CHAPTER TWO

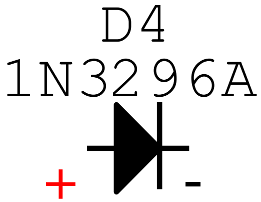
Diodes

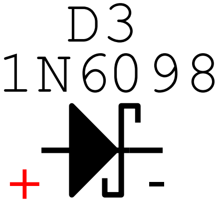
Digital Electronics.

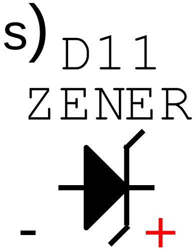
Introduction

- Types of diodes:
  - PN-junction (p-type & n-type)
  - Schottky (metal & n-type)
    (*MN diodes*) (but not all metals)
  - Zener (P^+N^+-junction)

Barrier







- Applications of diodes:
  - Variable capacitors
  - DC voltage level-shifting (faster switching speed)

Diode Modelling

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- Schockly's current-voltage characteristics:

$$I_D = I_S\left(\exp\left\{\frac{V_D}{\phi_T}\right\}-1\right)$$

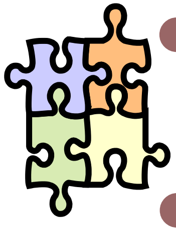
Thermal voltage : =25.9mV @ 300K

$$\phi_T = \frac{kT}{q}$$

T → Temerature [K]

q → Elementary charge=$1.6\text{x}10^{-19}$ [C]

k → Boltzmann's constant=$1.38\text{x}10^{-23}$ [J/K]



- Example

Using Schockly's expression, determine the diode current for V_D=0.1, 0.2, 0.5, 0.7, 0.8,1, 1.1; assuming $I_S=10^{-14}$ A.

- Solution

$I_D(V_D=0.1)$=465 fA

$I_D(V_D=0.2)$=22.6 pA

$I_D(V_D=0.5\ )$=2.42 μA

$I_D(V_D=0.7\ )$=5.47 mA

$I_D(V_D=1.1)$=27.9 kA

$I_D(V_D=0.8\ )$=260 mA

f,	p,	n,	μ,	m
-15,	-12,	-9,	-6,	-3

!Diode is damaged

Practical for IC devices

Diode Modelling

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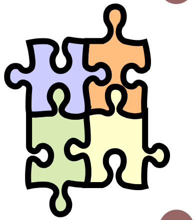
- Schockly‘s current-voltage characteristics:

$$I_D = I_S\left(\exp\left\{\frac{V_D}{\phi_T}\right\} - 1\right)$$

- Example



Using Schockly‵s expression, determine the diode current for V_D=-0.1, -0.2, -0.5, -0.8,-1, assuming $I_S=10^{-14}$ A.

- Solution

$I_D(V_D=-0.1)=-0.979\ I_S$

$I_D(V_D=-0.2)=-0.99956\ I_S$

$I_D(V_D=-0.5)=-0.999999996\ I_S$

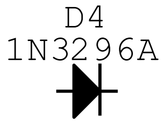
$$\boxed{I_D(V_D \geq 0.1) \approx I_S\left(e^{\frac{V_D}{\phi_T}}\right)}$$

$$\boxed{I_D(V_D \leq -0.1) \approx -I_S}$$

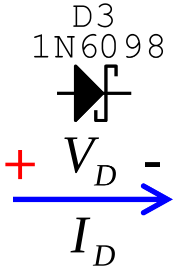
Diode Modelling

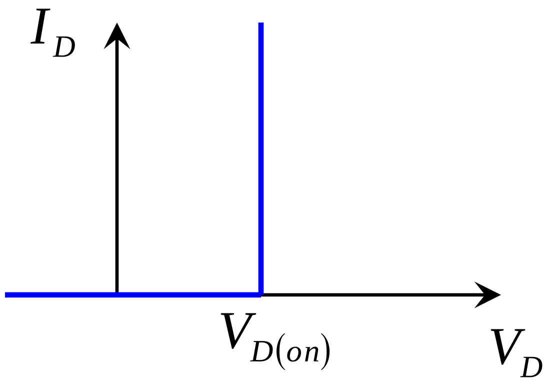
- Piecewise linear model:
  - Cutoff: $I_D = 0$ for $V_D < V_{D(on)}$
  - Conducting: $V_D = V_{D(on)}$ for $I_D > 0$

$V_{D(on)} = 0.7\,V$



$V_{D(on)} = 0.3\,V$





- Skip sections 2.3 & 2.4

Diode-Resistor Logic

- Consists only of diodes and resistors
- Performs AND and OR logic functions

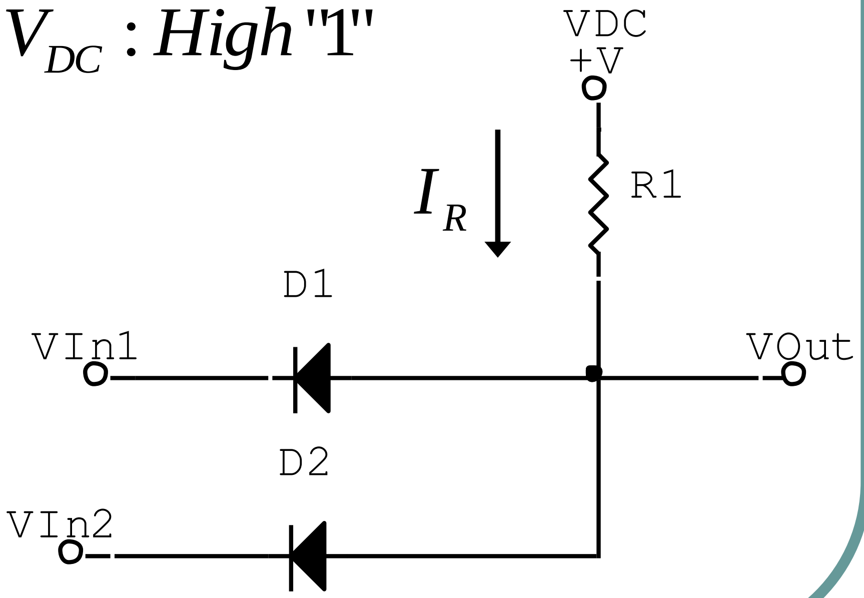
1. Diode AND gate

For $V_{in(1,2)} > V_{DC} - V_{D(ON)} \Rightarrow D_{(1,2)}$ is "OFF"

$$V_{in(1\&2)} : High\ "1" \Rightarrow V_{Out} = V_{DC} : High\ "1"$$

$$I_R = \begin{cases} 0; \\ \text{when } \underline{\text{both}} \text{ D}_1 \text{ and D}_2 \text{ are } OFF \\ \left(V_{DC} - V_{D_{ON}} - V_{In}\right)/R_1; \\ \text{when } \underline{\text{either}} \text{ D}_1 \text{ or D}_2 \text{ is } ON \end{cases}$$

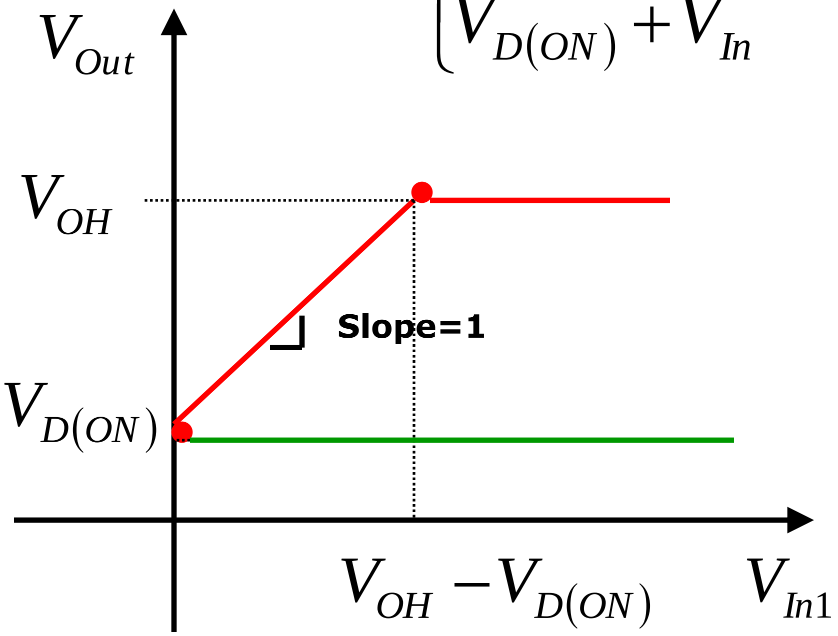
V1	V2	Vo
L	L	L
L	H	L
H	L	L
H	H	H

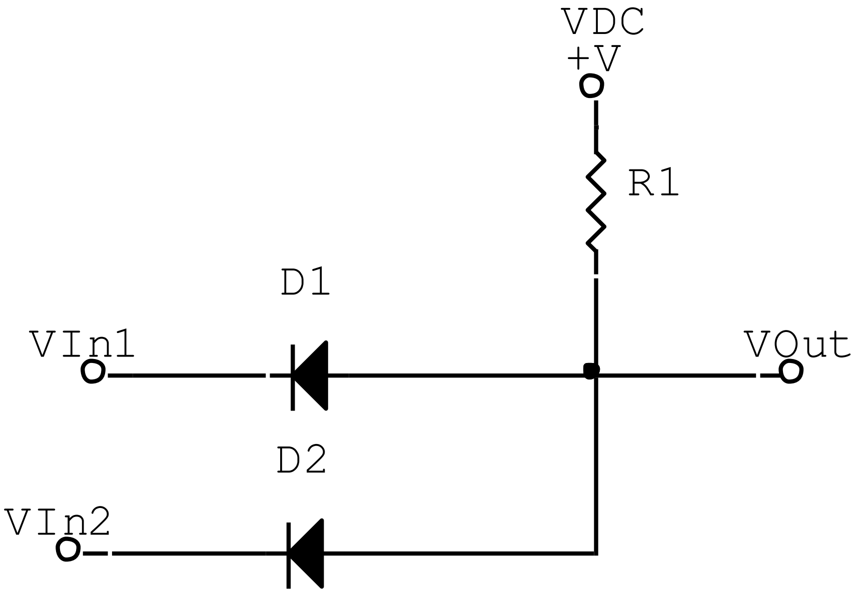


Diode-Resistor Logic

1. Diode AND gate

$$V_{Out} = \begin{cases} V_{DC} = V_{OH} \\ or \\ V_{D(ON)} + V_{In} \end{cases}$$





V_{In2} is high

V_{In2} is low $= 0V$

Diode-Resistor Logic

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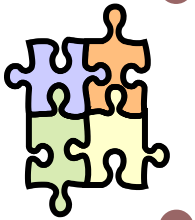


- **Example**

Show that if $V_{In1} \ge V_{In2} + 1$, then D_1 is cutoff

- **Solution**

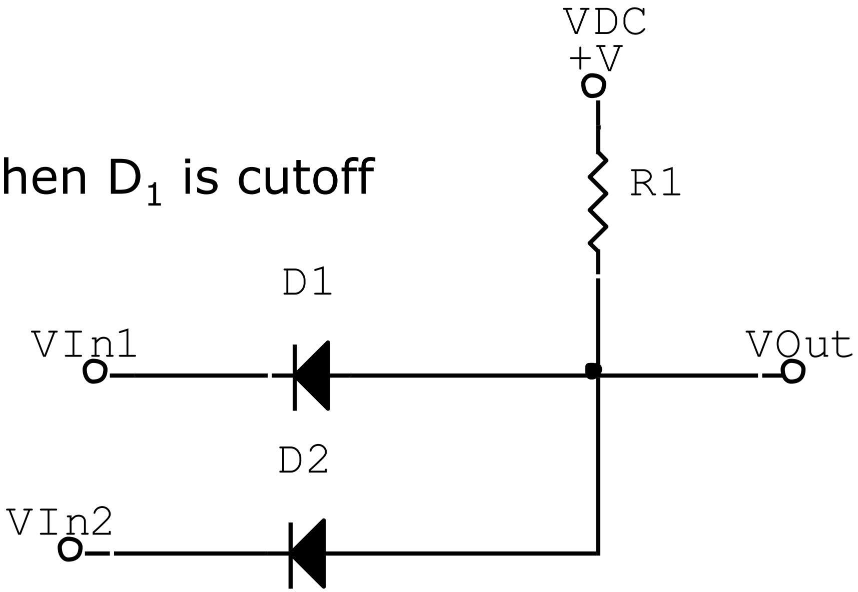
$$V_{Out1} = V_{D1} + V_{In1}$$

$$\ge V_{D1} + V_{In2} + 1$$

$$V_{Out2} = V_{D2} + V_{In2}$$

$$\boxed{\begin{array}{l} V_{Out2} = V_{Out1} \\ V_{D2} + V_{In2} \ge V_{D1} + V_{In2} + 1 \end{array}}$$

$$\boxed{V_{D2} \ge V_{D1} + 1}$$



If $V_{D1}= V_{D(on)}$ → $V_{D2} \ge 1.7$V

V_{D1} has to be -0.3V ≤$V_{D(on)}$

Max. Of V_{D1} and V_{D2} is $V_{D(on)}$ is 0.7V.

Diode-Resistor Logic

Ch 2

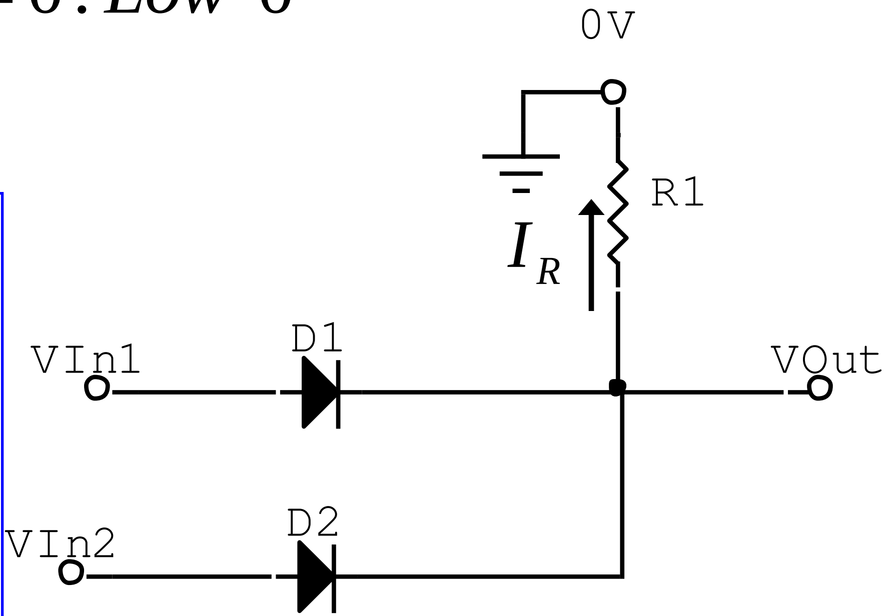
2. Diode OR gate

For $V_{in(1,2)} > V_{D(ON)} \Rightarrow D_{(1,2)} \text{ is "ON"}$

$$V_{in(1\&2)} : Low\text{"0"} \Rightarrow V_{Out} = 0 : Low\text{"0"}$$

$$I_R = \begin{cases} 0; \\ \text{when } \underline{\text{both}} \text{ D}_1 \text{ and D}_2 \text{ are } OFF \\ \\ \left(V_{In} - V_{D_{ON}}\right) / R_1; \\ \text{when } \underline{\text{either}} \text{ D}_1 \text{ or D}_2 \text{ is } ON \end{cases}$$

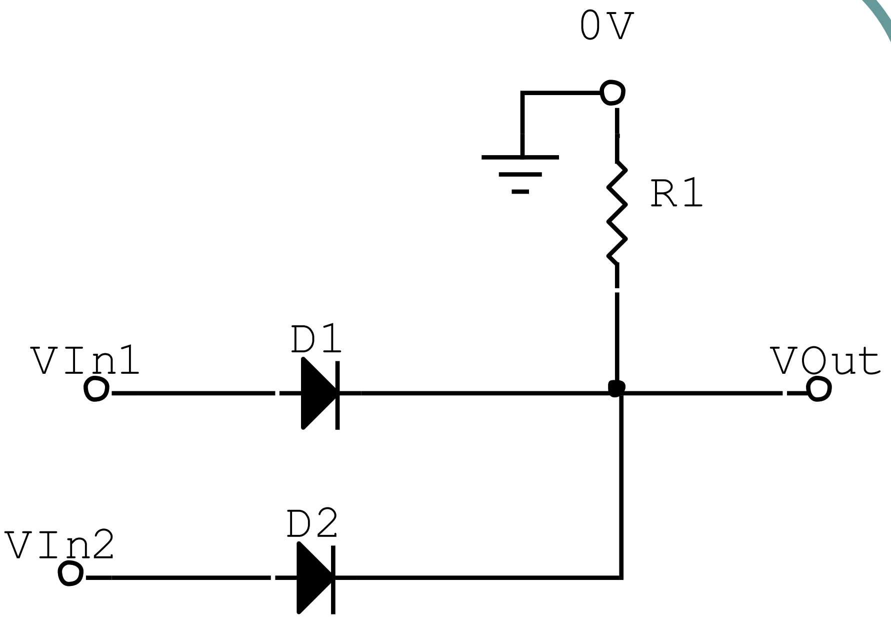
V1	V2	Vo
L	L	L
L	H	H
H	L	H
H	H	H

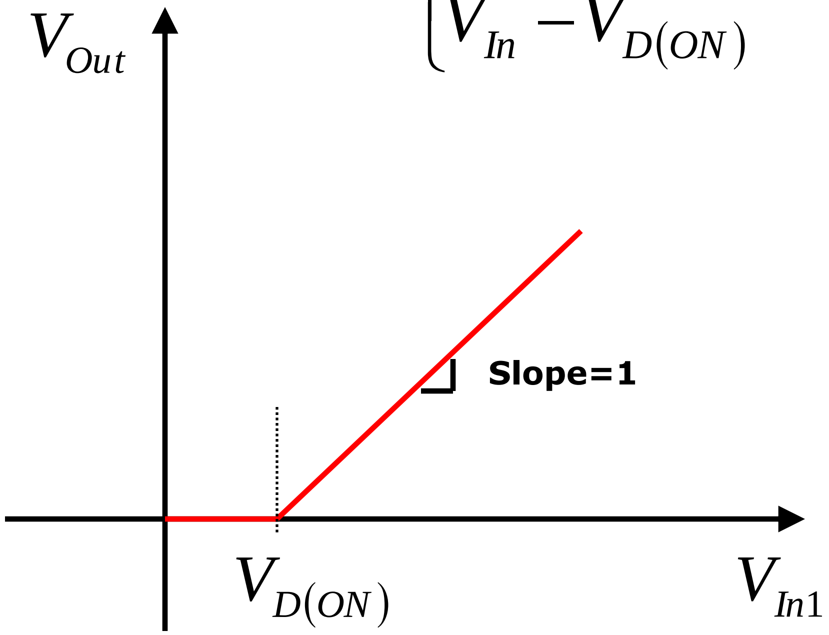


Diode-Resistor Logic

2. Diode OR gate

$$V_{Out} = \begin{cases} 0 = V_{OL} \\ or \\ V_{In} - V_{D(ON)} \end{cases}$$





V_{In2} is low

Level Shifted AND Gate

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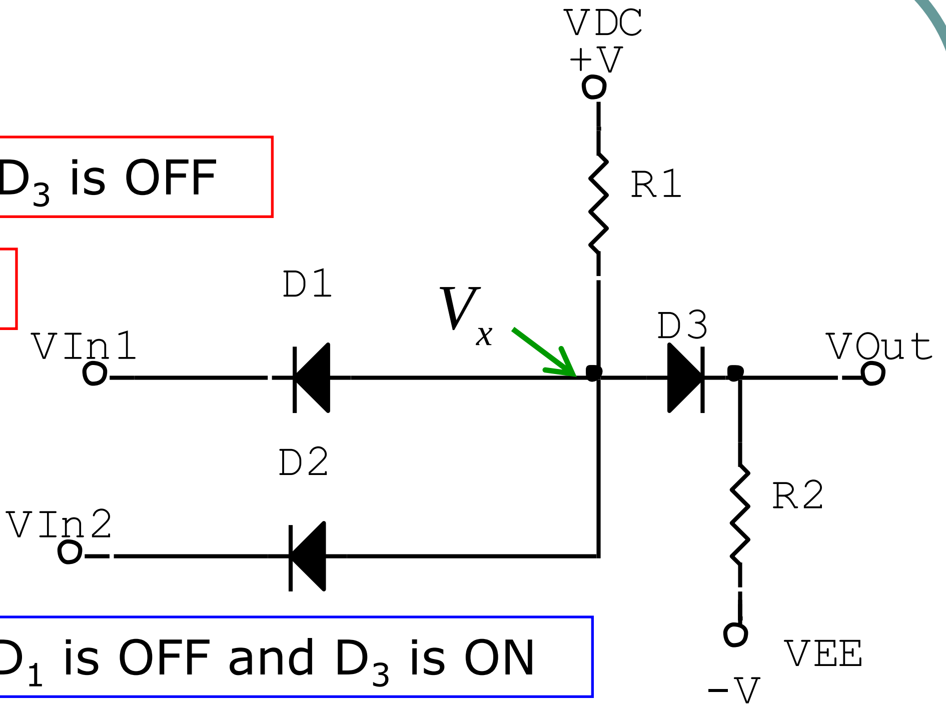
Ch 2

To plot the VTC:

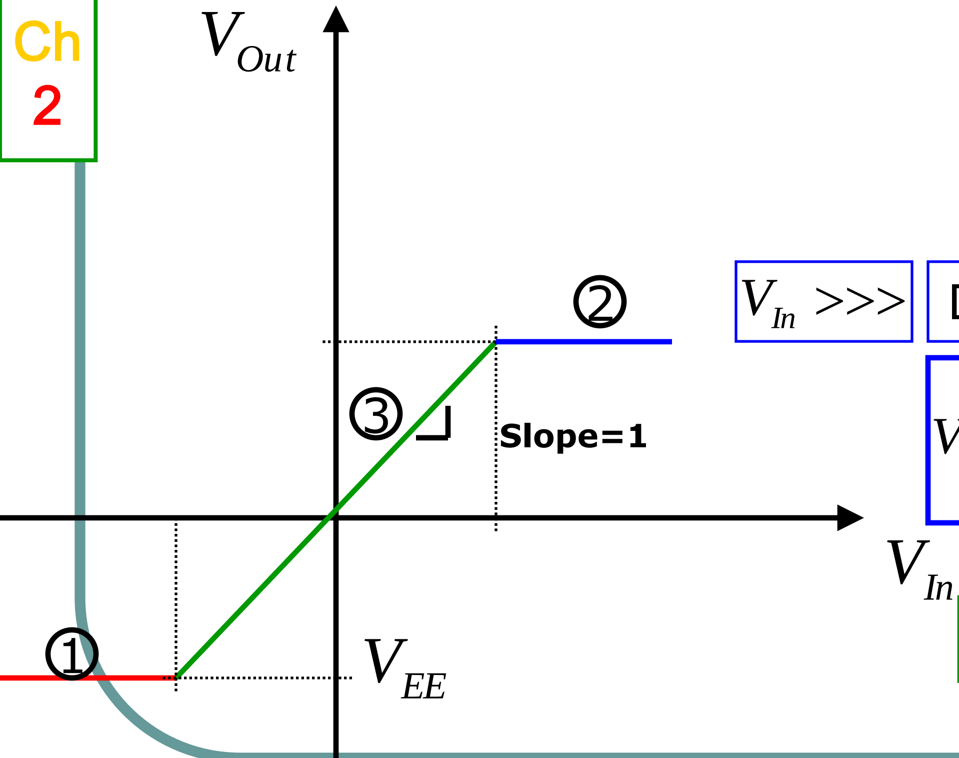
$V_{In} <<<$ D$_1$ is ON and D$_3$ is OFF

$V_{Out} = V_{EE}$ (-ve value)



$V_{In} >>>$ D$_1$ is OFF and D$_3$ is ON

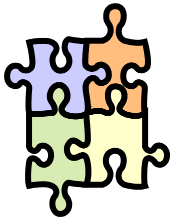
$$V_{Out} = V_{EE} + R_2\left(\frac{V_{DC} - V_{EE} - V_{D(ON)}}{R_1 + R_2}\right)$$



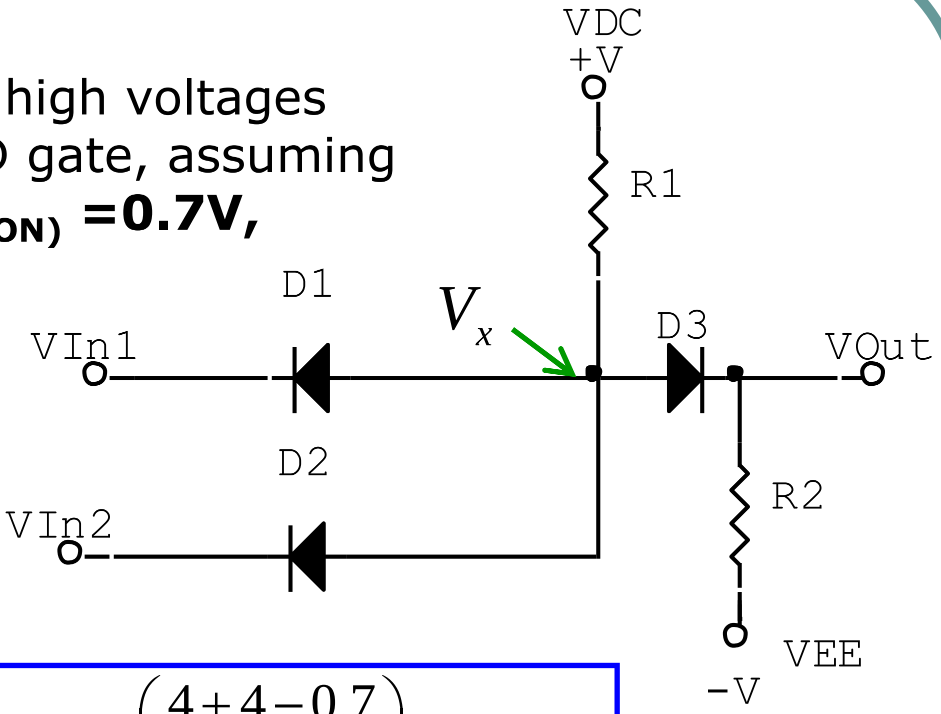
In between $V_{out}=V_{in}$

Level Shifted AND Gate

- Example

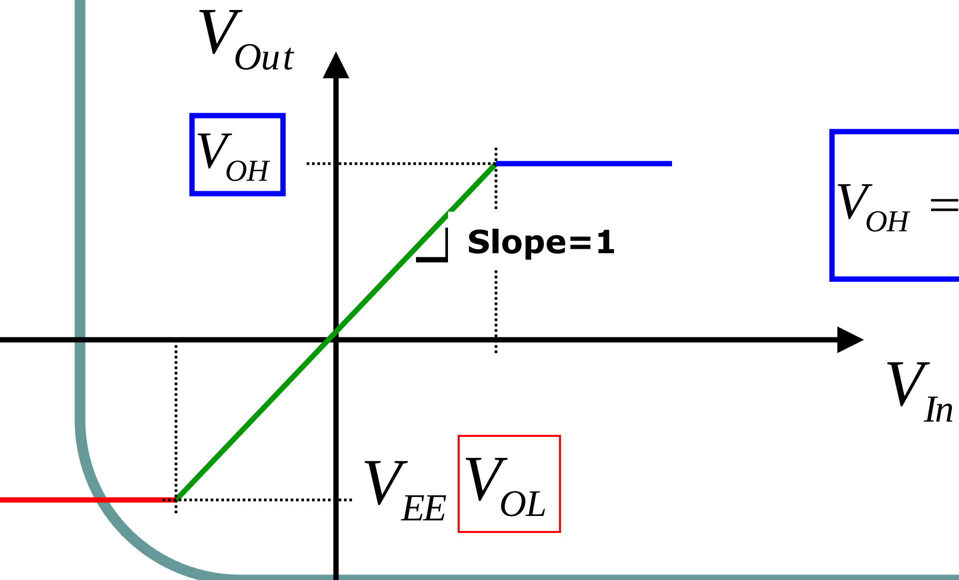


Find the output low and high voltages for the level-shifted AND gate, assuming **V_{DC}=4V, V_{EE}=-4V, $V_{D(ON)}$ =0.7V, R_1=1kΩ, R_2=2kΩ.**



- Solution

$$\boxed{V_{OL}=V_{EE}=-4V}$$



$$\boxed{V_{OH}=-4+2\left(\frac{4+4-0.7}{3}\right)=0.867V}$$

Level Shifted OR Gate

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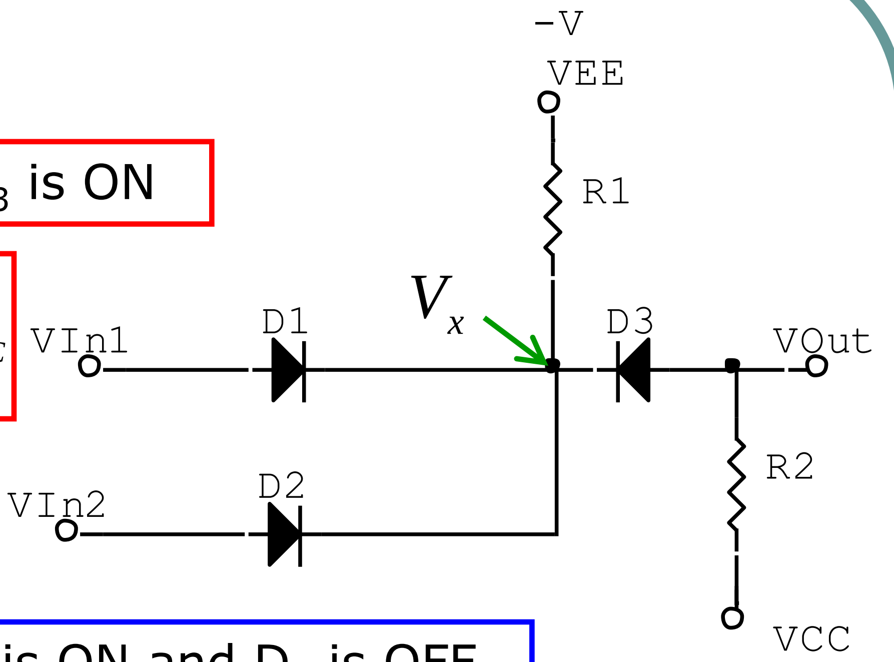
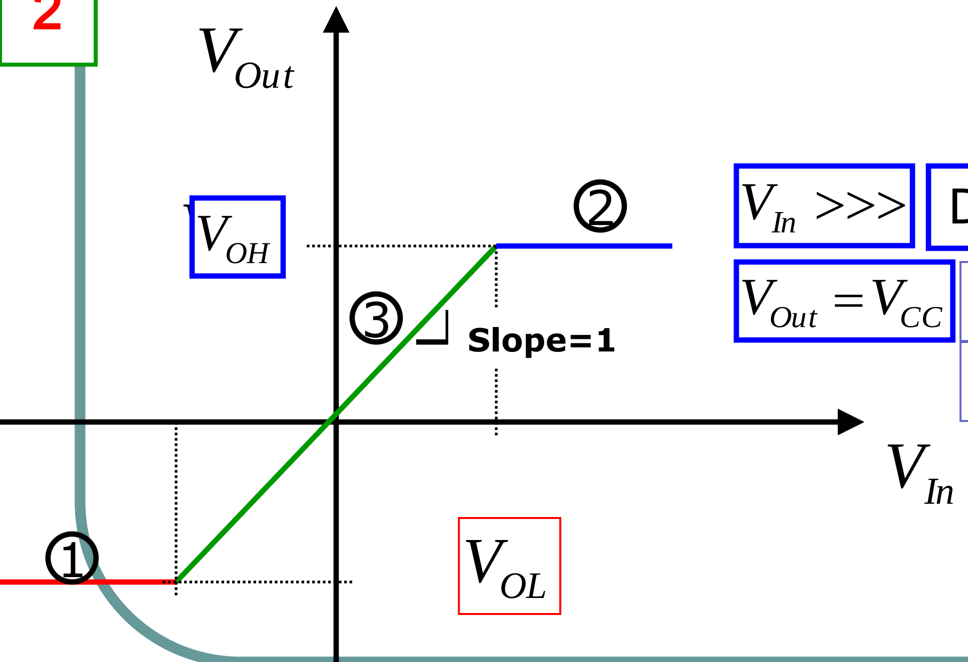
Ch 2

To plot the VTC:

$V_{In} <<<$ D$_1$ is OFF and D$_3$ is ON

$$V_{Out} = -R_2\left(\frac{V_{CC} - V_{EE} - V_{D(ON)}}{R_1 + R_2}\right) + V_{CC}$$





$V_{In} >>>$ D$_1$ is ON and D$_3$ is OFF

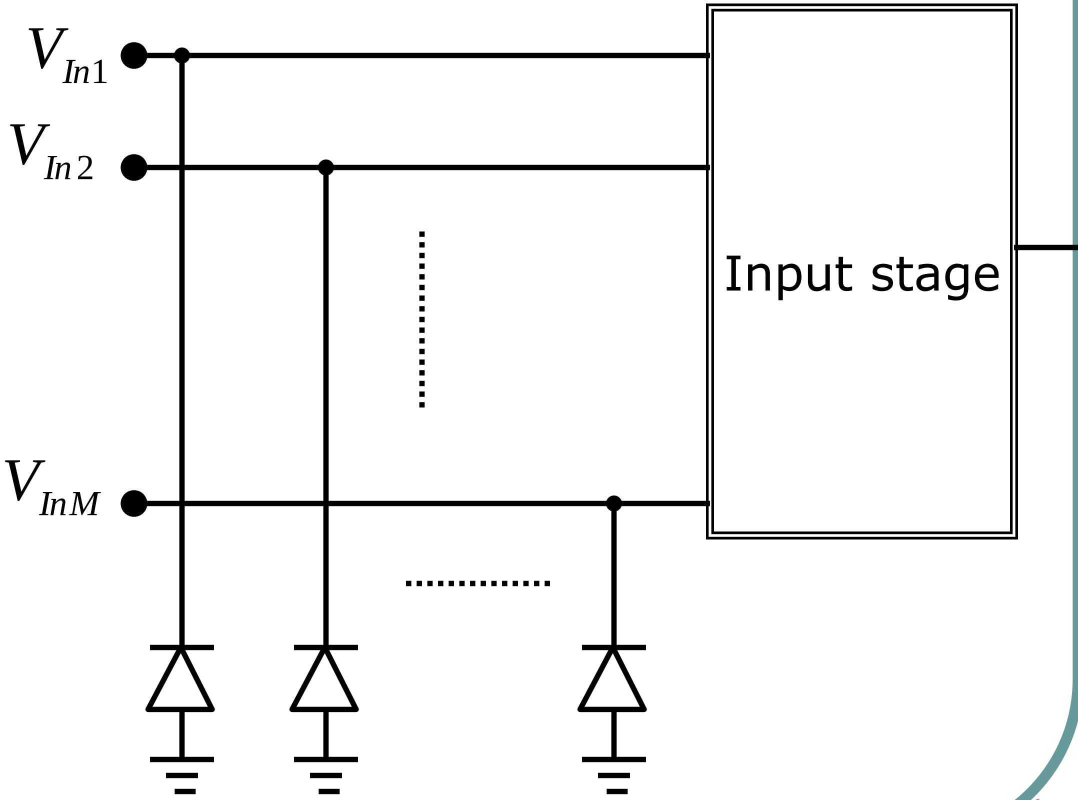
$V_{Out} = V_{CC}$ Such that $V_x > V_{CC} - V_{D(ON)}$

$V_{in} > V_x + V_{D(ON)}$

In between $V_{out} = V_{in}$

Clamping Diodes (other applications)

- Some gates may get damaged when their input voltages are negative



- The diodes prevent the inputs from falling below $-V_{D(ON)}$
- When the input voltages are positives, those diodes are open circuits

Level Shifting Diodes (other applications)

- Easy , and also stated before

- HW #2:Solve Problems: 2.6, 2.8, 2.12 , 2.18, 2.20, 2.21