COMPOSANTS SEMI-CONDUCTEURS

VII) Solutions S7

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EPFL

Exercice E7.1: question de réflexion

Répondez à la question de réflexion ci-dessous :

Attention on utilise un pnp !

7.1	Esquissez le schéma de bandes d'un transistor bipolaire **pnp**. À partir de ce schéma, expliquez les concepts de gain en configurations « base commune » et « émetteur commun ». Comment optimiser le gain ? Quel est l'effet limitant et pourquoi ?

Exercice E7.2: question de réflexion

Répondez à la question de réflexion ci-dessous :

Attention on utilise un npn !

7.2	Définissez la transconductance d'un transistor bipolaire en mode émetteur commun. Utilisez un transistor **npn** comme amplificateur de tension. Comment fixer le point de travail ? Comment introduire le signal AC ? Quel est le gain ? (Esquissez si possible une explication graphique).

Conductances et transconductances

Conductance

$$g \equiv \frac{\partial \text{ courant}}{\partial \text{ tension}} = \frac{\partial I}{\partial V}$$

Conductance d'entrée:

$$g_{in} \equiv \frac{\partial \text{ courant d'entrée}}{\partial \text{ tension d'entrée}} = \frac{\partial I_{in}}{\partial V_{in}}$$

Conductance de sortie:

$$g_{out} \equiv \frac{\partial \text{ courant de sortie}}{\partial \text{ tension de sortie}} = \frac{\partial I_{out}}{\partial V_{out}}$$

Trans-conductance:

$$g_m \equiv \frac{\partial \text{ courant de sortie}}{\partial \text{ tension d'entrée}} = \frac{\partial I_{out}}{\partial V_{in}} = \frac{\partial I_{out}}{\partial I_{in}} \cdot \frac{\partial I_{in}}{\partial V_{in}} = \beta \cdot g_{in}$$

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Question 7.5bis: trans-conductance

Caractéristique de sortie

$$\boxed{I_C(V_{CE}, I_B) \cong \beta_F \cdot I_B}$$

En mode actif:

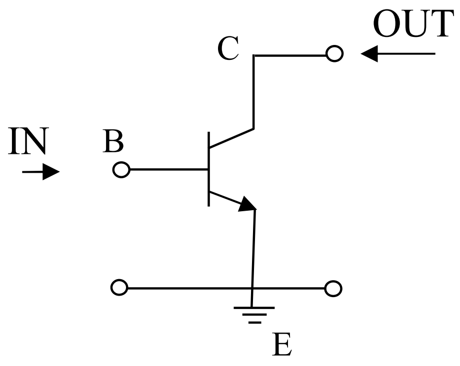
$$\boxed{I_C(V_{BE}) \cong \beta_F \cdot I_B = \beta_F \cdot I_s \cdot (e^{qV_{BE}/kT} - 1)}$$

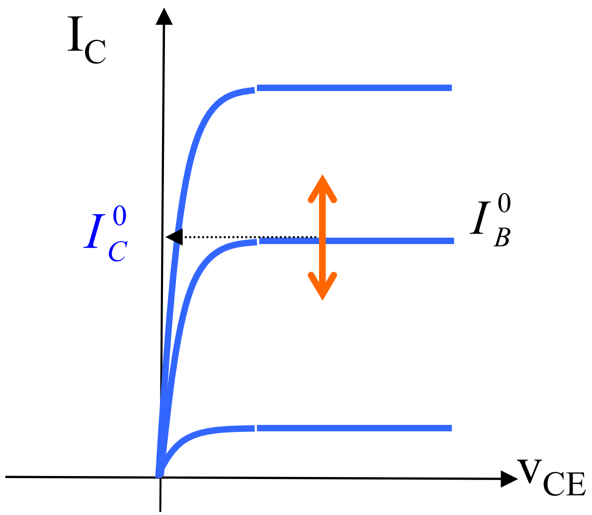
Conductance d'entrée $g_{BE} = \delta I_B / \delta V_{BE}$

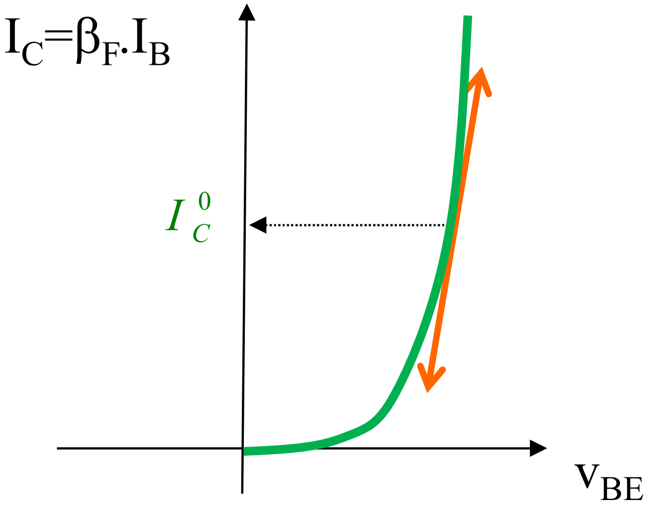
$$\boxed{g_{BE} \cong \frac{I_B^0}{U_{th}}} \qquad U_{th} \equiv \frac{kT}{q}$$

Trans-conductance $g_m = \delta I_C / \delta V_{BE}$

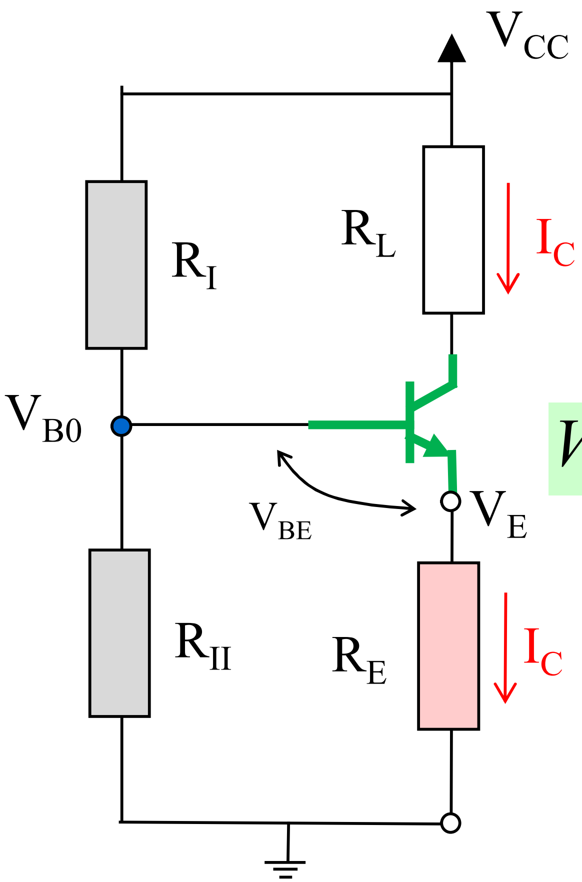
$$\boxed{g_m = \beta_F \cdot g_{BE} \cong \frac{I_C^0}{U_{th}}}$$







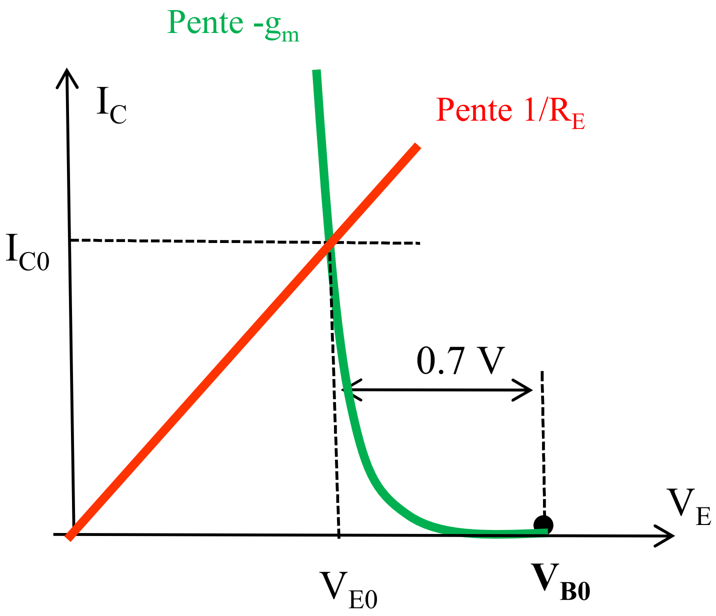
Transistor npn comme ampli de tension: point de travail



$$V_E \cong V_{B0} - 0.7$$

$$I_C \cong \frac{V_E}{R_E}$$

Courbe: $I_C(V_{BE}) = \beta_F \cdot I_B(V_{BE})$



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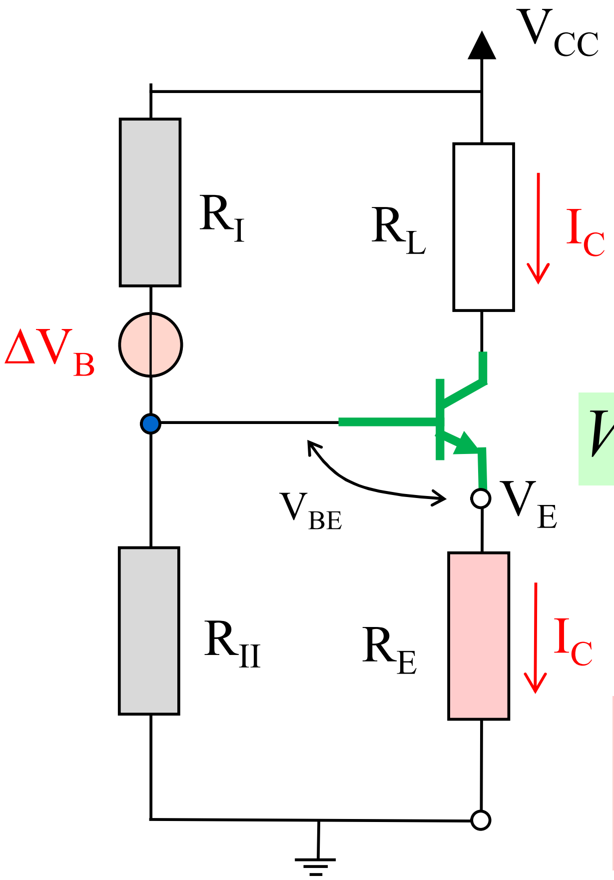
Transistor npn comme ampli de tension: point de travail



$$V_E \cong V_{B0} - 0.7$$

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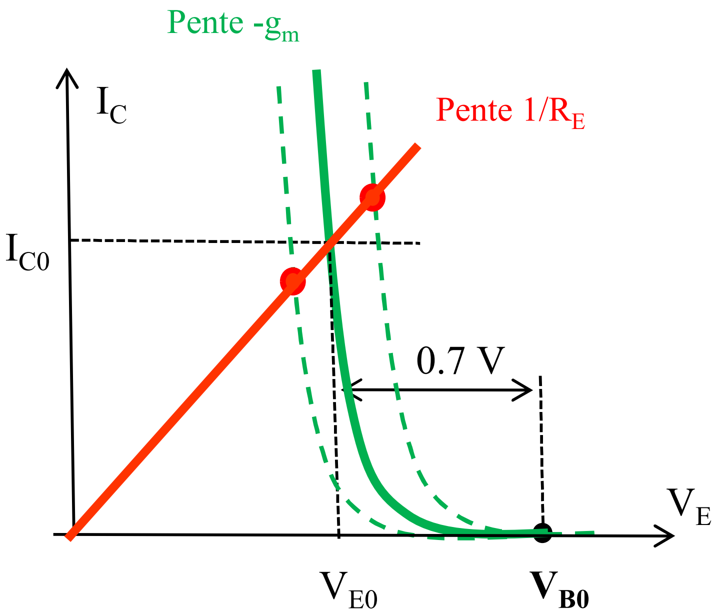
Courbe: $I_C(V_{BE}) = \beta_F \cdot I_B(V_{BE})$



R_E assure la stabilité du courant de bias I_{C0}.

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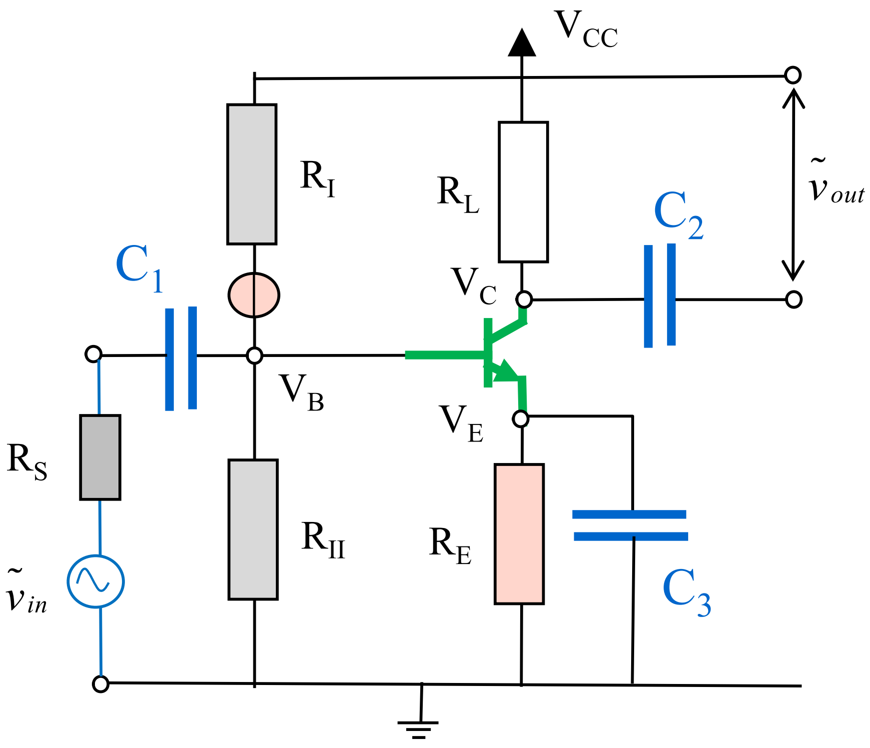
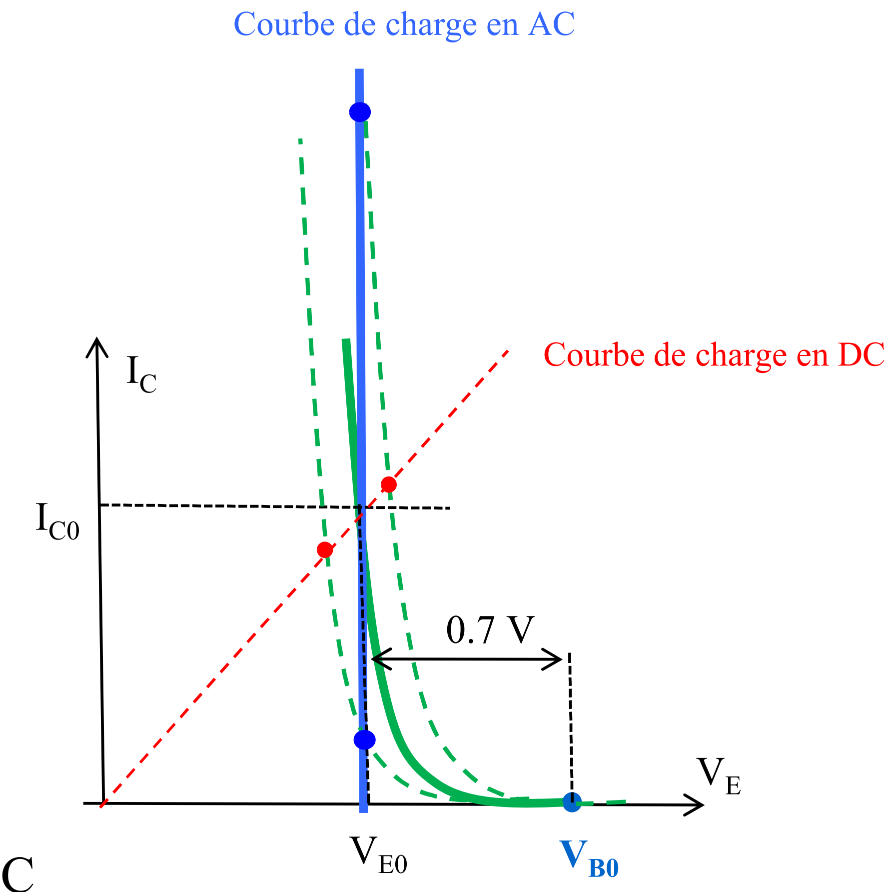
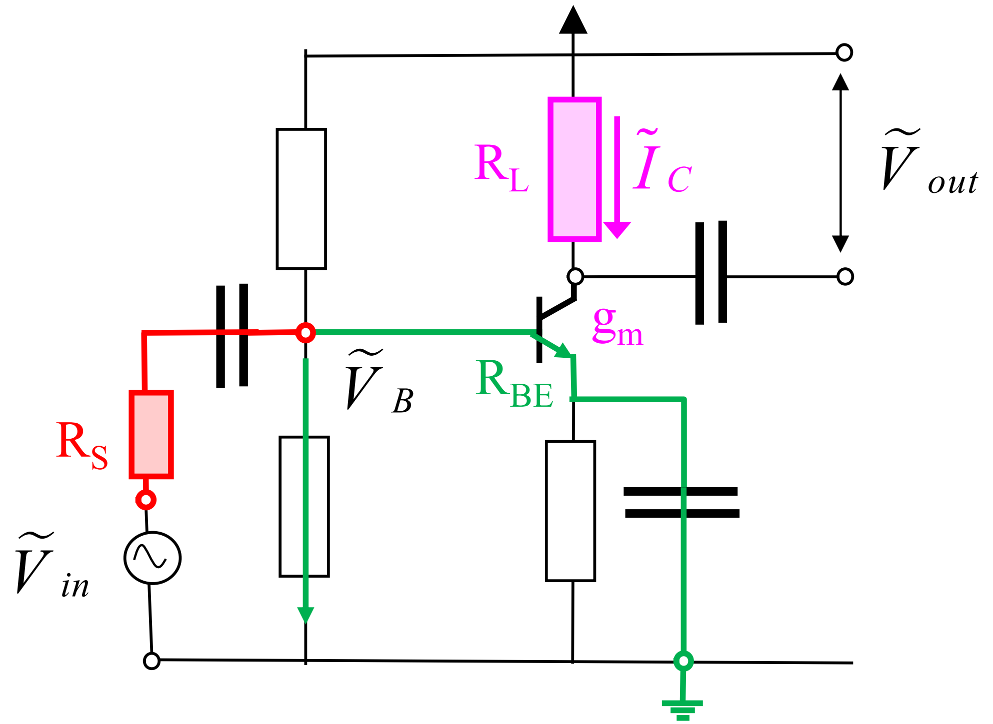
Transistor npn comme ampli de tension: signal AC

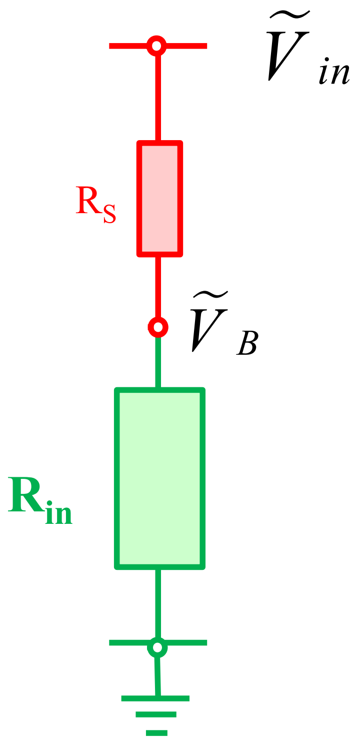




- Les capacités C_1 et C_2 assurent le couplage du signal AC à l’entrée et à la sortie
- La capacité C_3 maintient la tension de bias V_{E0} fixe et assure un transfert complet du signal v_{in} sur le courant I_C.
- R_S doit être beaucoup plus petit que $R_{BE}=1/g_{BE}$

Transistor npn comme ampli de tension: signal AC





$$\tilde V_B = \frac{R_{in}}{R_{in} + R_S}\tilde V_{in}$$

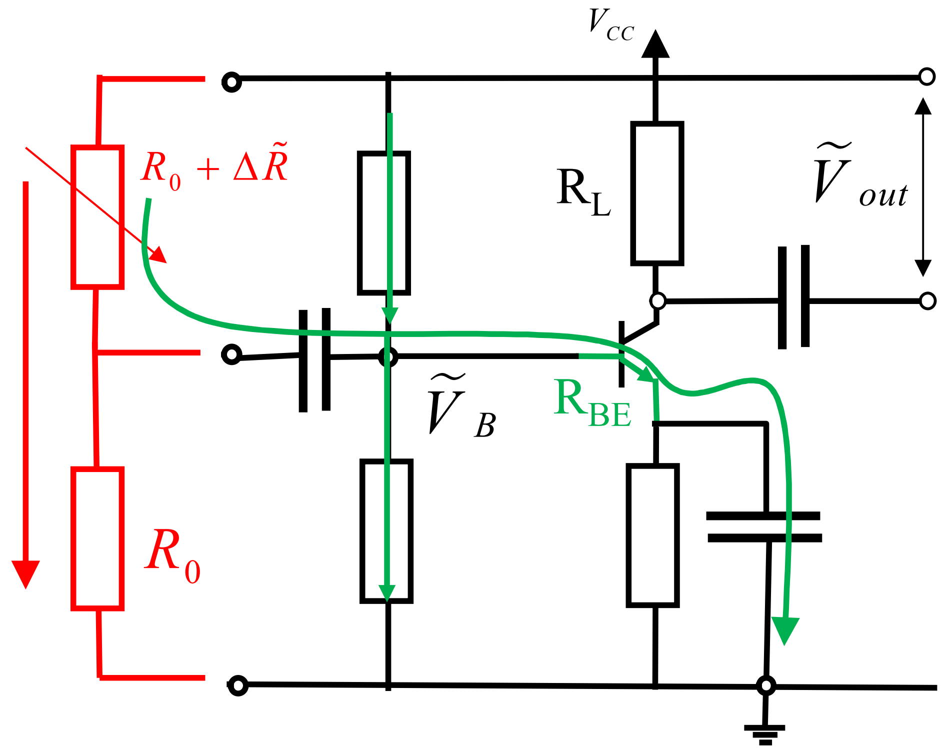
1) Eviter l'effet «diviseur de tension» $R_S \ll R_{in} \quad \Rightarrow \quad \tilde V_B \cong \tilde V_{in}$

2) Gain en tension:

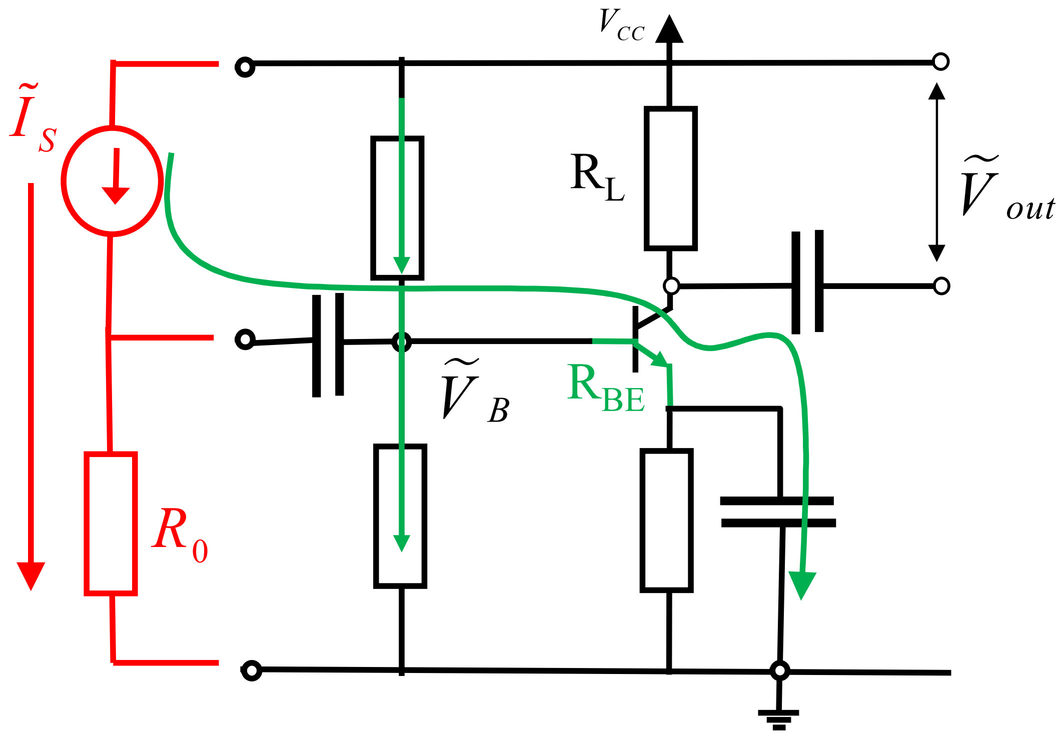
$$\frac{\tilde V_{out}}{\tilde V_{in}} \cong \frac{\tilde V_{out}}{\tilde I_C}\cdot\frac{\tilde I_C}{\tilde V_B}\cdot\frac{\tilde V_B}{\tilde V_{in}} = R_L\cdot g_m\cdot\left(\frac{\tilde V_B}{\tilde V_{in}}\right)$$

Exemples

- Piezo-résistance
- Senseur de température PT 100



- Photodiode
- Détecteur pyroélectrique



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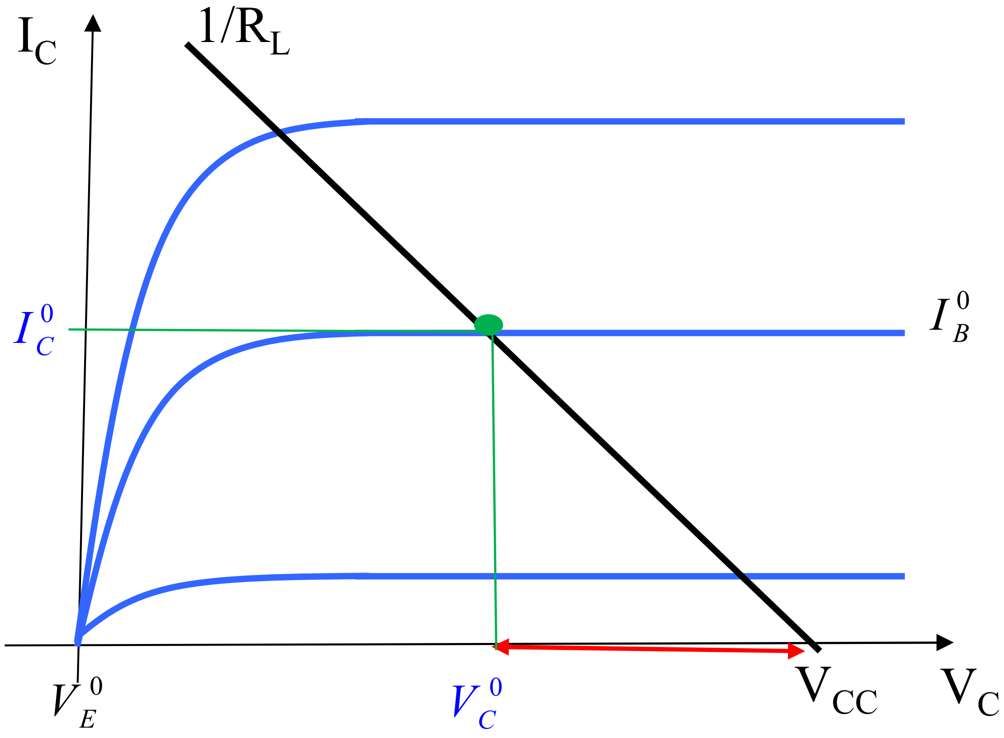
Caractéristique de sortie: $I_C(V_{CE}, I_B)$



$$\frac{\tilde{V}_{out}}{\tilde{V}_{in}} = g_m \cdot R_L = \left(\frac{g_m}{I_{c0}}\right) \cdot \left(R_L \ I_{c0}\right)$$

$$\frac{\tilde{V}_{out}}{\tilde{V}_{in}} = \frac{\left(V_{CC} - V_C^0\right)}{U_{th}} \cong 100 \qquad \left(V_{CC} = 5V\right)$$

Valeurs typiques pour le BJT en silicium

Gain en courant: $\beta_F \cong 300$

Transconductance:

$$\frac{g_m}{I_c^0} = \frac{q}{kT} \cong \frac{1}{25\ mV} \cong 40\ \left[1/V\right]$$

Gain en tension:

$$\frac{\tilde{V}_{out}}{\tilde{V}_{in}} = g_m \cdot R_L = \left(\frac{g_m}{I_{c0}}\right)\cdot\left(R_L\ I_{c0}\right)$$

$$\frac{\tilde{V}_{out}}{\tilde{V}_{in}} = \frac{g_m}{I_{C0}}\cdot\left(V_{CC} - V_C^0\right) \cong 100 \qquad \left(V_{CC} = 5V\right)$$

Résistance base-émetteur:

$$R_{BE} \equiv \frac{1}{g_{BE}} = \frac{\beta_F}{g_m} = \frac{\beta_F}{I_{C0}}\cdot\frac{I_{C0}}{g_m} = \frac{1}{I_{C0}}\cdot\beta_F\cdot\frac{kT}{q}$$

$$\cong 7.5\ k\Omega \qquad \left(I_C^0 = 1mA\right)$$

$$R_S \ll R_{BE}$$

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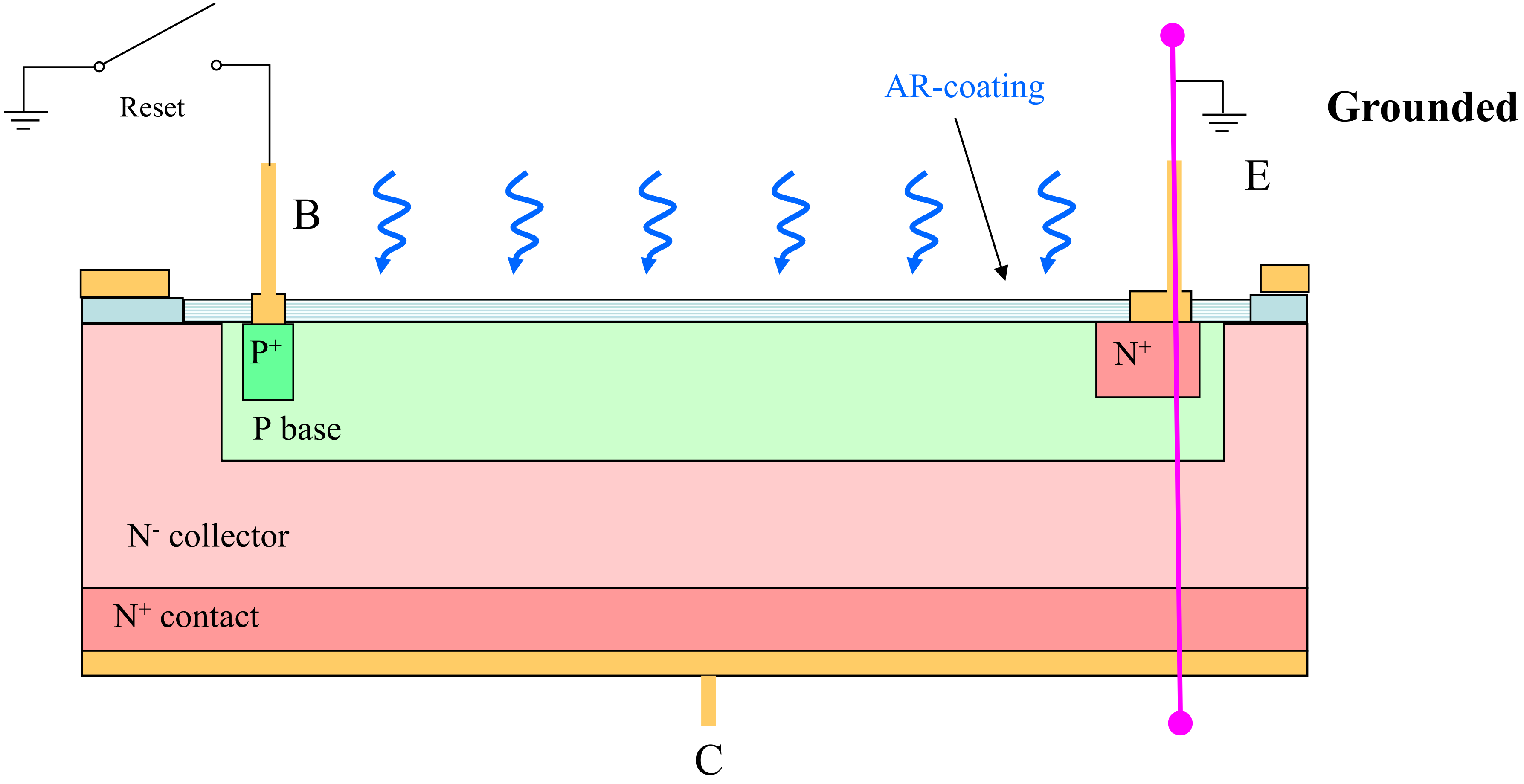
Ex 7.4 bipolar photo-transistor

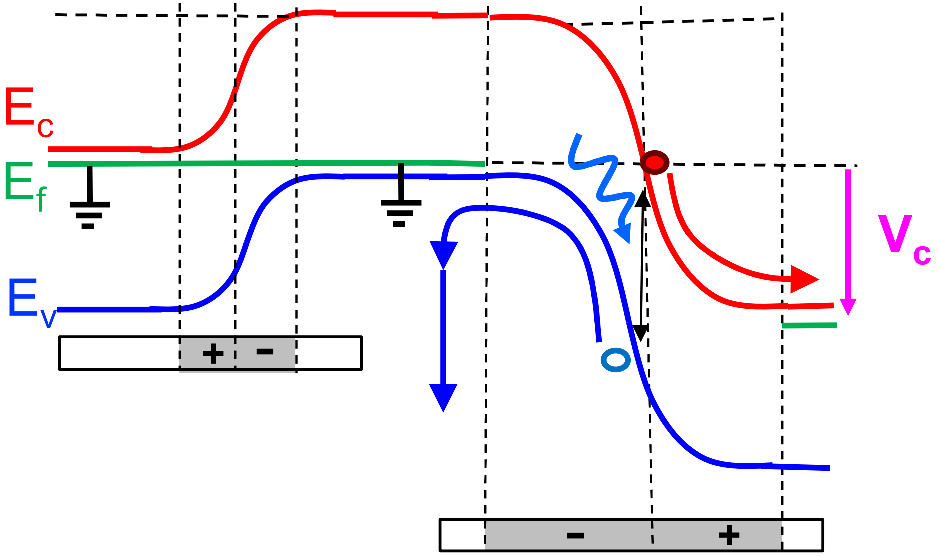


Vc=+5V

Dessinez le schéma de bande
le long de la ligne mauve
(avec la base «Reset» et
avec la base «floating»)

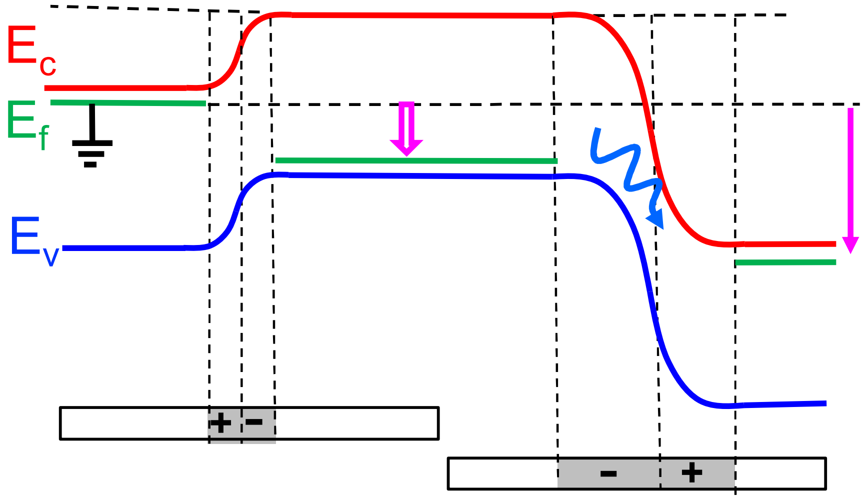
Photo-transistor BJT

BJT phototransistor at reset



Similar to a pn-photodiode
(based on the BC junction)

BJT phototransistor base «floating»
under illumination

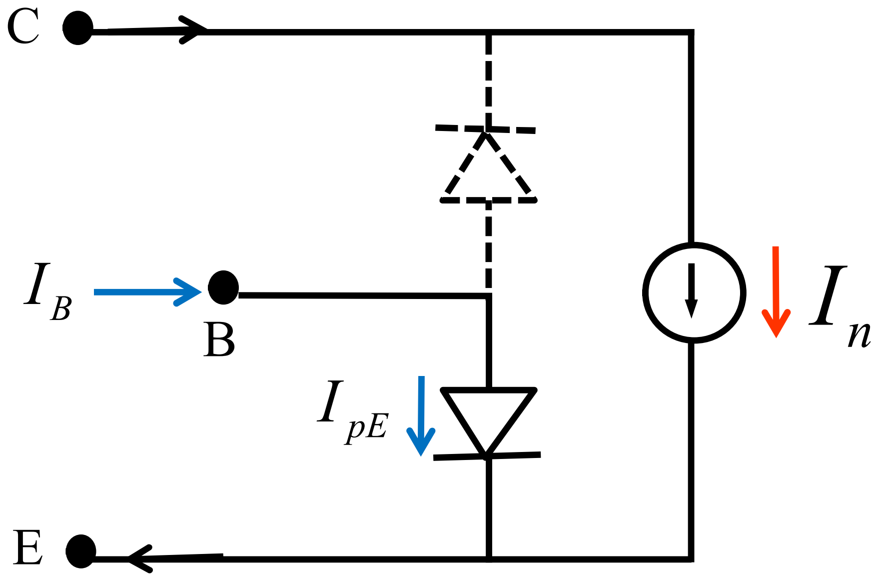


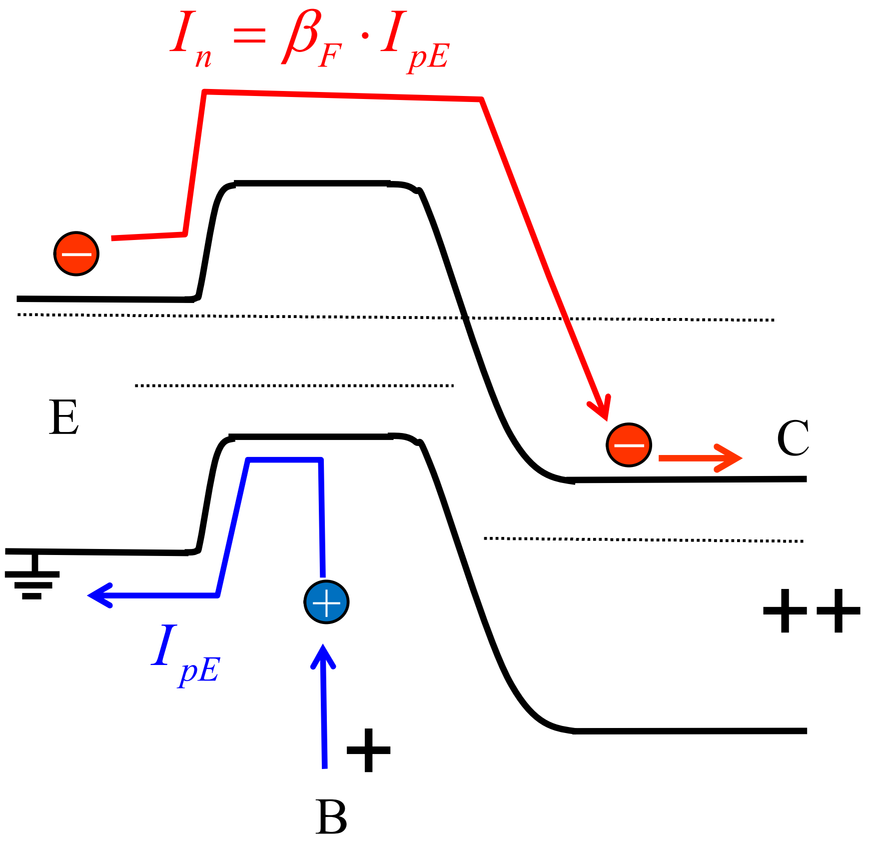
Faites le schéma Ebers-Moll et déterminez le courant I_C

Schéma Ebers-Moll:
npn en mode actif

Schéma électronique

$$I_n = \beta_F I_{pE}$$

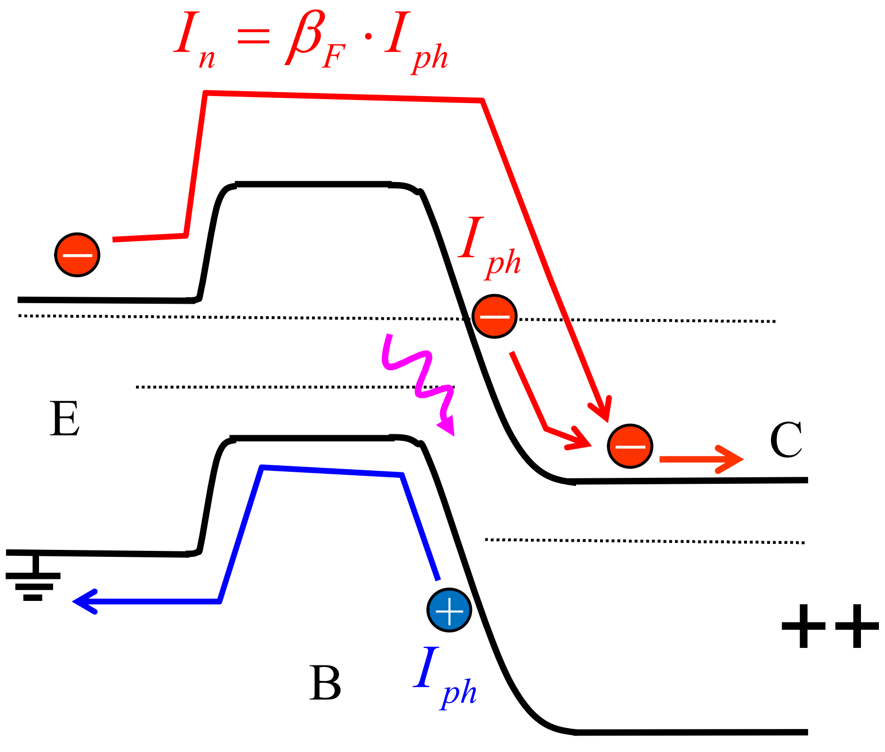




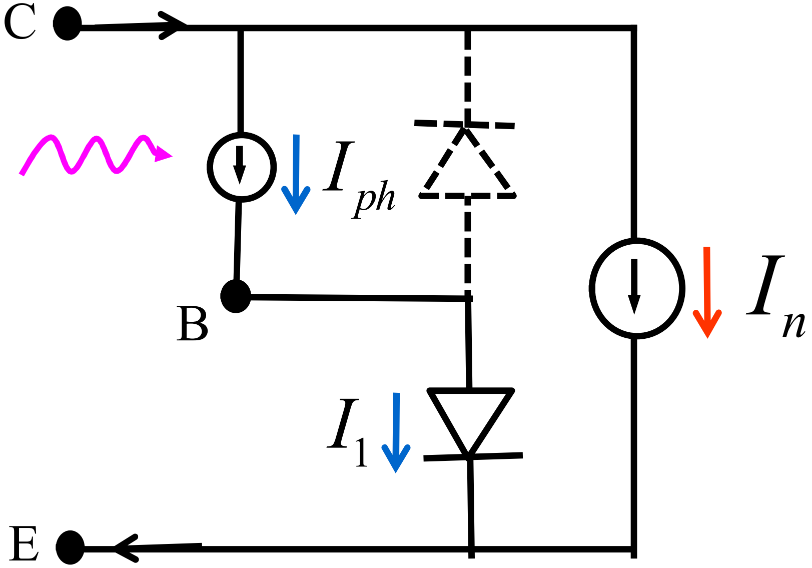
Comment le modifié pour tenir compte de l'illumination ?

BJT Phototransistors:
the Ebers-Moll Model

This model has a floating base B.
Sensitive base-collector junction



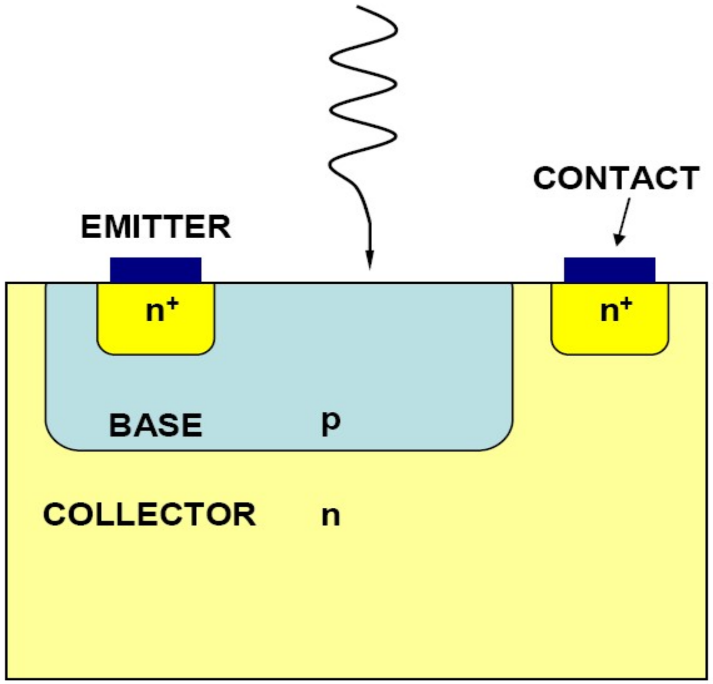
Electronic Diagram



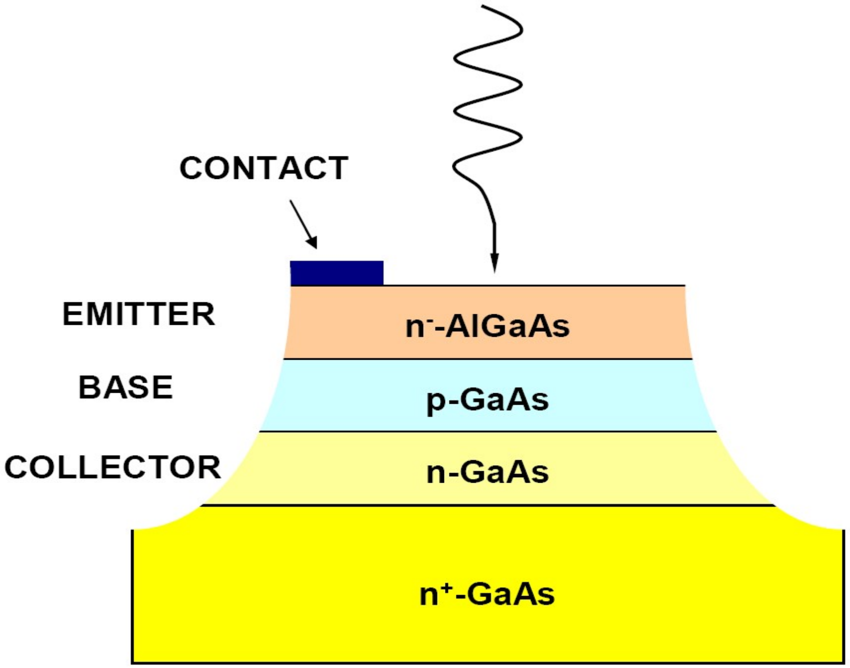
$$\boxed{I_C = I_{ph} + I_n = \underbrace{(\beta_F + 1)}_{\text{Gain}} \cdot I_{ph}}$$

Exemples de photo-transitors BJT

Homostructure



Heterostructure



A.K. Okyay, PhD thesis 2007, Stanford University.

I/V Characteristics

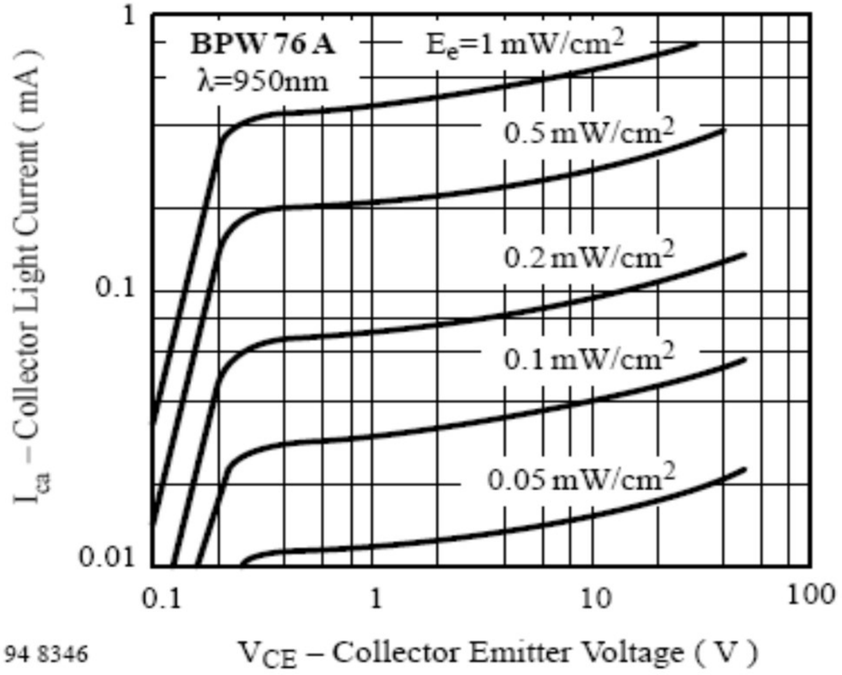


Figure 5. Collector Light Current vs. Collector Emitter Voltage

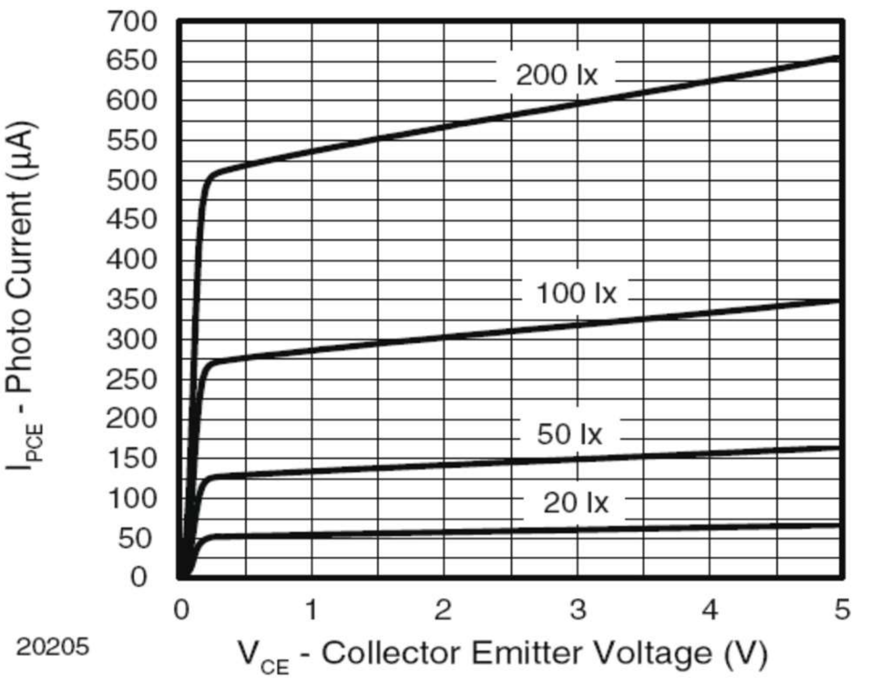
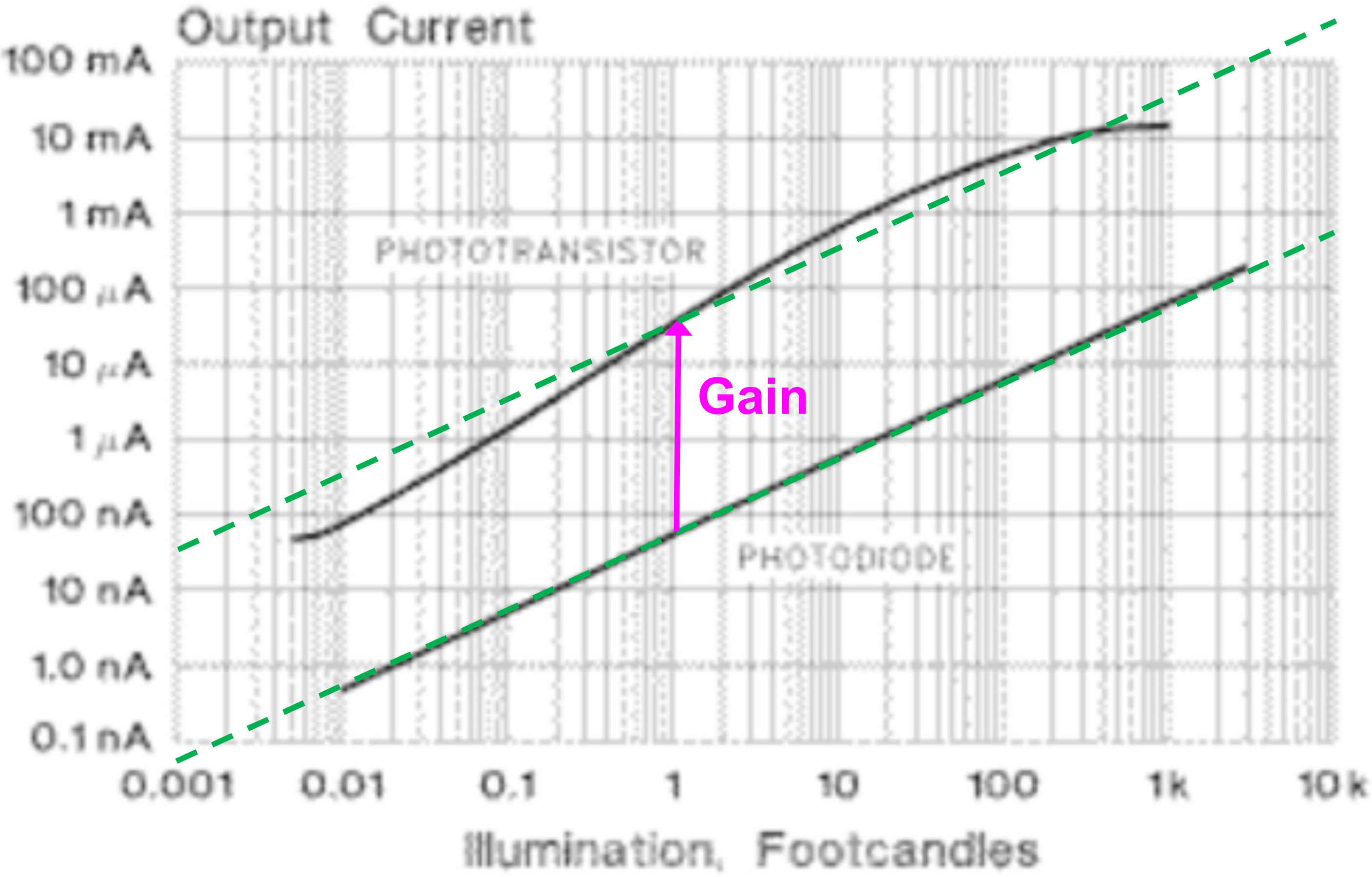


Fig. 4 - Photo Current vs. Collector Emitter Voltage

Datasheets, Vishay BPW76
Silicon NPN phototransistor

Datasheets, Vishay TEPT5600
Silicon NPN phototransistor
Adapted to human eye responsivity

Linearity of phototransistors

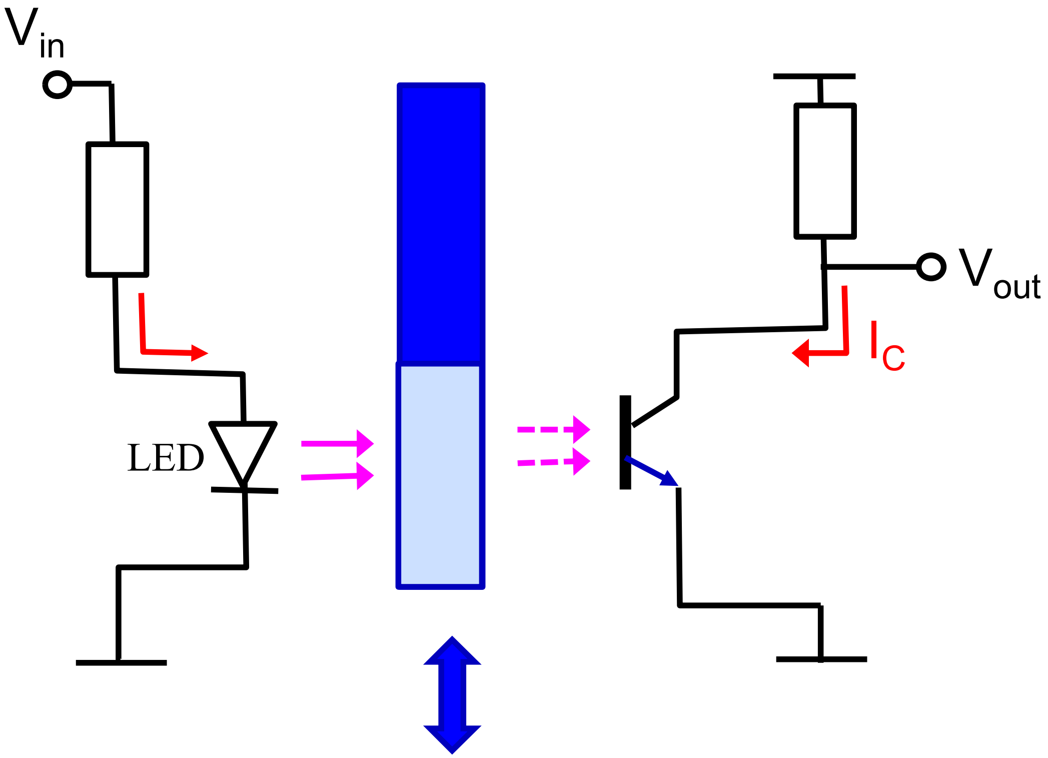


EG&G «Characteristics of phototransistors»

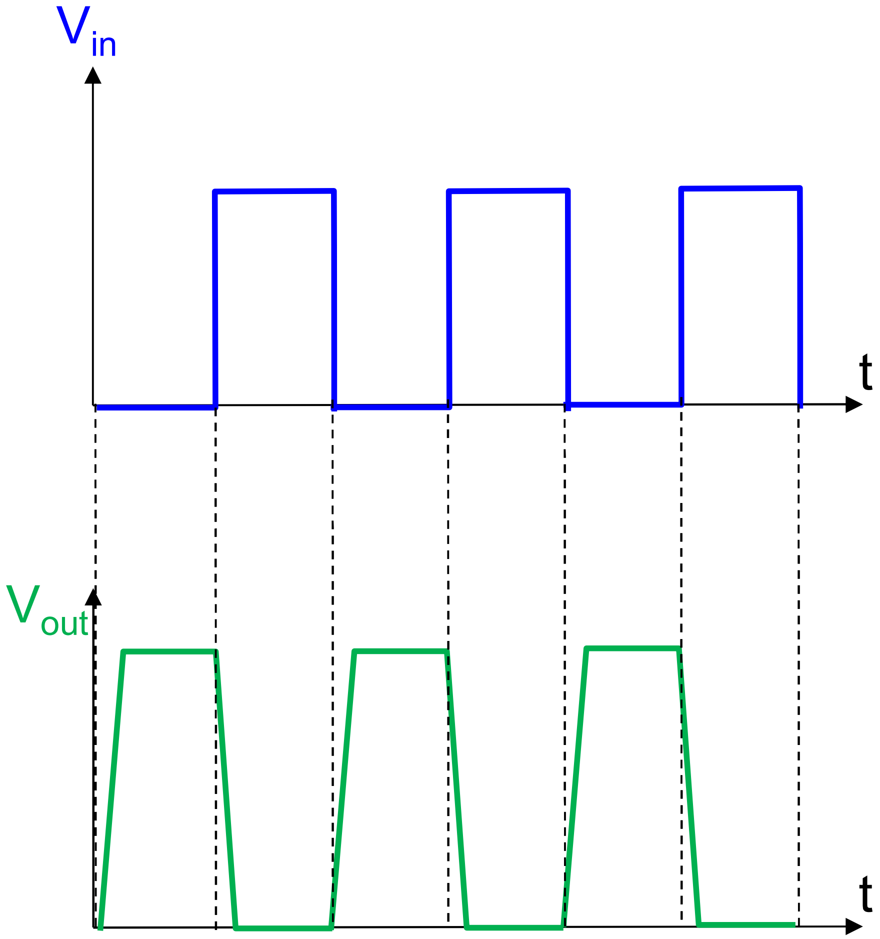
$$1\left[fc\right]=1\left[lm/ft^{2}\right]=10.76\left[lx\right]$$

Phototransistor as optical switch

Optical switch

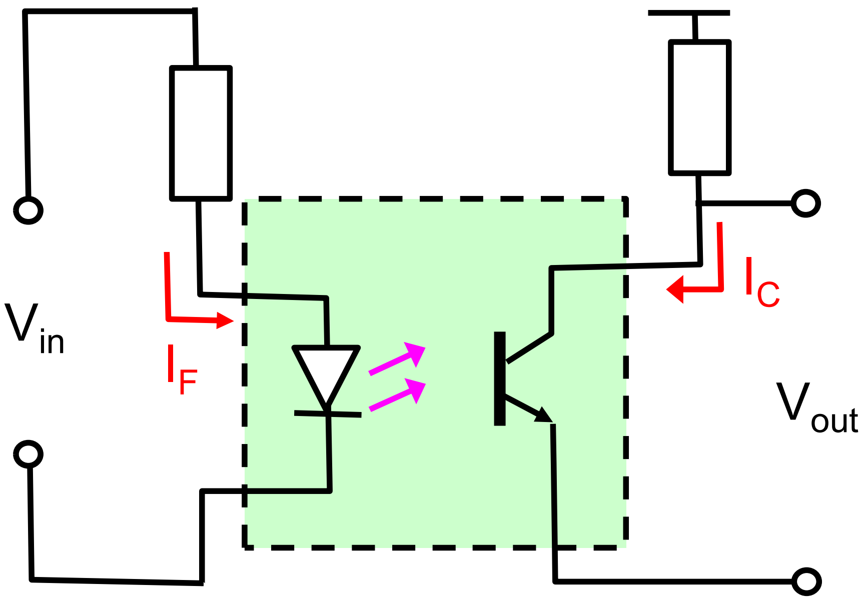


Light «ON»
→ V_{out} low



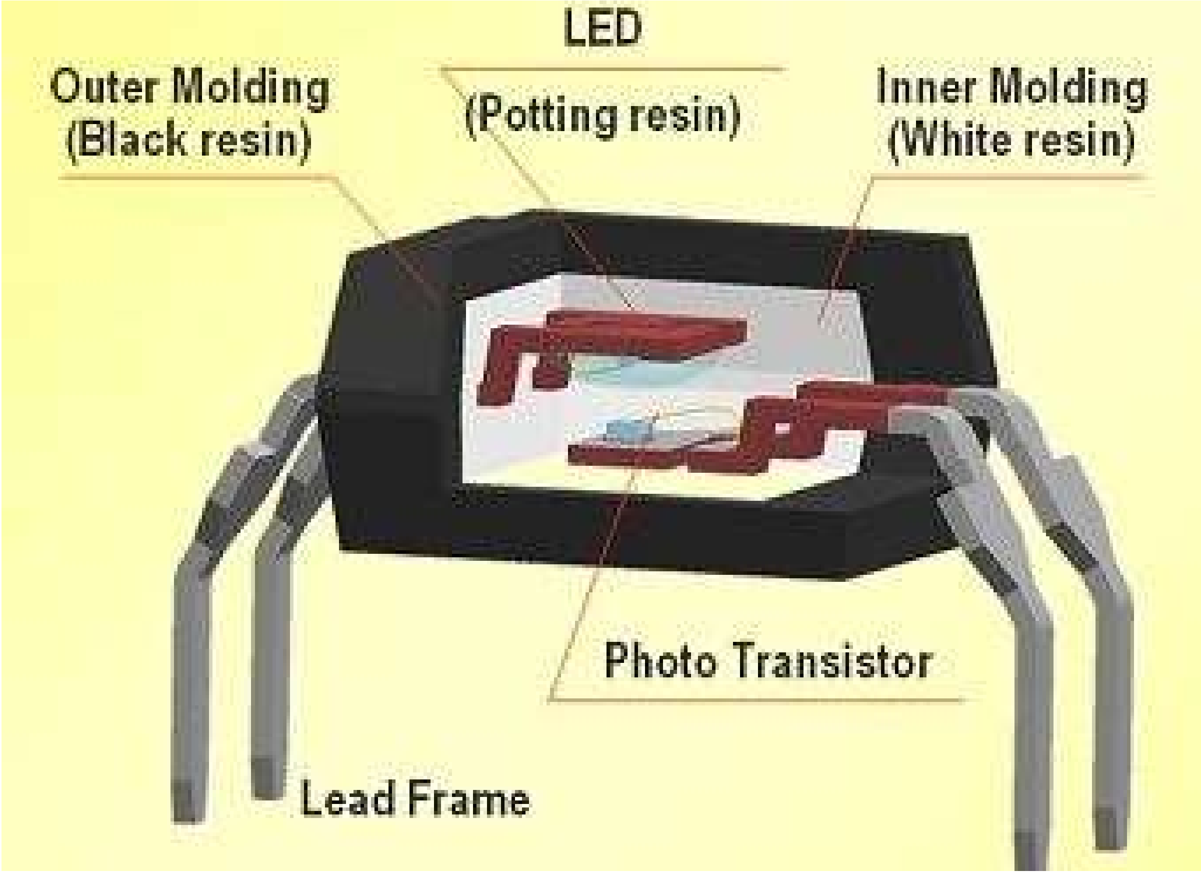
Phototransistor application examples

Opto-isolator



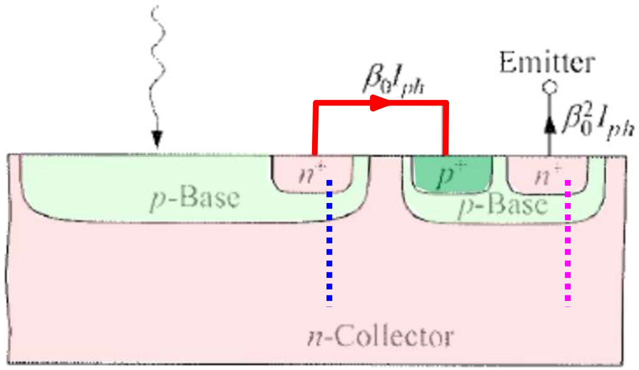
Light «ON»
→ V_{out} low

DIP package



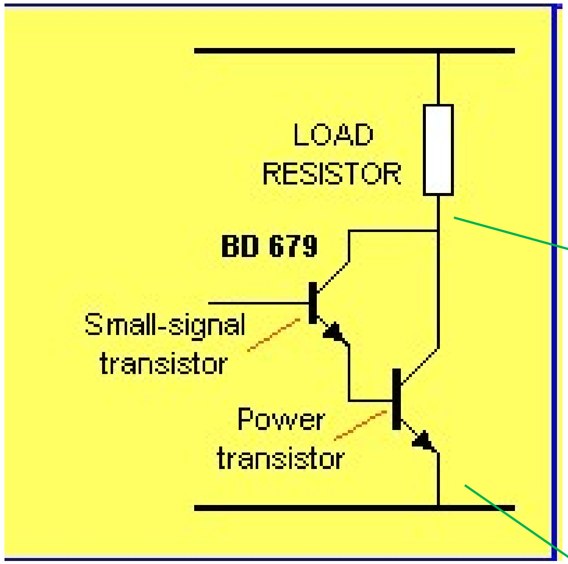
Darlington → Photo-Darlington

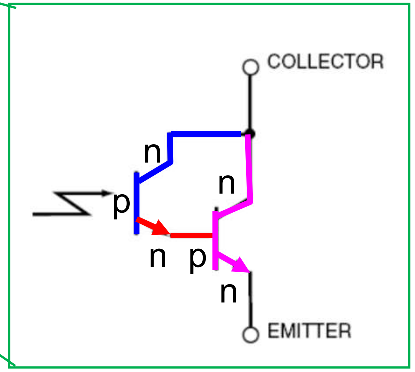
Photo-Darlington



S.M. Sze,
physics of semiconductor
devices

Darlington setup





Datasheets,
Fairchild QSE133

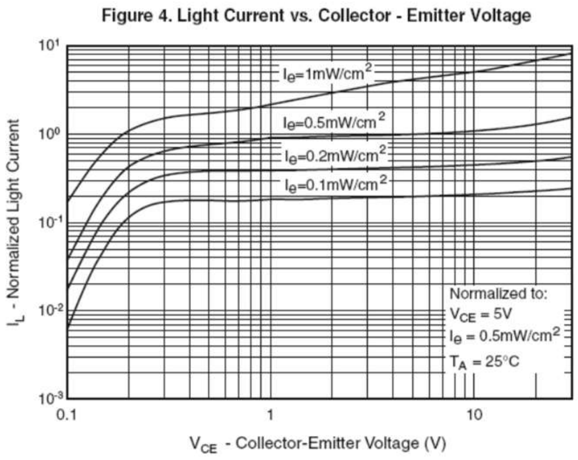


Figure 4. Light Current vs. Collector - Emitter Voltage

http://www.talkingelectronics.com.au/projects/How BD679 Works/HowBD679Works.html