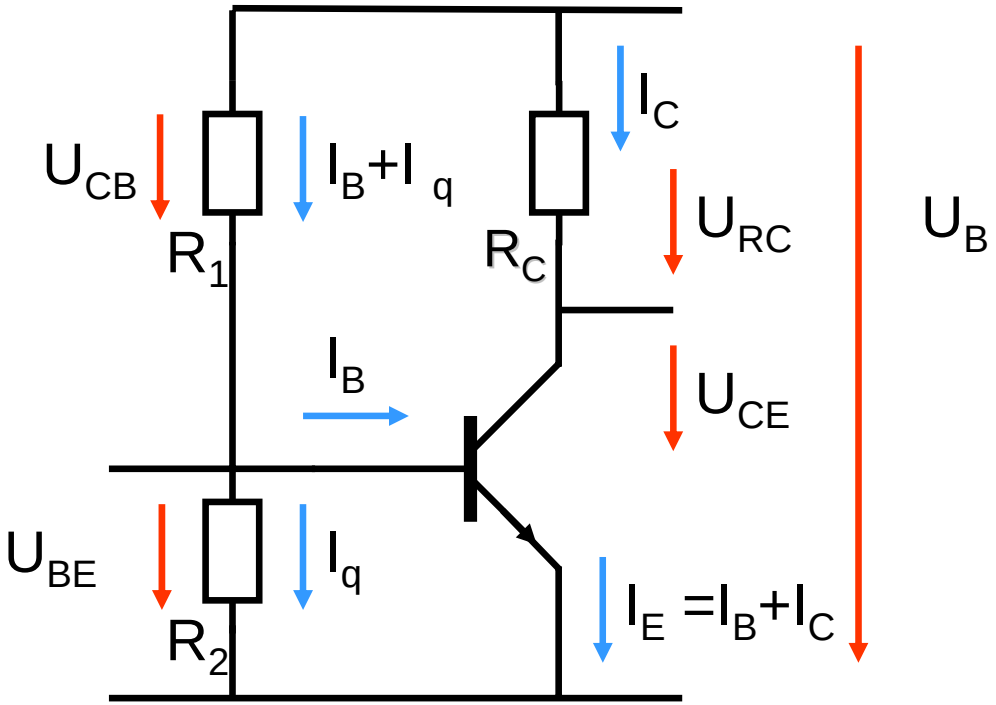


Transistor
Festlegung des Arbeitspunktes



$$R_V = \frac{U_B - U_{BE}}{I_B}$$

$$R_C = \frac{U_B - U_{CE}}{I_C}$$



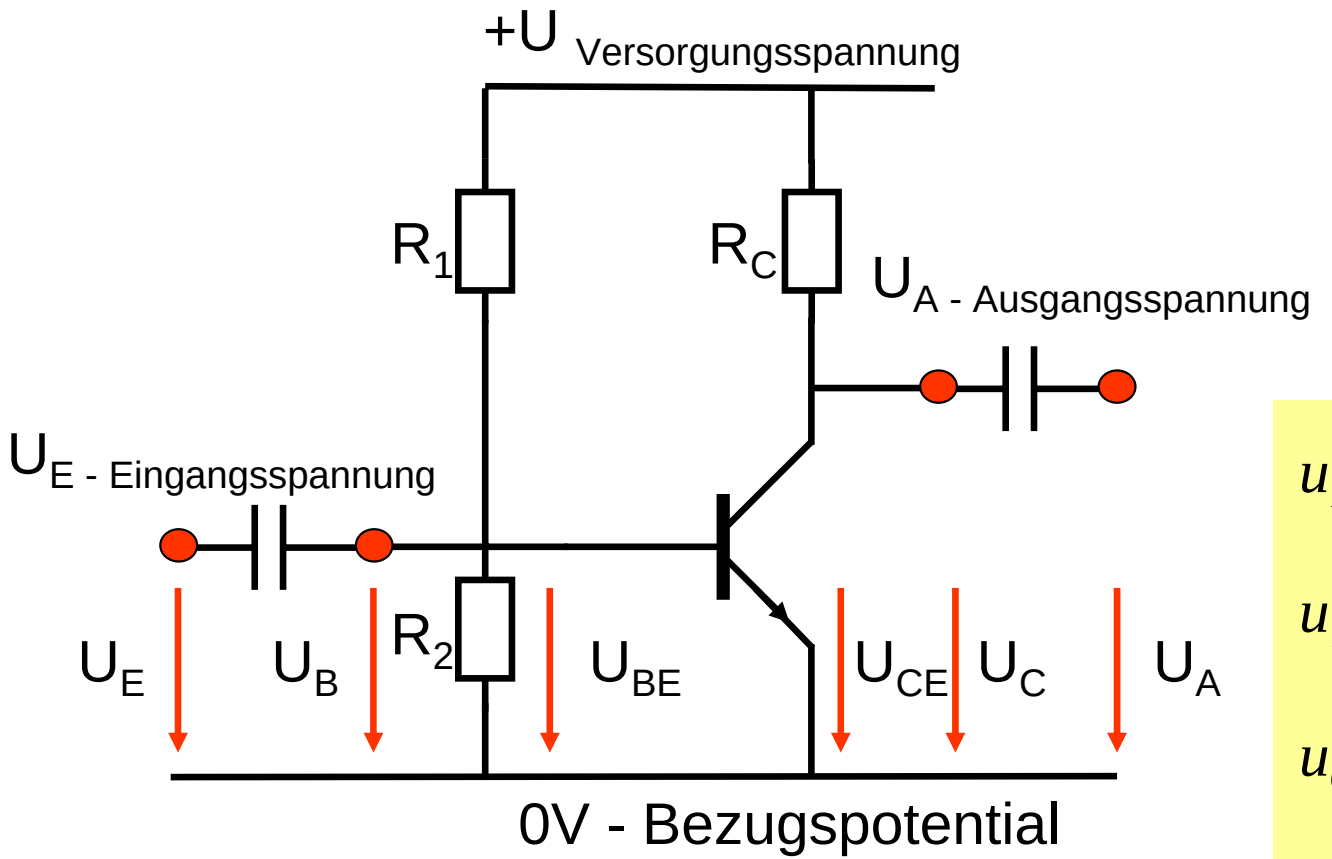
$$R_1 = \frac{U_B - U_{BE}}{I_B + I_q}$$

$$R_2 = \frac{U_{BE}}{I_q}$$

$$I_q = 2 \cdot I_B$$

$$R_C = \frac{U_B - U_{CE}}{I_C}$$

Transistor
Einstufiger Verstärker



$$u_E = U_= + \hat{u} \cdot \sin(\omega \cdot t)$$

$$u_B = U_{=BE} + \hat{u} \cdot \sin(\omega \cdot t)$$

$$u_C = U_{=CE} - V_u \cdot \hat{u} \cdot \sin(\omega \cdot t)$$

$$u_A = -V_u \cdot \hat{u} \cdot \sin(\omega \cdot t)$$

Anwendungsbereites Wissen

- Halbleiter
  - pn-Übergang
  - Diode
  - Zenerdiode
- npn-Transistor
  - Funktionsweise
    - Bipolare Nutzung des pn-Übergangs
    - Ströme
    - Spannungen
  - Kennlinienfeld
  - Anwendung als Schalter
  - Anwendung als Verstärker
  - Festlegung des Arbeitspunktes