3C2 - Simulation Lab

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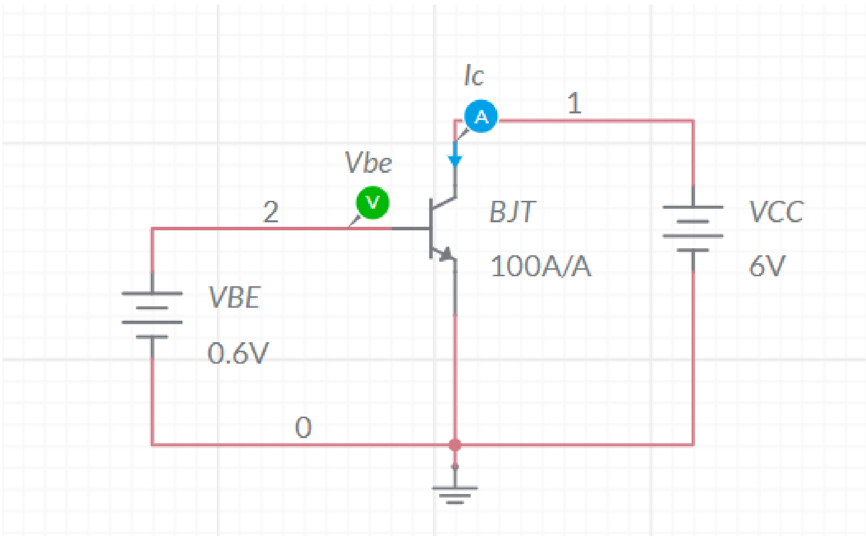
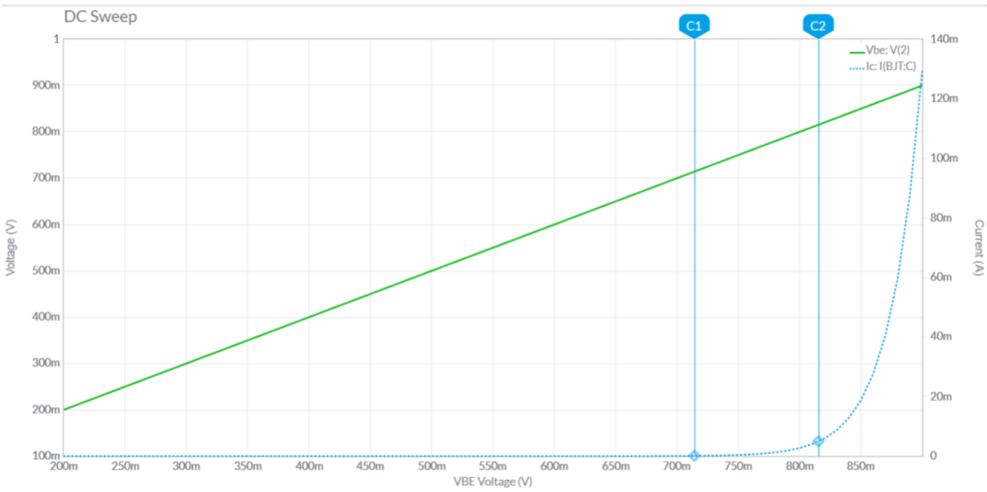
Bipolar Junction Transistor Current-Voltage Characteristic

1. Plot the collector current (IC) against the base-emitter voltage (VBE).



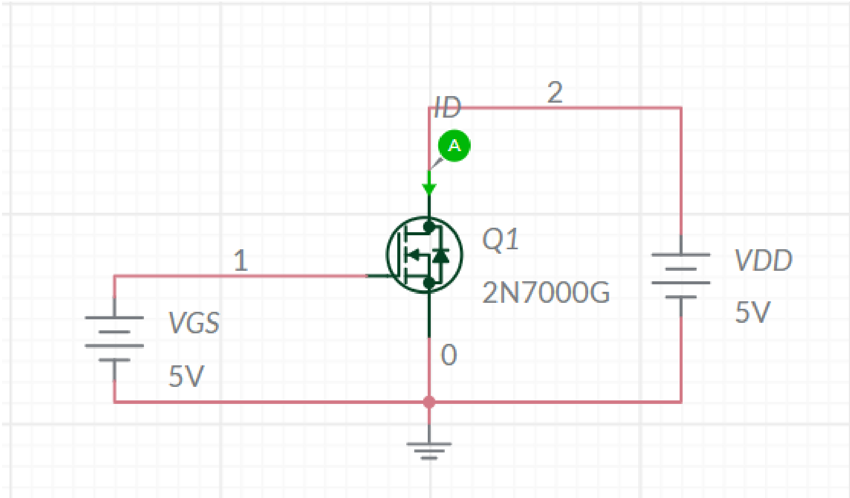


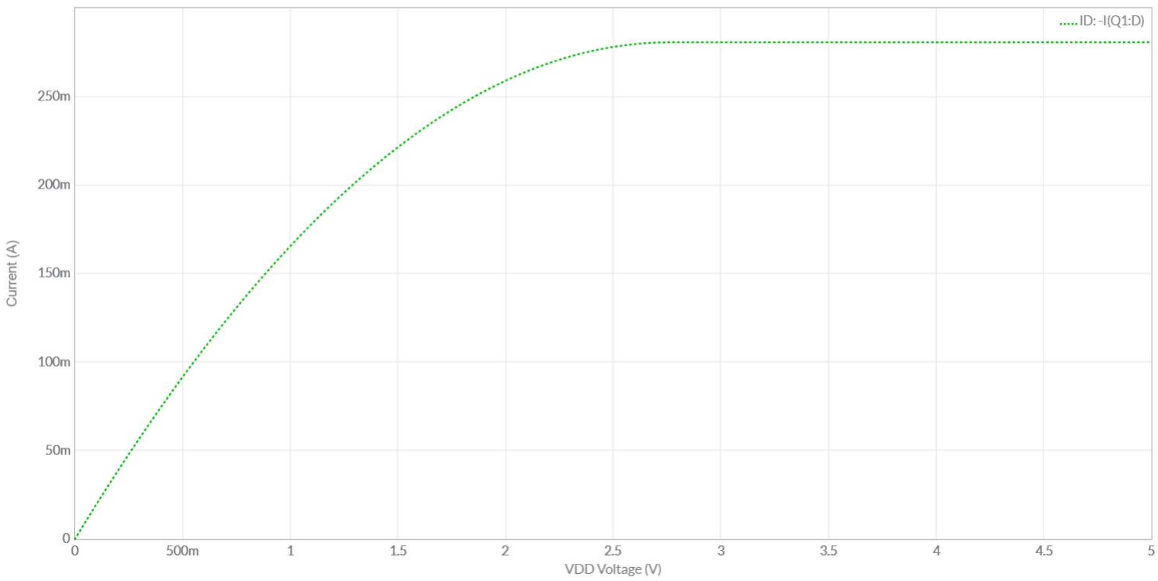
2. Find the two voltages:

$V_{BE}^{cut\ in}(@100.00\ \mu A) = 714.18\ mV$ $\qquad$ $V_{BE}^{on}(@5.00\ mA) = 815.36\ mV$

Transistor Characteristics

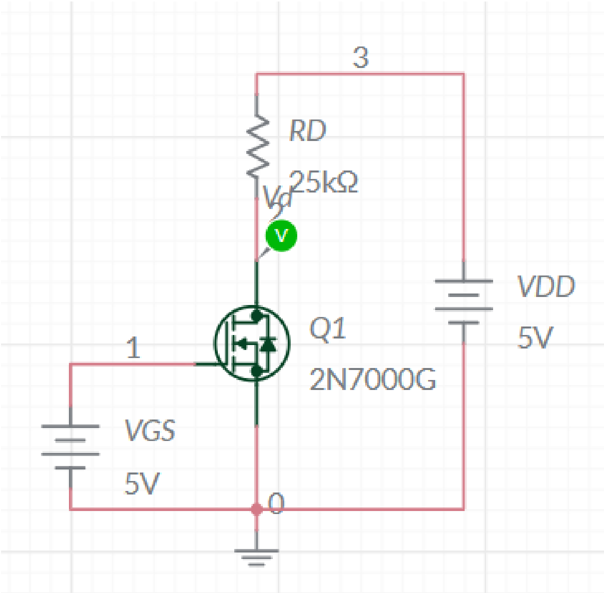
1. Plot ID against VDD.

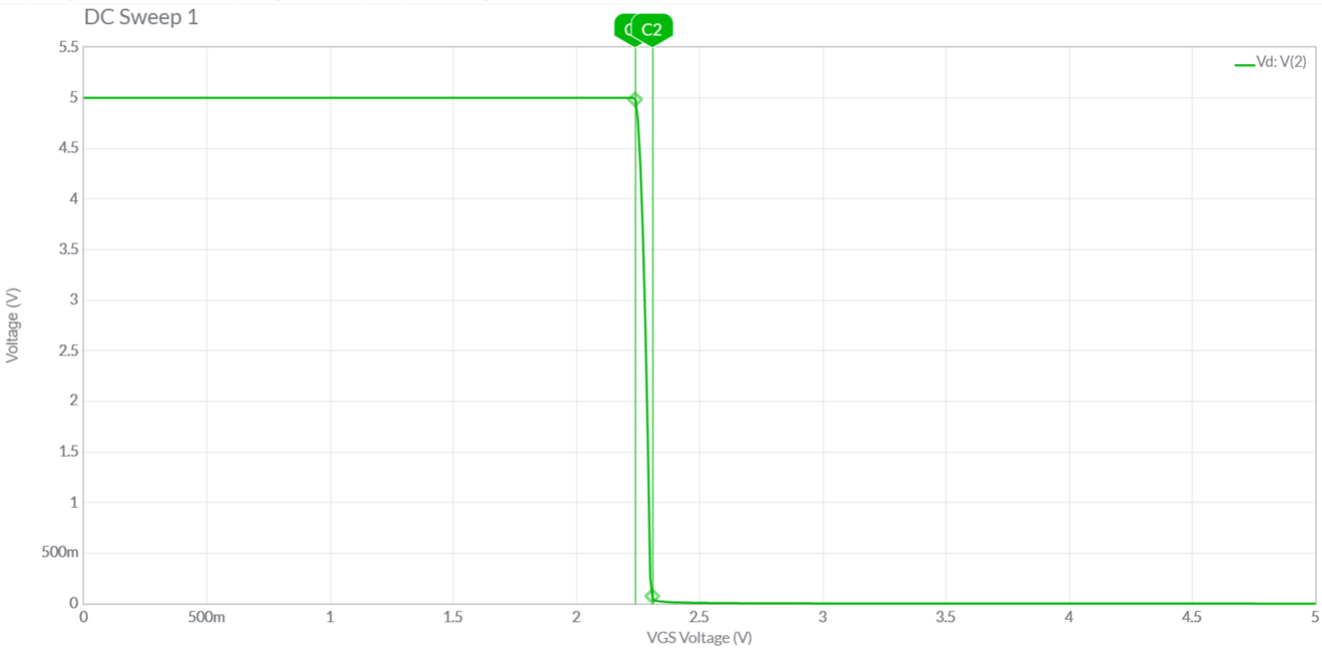




Resistor Load Inverters

-NMOS Inverter





1. Are the outputs as expected?

"For VGS < VT, VO should be VDD"

- While V_{GS} is at 0V, V_O (represented by the y-axis) remains at 5V, and is equal to V_{DD} as expected.

" "

For $V_{GS} = V_{DD}$, V_O should be

$$(V_{DD} - V_T + \frac{1}{kR_D}) \pm \sqrt{(V_{DD} - V_T + \frac{1}{kR_D})^2 - \frac{2V_{DD}}{kR_D}}$$

$V_{DD} = 5V$ $\quad V_{GS} = 5V$ $\quad R_D = 25k\Omega$

$k = g_{fs}(datasheet(1)) = 0.6$ $\quad V_T \approx 2.2299\text{V}(approx.\,from\ graph)$

$$V_O \approx \left(5 - 2.2299 + \frac{1}{(0.6)(25000)}\right) \pm \sqrt{\left(5 - 2.2299 + \frac{1}{(0.6)(25000)}\right)^2 - \frac{2(5)}{(0.6)(25000)}}$$

$$\approx 2.770166 \pm 2.770046$$

$$\therefore V_O \approx 2.77V \pm 2.77V$$

<u>Voltage Levels (Measured using cursors)</u>

$V_{IL} = 2.2395V$

$V_{IH} = 2.31V$

$V_{OL} = 39.838\ mV$

$V_{OH} = 4.9823V$

<u>Voltage Levels (Theoretical)</u>

$$V_{IL} = V_T + \frac{1}{2(K_n)(R_D)}$$

$$\approx 2.2299 + \frac{1}{2(0.6)(25000)}$$

$$\approx 2.229933$$
$$\therefore V_{IL} \approx 2.229V$$

$$V_{IH} = V_T + 2\sqrt{\frac{V_{DD}}{3(K_n)(R_D)}} - \frac{1}{2(K_n)(R_D)}$$

$$\approx 2.2299 + 2\sqrt{\frac{5}{3(0.6)(25000)}} - \frac{1}{2(0.6)(25000)}$$

$$\approx 2.25094$$

$$\therefore V_{IH} \approx 2.25V$$

$$V_{OL} = \sqrt{\frac{V_{DD}}{3(K_n)(R_D)}}$$

$$= \sqrt{\frac{5}{3(0.6)(25000)}}$$

$$= 0.0105V$$

$$\therefore V_{OL} = 10.5mV$$

$$V_{OH} = V_{DD} - \frac{1}{4(K_n)(R_D)}$$

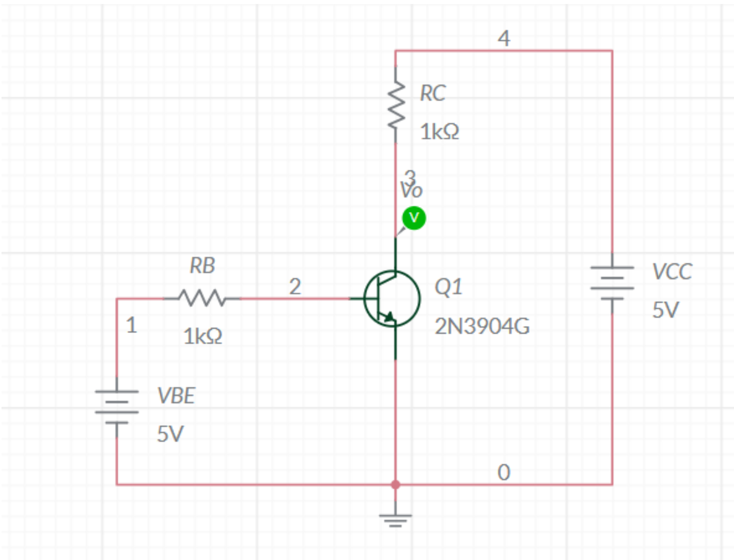
$$= 5 - \frac{1}{4(0.6)(25000)}$$

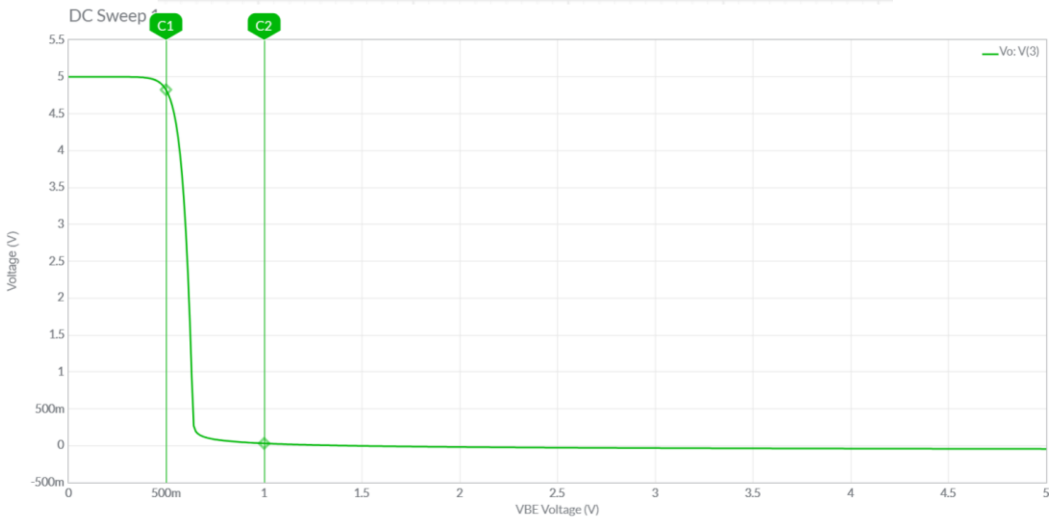
$$= 4.99998$$

$$\therefore V_{OH} = 4.99V$$

The voltage levels found using the cursors roughly match the values derived using the theoretical methods

- NPN BJT Inverter





Critical Voltages (Measured using cursors)

$V_{IL} = 497.8mV$

$V_{IH} = 1V$

$V_{OL} = 29.917mV$

$V_{OH} = 4.8157V$

Critical Voltages (Circuit Theory)

$V_{BE} = 5V$ $V_{CC} = 5V$ $R_B, R_C = 1k\Omega$ $B_f = h_{FE}\big(datasheet(2)\big) = 300$

$V_{IL}^{MAX} = V_{BE}^{CUT-IN} \sim 0.6V\ (L10: BJT\ Applications)$

$$V_{IH}^{MIN} = V_{BE}^{SAT} + \frac{R_B}{\mathrm{\beta_F R_C}}(V_{CC} - V_{CE}^{SAT})$$

$V_{BE}^{SAT} \sim 0.8V\ (L10: BJT\ Applications)$ $V_{CE}^{SAT} \sim 0.2V\ \big(datasheet(2)\big)$

$V_{IH}^{MIN} = 0.8 + \frac{1000}{(300)(1000)}(5 - 0.2)$

$\therefore V_{IH}^{MIN} = 0.816V$

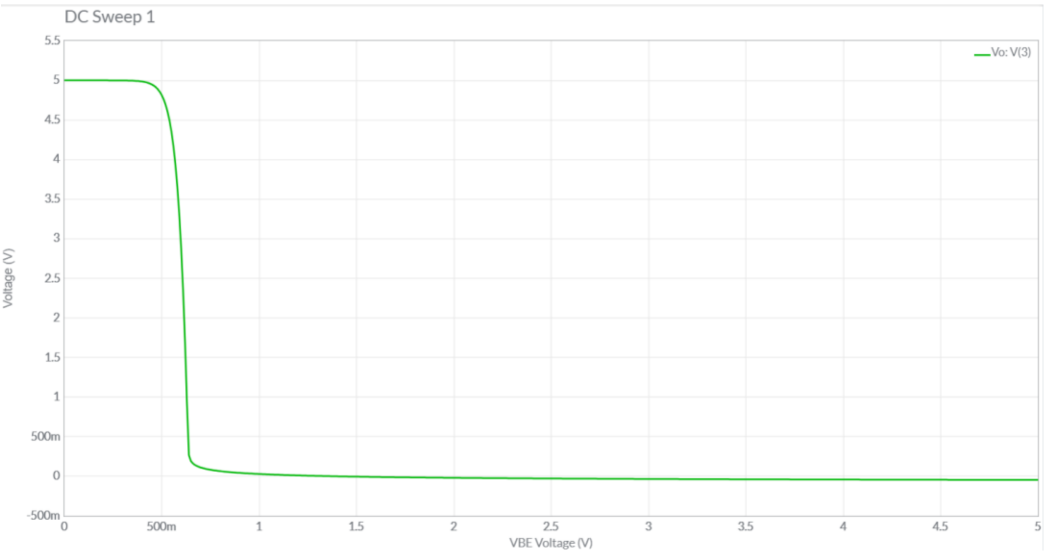
$$V_{OL} = V_{CE}^{SAT}(L10: BJT\ Applications)$$

$\therefore V_{OL} = 0.2V$

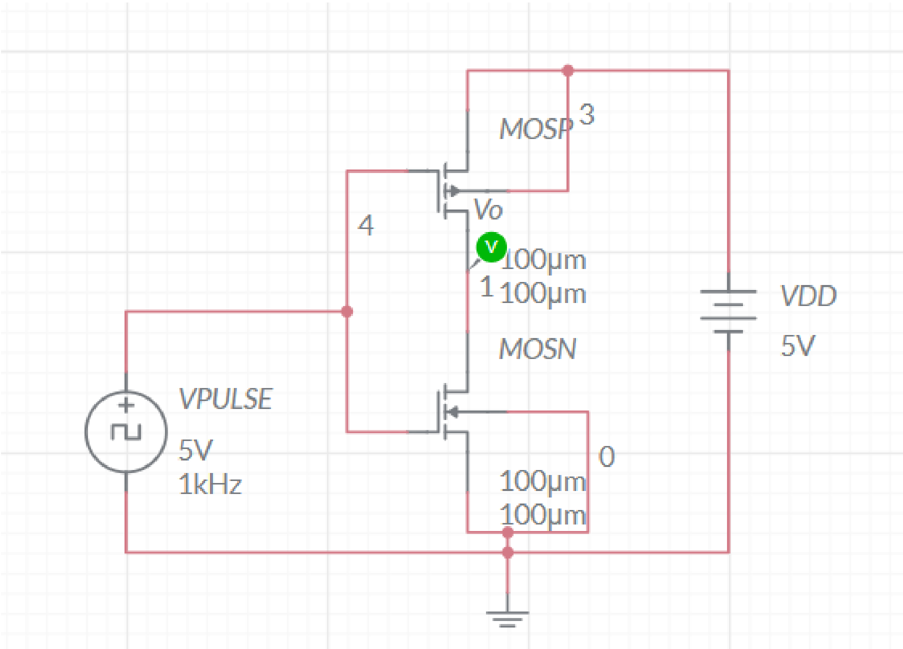
$$V_{OH} = V_{CC}(L10: BJT\ Applications)$$

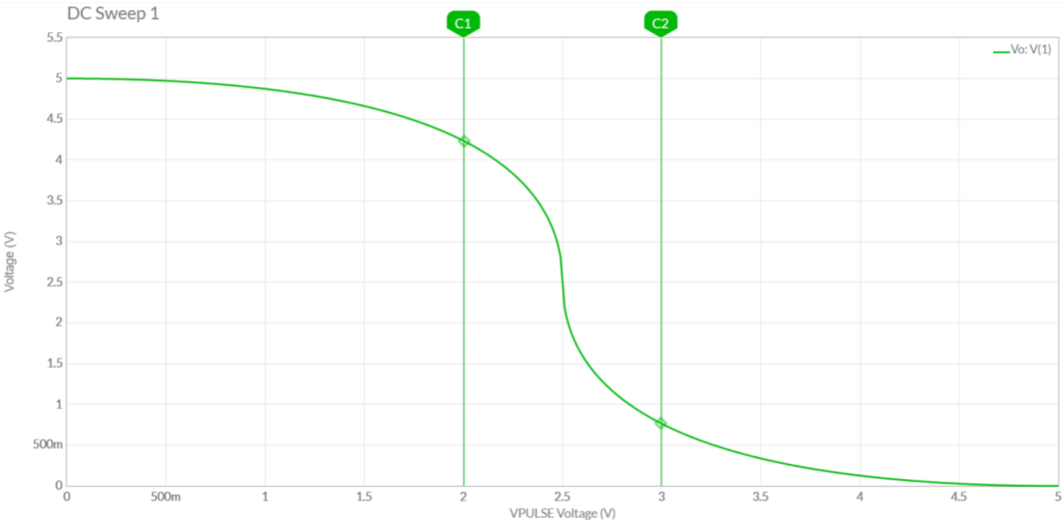
$\therefore V_{OH} = 5V$

$@R_C = 4k\Omega$



CMOS Inverter





Critical Voltages (Measured using cursors)

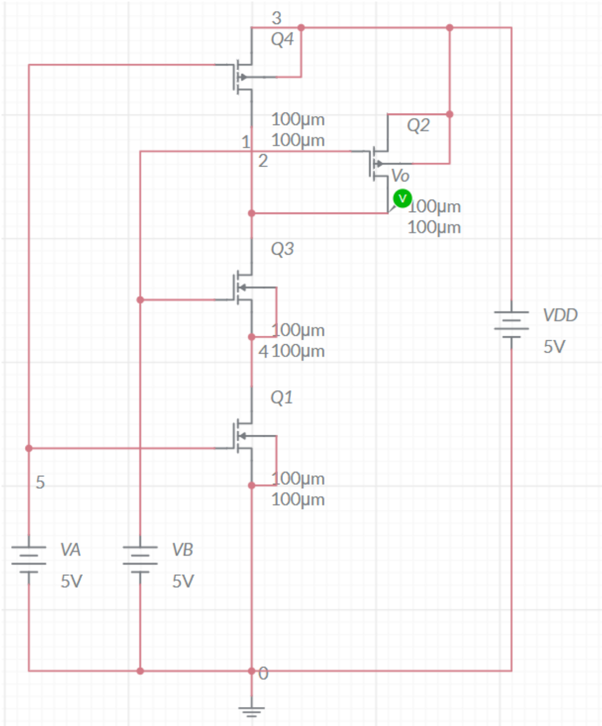
$V_{IL} = 2.0044V$

$V_{IH} = 2.9956V$

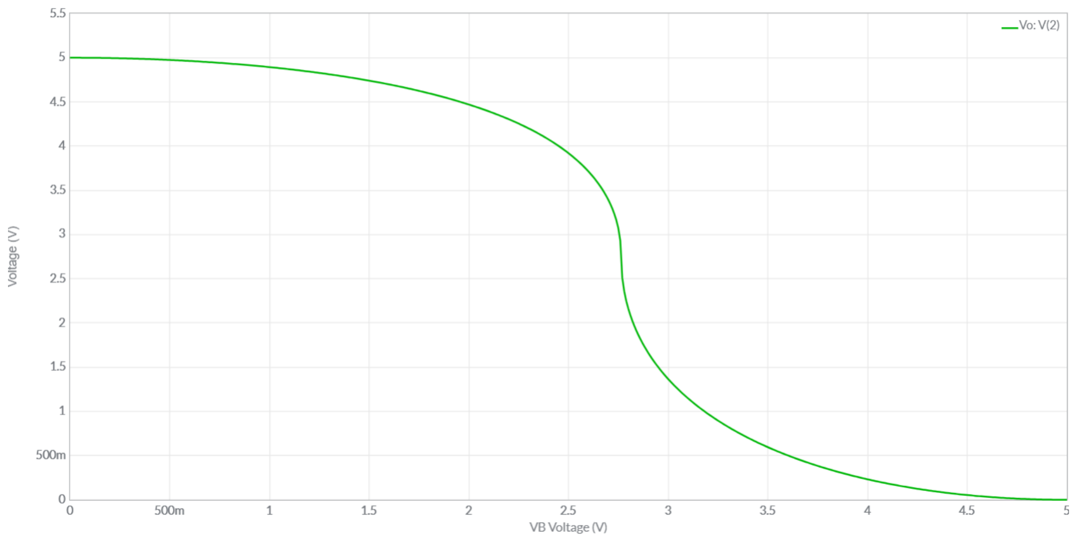
$V_{OL} = 769.43mV$

$V_{OH} = 4.2306V$

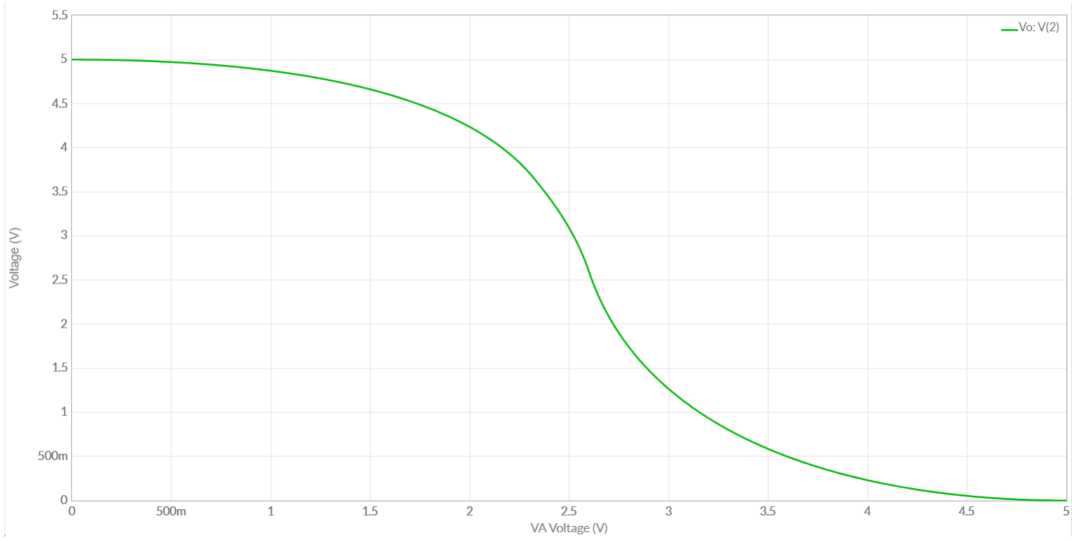
CMOS NAND Gate



• VB with VA = 5 V, plot VO against VB



• VA with VB = 5 V, plot VO against VA



The decline of the output voltage is more gradual in the in the VO/VA plot compared to the VO/VB plot, where the output sharply decreases when VB is within the range of 2.72V to 2.82V.

Datasheets

(2N7000)

1. https://www.st.com/resource/en/datasheet/cd00005134.pdf

(2N3904)

2. https://www.onsemi.com/pdf/datasheet/2n3904-d.pdf