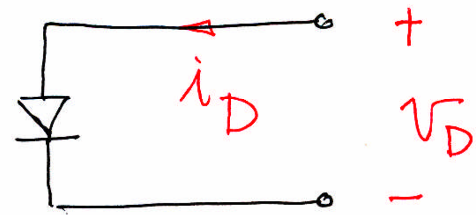
6.002 - Lecture 23

Diodes Revisited

- Diode Review
- Several Views
- Piece-wise Linear Models
- Method Of Assumed States

Exponential Diode I

Nonlinear Resistor



$$i_D = I_s \left(e^{v_D / V_T} - 1 \right)$$

$$V_T = \frac{KT}{q} \approx 26 \text{ mV @ } 27^\circ C$$

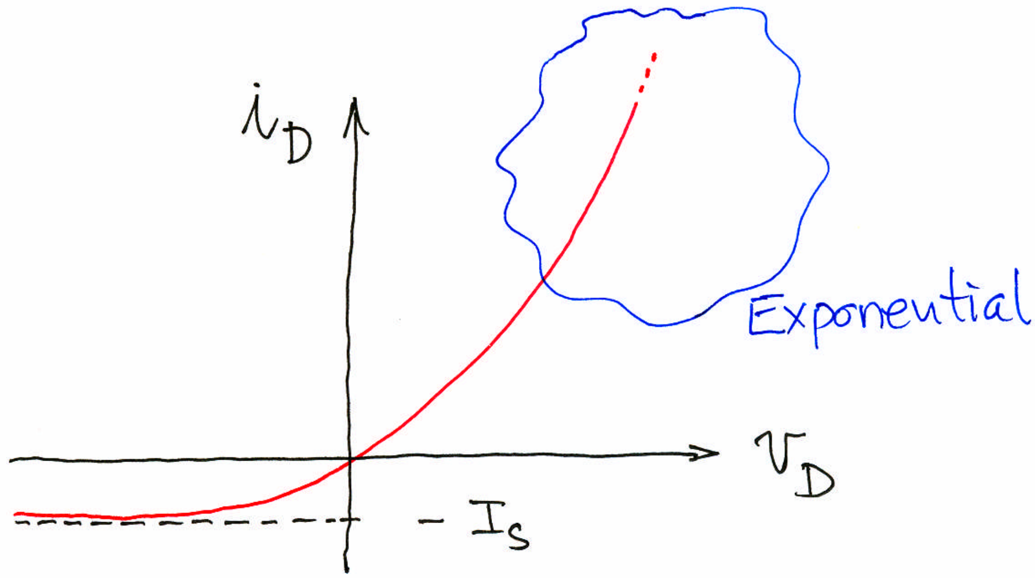
I_s = Saturation Current = 10^{-13} A … 10^{-9} A

K = Boltzmann's Constant = $1.38 * 10^{-23}$ J/°K

T = Temperature [K]

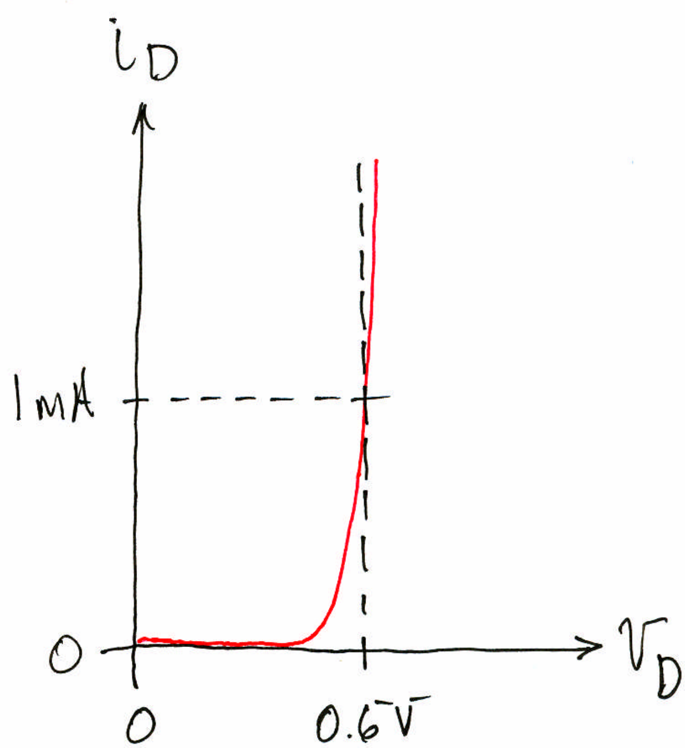
q = Electron Charge = 1.6×10^{-19} C

Exponential Diode II



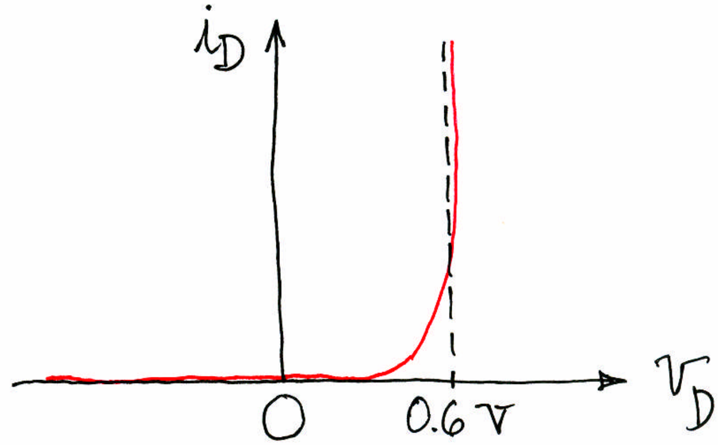
v_D	i_D
0.54 V	100 nA
0.60 V	1 mA
0.66 V	10 mA
0.72 V	100 mA
0.78 V	1 A
0.84 V	10 A

$I_S \equiv 10^{-13}$ A

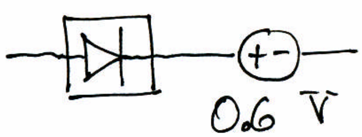


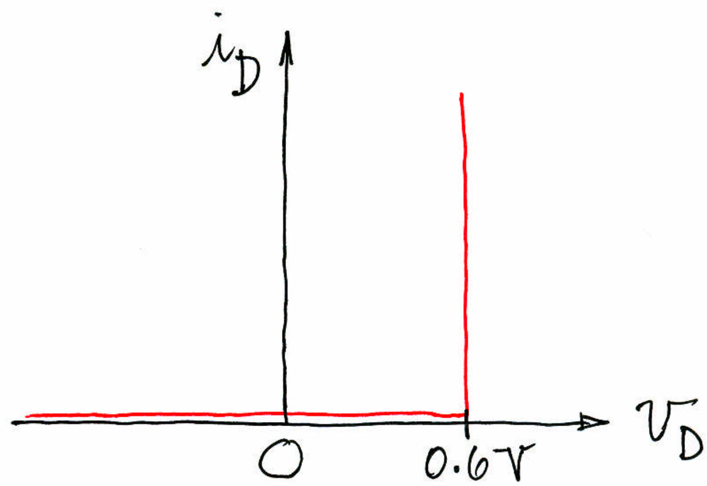
Several Models

Exponential

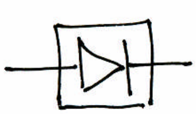


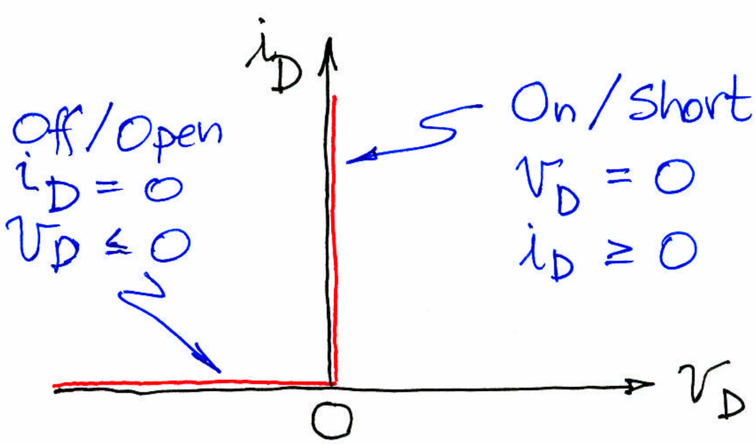
Compromise





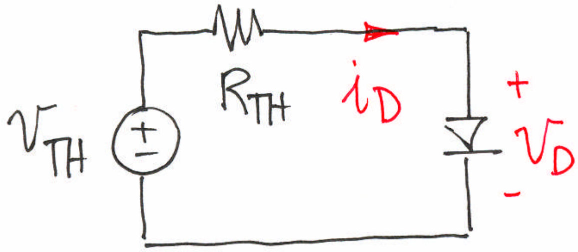
Ideal





Model selection depends on the viewpoint.

Analyses Revisited



$$i_D = I_S\left(e^{v_D/V_T} - 1\right)$$

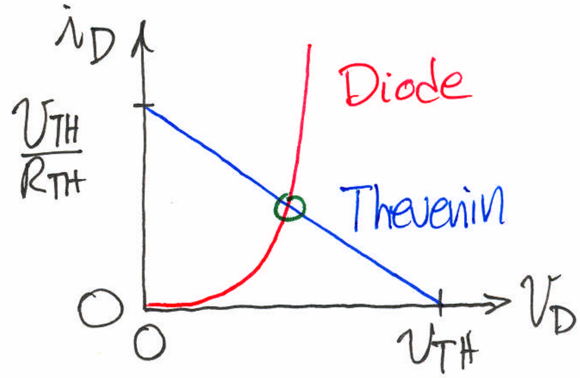
$$v_{TH} - R_{TH}\, i_D = v_D$$

- Node Analysis (No closed-form solution)
- Graphical Analysis (Valuable for insight)
- Numerical Analysis (Initial value: $v_D = 0.6\,V$)
- Incremental Analysis (Requires bias analysis)
- Approximate Models → Method Of Assumed States

Node Analysis:

$$v_{TH} = R_{TH} I_S\left(e^{v_D/V_T} - 1\right) + v_D$$

Graphical Analysis:



Method Of Assumed States

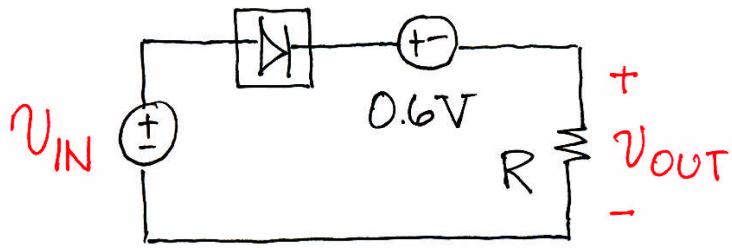
Model each diode as ideal with an optional voltage offset or series resistance

- Diode = On/Off $\Rightarrow$ 2 States
- N Diodes $\rightarrow$ 2^N possible state combinations

For each state combination, analyze the network/circuit. Use the constraints on v_D ($On \Rightarrow i_D \geq 0$) and i_D ($Off \Rightarrow v_D \leq 0$) to determine the valid operating range for each state-combination analysis.

- Advantage: diode models become simple
- Disadvantage: 2^N analyses

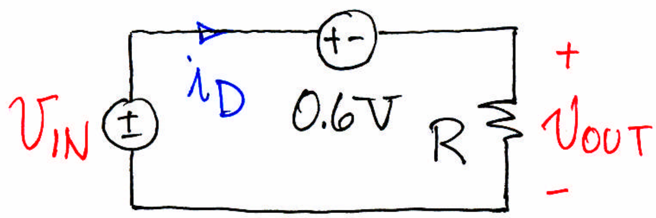
Half-Wave Rectifier I



2 States:

Diode = On/off

Diode ≡ On $(v_D \equiv 0 \quad i_D \geq 0)$

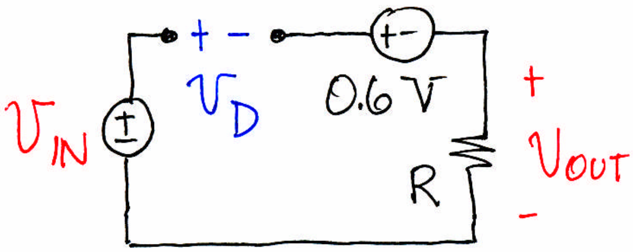


$$v_{OUT} = v_{IN} - 0.6V$$

$$i_D = \frac{v_{IN} - 0.6V}{R} \geq 0$$

$$v_{IN} \geq 0.6V$$

Diode ≡ Off $(i_D \equiv 0 \quad v_D \leq 0)$

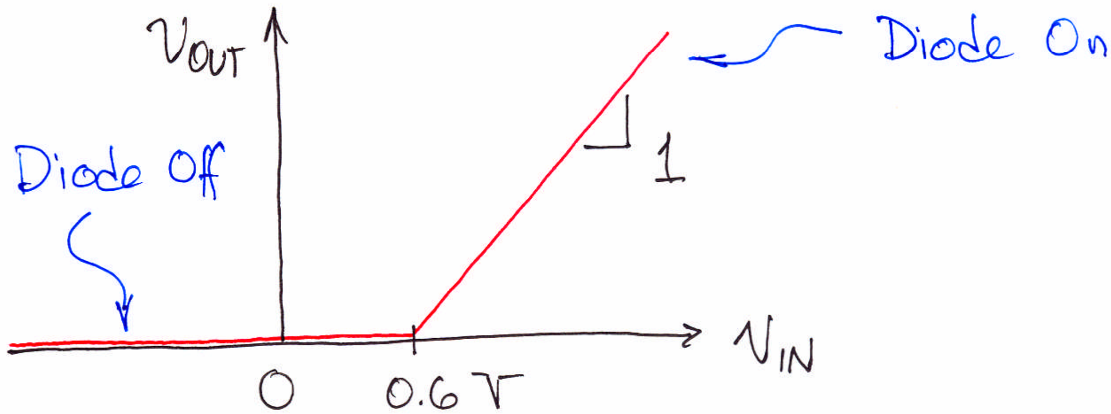


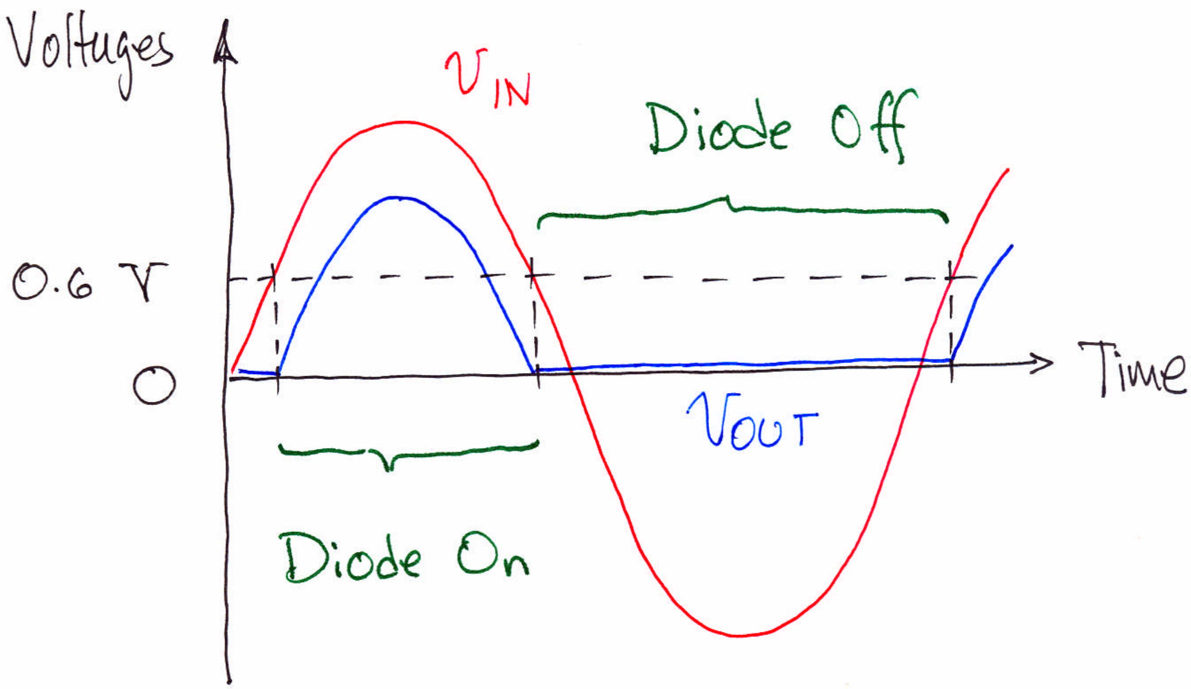
$$v_{OUT} = 0$$

$$v_D = v_{IN} - 0.6V \leq 0$$

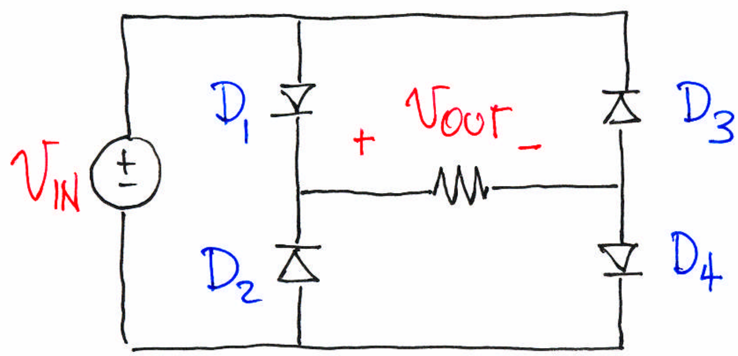
$$v_{IN} \leq 0.6V$$

Half-Wave Rectifier II





Full-Wave Rectifier

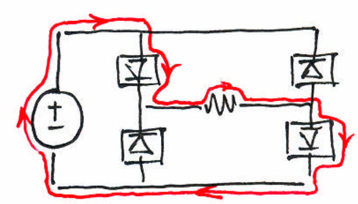


4 Diodes
⇒ 16 states

Only 3 diode state combinations are feasible.

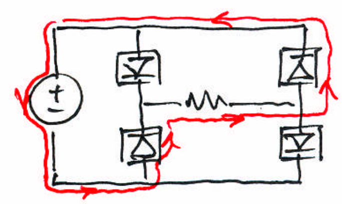
① $v_{IN} > 0 \Rightarrow D_1 = D_4 = On$

$D_2 = D_3 = Off$



② $v_{IN} < 0 \Rightarrow D_1 = D_4 = Off$

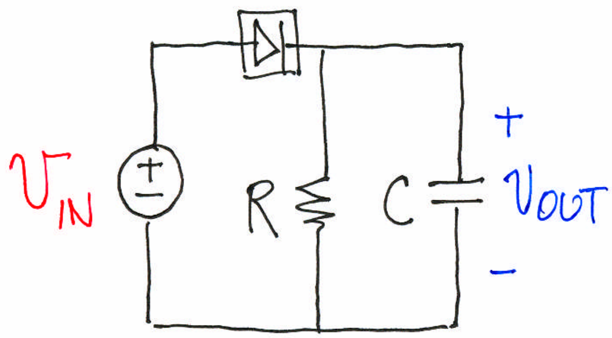
$D_2 = D_3 = On$

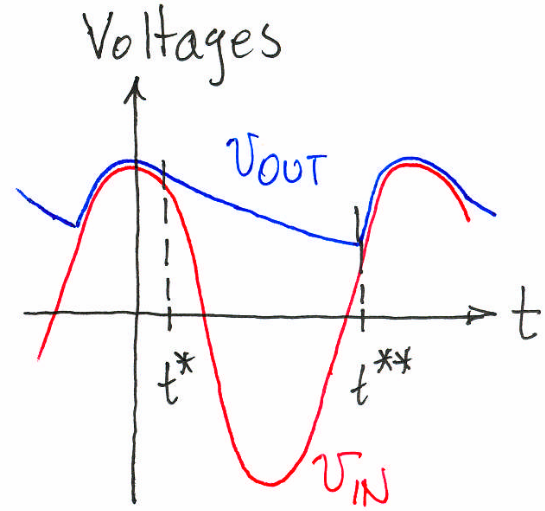


③ $v_{IN} = 0 \Rightarrow D_1 = D_2 = D_3 = D_4 = Off$

$V_{OUT} = |v_{IN}|$ (Also useful for power supplies)

Peak Detector / Power Supply





Suppose $v_{IN} = V\cos(\omega t)$, for example.

Diode On: $i_D \approx \dfrac{V}{R}\cos(\omega t) - CV\omega\sin(\omega t) \geq 0$

Departure $\Rightarrow$ $\dfrac{1}{\omega RC} = \tan^{-1}(\omega t^*)$

Diode Off: $v_D = V\cos(\omega t) - V\cos(\omega t^*)\, e^{-\left(\frac{t-t^*}{RC}\right)} \leq 0$

Intersection $\Rightarrow$ $\cos(\omega t^{**}) = \cos(\omega t^*)\, e^{-\left(\frac{t^{**}-t^*}{RC}\right)}$