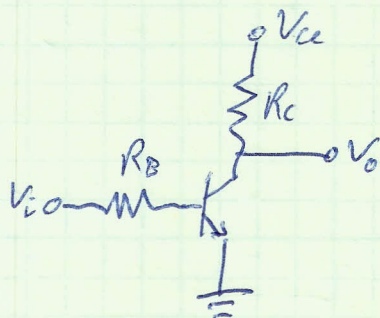
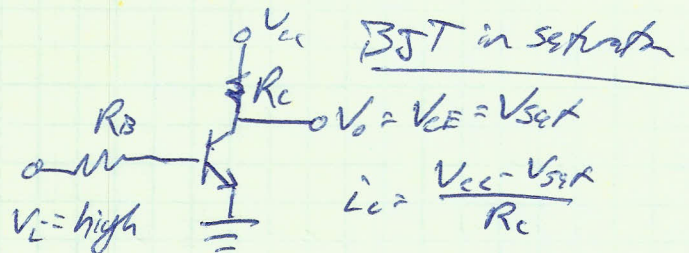
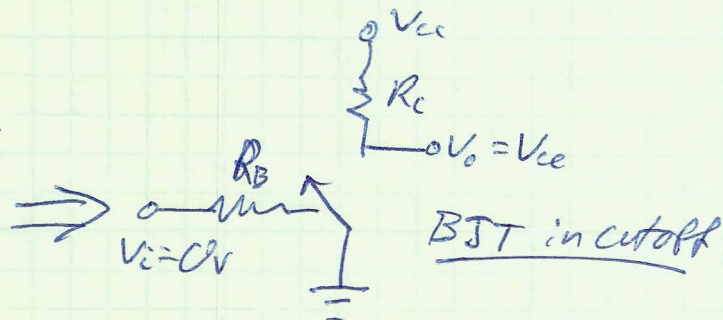


BJT Switches and Logic Gates

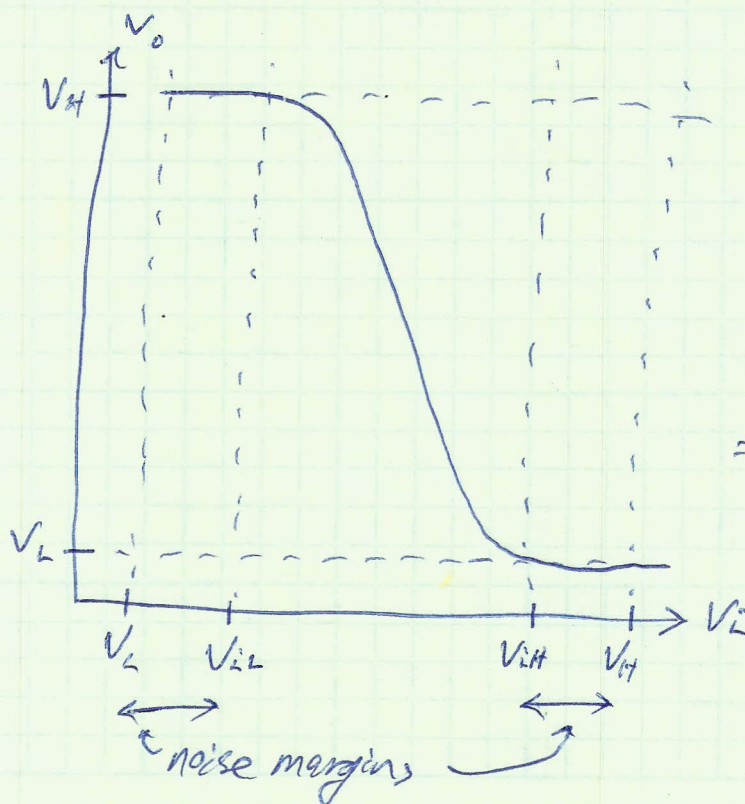


Basic element
(Inverter, or NOT gate)



- In computer science, logic, etc., "0" = "OFF", "1" = "ON"
- To design logic circuits, we need to worry about actual voltage
- Choose e.g. $V_L = 0V$, $V_H = 5V$
 - must consider noise margin in low and high states

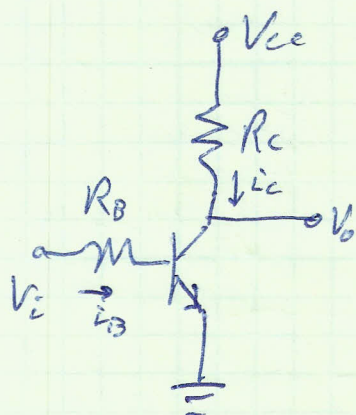
Transfer function of inverter:



low side noise margin
= range of inputs V_i
that still give $V_o = V_{Ht}$

high side noise margin
= range of inputs V_i
that still give $V_o = V_L$

Resistor - Transistor Logic (RTL)



Inverter circuit

low state $V_L = V_{sat} = 0.2V$

high state $V_H = V_{CC}$

Transfer function: (V_O for any V_I)

BE-KVL:

$$V_I = R_B I_B + V_{BE}$$

for $V_I < V_{DO}$, CUT-OFF, $I_C = 0$, $V_O = V_{CC}$ (high)

(when $V_I = V_L = V_{sat}$, $V_O = V_{CC} = V_H$)

output high as long as $V_I < V_{DO}$, $\rightarrow V_{OL} = V_{DO}$

- assume current just begins to flow at $V_I = V_{DO} \rightarrow I_B > 0$ but small

when $V_I > V_{DO}$, BE junction forward biased

$$I_B = \frac{V_I - V_{DO}}{R_B} \quad - \text{transistor either in active or saturation region}$$

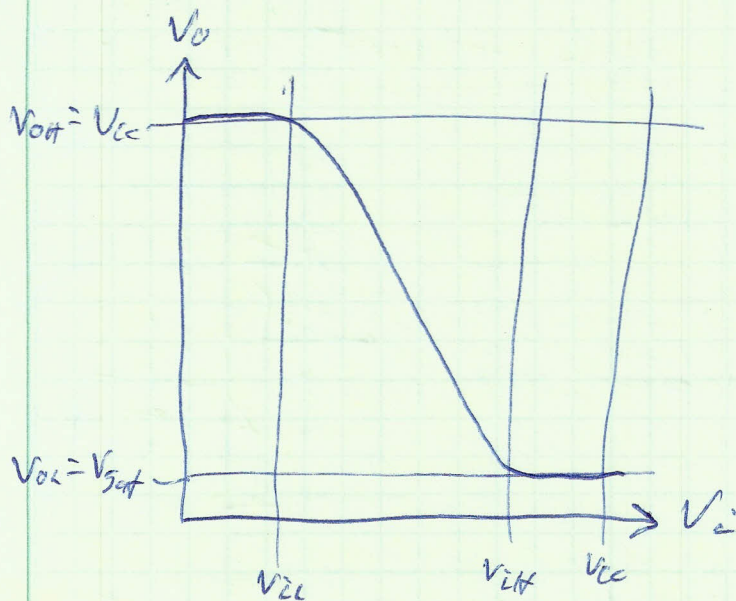
assume saturation: ($\frac{I_C}{I_B} < \beta$)

$$I_C = \frac{V_{CC} - V_{sat}}{R_C} \rightarrow I_B > \frac{I_C}{\beta} = \frac{V_{CC} - V_{sat}}{\beta R_C}$$

V_I required to keep transistor in saturation?

$$V_I = V_{DO} + R_B I_B > V_{DO} + R_B \frac{V_{CC} - V_{sat}}{\beta R_C} = V_{IH}$$

* choose R_B and R_C so that $V_{IH} < V_{CC}$



we can control this value with R_C, R_B

this value is fixed at $V_{DO} \approx 0.7V$

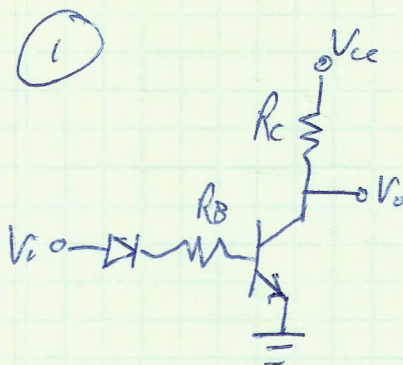
in reality, there will be some conduction at $V_i \approx 0.5V$

- Low side noise margin is only $V_{DO} - V_{sat} \approx 0.3 \text{ to } 0.5V$

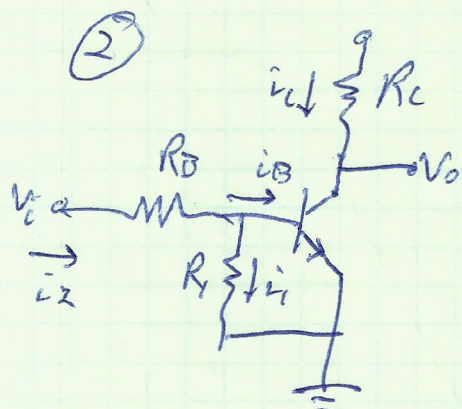
Two solutions:

$$V_i = R_B i_B + V_{BE}$$

1. add series diode to allow large voltage drop for small current
2. add shunt resistor to allow current in R_B to be $\gg i_B$



- Increases V_{IH} to $2V_{DO}$ (and we can add more diodes if necessary)
- Only works well in ICs, where diodes and transistors are matched
- For discrete devices, I_S saturation current 2-3 orders of magnitude larger in diodes than transistors
 - only gives $0.2-0.3V$ drop per diode



$$i_1 = \frac{V_{BE}}{R_1}$$

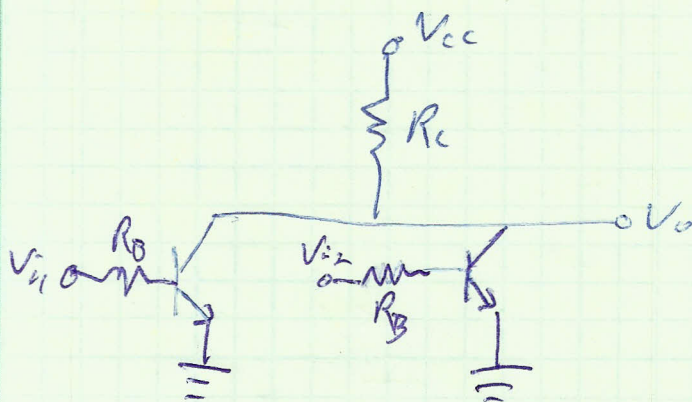
$$i_2 = i_B + i_1 \approx i_1 = \frac{V_{BE}}{R_1}$$

$$V_{IL} = R_B i_2 + V_{BE} = V_{BE} \frac{R_B}{R_1} + V_{BE}$$

$$V_{IL} = V_{DO} \left(1 + \frac{R_B}{R_1} \right)$$

- for $R_1 = R_B$, we can increase V_{IL} from 0.7 to 1.4 V
- we can now determine V_{IL} and V_{IH} arbitrarily
- typically, R_1 does not affect V_{IH}
 - i_B needed for saturation is several times higher than i_1

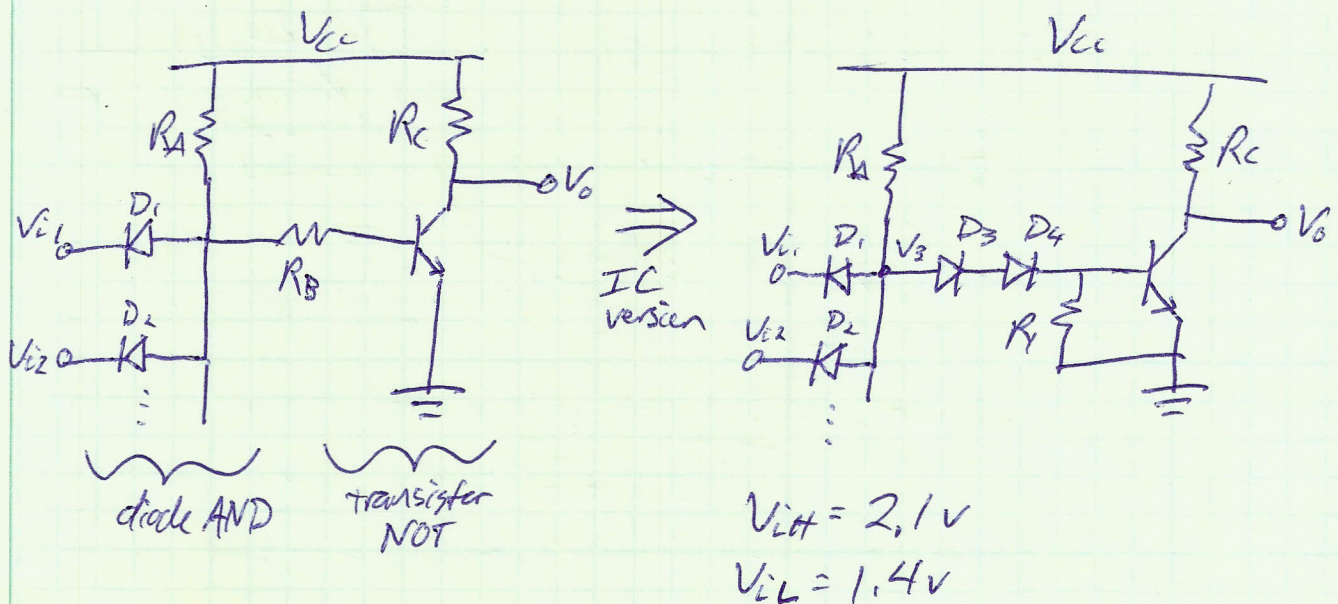
RTL NOR gate:



- RTL - first digital logic circuits using transistors
- replaced by diode-transistor logic DTL and transistor-transistor logic TTL or emitter-coupled logic ECL
- BJT logic is now rarely used because we have CMOS

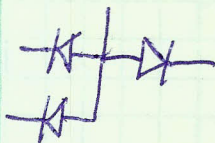
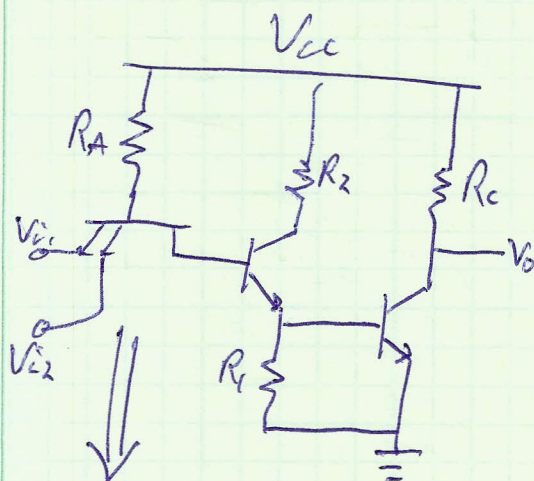
Diode Transistor Logic (DTL) NAND gate

- constructed with Diode AND + transistor inverter



- R_I is necessary to keep voltage across D_3 and D_4 at $0.7V$ otherwise current i_B will not be enough, and voltage across each of the junctions will be $\approx V_3/3$
- Remember, there are 2 current paths - to input, and to output through R_A

Transistor-Transistor Logic (TTL)



multiple-emitter transistor

