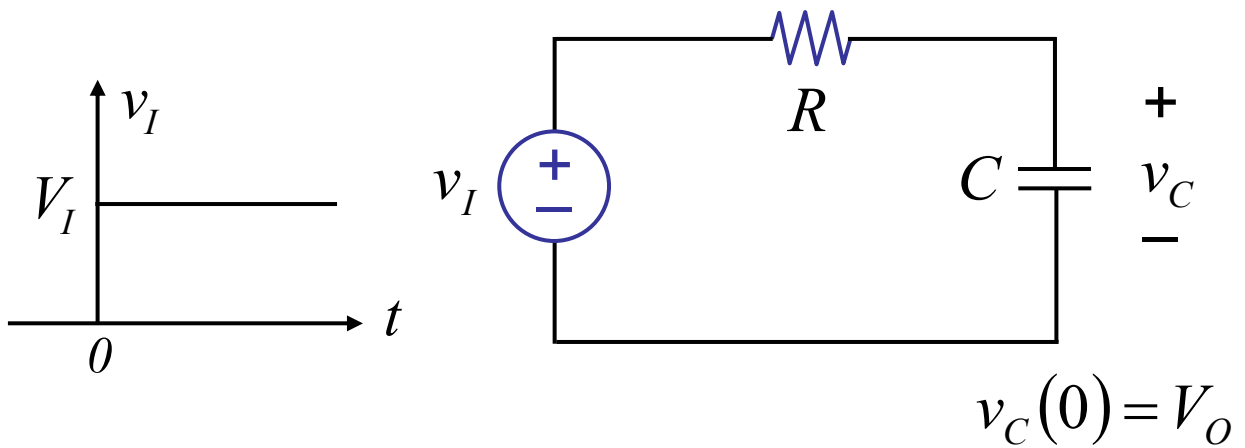


6.002

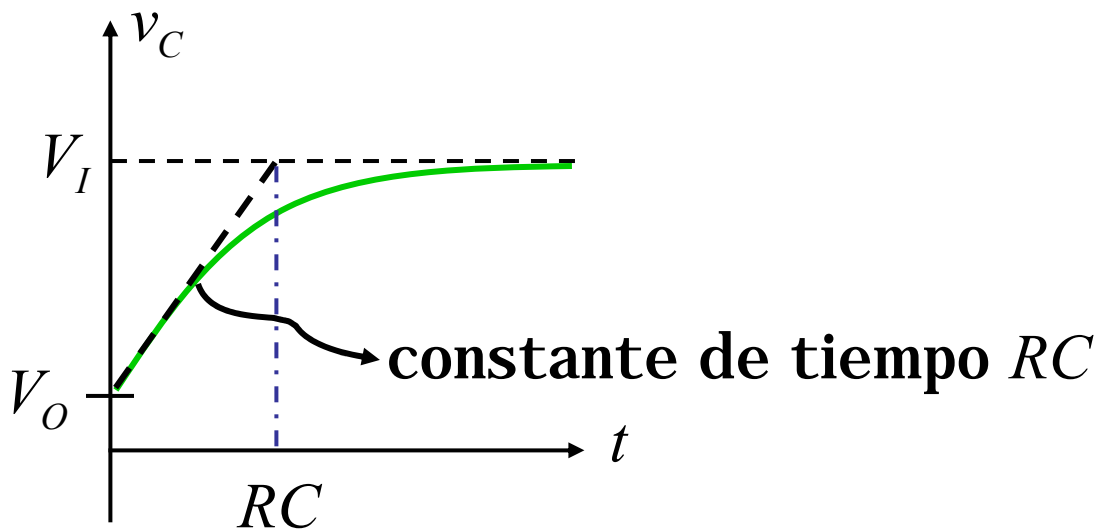
CIRCUITOS Y  
ELECTRÓNICA

Circuito digital, **Speed**  
(velocidad)

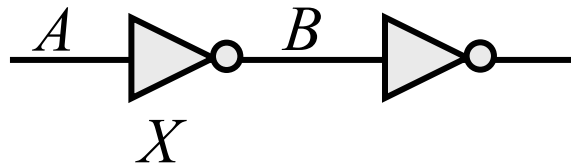
# Repaso



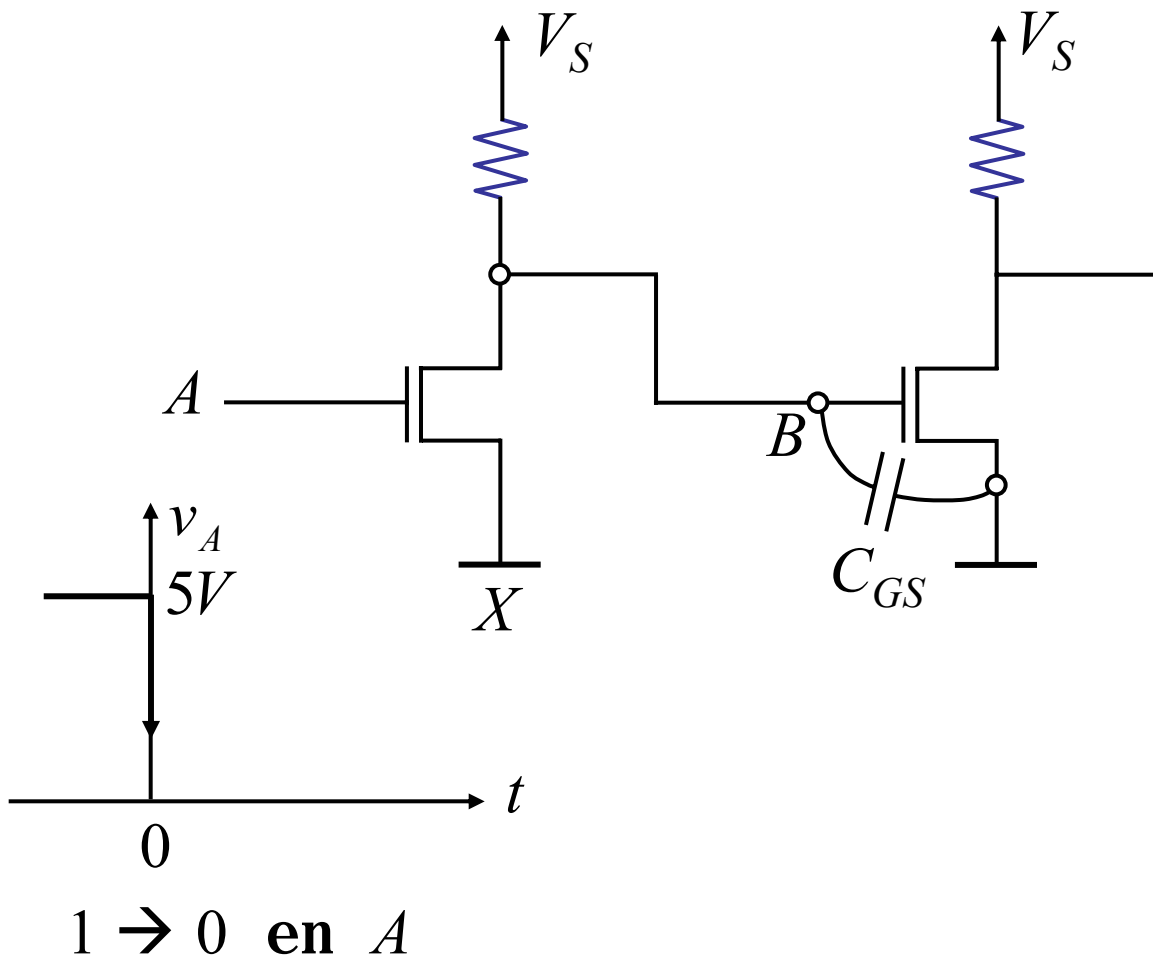
$$v_C = V_I + (V_O - V_I) e^{\frac{-t}{RC}} \quad \text{—————} \quad \textcircled{1}$$



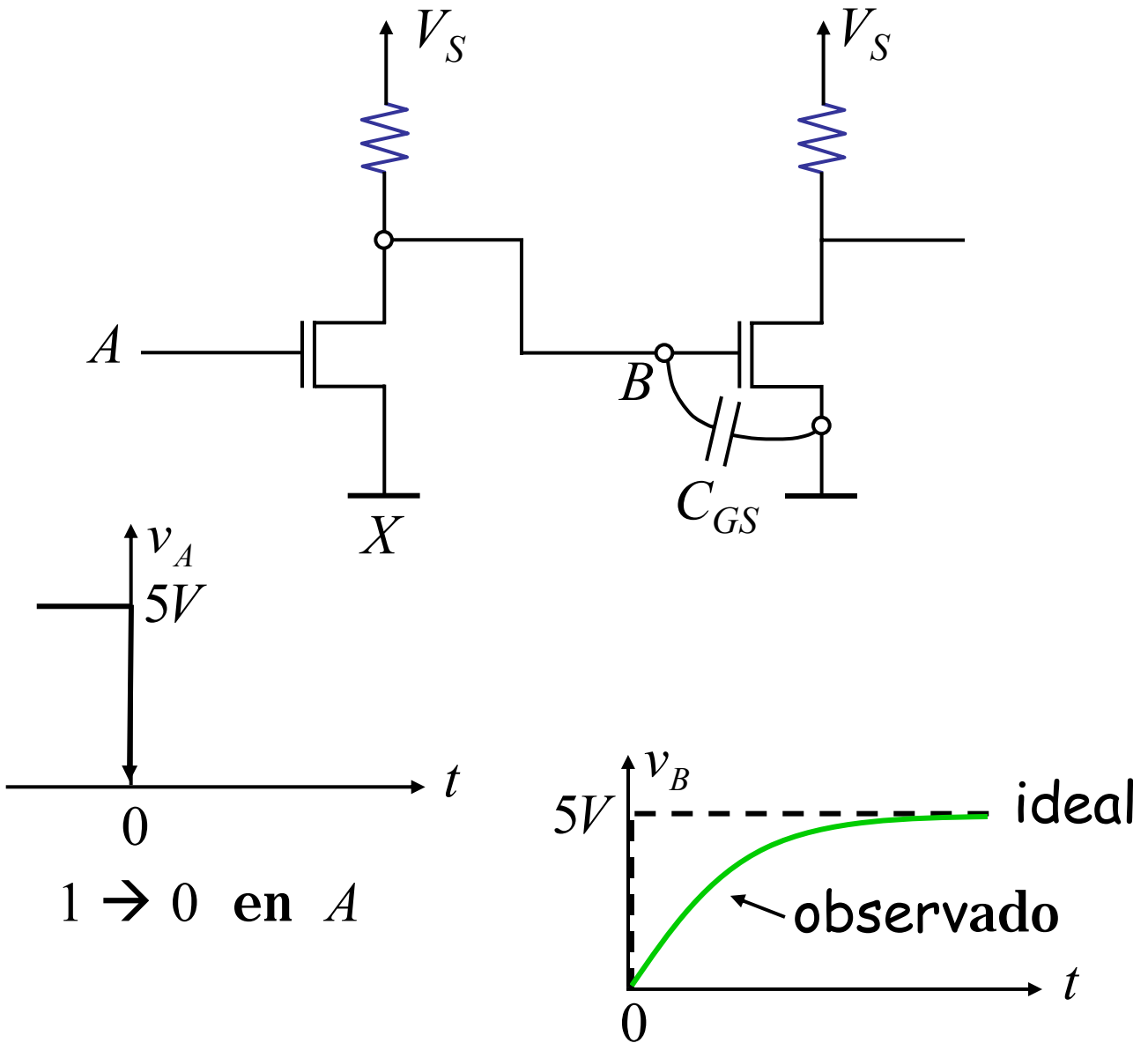
# Apliquemos el resultado en un inversor.



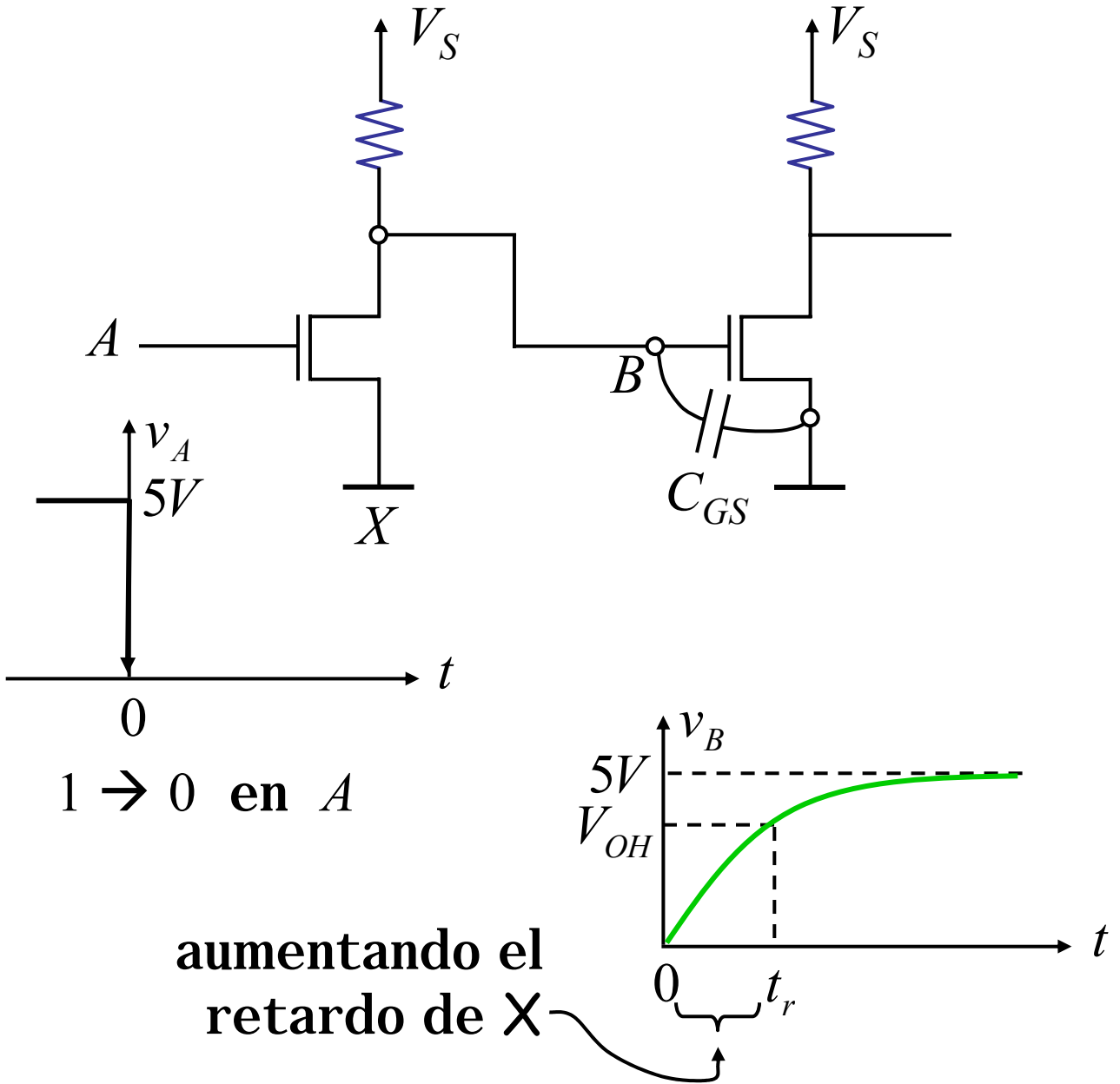
Primero, el retardo de subida  $t_r$  en  $B$



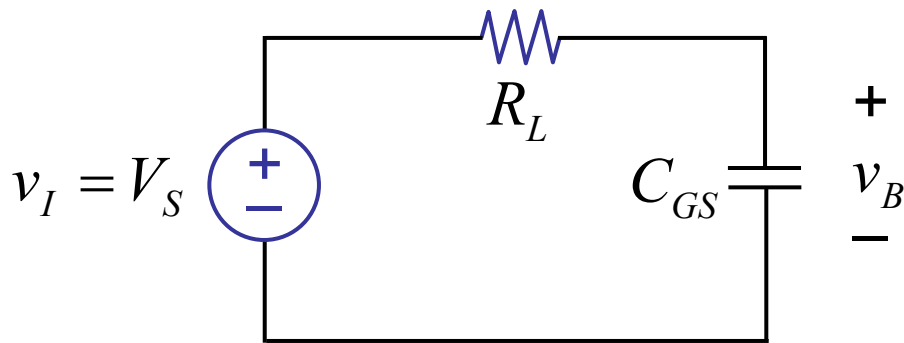
# Primero, el retardo de subida $t_r$ en $B$



# Primero, el retardo de subida $t_r$ en $B$



# Circuito equivalente para $0 \rightarrow 1$ en $B$



$$v_I = V_S$$
$$v_B(0) = 0 \quad \text{para } t \geq 0$$

A partir de **①**

$$v_B = V_S + (0 - V_S) e^{\frac{-t}{R_L C_{GS}}}$$

A continuación, es necesario hallar  $t$  para el que

$$v_B = V_{OH} .$$

O,

$$v_{OH} = V_S - V_S e^{\frac{-t}{R_L C_{GS}}}$$

Halle  $t_r$  :

$$V_S e^{\frac{-t_r}{R_L C_{GS}}} = V_S - V_{OH}$$

$$\frac{-t_r}{R_L C_{GS}} = \ln \frac{V_S - V_{OH}}{V_S}$$

$$t_r = -R_L C_{GS} \ln \frac{V_S - V_{OH}}{V_S}$$

O,

$$v_{OH} = V_S - V_S e^{\frac{-t}{R_L C_{GS}}}$$

Halle  $t_r$  :

$$V_S e^{\frac{-t_r}{R_L C_{GS}}} = V_S - V_{OH}$$

$$\frac{-t_r}{R_L C_{GS}} = \ln \frac{V_S - V_{OH}}{V_S}$$

$$t_r = -R_L C_{GS} \ln \frac{V_S - V_{OH}}{V_S}$$

ej.

$$R_L = 1K$$

$$V_S = 5V$$

$$C_{GS} = 0.1 pF$$

$$V_{OH} = 4V$$

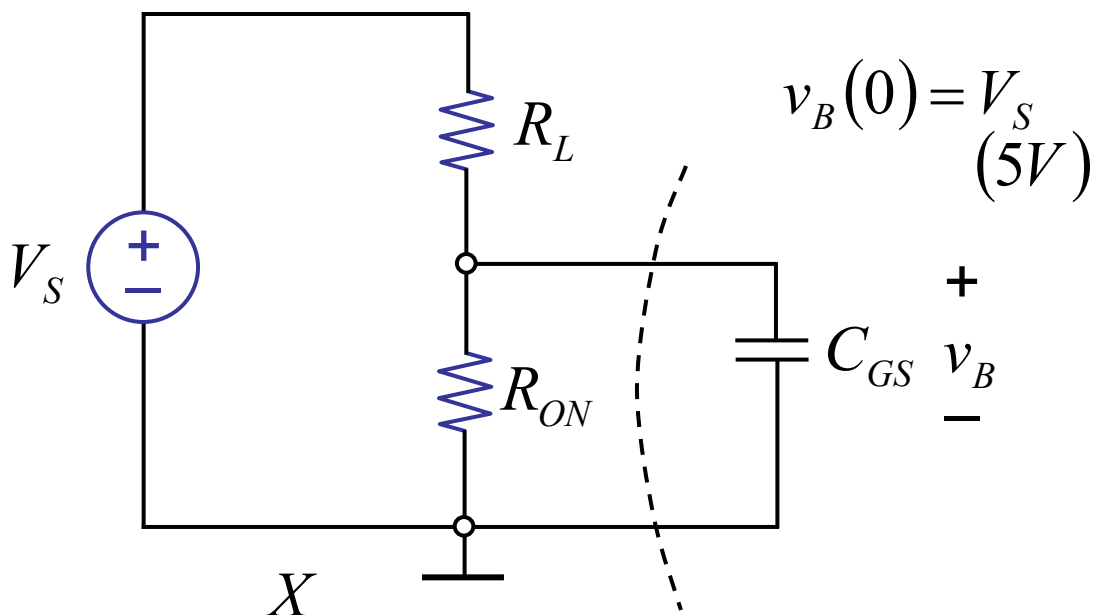
$$\begin{aligned} t_r &= -1 \times 10^3 \times 0.1 \times 10^{-12} \ln \frac{5-4}{5} \\ &= 0.16 ns \end{aligned}$$

$$RC = 0.1 ns !$$

# Retardo de caída $t_f$

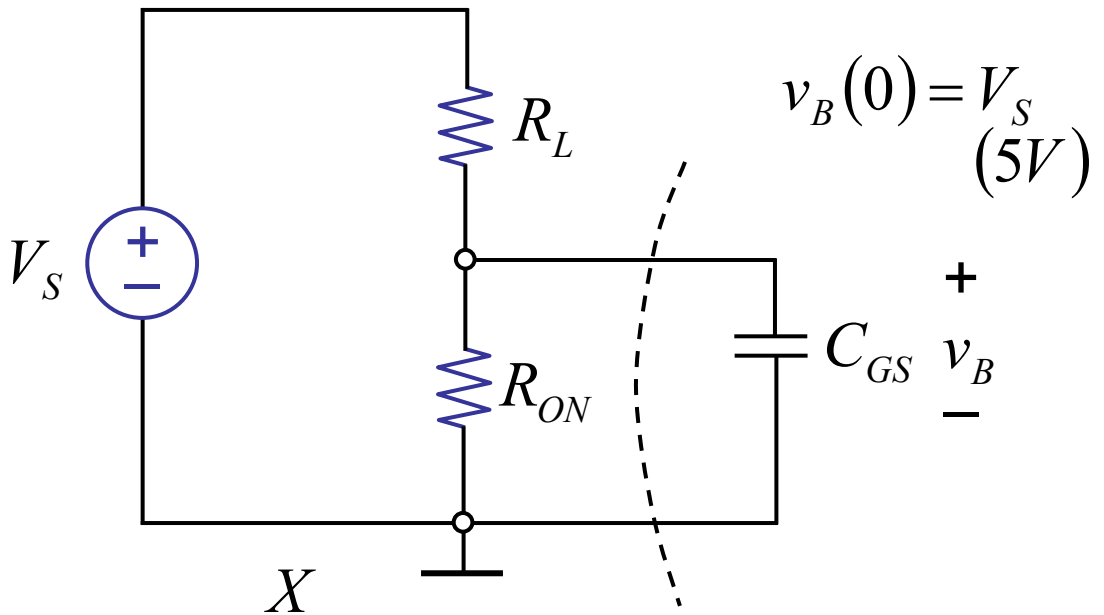
El retardo de caída  $t_f$  es el  $t$  por el que  $v_B$  cae a  $V_{OL}$

**Circuito equivalente para  $1 \rightarrow 0$  en  $B$**

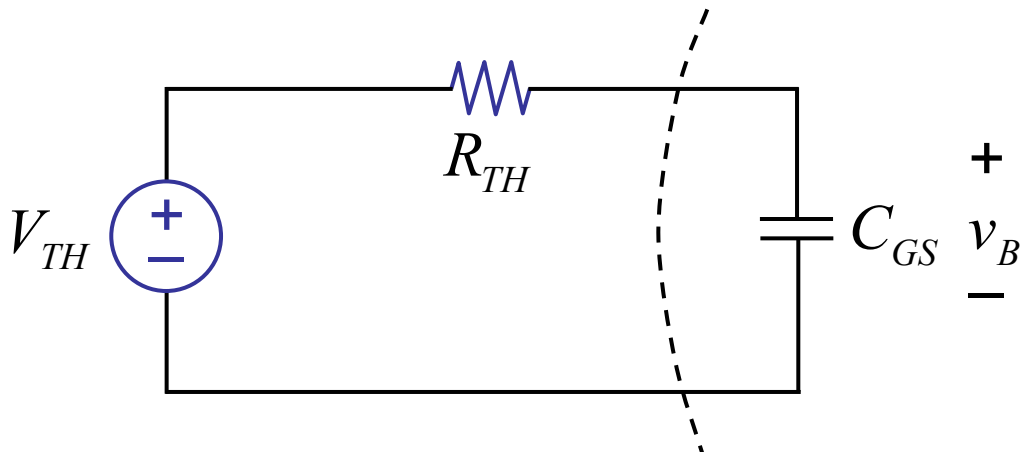


# Retardo de caída $t_f$

Circuito equivalente para  $1 \rightarrow 0$  en  $B$



Sustitución de Thévenin...



$$R_{TH} = R_L \parallel R_{ON}$$

$$V_{TH} = V_S \frac{R_{ON}}{R_{ON} + R_L}$$

A partir de **①**

$$v_B = V_{TH} + (V_S - V_{TH}) e^{\frac{-t}{R_{TH}C_{GS}}}$$

El tiempo retardo de caída  $t_f$  es el  $t$  por el que  $v_B$  cae a  $V_{OL}$

$$V_{OL} = V_{TH} + (V_S - V_{TH}) e^{\frac{-t_f}{R_{TH}C_{GS}}}$$

**o,**

$$t_f = -R_{TH}C_{GS} \ln \frac{V_{OL} - V_{TH}}{V_S - V_{TH}}$$

$$t_f = -R_{TH} C_{GS} \ln \frac{V_{OL} - V_{TH}}{V_S - V_{TH}}$$

ej.  $R_L = 1K$        $V_S = 5V$        $R_{ON} = 10\Omega$

$C_{GS} = 0.1 pF$        $V_{OL} = 1V$

$R_{TH} \approx 10\Omega$ ,       $V_{TH} \approx 0V$

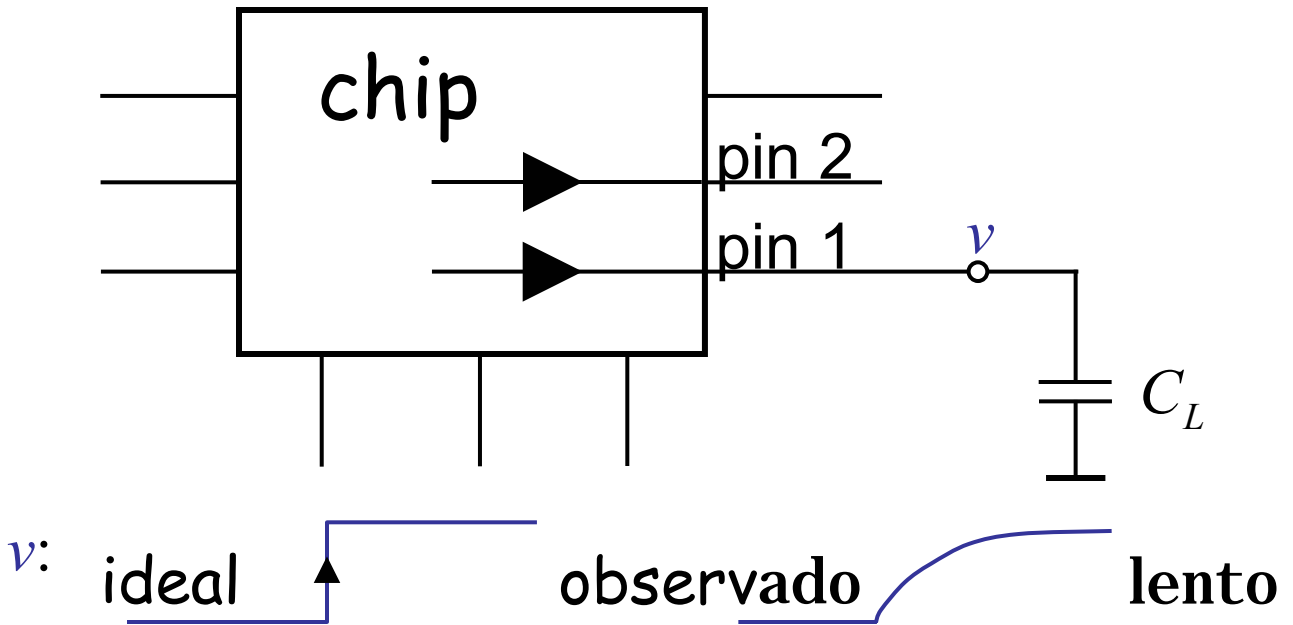
$$t_f = -10 \cdot 0.1 \cdot 10^{-12} \ln \frac{1}{5}$$

$$= 1.6 ps$$

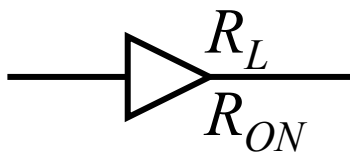
$$RC = 1 ps !$$

Para la clase de repaso: sería mejor lento

## Problema



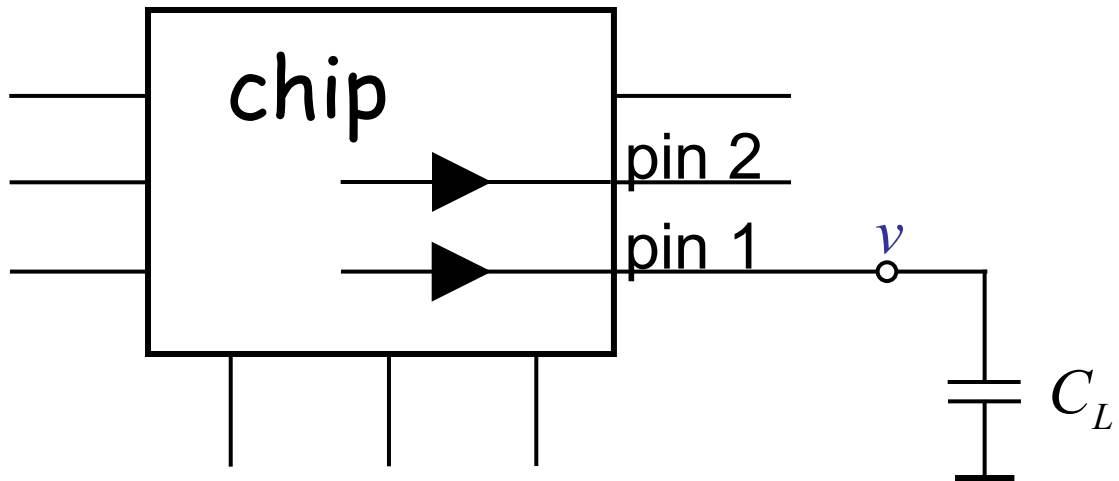
Así que los ingenieros decidieron acelerarlo...



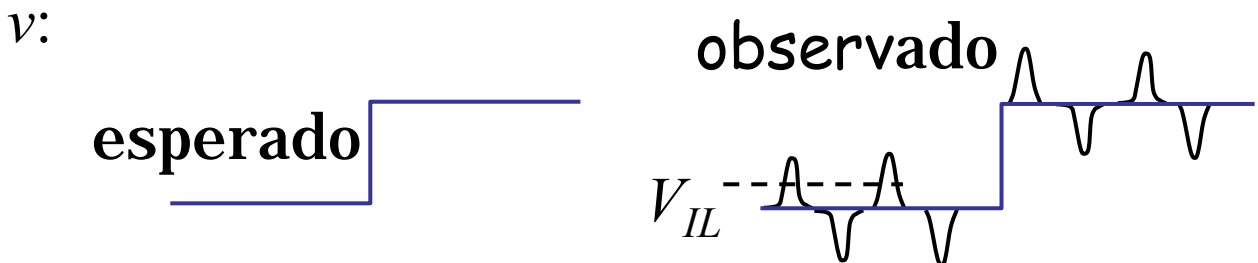
disminuyeron  $R_L$   
disminuyeron  $R_{ON}$

Para la clase de repaso: sería mejor lento

## Problema



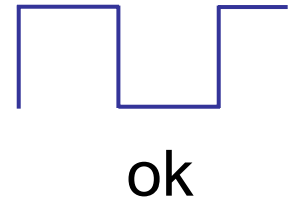
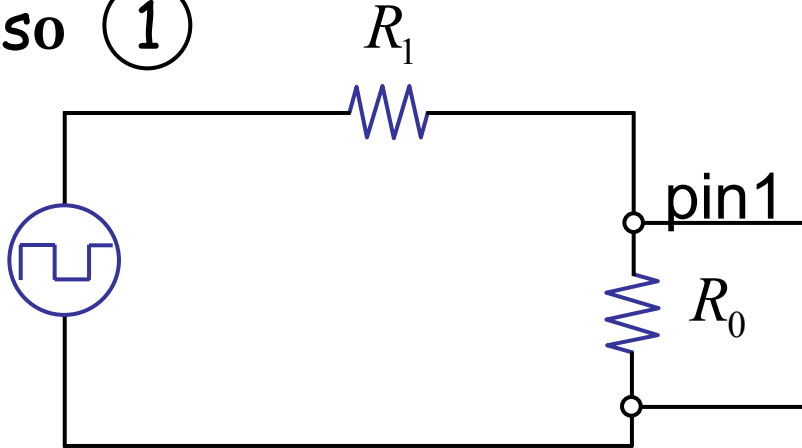
... pero, es un desastre



# ¿Por qué? Considere ...



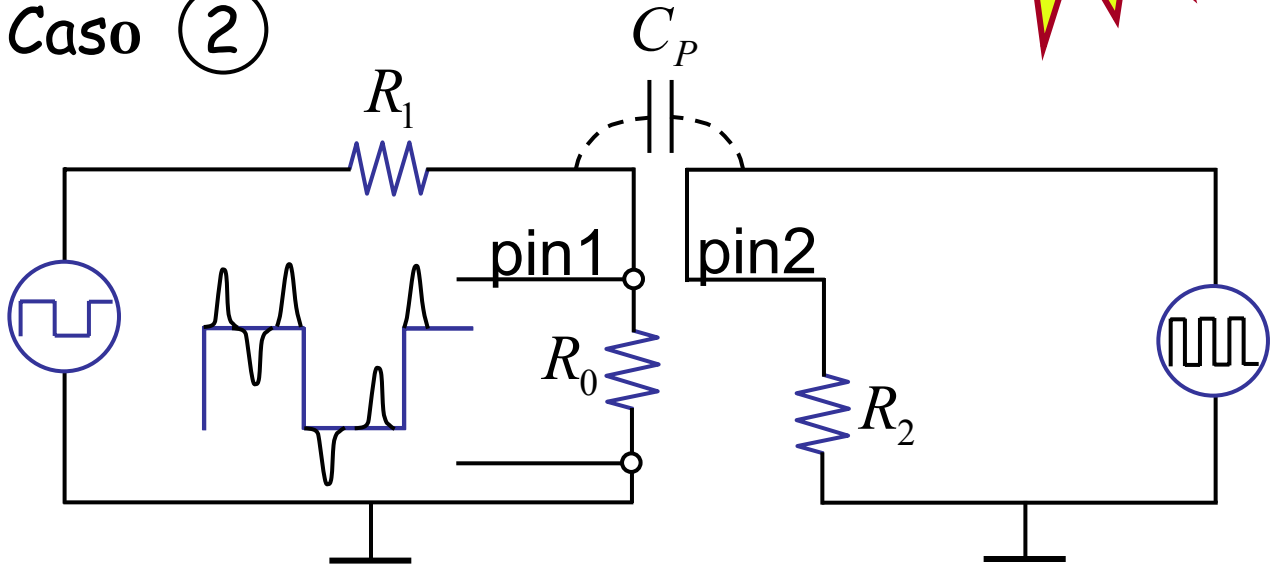
Caso ①



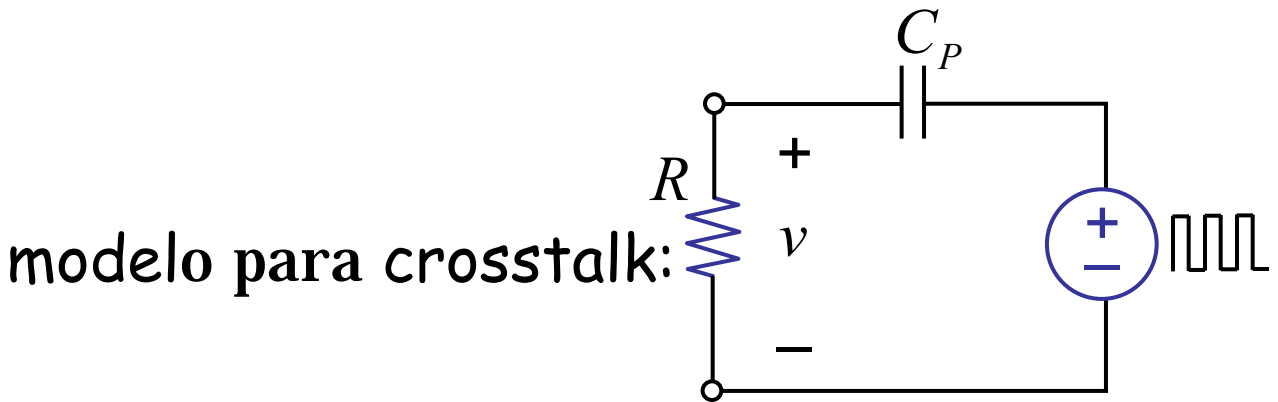
¿Por qué? Considere ...



Caso (2)

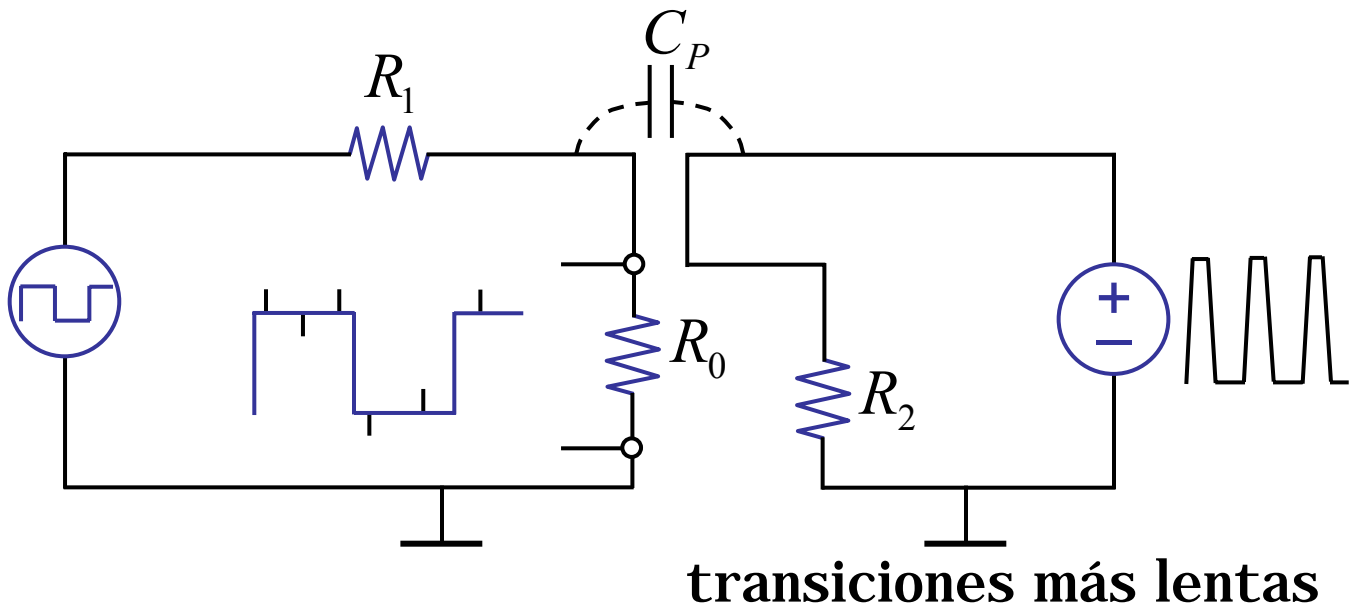


superposición de sonidos (*crosstalk*)



## Caso ③

...un experto del curso 6.002 vio la solución



Análisis detallado en la clase de repaso.