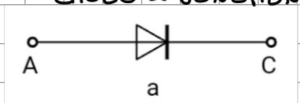
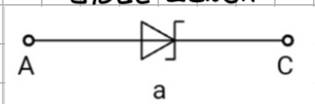
Electronique analogique

Symboles

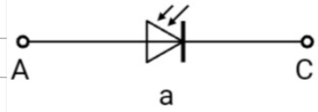
diode à jonction



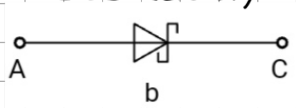
diode zener



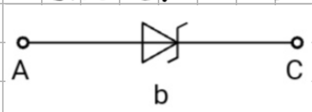
Photodiode



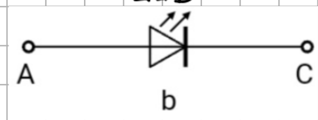
diode schottky



diode avalanche



LED



Formules de diodes

Courant passant

$$I_j(U) = I_{sj} \cdot \left(e^{\frac{U}{M_j \cdot U_T}} - 1\right)$$

M_j : coefficient d'émission

I_{sj} : courant de saturation inverse

Dépendances thermiques

$$U_T = \frac{k_B \cdot T}{q}$$

$$I_{sj}(T) = I_{sj}(T_0) \cdot \left(\frac{T}{T_0}\right)^{\frac{K}{M_j}} \cdot e^{\left(\frac{T}{T_0} - 1\right) \cdot \frac{\Delta W_{BG}}{M_j \cdot k_B \cdot T}}$$

ΔW_{BG} : largeur de la bande interdite [J]

Bruit du courant de diode

$$\Phi(f) = q \cdot I_j$$

Photo-courant

$$I_{pha} = -\alpha_{pha} \cdot E_e$$

E_e : irradiance $\left[\frac{W}{m^2}\right]$, α_{pha} : coeff. de photo-courant $\left[\frac{A \cdot m^2}{W}\right]$

Emission de lumière

$$I_e = \alpha_{phe} \cdot I_j$$

I_e : Intensité énergétique, α_{phe} : coeff. d'émission lumineuse $\left[\frac{W}{A \cdot sr}\right]$

Conductance petit signaux

$$g_j = \frac{\partial I_j}{\partial U} = \frac{I_j}{M_j \cdot U_T} = \frac{I_{sj}}{M_j \cdot U_T} \cdot \left(e^{\frac{U}{M_j \cdot U_T}} - 1\right)$$

Capacité de charge d'espace

$$C_s(U) = \frac{C_{s0}}{\left(1 - \frac{U}{\Delta \varphi_{B0}}\right)^{M_c}}$$

$$I_{cs} = C_s(U) \cdot \dot{U}$$

C_{s0} : capacité de charge d'espace en equilibre

M_c : coefficient , $0,3 < M_c < 0,5$

Capacité de diffusion

$$C_D(U) = \tau_T \cdot \frac{I_j(U)}{M_j \cdot U_T}$$

$$I_{cD}(U) = C_D(U) \cdot \dot{U}$$

Claquage avalanche

$$I_{BA} = -I_{sA}\left(e^{\frac{U_A - U}{M_A \cdot U_T}} - 1\right)$$

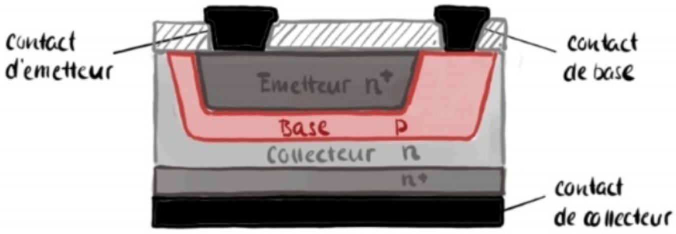
Claquage Zener

$$I_{BZ} = -I_{sZ}\left(e^{\frac{U_Z - U}{M_Z \cdot U_T}} - 1\right)$$

Transistor bipolaire

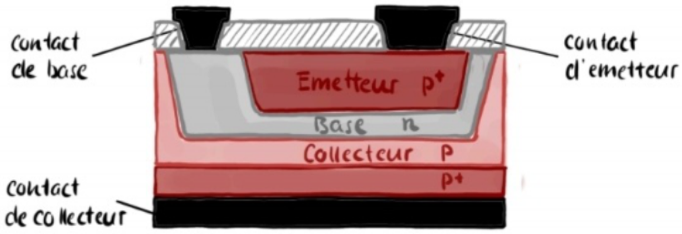
Transistors bipolaire / • Structure du transistor bipolaire

Transistor bipolaire npn

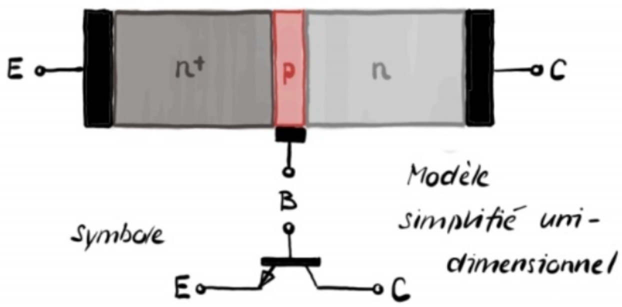


Vue de coupe d'un transistor bipolaire npn épitaxial planaire

Transistor bipolaire pnp

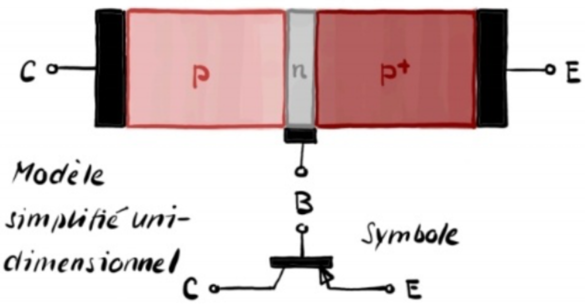


Vue de coupe d'un transistor bipolaire pnp épitaxial planaire



Modèle simplifié uni-dimensionnel

Modèle simplifié uni-dimensionnel



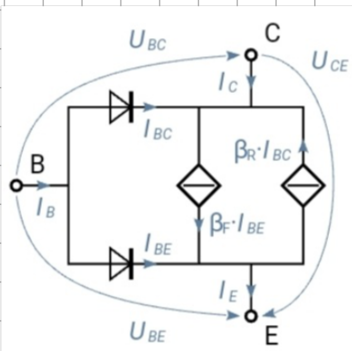
NPN

- Mode bloqué : les deux jonctions sont bloquées
- Conduction directe : la jonction base-émetteur est passante, la jonction base-collecteur est bloquée
- Conduction inverse : la jonction base-collecteur est passante, la jonction base-émetteur bloquée
- Saturation : Les deux jonctions sont passantes

PNP

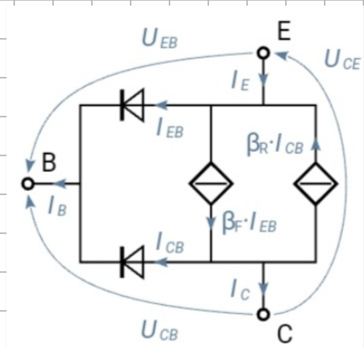
- Mode bloqué : les deux jonctions sont bloquées.
- Conduction directe : la jonction émetteur-base est passante. la jonction collecteur-base bloquée
- Conduction inverse : la jonction collecteur-base est passante, la jonction émetteur-base est bloquée.
- Saturation : les deux jonctions sont passantes.

Modèles idéales



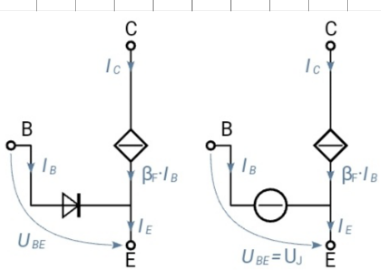
β_F : gain en courant passant

β_R : gain en courant inverse

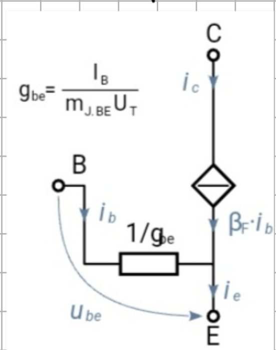


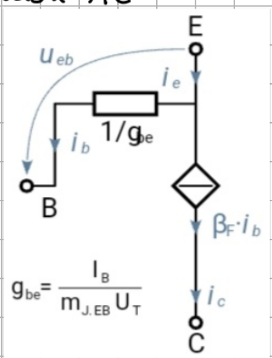
Mode actif direct

grands signaux DC

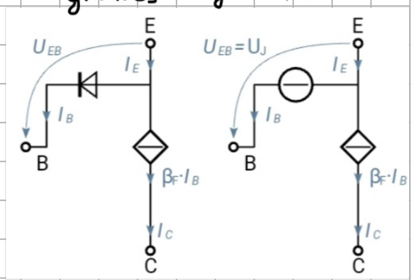


petits signaux AC





grands signaux DC



$U_{BE} > 0,\ U_{BC} < 0$

$U_{EB} > 0,\ U_{CB} < 0$

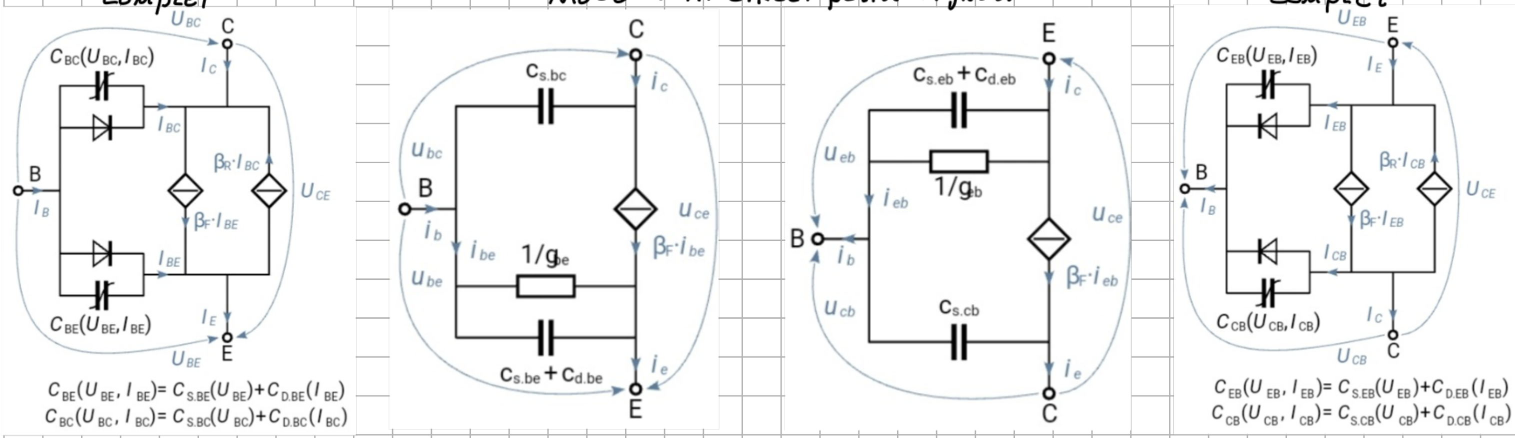
Comportements non-Idéale

Capacités

NPN — Capacités — PNP

Mode actif direct petits signaux

complet — complet

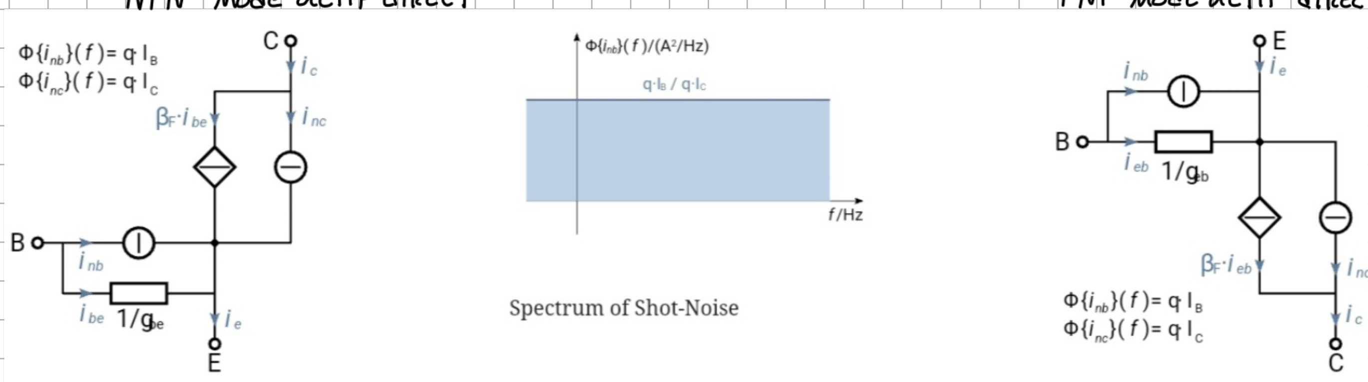


- Les capacités de diffusion sont négligeable pour les diodes en sens bloqué
- Les capacités de charge ont encore plus d'influence en sens bloqué

Bruits

- Le bruit est caractérisé par des sources de courant AC

NPN Mode actif direct — PNP mode actif direct



Dépendance thermique

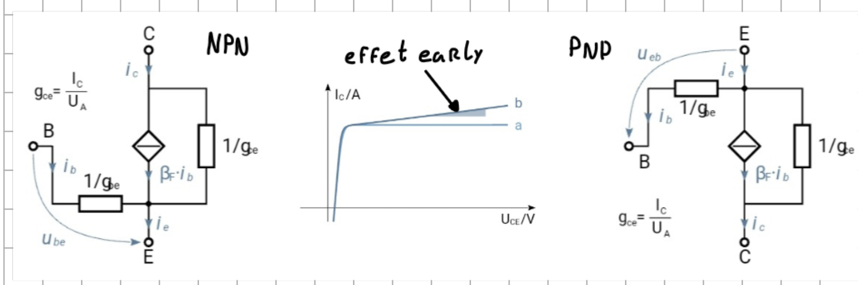
$$U_T = \frac{k_B \cdot T}{q}$$

$$I_{S_{Be}}(T) = I_{S_{Be}}(T_0) \cdot \left(\frac{T}{T_0}\right)^{\frac{K}{M_j}} \cdot e^{\left(\frac{T}{T_0} - 1\right) \cdot \frac{q \cdot \Delta U_{BG}}{M_{j_{Be}} \cdot k_B \cdot T}}$$

ΔU_{BG} : tension de bande interdite

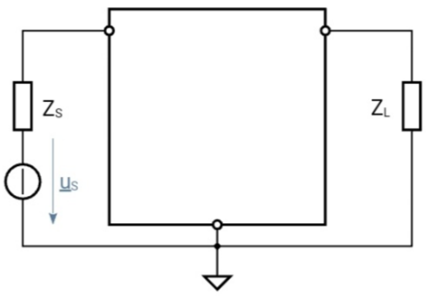
K : paramètre sans dimension, $K \approx 3$

Effet Early



- Modelisé avec une faible conductance entre emetteur et collecteur
- L'effet est du au courant inverse de la jonction bloquée

Configurations biportes



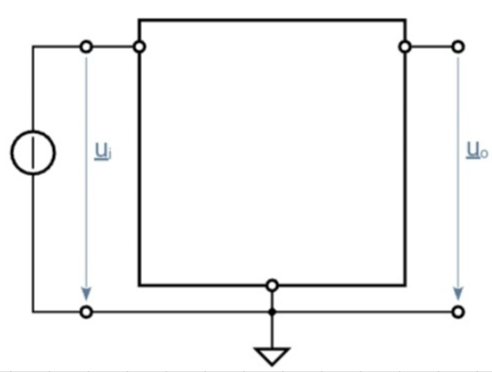
Schematic of Two-Port with Source and Load

Overview of bipolar Junction-Transistor's Two-Port-Configurations

Configuration	Input	Grounded	Output
Common-Emitter	Base	Emitter	Collector
Common-Base	Emitter	Base	Collector
Common-Collector	Base	Collector	Emitter

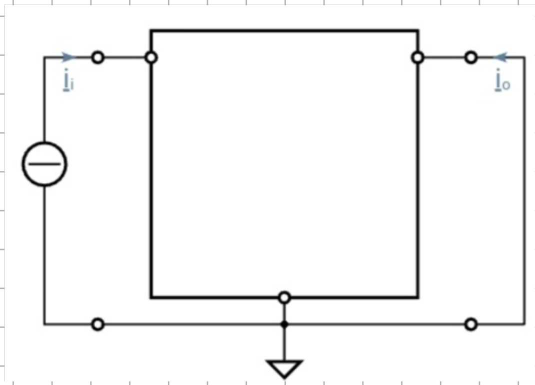
Paramètres de caractérisation

Gain en tension sans charge



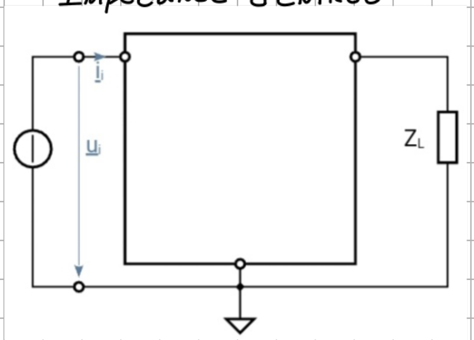
$$\underline{A}_{vu} = \frac{\underline{u}_o(f)}{\underline{u}_i(f)} \quad , \underline{I}_o = 0$$

Gain en courant sans charge



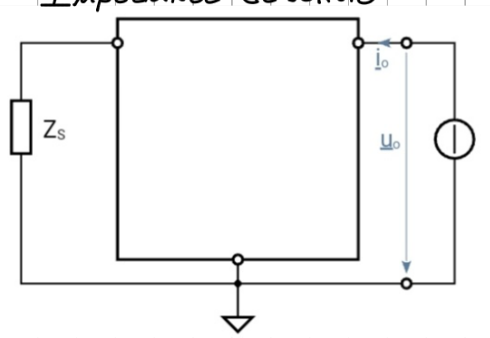
$$\underline{A}_{vu} = \frac{\underline{I}_o(f)}{\underline{I}_i(f)} \quad , \underline{u}_o = 0$$

Impédance d'entrée



$$\underline{Z}_i(f) = \frac{\underline{u}_i(f)}{\underline{I}_i(f)}$$

Impédance de sortie

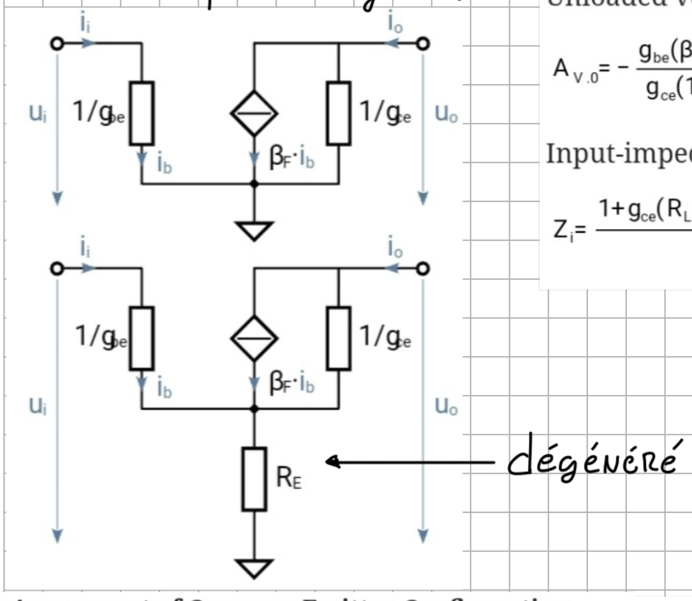


$$\underline{Z}_i(f) = \frac{\underline{u}_o(f)}{\underline{I}_o(f)} \quad , \underline{u}_s = 0$$

Il existe d'autres combinaisons de paramètre possible

Configuration emetteur commun

Schémas petits signaux



Unloaded voltage-gain:

$$A_{V.0} = -\frac{g_{be}(\beta_F - g_{ce}R_E)}{g_{ce}(1+g_{be}R_E)}$$

Unloaded current-gain:

$$A_{I.0} = \frac{\beta_F - g_{ce}R_E}{1+g_{ce}R_E}$$

Input-impedance:

$$Z_i = \frac{1+g_{ce}(R_L+R_E)+g_{be}[R_E(\beta_F+1)+g_{ce}R_L R_E]}{g_{be}[1+g_{ce}(R_L+R_E)]}$$

Output-impedance:

$$Z_o = \frac{1+g_{be}[(\beta_F+1)R_E+(1+g_{ce}R_E)R_S]+g_{ce}R_E}{g_{ce}[1+g_{be}(R_S+R_E)]}$$

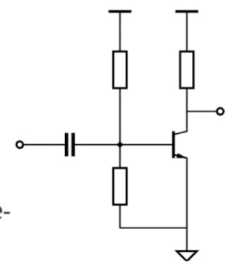
Overview of Parameters of non-degenerate Common-Emitter-Configuration

Param	Approx	Cond	+/-
$A_{V.0}$	$-\beta_F g_{be}/g_{ce}$	-	++
$A_{I.0}$	β_F	-	++
Z_i	$1/g_{be}$	-	+
Z_o	$1/g_{ce}$	-	++

Assessment of Common-Emitter-Configuration

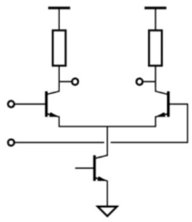
Characteristics:

- The configuration has very high inverting voltage-gain and very high current-gain and consequently decent power-gain.
- The input-impedance is high and the configuration thus presents a low load to a preceding stage.
- The output-impedance is very high and thus voltage-gain collapses with low load-impedance.
- Degeneration reduces voltage- and current-gain, increases input-impedance and reduces output-impedance.
- Degeneration increases noise but reduces non-linearity.
- The common-emitter-configuration is best used as gain-stage, either with low noise (non-degenerate) or low non-linearity (degenerate).



Application-Example: Common-Emitter-Amplifier

The example of non-degenerate, capacitively coupled and single-ended common-emitter-amplifier might be used as first stage of an audio-amplifier featuring low noise and high gain.



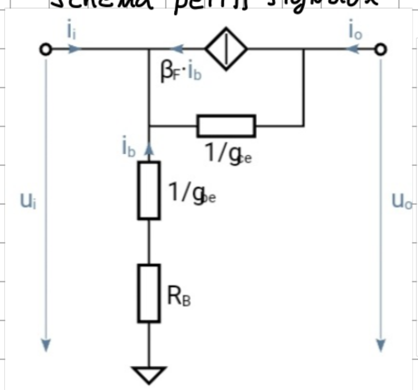
Differential pair

Application-Example: Differential Pair

The differential pair shown behaves like a common-emitter-configuration with differential input and output. Differential pairs are almost always used as first stage of an operational amplifiers.

Configuration base commune

Schéma petits signaux



Overview of Parameters of non-degenerate Common-Base-Configuration

Parameter	Approximation	Condition	Rating
$A_{V.0}$	$+\beta_F \cdot g_{be}/g_{ce}$	$g_{ce} \ll \beta_F g_{be}$	++
$A_{I.0}$	-1	$\beta_F \gg 1$, $g_{ce} \ll \beta_F g_{be}$	-
Z_i	$1/(\beta_F g_{be})$	$\beta_F \gg 1$, $g_{ce}R_L \ll 1$	- -
Z_o	$\beta_F g_{be} R_S/[g_{ce}(1 + g_{be}R_S)]$	$\beta_F \gg 1$, $g_{be} > g_{ce}$	++

Unloaded voltage-gain:

$$A_{V.0} = \frac{g_{be}(\beta_F+g_{ce}R_B)+g_{ce}}{g_{ce}(g_{be}R_B+1)}$$

Input-impedance:

$$R_i = \frac{(g_{be}R_B+1)(g_{ce}R_L+1)}{g_{be}[\beta_F+1+g_{ce}(R_B+R_L)]}$$

Unloaded current-gain:

$$A_{I.0} = -\frac{g_{be}(\beta_F g_{ce}R_B)+g_{ce}}{g_{be}(\beta_F+1+g_{ce}R_B)+g_{ce}}$$

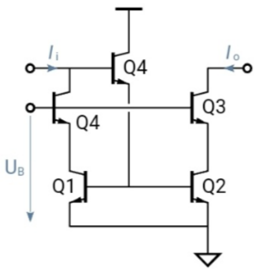
Output-impedance:

$$R_o = \frac{\beta_F g_{be}R_S+g_{be}(R_S+R_B)+g_{ce}R_S(1+g_{be}R_B)}{g_{ce}[1+g_{be}(R_S+R_B)]}$$

Assessment of Common-Base-Configuration

Characteristics:

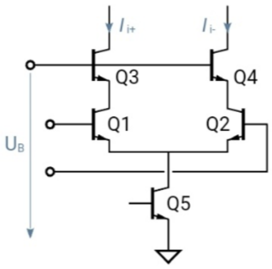
- The configuration has very high non-inverting voltage-gain and unity current-gain, power-gain is moderate at most.
- The input-impedance is very low and well suited to load preceding stages with current-output and of which no voltage-gain is required.
- The output-impedance is very high and thus voltage-gain collapses with low load-impedance.
- Degeneration is rarely used, it reduces voltage-gain, does not significantly affect current-gain, input- and output-impedance.
- Degeneration does not significantly affect noise and non-linearity.
- The common-base-configuration is best used to increase the output-impedance of a preceding stage with current-output, usually with transconductance-amplifiers or current-mirrors.



Current-Mirror with Cascode-Device

Application-Example: Cascoded Current-Mirror

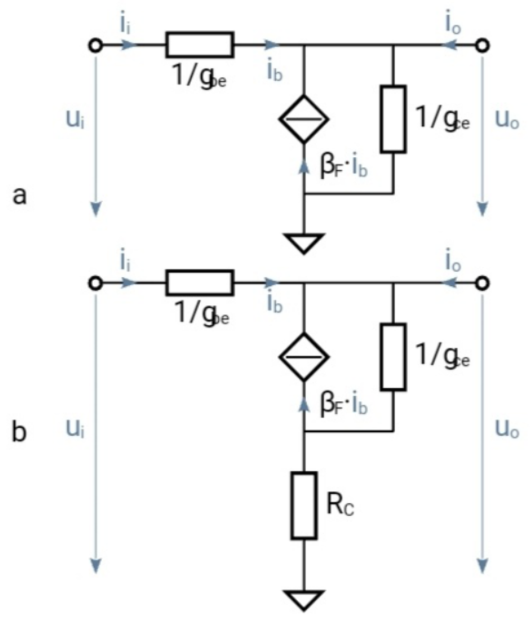
Transistors Q1 and Q2 are matched (made as similar as possible) and implement, together with Q5, a current-mirror. It provides to its output a current I_o which is a copy of the current I_i flowing into its input. Without transistor Q3, the current-mirror's output-impedance would be $1/g_{ce}$ which is already quite high but ideally should be even higher. Thanks to Q3, which is in common-base-configuration, the circuit's output-impedance is considerably increased. The common-base-configuration is also called **cascode**, if its input is connected to the emitter of a preceding stage.



Application-Example: Cascoded differential Pair

The two transistors Q1 and Q2 constitute, together with transistor Q5 which acts as current-source, the differential pair. Without transistors Q3, Q4 the differential pair's output-impedance would be $1/g_{ce}$. Thanks to Q3 and Q4, the circuit's output-impedance is significantly increased which may result in a significant improvement of the low-frequency-gain. However, the gain-bandwidth-product is not increased by adding a cascode-stage.

Configuration collecteur commun



Unloaded voltage-gain:

$$A_{V.0} = \frac{g_{be}[\beta_F+1+g_{ce}R_C]}{g_{be}[\beta_F+1+g_{ce}R_C]+g_{ce}}$$

Unloaded current-gain:

$$A_{I.0} = -\frac{\beta_F+1+g_{ce}R_C}{1+g_{ce}R_C}$$

Input-impedance:

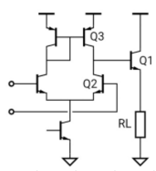
$$R_i = \frac{g_{be}R_L(\beta_F+1+g_{ce}R_C)+g_{ce}(R_L+R_C)+1}{g_{be}[1+g_{ce}(R_L+R_C)]}$$

Output-impedance:

$$R_o = \frac{g_{be}R_S(1+g_{ce}R_C)+g_{ce}R_C+1}{g_{be}[\beta_F+1+g_{ce}(R_S+R_C)]+g_{ce}}$$

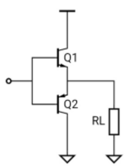
Overview of Parameters of non-degenerate Common-Base-Configuration

Parameter	Approximation	Condition	Rating
$A_{V.0}$	1	$g\_ce \ll \beta_F g_{be}$	-
$A_{I.0}$	$-\beta_F$	$\beta_F \gg 1$	++
Z_i	$(g_{be}R_L\beta_F+1)/[g_{be}(1+g_{ce}R_L)$	$\beta_F \gg 1$, $\beta_F g_{be} \gg g_{ce}$	++
Z_o	$(g_{be}R_S+1)/(\beta_F g_{be})$	$\beta_F g_{be} \gg g_{ce}$, $g_{ce}R_S \ll \beta_F$	- -



Application-Example: Voltage-Regulator

The transistor Q1 is in common-collector-configuration and drives the load RL. The base of Q1 is driven by an operational transconductance-stage composed of transistors Q2, Q3. The operational transconductance-stage alone would not be able to drive a low load-impedance. The circuit shown might be used as voltage-regulator.



Application-Example: Push-Pull-Stage

A single transistor in common-collector-configuration does not provide a large dynamic-range at its output. To obtain an output with dynamic voltage-range nearly between lower and upper supply, a npn-BJT (Q1) in common-collector-configuration is combined with a pnp-BJT (Q2) in common-collector-configuration. This so-called push-pull-stage provides the ability to drive low load-impedances with extended dynamic voltage-range.

Assessment of Common-Collector-Configuration

Characteristics:

- The configuration has non-inverting nearly unity-voltage-gain and high inverting current-gain, power-gain is moderate at most.
- The input-impedance is essentially the load-impedance multiplied by β_F and thus rather high. The configuration does thus not heavily load preceding stages.
- The output-impedance is essentially the source-impedance divided by β_F and thus rather low. The is thus well suited to drive rather low load-impedances.
- Degeneration is rarely used, it does not significantly affect voltage-gain, current-gain, input- and output-impedance.
- Degeneration does not significantly affect noise and non-linearity.
- The common-base-configuration is best used as a unity-voltage-gain-stage driving low load-impedances such as e.g loudspeakers.

Analyse par approximation petits signaux

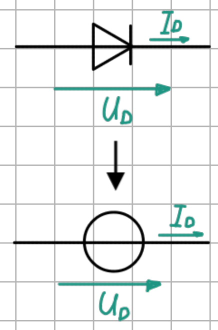
1. **Circuit grand signaux DC**
   - Remplacer les condensateurs par des interruptions
   - Remplacer les bobines par des court-circuits
   - Enlever les composantes alternative des sources
   - Remplacer les diodes par des sources sources de tension

2. **Analyser le circuit et trouver les points d'opérations**

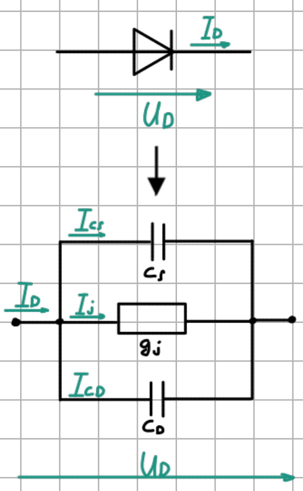
3. **Circuit petits signaux AC**
   - Linéariser les composants non-linéaires autour de leur points d'opération
   - Annuler les composantes DC des sources

4. **Trouver la fonction de transfert**

diode grands signaux



diode petits signaux



Les capacités sont constantes en petits signaux (et parfois négligeable)

Approximation des transistors

- Remplacer les jonctions en sens bloqué par des interruptions
- Annuler les sources de courants pilotées en sens bloqué
- Vérifier le mode de conduction avec les tensions entre les bornes