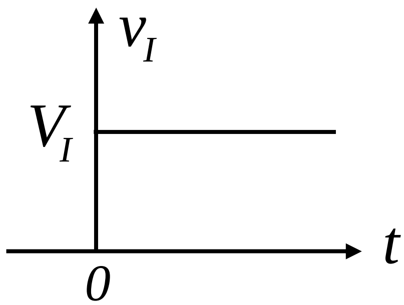
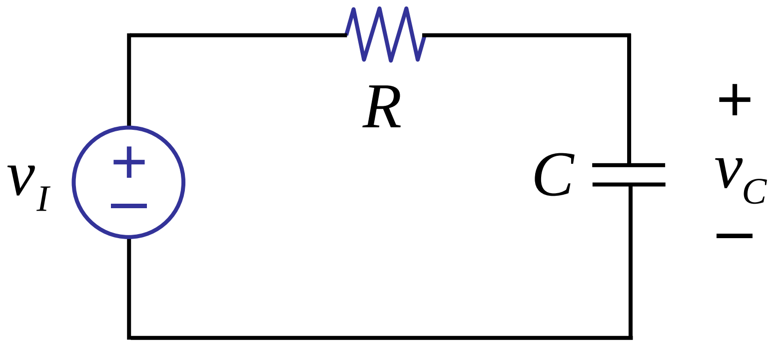
Digital Circuit Speed

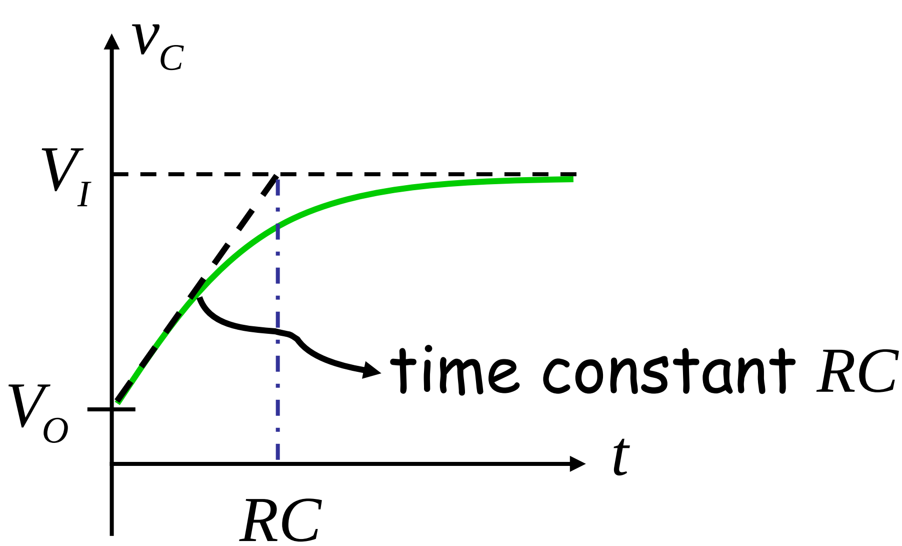
Review



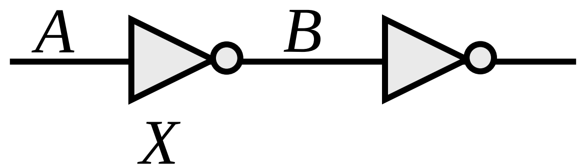


$$v_C(0) = V_O$$

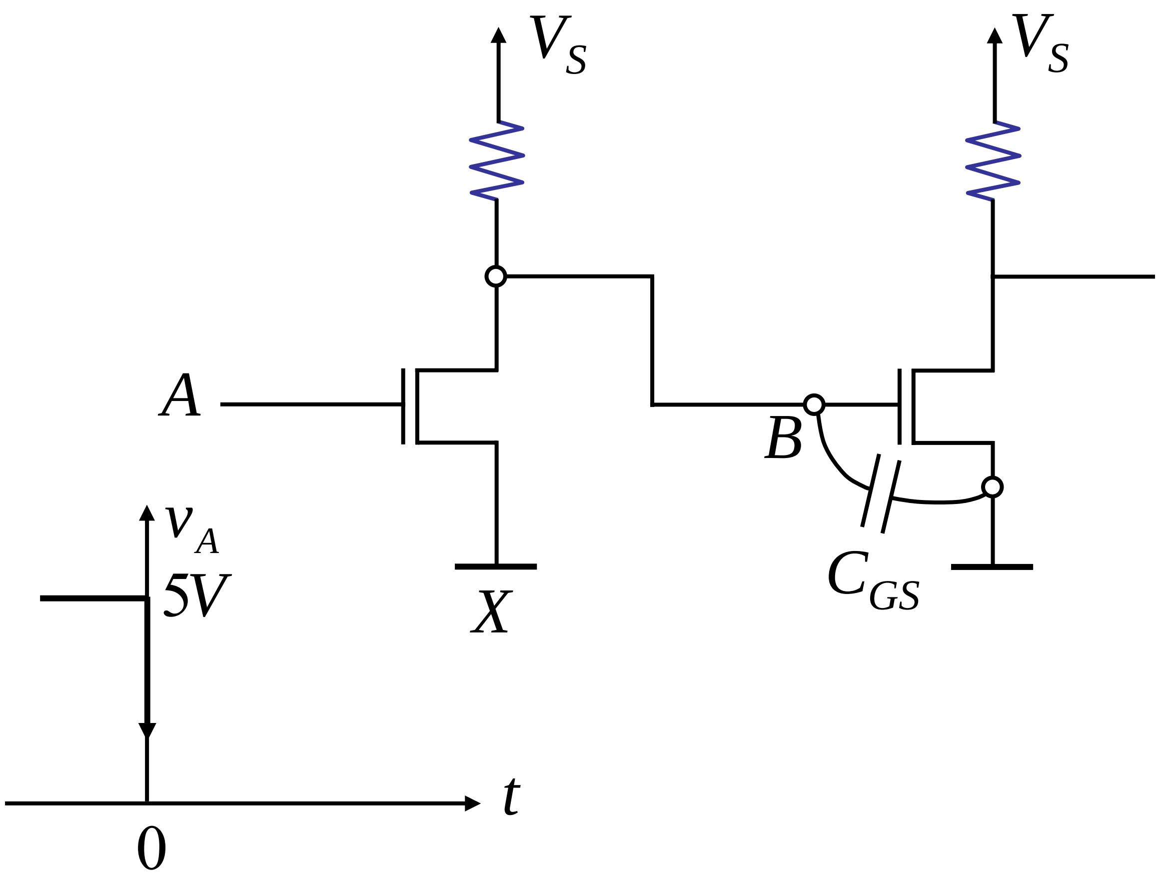
$$v_C = V_I + (V_O - V_I)\, e^{\frac{-t}{RC}} \qquad \text{①}$$



Let's apply the result to an inverter.

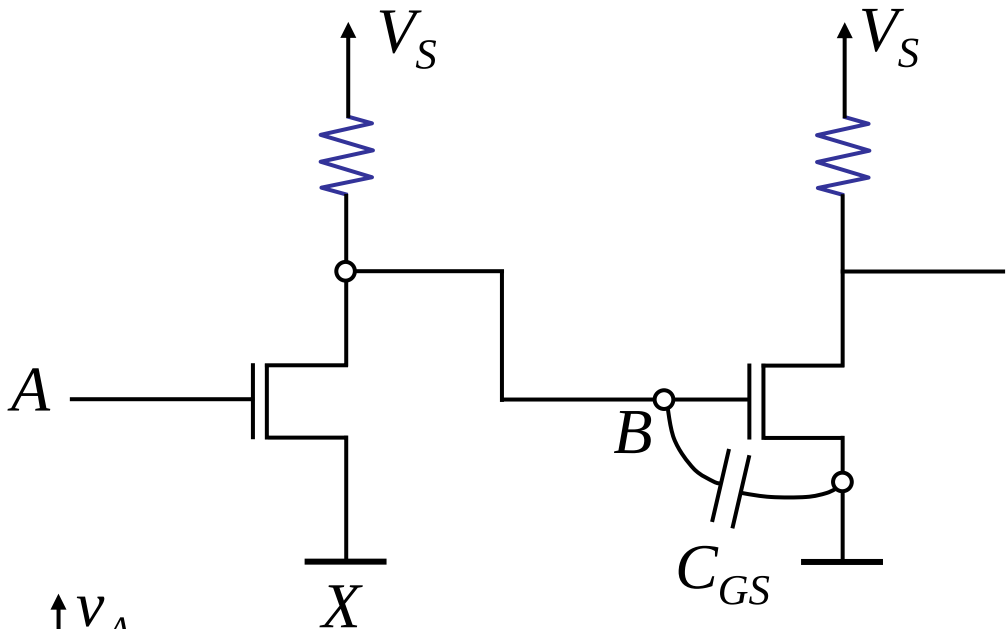


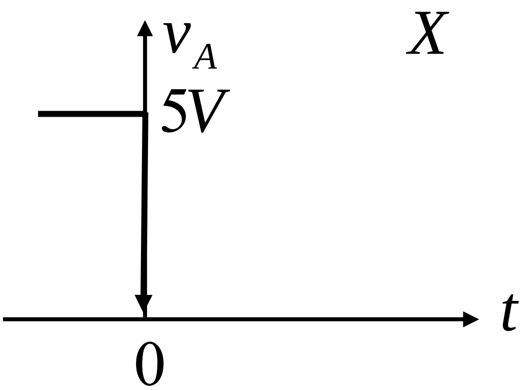
First, rising delay t_r at B



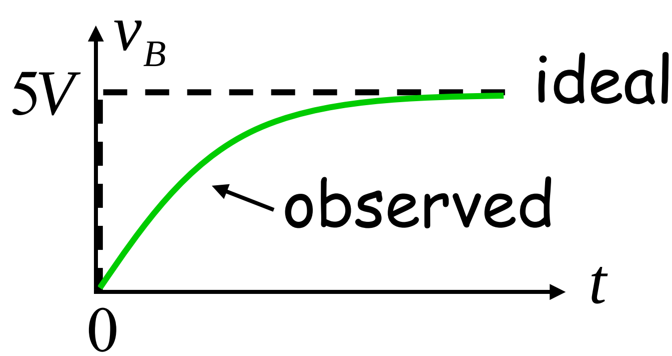
$1 \rightarrow 0$ at A

First, rising delay t_r at B

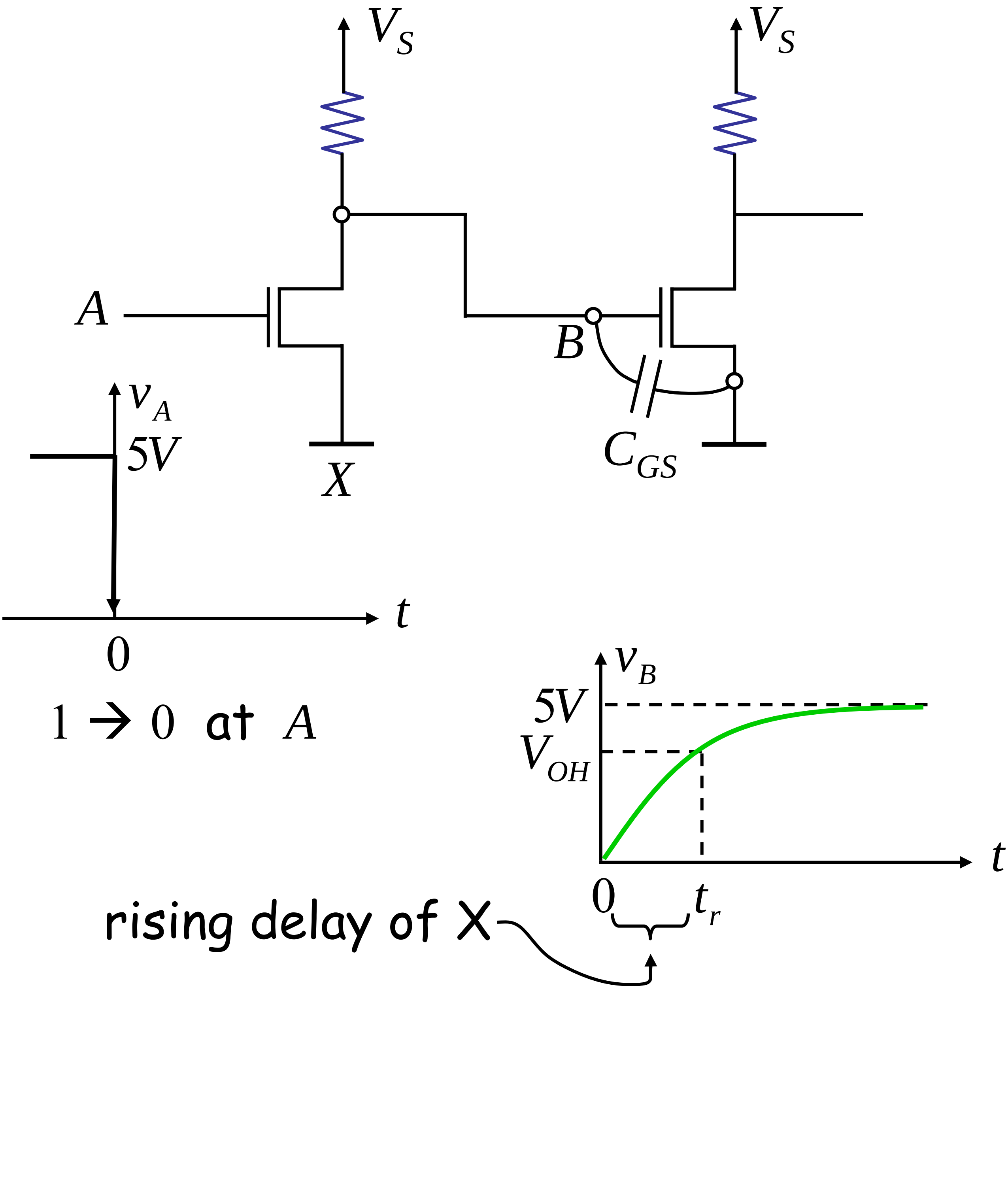




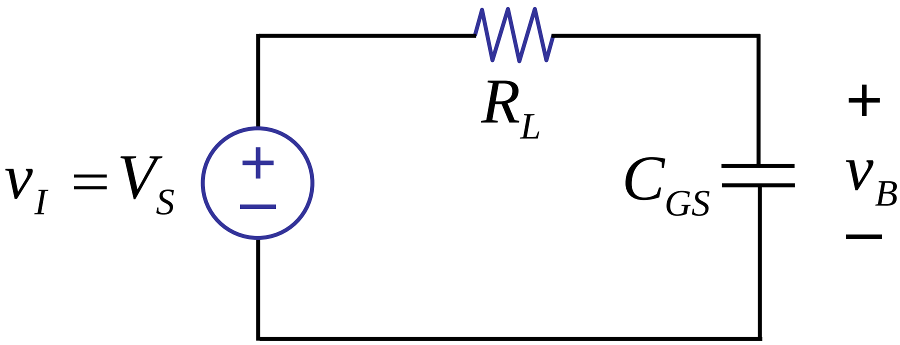
$1 \rightarrow 0$ at A



First, rising delay t_r at B



Equivalent circuit for 0→1 at B



$$v_I = V_S$$

$$v_B(0) = 0$$

for $t \geq 0$

From ①

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

Now, we need to find t for which $v_B = V_{OH}$.

Or

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

Find t_r :

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

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

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

Or

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

Find t_r :

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

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

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

e.g. $R_L = 1K$ $V_S = 5V$

$C_{GS} = 0.1\, pF$ $V_{OH} = 4V$

$$t_r = -1 \times 10^3 \times 0.1 \times 10^{-12} \ln \frac{5-4}{5}$$

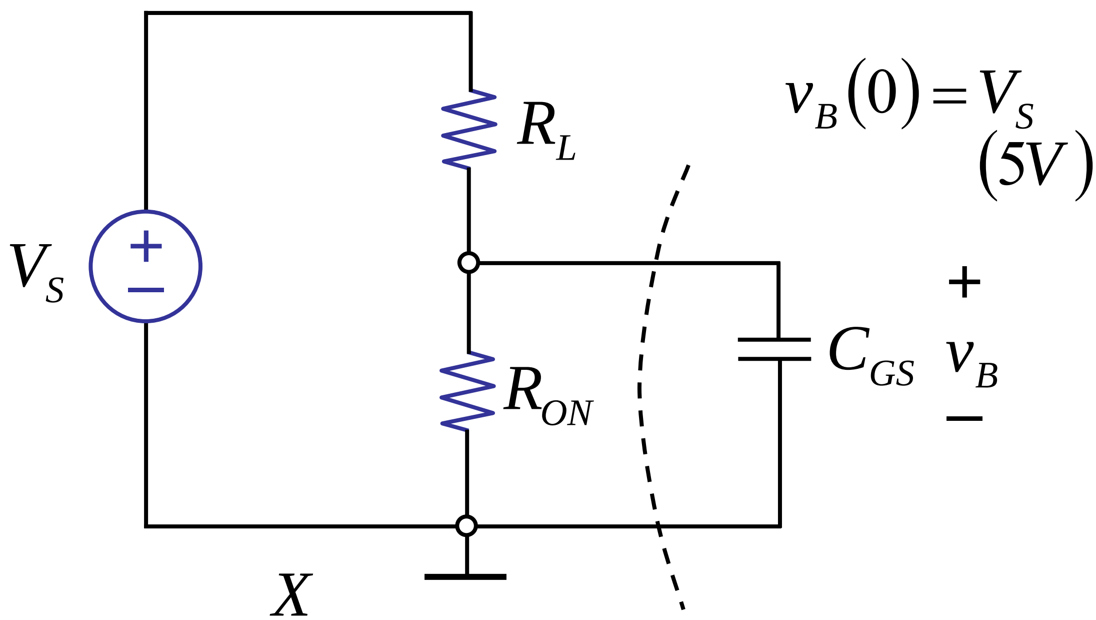
$$= 0.16\, ns$$

$$RC = 0.1\, ns\,!$$

Falling Delay t_f

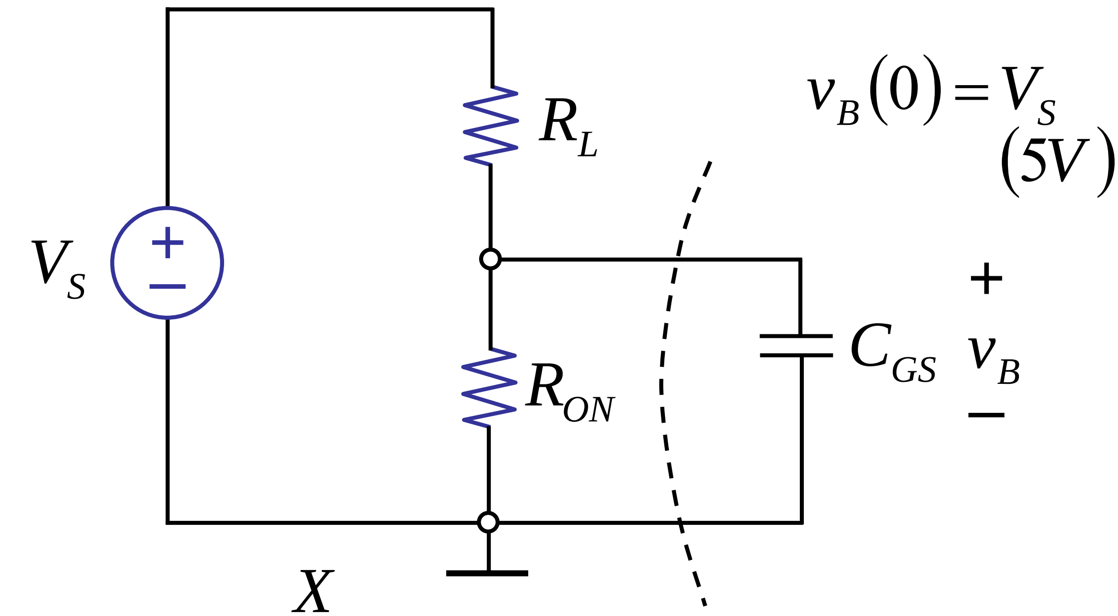
Falling delay t_f is
the t for which v_B falls to V_{OL}

Equivalent circuit for 1 → 0 at *B*

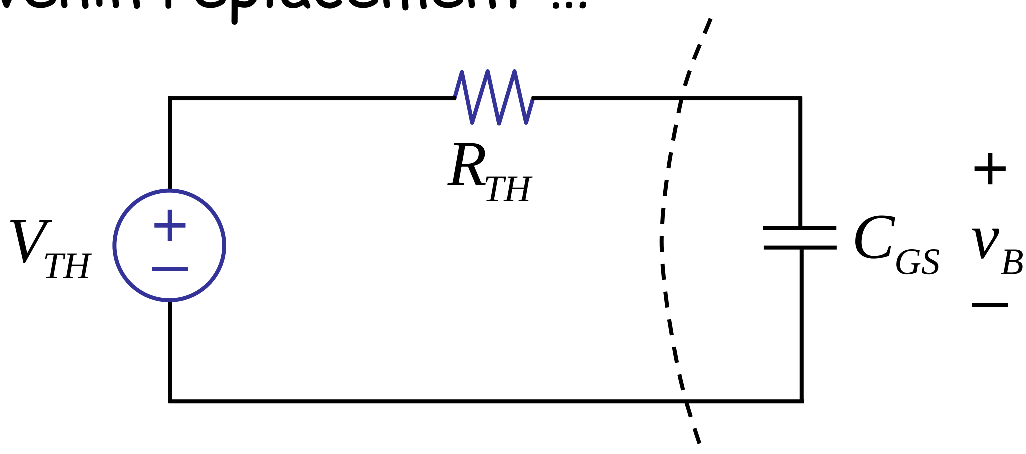


Falling Delay t_f

Equivalent circuit for $1 \to 0$ at B



Thévenin replacement ...



$$R_{TH} = R_L \,||\, R_{ON}$$

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

From ①

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

Falling decay t_f is
the t for which v_B falls to V_{OL}

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

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

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

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

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

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

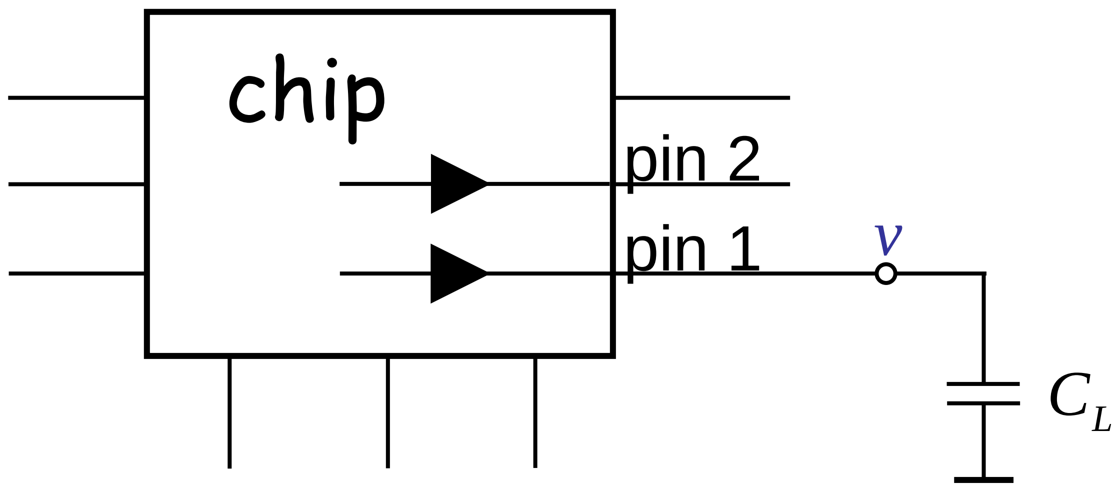
$$t_f = -10 \cdot 0.1 \cdot 10^{-12} \ln \frac{1}{5}$$

$$= 1.6\,ps$$

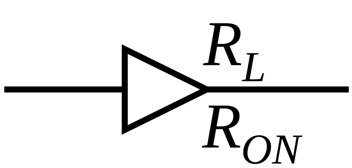
$$RC = 1\,ps\,!$$

For recitation: Slow may be better

Problem

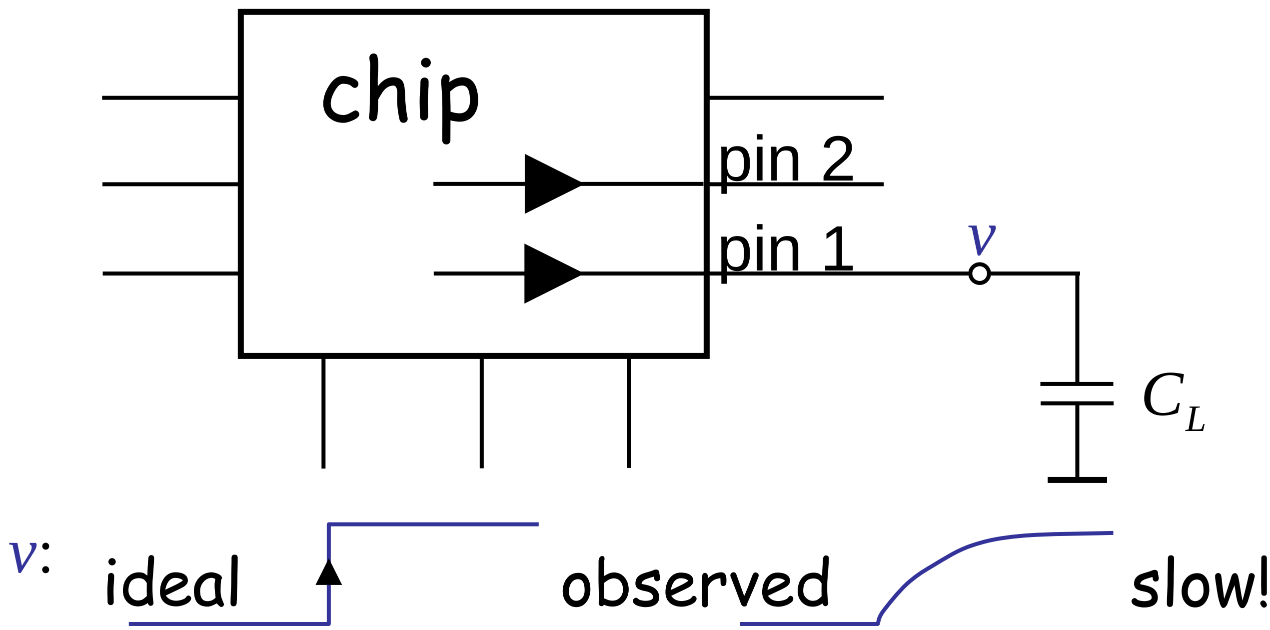


So the engineers decided to speed it up…

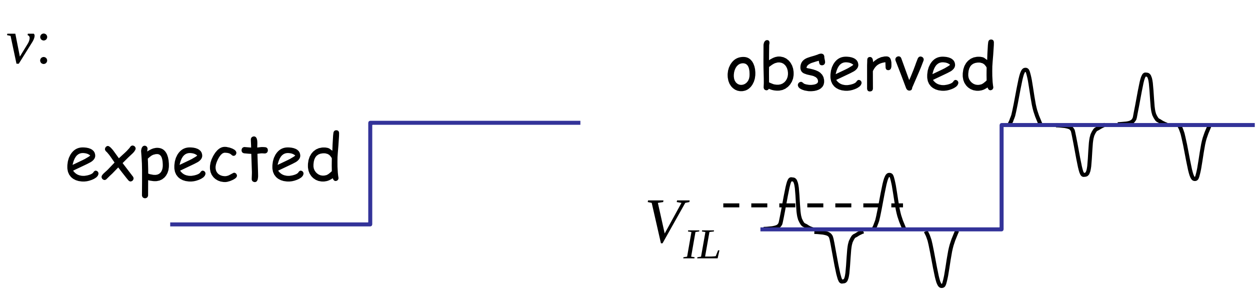


made R_L small
made R_{ON} small

For recitation: Slow may be better Problem

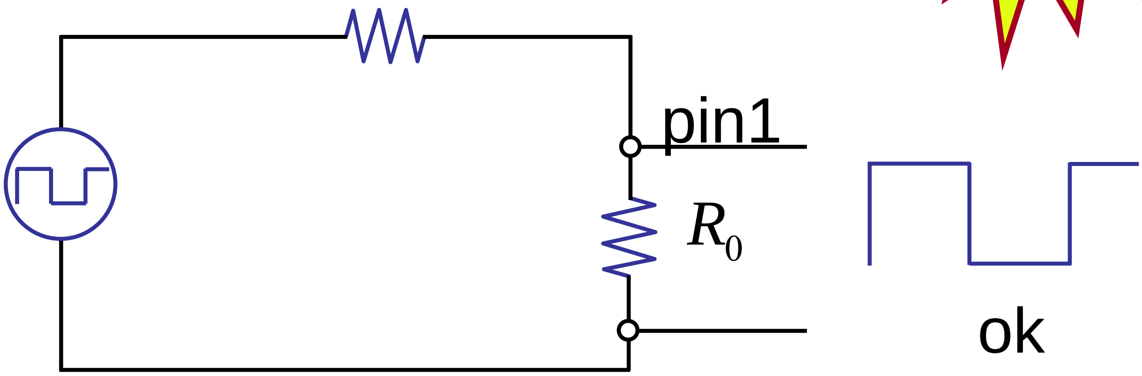


... but, disaster!



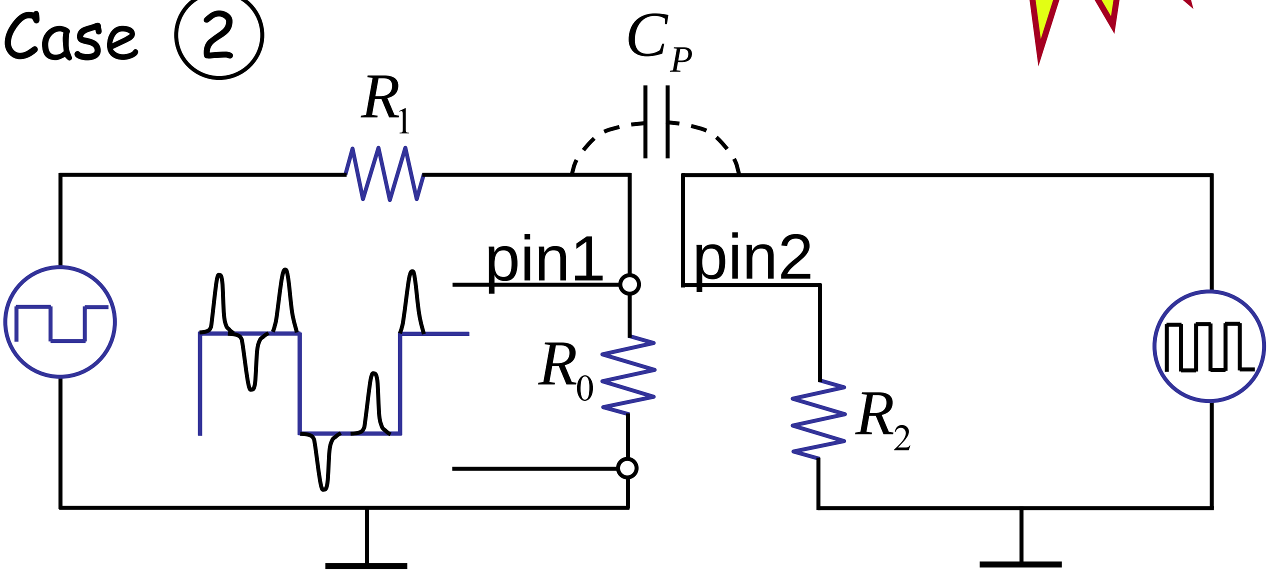
Why? Consider ...

Case ①



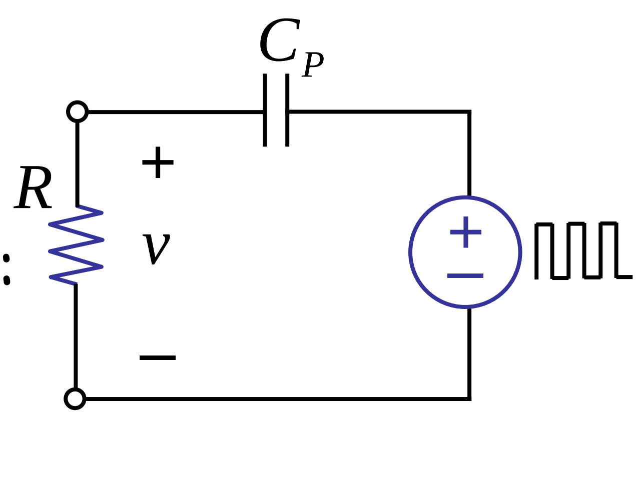
Why? Consider ...

Case ②



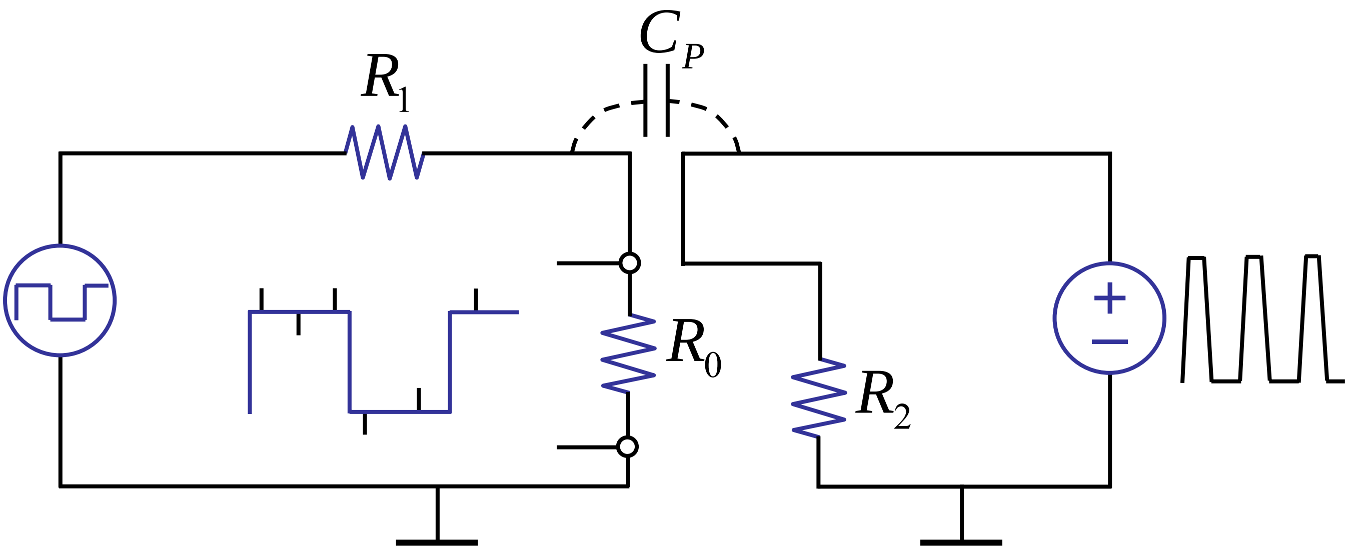
crosstalk!

model for crosstalk:



Case ③

... 6.002 expert saw the solution



slower transitions!

Detailed analysis in recitation.