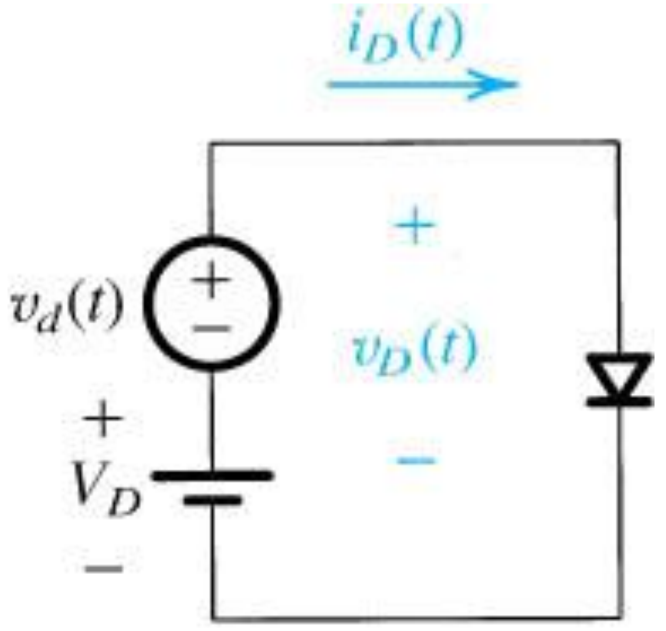
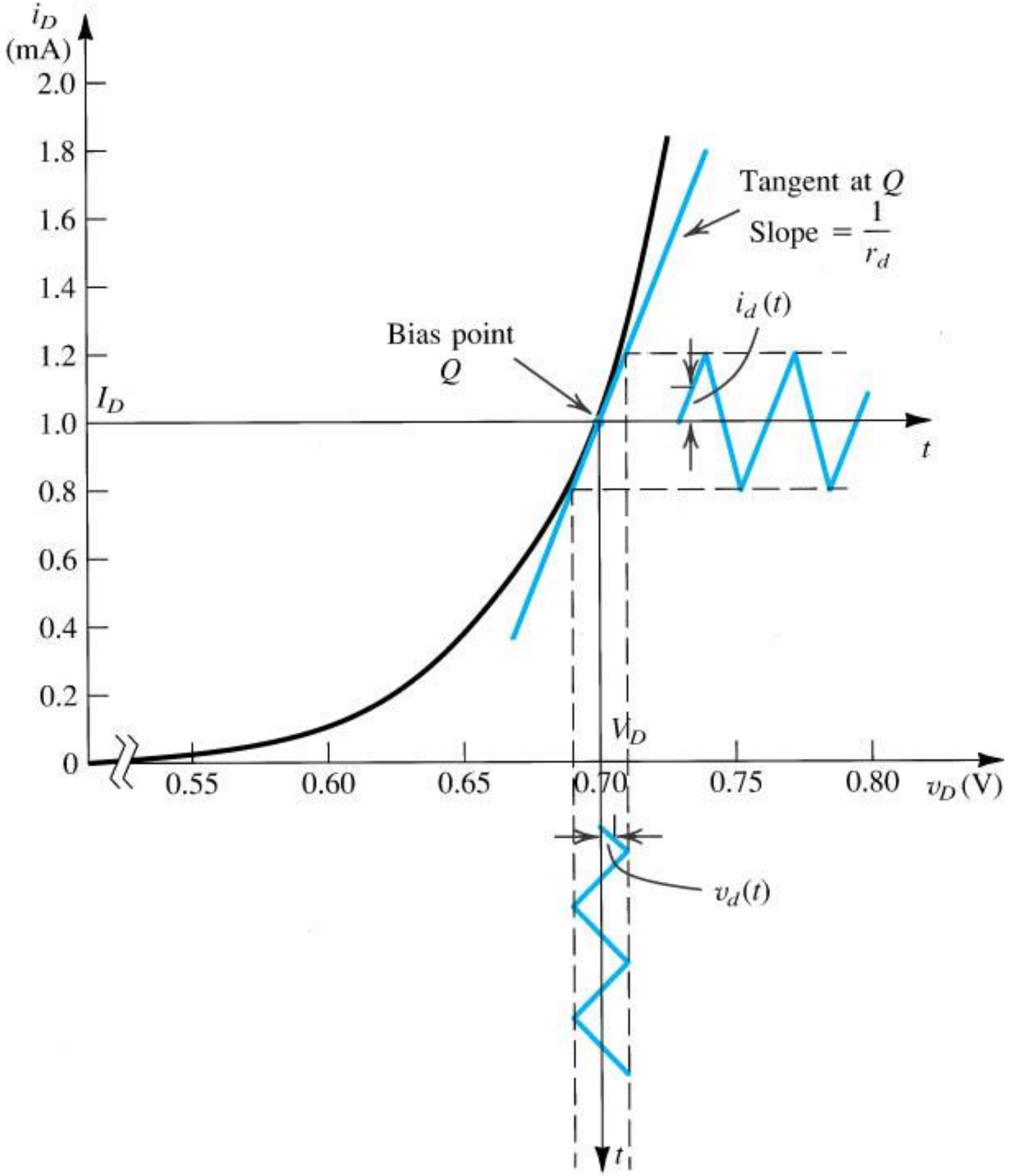
Elettronica Digitale
A.A. 2020-2021

Lezione 17/03/2021

Modello del diodo per piccoli segnali

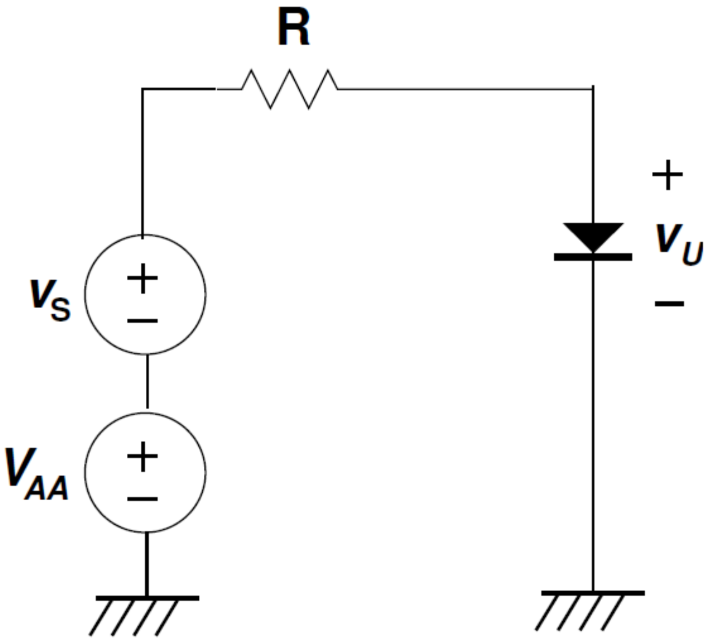




$$v_D(t) = V_D + v_d(t)$$

Microelectronic Circuits - Fifth Edition Sedra/Smith

Modello del diodo per piccoli segnali

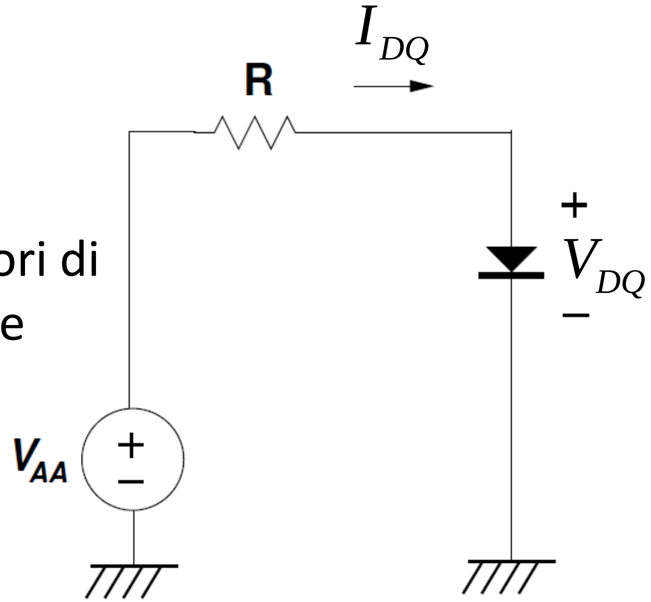


$$i_D = f(v_D)$$

$$\begin{cases} V_{AA} + v_s(t) = Ri_D(t) + v_D(t) \\ i_D(t) = f(v_D) \end{cases}$$

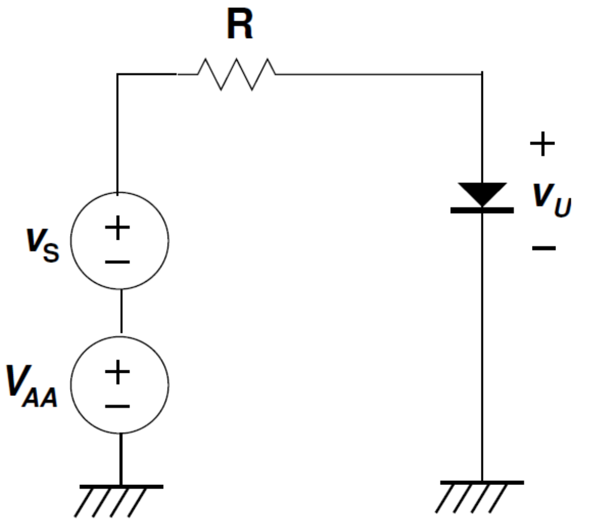
$$\begin{cases} v_D(t) \triangleq V_{DQ} + v_d(t) \\ i_D(t) \triangleq I_{DQ} + i_d(t) \end{cases}$$

Solo generatori di polarizzazione



$$\begin{cases} V_{AA} = RI_{DQ} + V_{DQ} \\ I_{DQ} = f(V_{DQ}) \leftrightarrow grandi\ segnali \end{cases}$$

Modello del diodo per piccoli segnali



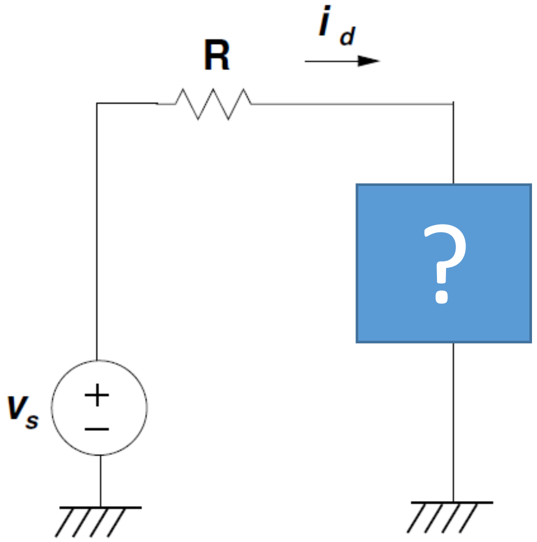
$$i_D = f(v_D)$$

$$\begin{cases} V_{AA} + v_s(t) = Ri_D(t) + v_D(t) \\ i_D(t) = f(v_D) \end{cases}$$

$$\begin{cases} v_D(t) \triangleq V_{DQ} + v_d(t) \\ i_D(t) \triangleq I_{DQ} + i_d(t) \end{cases}$$

$$\begin{cases} V_{AA} + v_s(t) = R(I_{DQ} + i_d(t)) + V_{DQ} + v_d(t) \\ V_{AA} = RI_{DQ} + V_{DQ} \end{cases}$$

$$\boxed{v_s(t) = Ri_d(t) + v_d(t)}$$



$$\boxed{i_d = f_1(v_d)}$$

Modello del diodo per piccoli segnali

Ipotesi $\boxed{\left|v_d(t)\right| \ll V_{DQ}}$

$$i_D(t) = I_{DQ} + i_d(t) = f\left(V_{DQ} + v_d(t)\right) =$$

$$= f\left(V_{DQ}\right) + \left(\left.\frac{df}{dv_D}\right|_{v_D = V_{DQ}}\right) v_d(t) + \left(\frac{1}{2}\left.\frac{d^2 f}{dv_D^2}\right|_{v_D = V_{DQ}}\right) v_d^2(t) + \dots$$

$$\begin{cases} i_D(t) = I_{DQ} + i_d(t) \approx f\left(V_{DQ}\right) + \left(\left.\frac{df}{dv_D}\right|_{v_D = V_{DQ}}\right) v_d(t) \\ I_{DQ} = f\left(V_{DQ}\right) \end{cases} \Rightarrow \quad i_d(t) \approx \left(\left.\frac{df}{dv_D}\right|_{v_D = V_{DQ}}\right) v_d(t)$$

Modello del diodo per piccoli segnali

Ipotesi $\boxed{\left| v_d(t) \right| \ll V_{DQ}}$

$$i_d(t) \approx \left(\left. \frac{df}{dv_D} \right|_{v_D = V_{DQ}} \right) v_d(t)$$

$$\left(\left. \frac{df}{dv_D} \right|_{v_D = V_{DQ}} \right) = \left. \frac{di_D}{dv_D} \right|_Q = g_d$$

Conduttanza differenziale

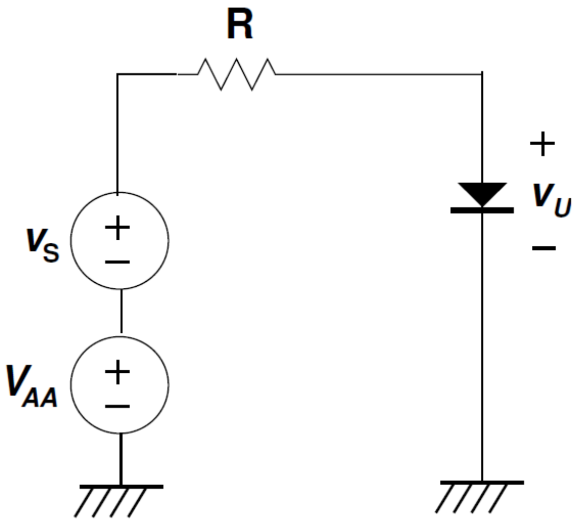
$$i_d(t) \approx g_d v_d(t)$$

$$r_d = \frac{1}{g_d} = \frac{1}{\left. \dfrac{di_D}{dv_D} \right|_Q}$$

Resistenza differenziale

$$\boxed{v_d(t) \approx r_d i_d(t)}$$

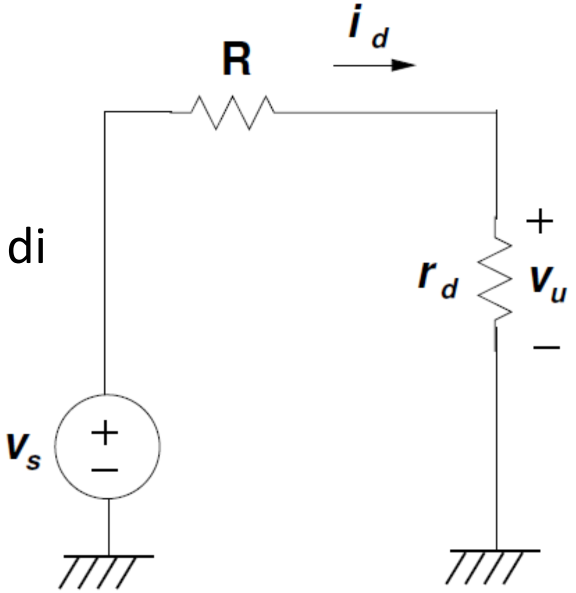
Modello del diodo per piccoli segnali



$i_D = f(v_D)$

$$\begin{cases} V_{AA} + v_s(t) = Ri_D(t) + v_D(t) \\ i_D(t) = f\left(v_D\right) \end{cases}$$

$$\begin{cases} v_D(t) \triangleq V_{DQ} + v_d(t) \\ i_D(t) \triangleq I_{DQ} + i_d(t) \end{cases}$$



Solo generatori di segnale

$$\boxed{\begin{cases} v_s(t) = Ri_d(t) + v_d(t) \\ v_d(t) = r_d i_d(t) \end{cases}}$$

Modello del diodo per piccoli segnali

Calcolo della resistenza differenziale

$$i_D = I_S\left(\exp\left(\frac{v_D}{\eta V_T}\right)-1\right)\approx I_S\exp\left(\frac{v_D}{\eta V_T}\right)$$

$$g_d = \left.\frac{di_D}{dv_D}\right|_Q = \left.\frac{1}{\eta V_T} I_S \exp\left(\frac{v_D}{\eta V_T}\right)\right|_Q = \frac{I_{DQ}}{\eta V_T}$$

$$\boxed{r_d = \frac{\eta V_T}{I_{DQ}}}$$

Modello del diodo per piccoli segnali

Limiti di validità del modello

$$\left(\left. \frac{df}{dv_D} \right|_{v_D = V_{DQ}} \right) v_d(t) \gg \left(\frac{1}{2} \left. \frac{d^2 f}{dv_D^2} \right|_{v_D = V_{DQ}} \right) v_d^2(t)$$

$$\frac{I_{DQ}}{\eta V_T} v_d(t) \gg \frac{1}{2} \frac{I_{DQ}}{(\eta V_T)^2} v_d^2(t)$$

$$v_d(t) \ll 2\eta V_T$$

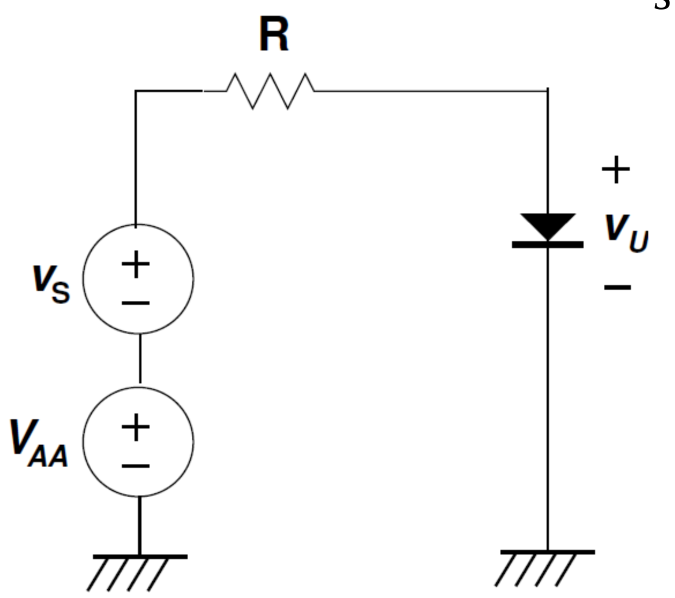
$$\eta = 1$$
$$T = 300\ K$$

$$v_d(t) \ll 52\ mV$$

$$\boxed{v_d(t) < \frac{V_T}{10}}$$

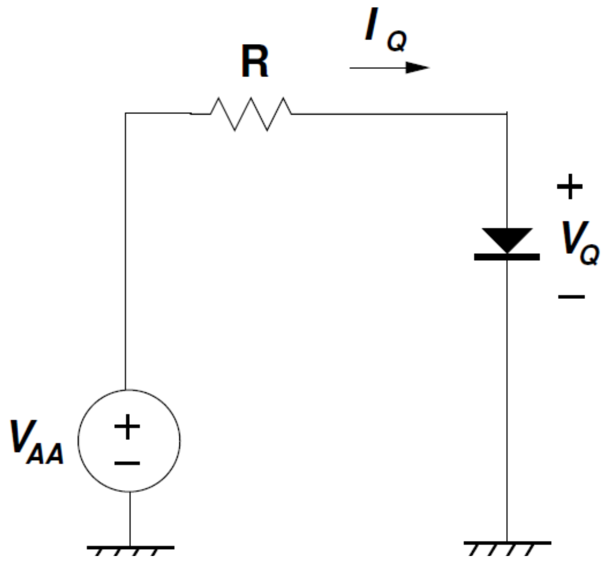
$$\boxed{v_d(t) < \frac{V_T}{5}}$$

Modello del diodo per piccoli segnali



$$v_s(t) = V_M \sin(\omega t)$$

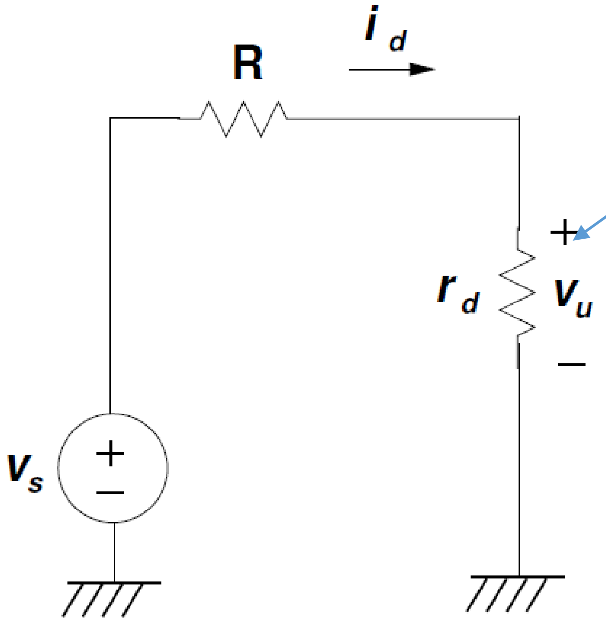
1 $$v_s(t) = 0$$



2 $$I_{DQ} = \frac{V_{AA} - V_\gamma}{R}$$

3 $$r_d = \frac{\eta V_T}{I_{DQ}}$$

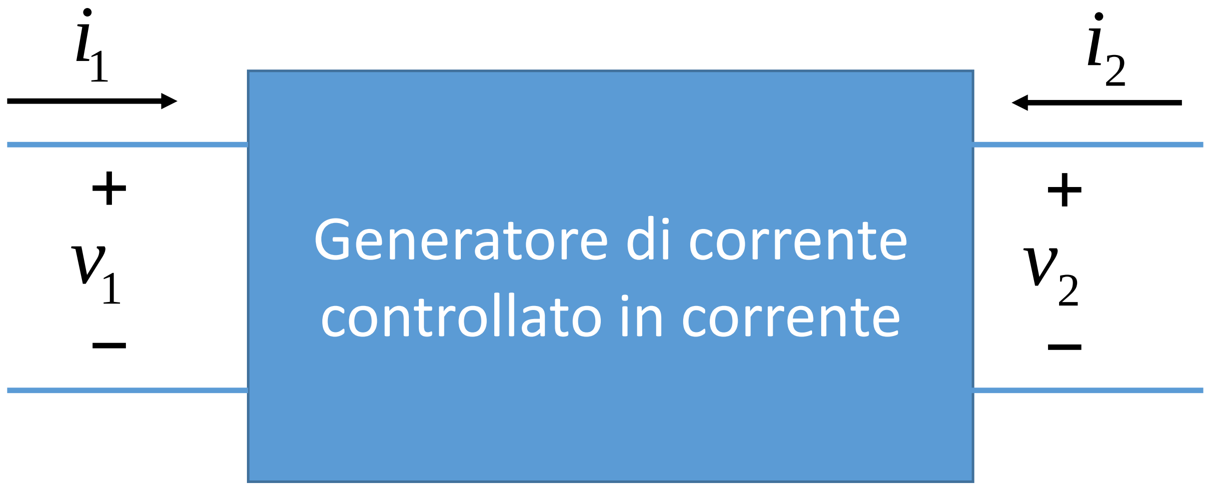
4 $$V_{AA} = 0$$

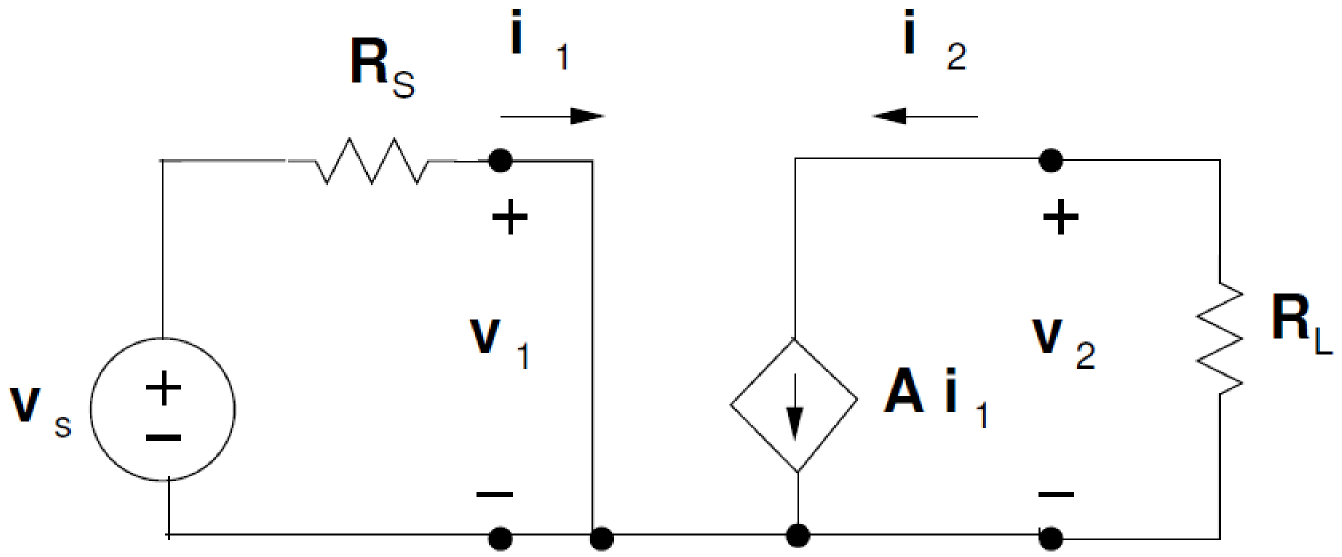


5 $$i_d(t) = \frac{v_s(t)}{R + r_d} = \frac{V_M \sin(\omega t)}{R + r_d}$$

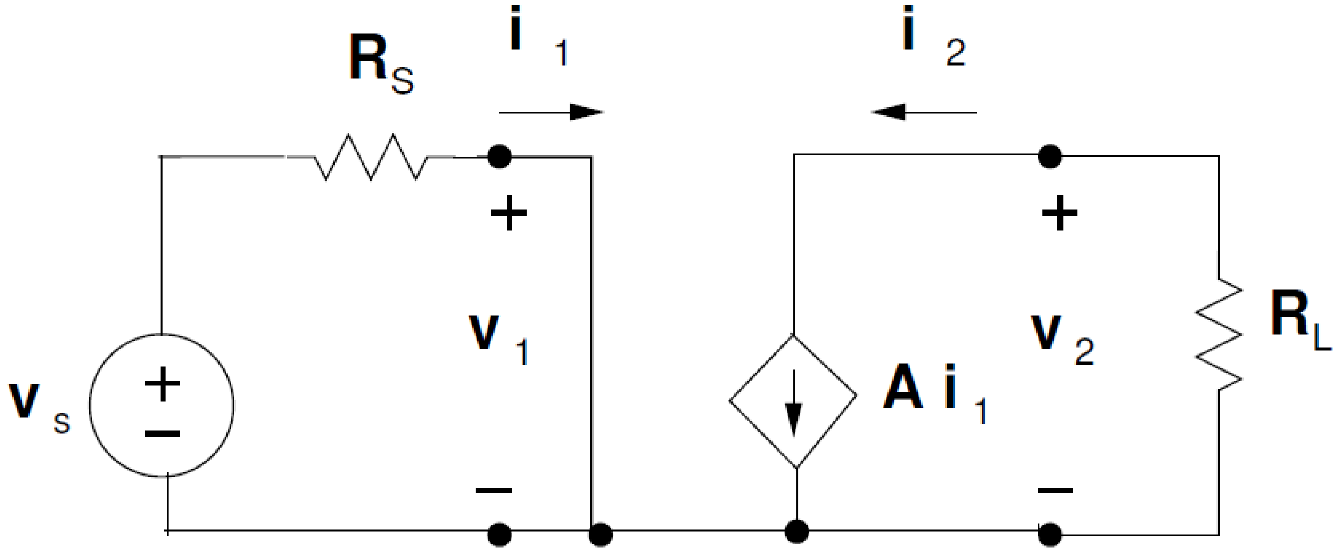
6 $$i_D(t) = I_{DQ} + i_d(t) = \frac{V_{AA} - V_\gamma}{R} + \frac{V_M \sin(\omega t)}{R + r_d}$$

Transistore Bipolare (BJT)





Transistore Bipolare (BJT)



$$i_2 = Ai_1 \qquad A = \frac{i_2}{i_1}$$

Guadagno di corrente

$$v_2 = -R_L i_2 = -R_L A i_1 = -R_L A \frac{v_s}{R_s} \qquad A_v = \frac{v_2}{v_s} = -\frac{AR_L}{R_s}$$

Guadagno di tensione

Transistore Bipolare (BJT)

$$A_i \triangleq \frac{i_{out}}{i_{in}}$$ Guadagno di corrente

$|A_i| > 1$ Amplificazione di corrente

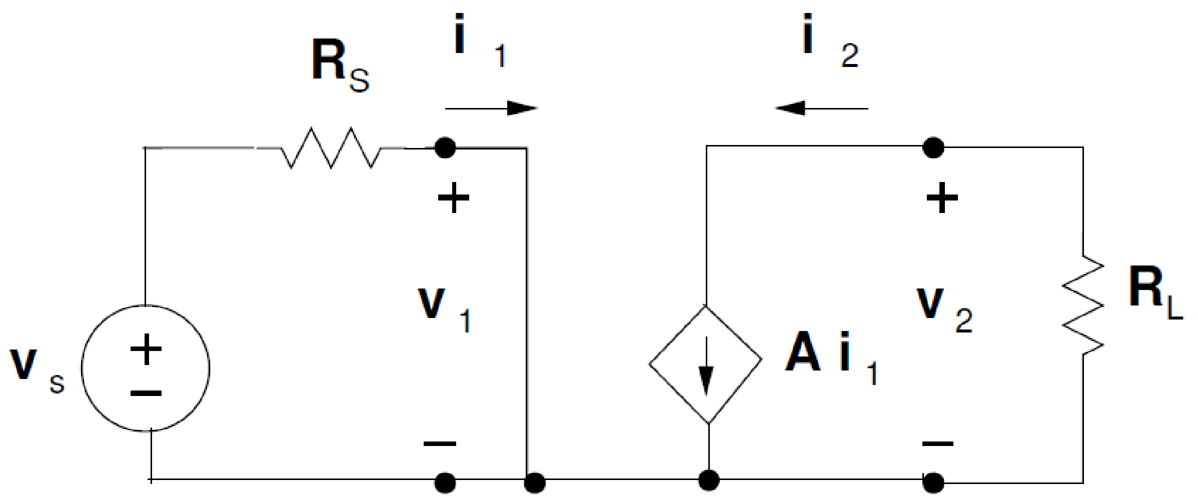
$|A_i| < 1$ Attenuazione di corrente

$$A_v \triangleq \frac{v_{out}}{v_{in}}$$ Guadagno di tensione

$|A_v| > 1$ Amplificazione di tensione

$|A_v| < 1$ Attenuazione di tensione

Transistore Bipolare (BJT)



$$P_{out} = -v_2 i_2$$ Potenza sul carico

$$P_{in} = v_s i_1$$ Potenza in ingresso

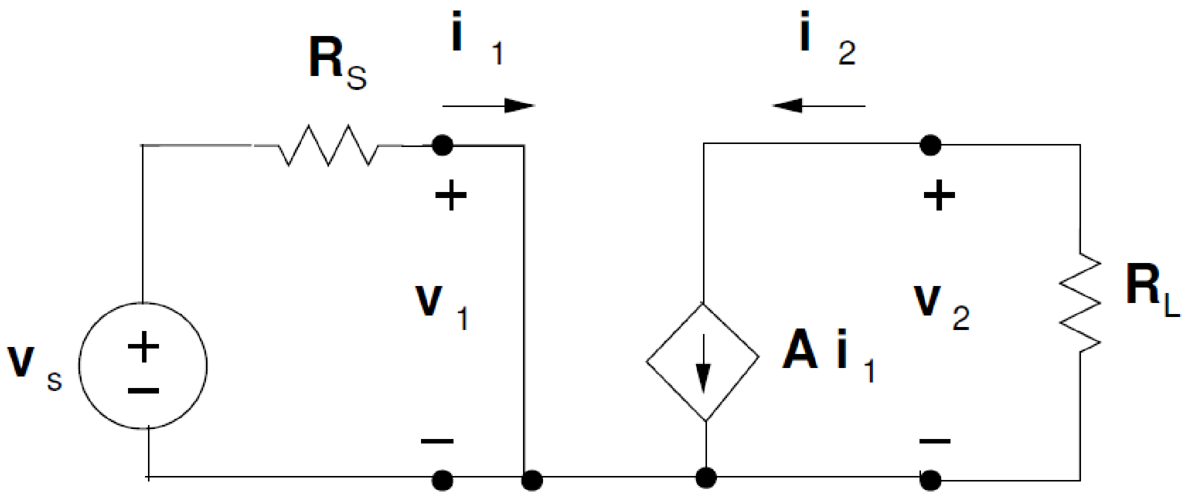
$$A_P \triangleq \frac{P_{out}}{P_{in}}$$ Guadagno di potenza

$$A = \frac{i_2}{i_1} \qquad A_v = \frac{v_2}{v_s} = -\frac{AR_L}{R_s}$$

$$A_P = \frac{P_{out}}{P_{in}} = -\frac{v_2 i_2}{v_s i_1} = -AA_v = A^2\frac{R_L}{R_s}$$

$$|A_P| > 1$$ Amplificazione di potenza → Componenti attivi (BJT, MOSFET)

Transistore Bipolare (BJT)



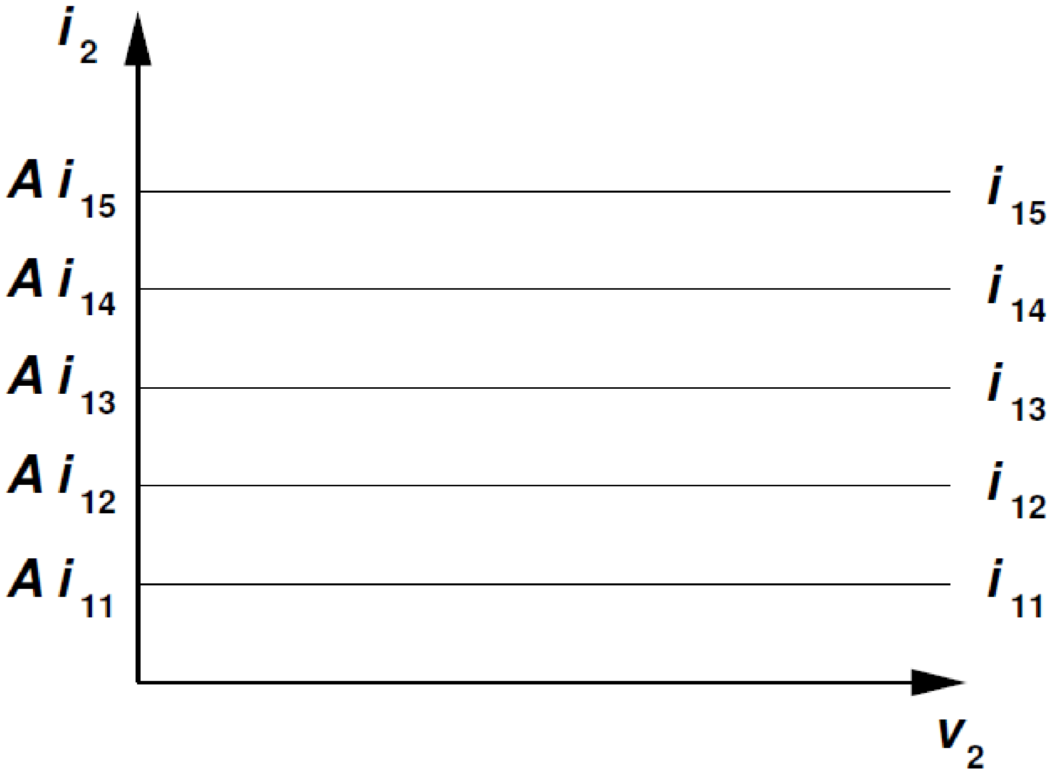
Caratteristiche di ingresso

$$i_1 = f(v_1, i_2\ o\ v_2)$$

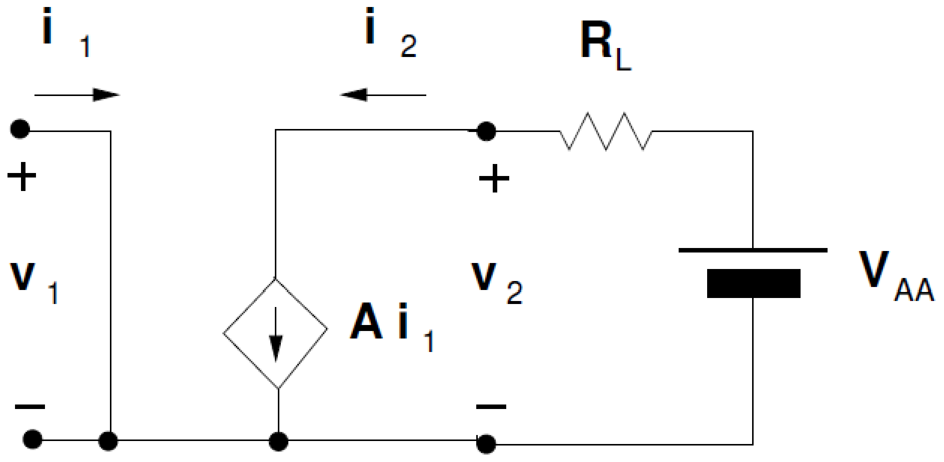
Caratteristiche di uscita

$$i_2 = f(v_2, i_1\ o\ v_1)$$

Caratteristiche di uscita



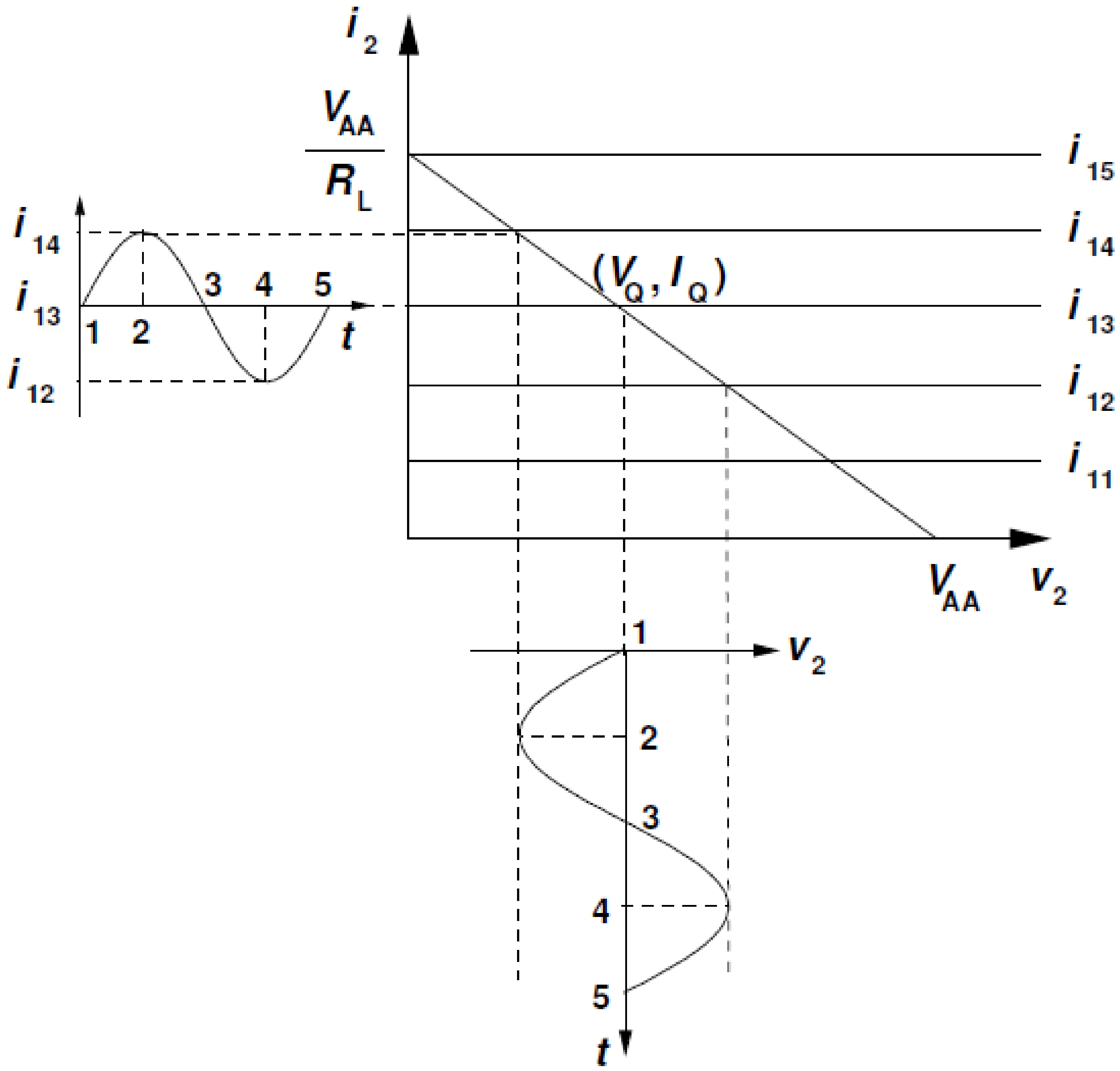
Transistore Bipolare (BJT)



$$V_{AA} = R_L i_2 + v_2$$

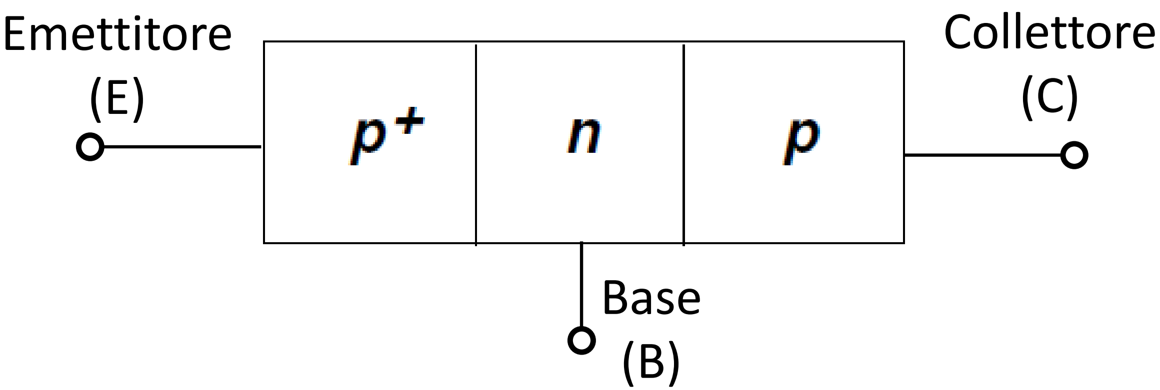
$$i_2 = \frac{V_{AA}}{R_L} - \frac{v_2}{R_L}$$

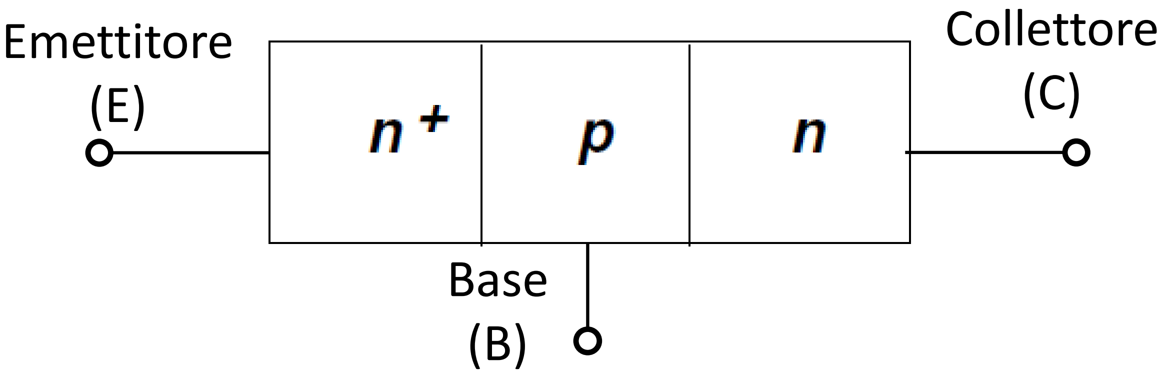
Retta di carico

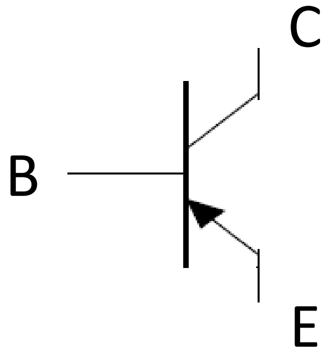


Transistore Bipolare (BJT)

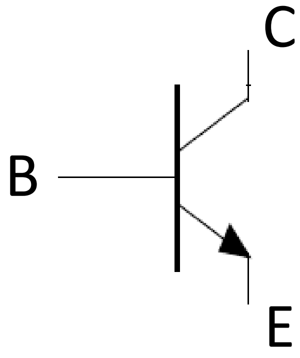
Il transistore bipolare a giunzione consiste di due giunzioni *pn* poste una di seguito all’altra e orientate in senso inverso







pnp



npn

Transistore Bipolare (BJT)

Il transistore bipolare a giunzione consiste di due giunzioni *pn* poste una di seguito all’altra e orientate in senso inverso