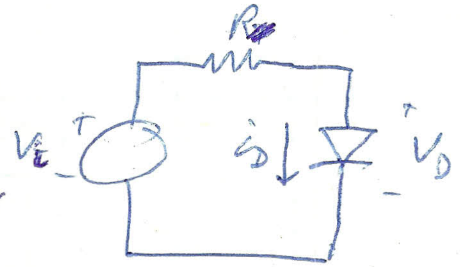
Solving Diode Circuits



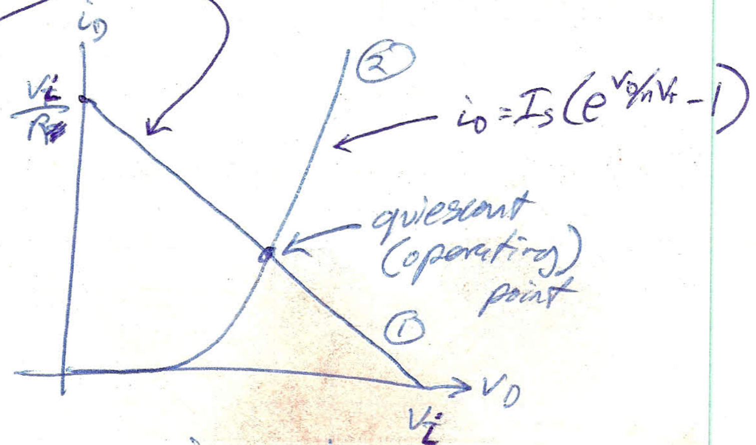
① $V_i = i_D R + V_D$ $\quad V_T = \frac{kT}{q} = 26mV$

② $i_D = I_S(e^{V_D/nV_T} - 1)$

2 equations and 2 unknowns, but difficult to solve because <u>nonlinear</u>

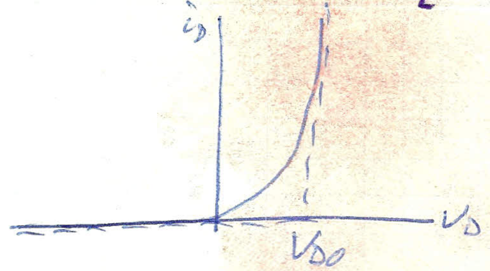
Load Line

$\rightarrow V_i = i_D R + V_D$



• Useful graphical solution, but does not easily give numerical result

Piecewise Linear Model



Diode ON: $V_D = V_{D0}$, $i_D \geq 0$

Diode OFF: $i_D = 0$, $V_D < V_{D0}$

V_{D0} is "cut-in" voltage, for Si $V_{D0} \approx 0.6 - 0.7V$

for GaAs, $V_{D0} \approx 1.7 - 1.9V$

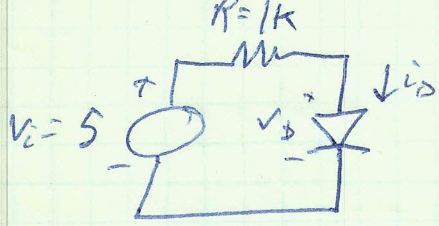
Recipe for solving:

① write down circuit equations, with i_D, V_D as parameters

② assume either ON or OFF and solve circuit

③ check for self-consistency with values of i_D, V_D that you found

Example



$V_i = i_D R + V_D$

$5 = 10^3 i_D + V_D$

assume diode is OFF $\longrightarrow i_D = 0$

$5 = 10^3 \times 0 + V_D \longrightarrow V_D = 5V$

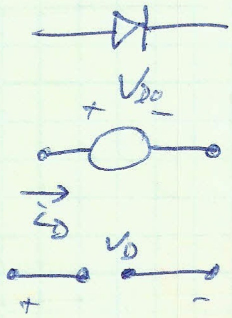
is $V_D < V_{D0}$ $(V_{D0} = 0.7v)$? NO.

assume diode is ON

$5 = 10^3 \times i_D + 0.7 \longrightarrow i_D = 4.3mA$

is $i_D > 0$? Yes

Diode Circuit Model



Diode ON $i_D \geq 0$

Diode OFF $V_D < V_{D0}$

- Can use the same procedure, but check for self-consistency

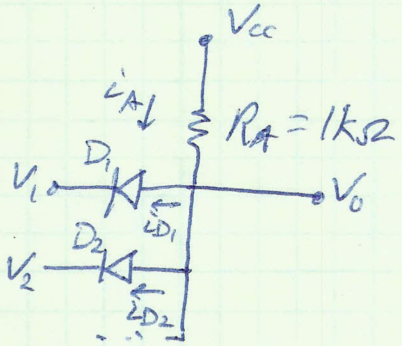
Recipe for solving with diode circuit model

- Draw circuit for each state of the diode (or all diode combinations)
- solve each circuit, find i_D + V_D
- check for self consistency. If not, go on to the next circuit

Diode Logic Gates

- Since diodes are nonlinear devices, they can be used to build simple logic circuits
- Assume a supply of 5v
- Define any voltage <1v as "0" and >4v as "1"

Diode AND gate:



Case 1: $V_1 = V_2 = 0v$

$$V_0 = V_1 + V_{D0} = V_2 + V_{D0} = 0.7v$$ (assume both are ON)

$$i_A = \frac{V_{cc} - V_0}{R_A} = \frac{5-0.7}{1000} = 4.3mA$$

$$i_{D1} = i_{D2} = \frac{i_A}{2} = 2.1\,mA$$ (by symmetry)

assumption that diodes are ON is correct

$V_0 = 0.7v$, or logical "0"

Case 2: $V_1 = 0$, $V_2 = 5v$

Assume D_1 is ON

$$i_A = \frac{V_{cc} - V_0}{R_A} = \frac{5-0.7}{1000} = 4.3mA$$

$i_{D1} = 4.3mA \rightarrow$ yes, D_1 is ON

$V_0 = 0.7v$, or logical "0"

note: D_2 must be OFF because it doesn't matter what the current through R_A is, V_0 will always be less than or equal to 5V

Case 3 : $V_1 = 5V$, $V_2 = 0V$

Because of symmetry, this is the same as case 2 but with D_1 and D_2 switched

Case 4 : $V_1 = V_2 = 5V$

Assume both diodes are off

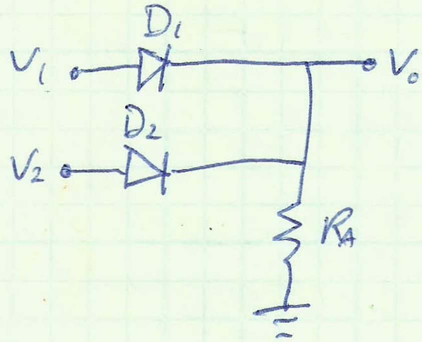
$$i_A = i_{D1} + i_{D2} = 0$$

$$V_O = V_{CC} - i_A R_A = 5 - 0 = 5V$$ or logical "1"

$$V_{D1} = V_{D2} = 5 - 5 = 0$$ → both are OFF

- Why are simple diode logic gates not used?
  - Diodes do not have gain
  - signal degrades by 0.7V with each gate.
  - only a few gates could be used before signal would fall in "undefined" range

Diode OR Gate



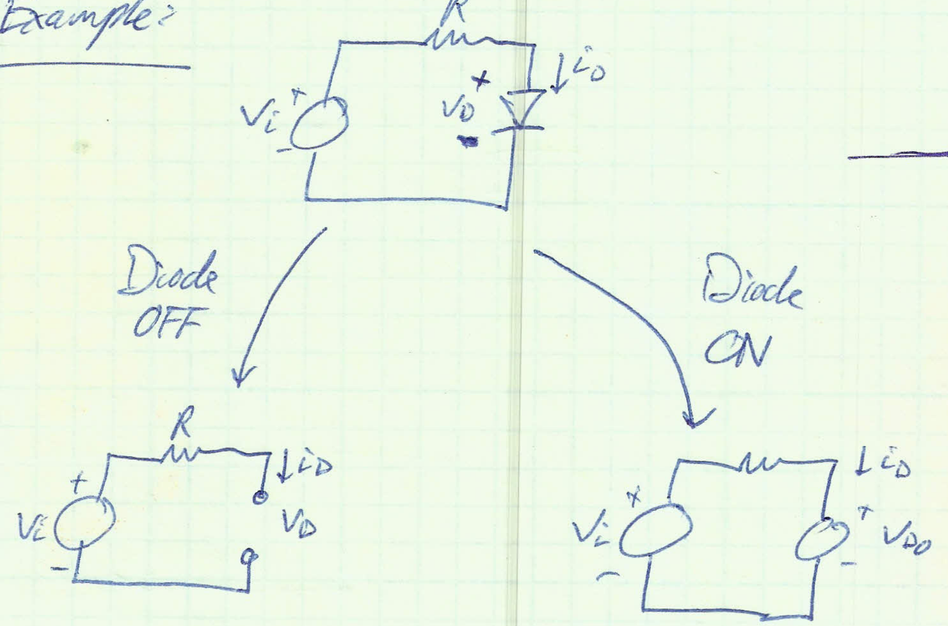
Parametric Solution of Diode Circuits

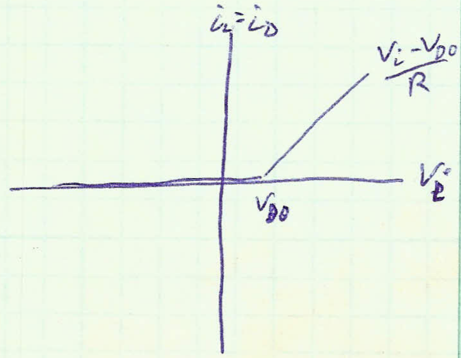
- Instead of solving for specific values of sources and elements, solve for general transfer function, then apply desired values
- Necessary for dynamic circuits, where values are changing

Recipe:

1) Draw all possible circuits for various diode states (2^N, N = # diodes)
2) Solve each circuit to find voltages and currents
3) Use range of validity of diode states to find range of circuit parameters that lead to that state

Example:





$V_D = V_i$

for OFF, we need $V_D < V_{D0}$

therefor diode OFF for $\underline{V_i < V_{D0}}$

$$i_D = \frac{V_i - V_{D0}}{R}$$

for ON, $i_D \geq 0 \rightarrow \frac{V_i - V_{D0}}{R} \geq 0$

$\underline{V_i \geq V_{D0}}$

~~Transfer Function~~ Parametric Solution:

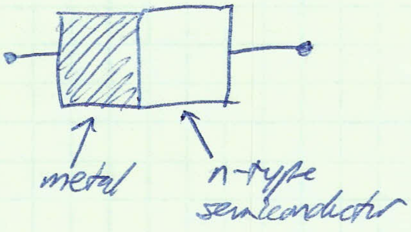
$V_i \geq V_{D0} \rightarrow ON \rightarrow V_D = V_{D0}, \quad i_D = \frac{V_i - V_{D0}}{R}$

$V_i < V_{D0} \rightarrow OFF \quad V_D = V_i, \quad i_D = 0$

Other types of Diodes

- Schottky barrier diode

- has larger I_S
- $V_{D0} \approx 0.3V$
- faster switching speed
- examples with near-zero turn-on voltage can be made
- early "cat's whisker" detectors are first semiconductor device

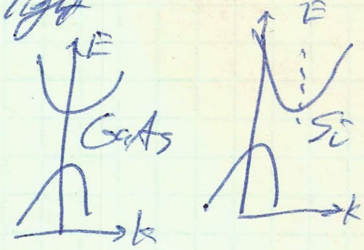


- Light-emitting diode (LED)

- Emits light when forward biased
- photon energy (frequency) is related to band gap

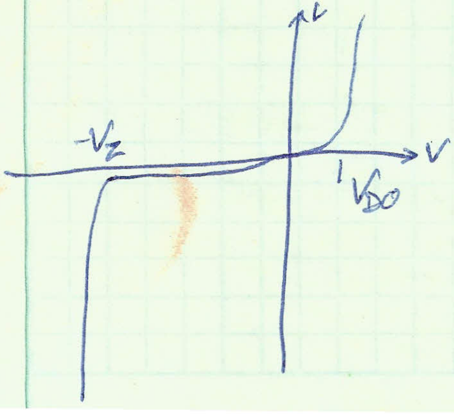
IR, Red, Orange, Yellow : usually combination of In, Ga, Al, As, P
Blue, Violet, UV : usually combination of In, Ga, N
Green can be various combinations
However, Green laser pointers are still made by frequency-doubling an IR diode

- Must have a direct bandgap to emit light



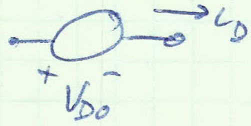
- Zener diodes

- designed to work in the breakdown region without being destroyed!

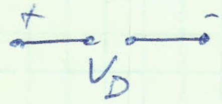


Model for Zener Diodes

ON : $V_D = V_{D0}$, $i_D \geq 0$



OFF : $-V_Z < V_D < V_{D0}$, $i_D = 0$

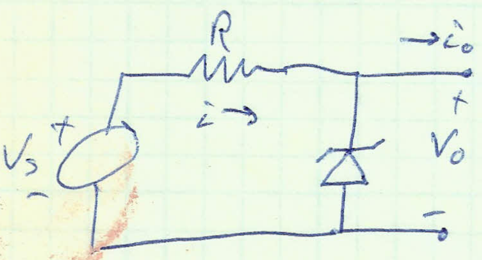


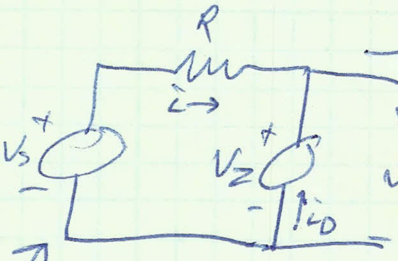
Zener Region : $V_D = -V_Z$, $i_D \leq 0$

note change in sign

A Simple Power Supply

- Assume that a power supply has some variation or ripple
- Zener diodes can be used to take out the ripple





Case 1: Zener region

$V_o = V_Z =$ constant

output voltage is independent of i_o – <u>ideal voltage source</u>

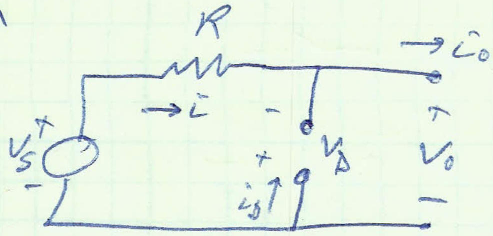
KCL: $i_D = i_o - i$ $\longrightarrow$ $i_D = i_o - \dfrac{V_s - V_Z}{R} \leq 0$

KVL: $v_s = R \cdot i + V_Z$ $\longrightarrow$

$\hookrightarrow i_o \leq \dfrac{V_s - V_Z}{R}$

- As long as this condition is satisfied, diode will be in Zener region

Case 2: Reverse bias region



$i_D = 0$

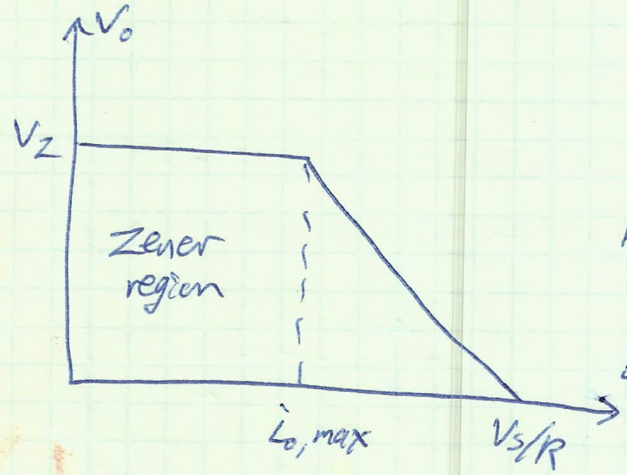
$i = i_o$

$V_S - R i_o = V_o$

- Output voltage drops as more current is drawn from circuit

Case 3: forward bias region

not possible – V_S is positive.



$$\boxed{i_{o,max} = \frac{V_S - V_Z}{R}}$$

- In reality, there is a slight slope to the Zener region of the curve – real voltage sources are made with transistors and opamps, etc.

Other Diode Models