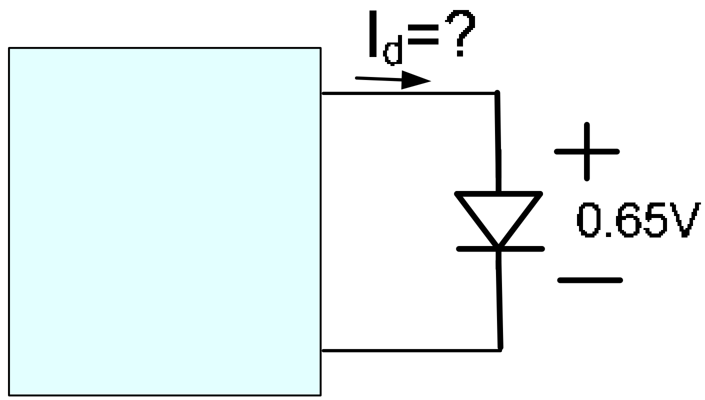
EE 230
Lecture 30

Nonlinear Circuits and Nonlinear Devices

- Diode
- BJT
- MOSFET

Quiz 18

If a diode has a value of I_S=1E-14A and the diode voltage is .65V, what will be the diode current if operating at T=300K?



And the number is ?

1 3 8

5 4

2 6

9 7

And the number is ?

1 3 8

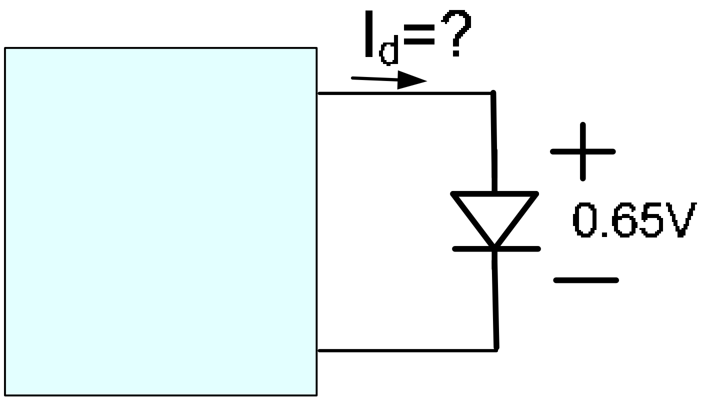
5 3 4

2 6

9 7

Quiz 18

If a diode has a value of I_S=1E-14A and the diode voltage is .65V, what will be the diode current if operating at T=300K?



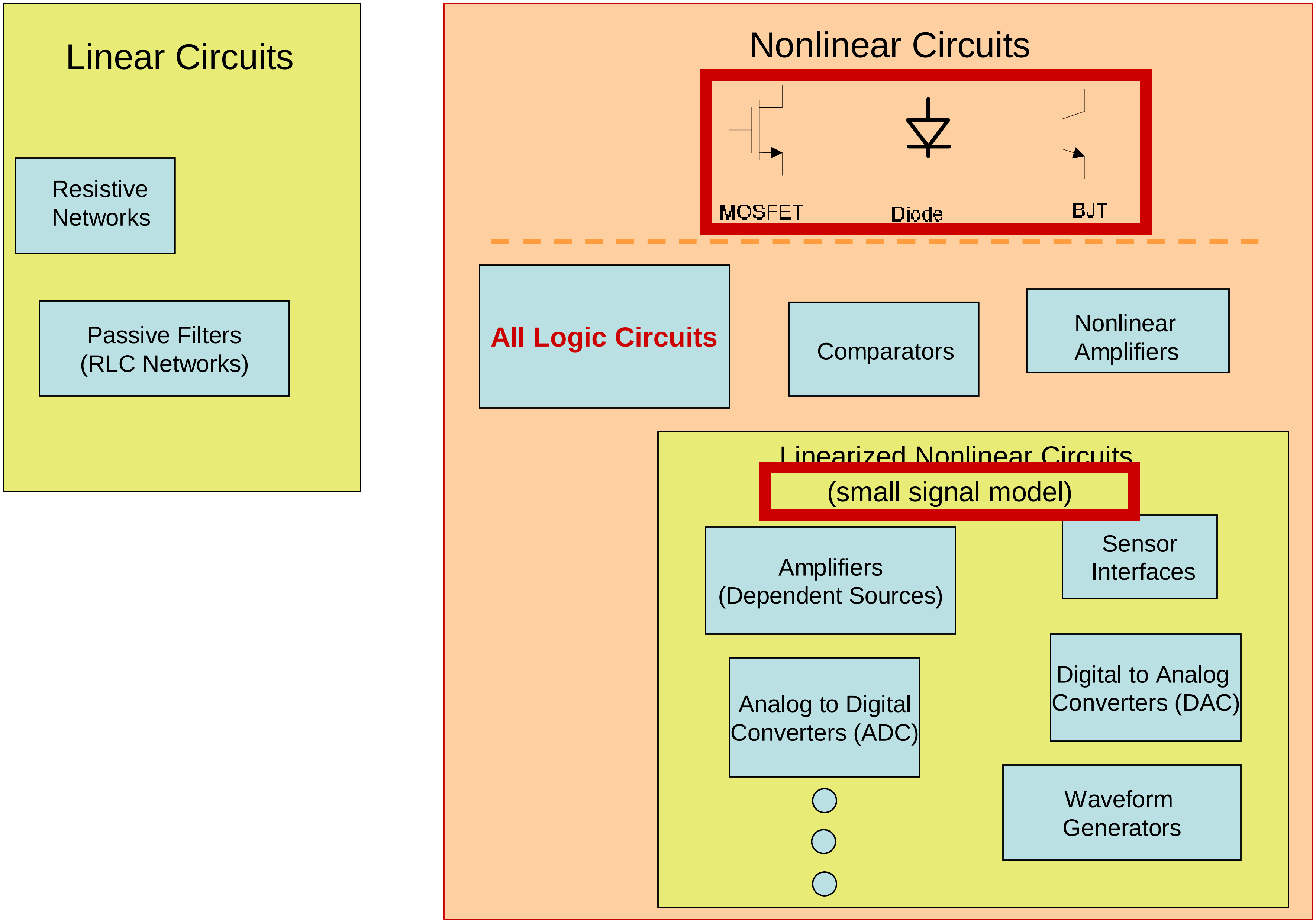
Solution:

$$I_d = I_S\left(e^{\frac{V_d}{V_t}} - 1\right)$$

$$I_d = 1E\text{-}14\left(e^{\frac{0.65}{300 \bullet 8.63E-5}}\right) = 1E\text{-}14 \bullet 8E10 = 800uA$$

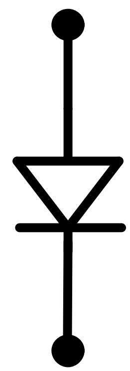
Review from Last Time:

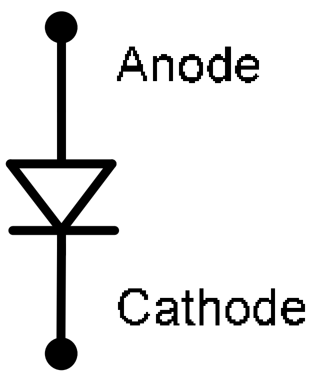
The Real Electronics World

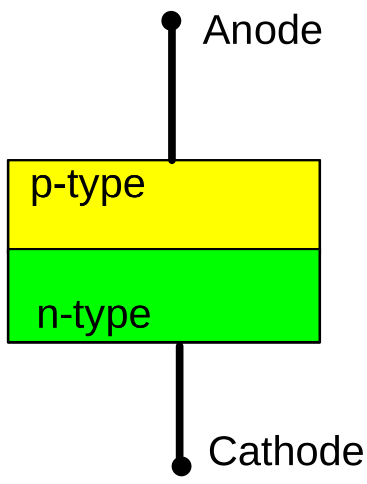


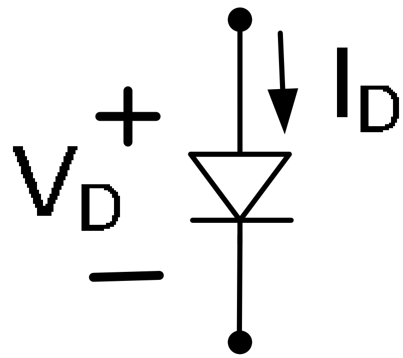
Review from Last Time:

The Diode





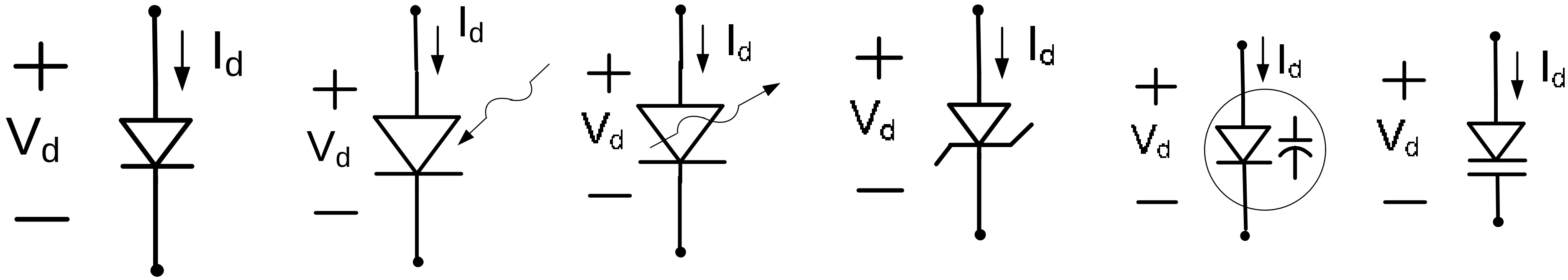




Review from Last Time:

Types of Diodes

pn junction diodes



Signal or Rectifier

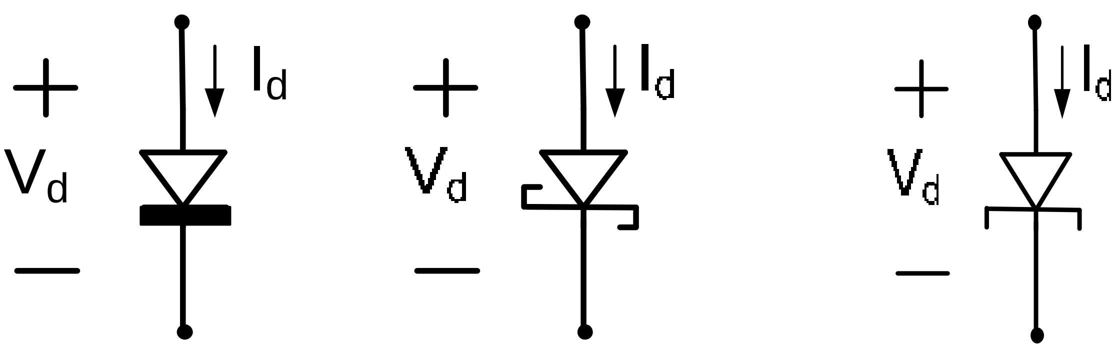
Pin or Photo

Light Emitting LED Laser Diode

Zener

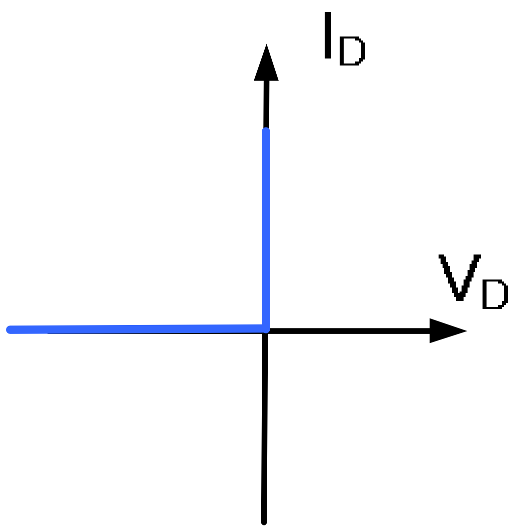
Varactor or Varicap

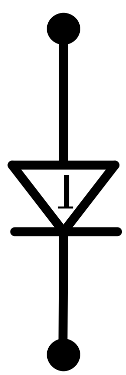
Metal-semiconductor junction diodes



Schottky Barrier

The Ideal Diode

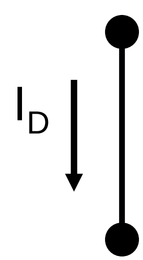


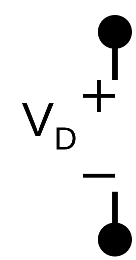


$I_D = 0 \quad \text{if} \quad V_D \le 0$ "OFF"

$V_D = 0 \quad \text{if} \quad I_D > 0$ "ON"

"ON" "OFF"



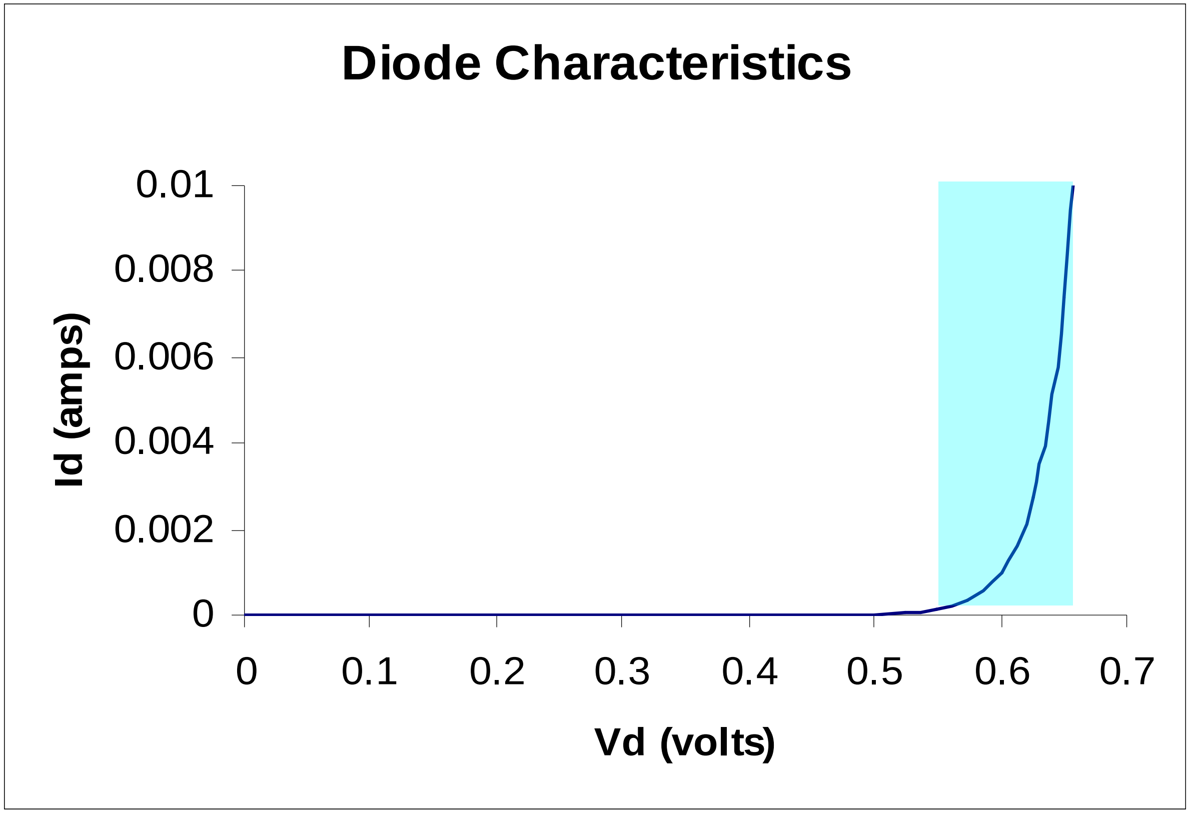


Valid for $I_D > 0$ $V_D \le 0$

Review from Last Time:

Diode equation (silicon pn junction diodes)

$$I_d = I_S\left(e^{\frac{V_d}{V_t}} - 1\right)$$

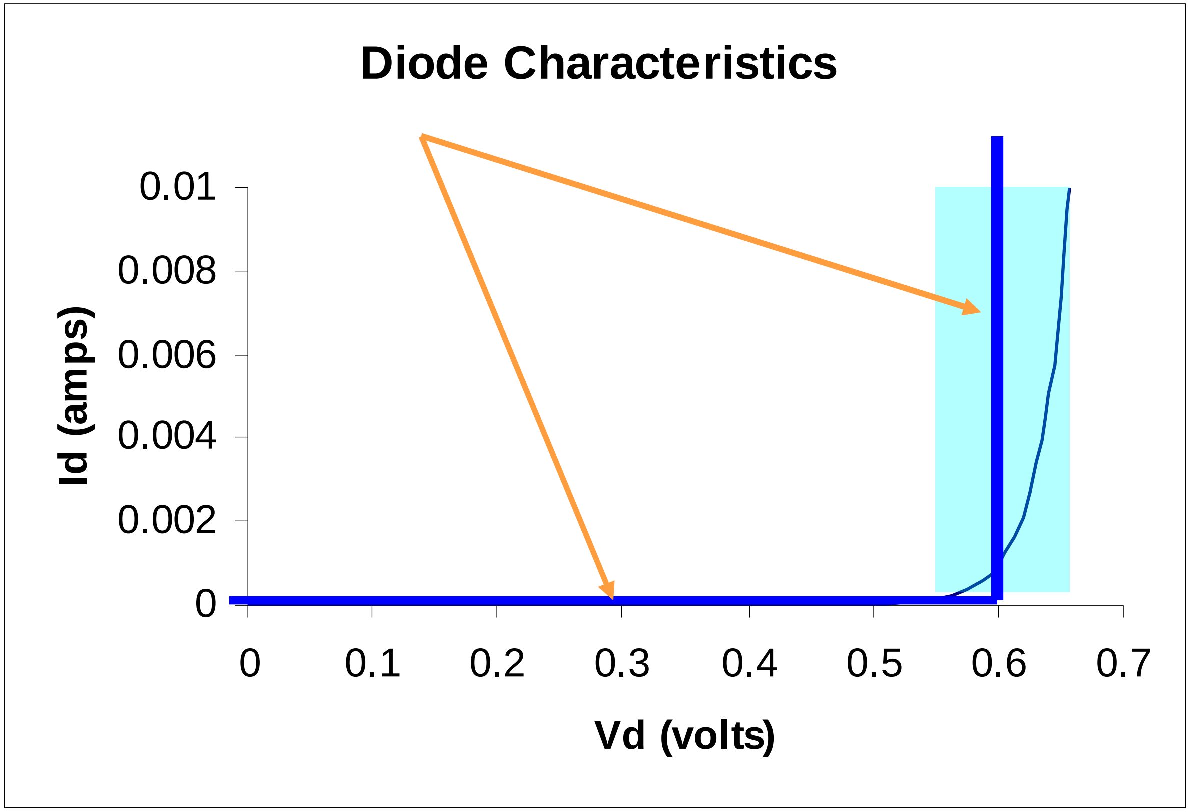


Widely Used Piecewise Linear Model

Review from Last Time:

A more accurate approximation to the diode equation

$$I_d = I_S\left(e^{\frac{V_d}{V_t}} - 1\right)$$



More accurate pn junction diode model:

$$I_d = 0 \qquad V_d < 0.6V$$

$$V_d = 0.6V \qquad I_d > 0$$

Review from Last Time:

A more accurate approximation to the diode equation

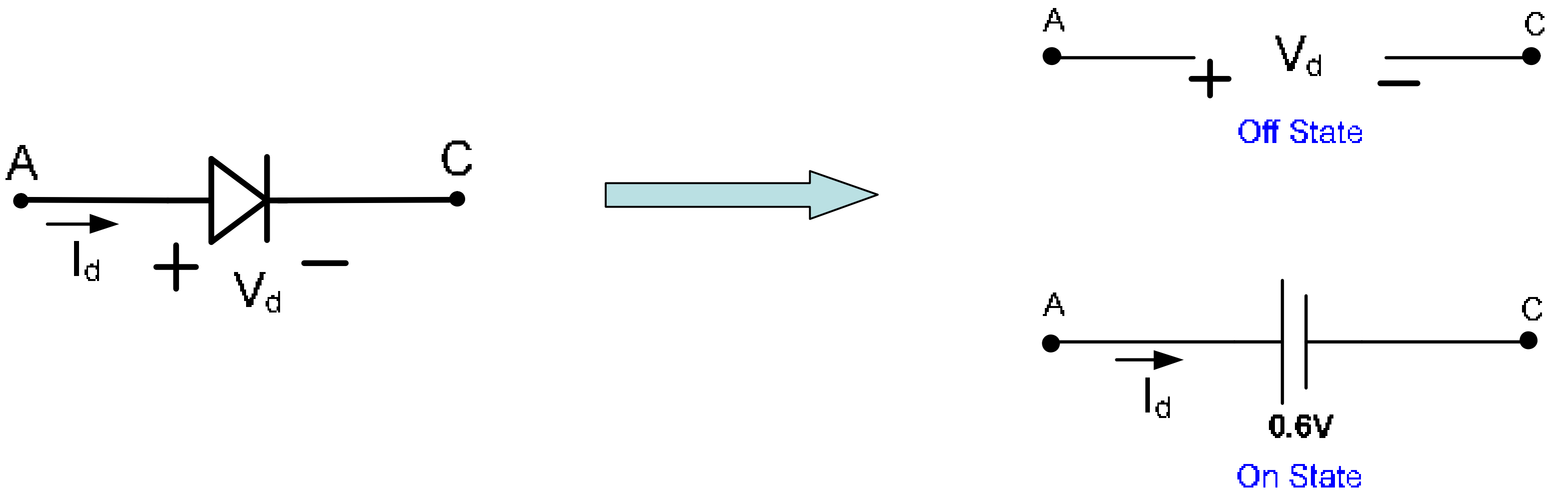
$$I_d = I_S\left(e^{\frac{V_d}{V_t}} - 1\right)$$

Piecewise Linear Model

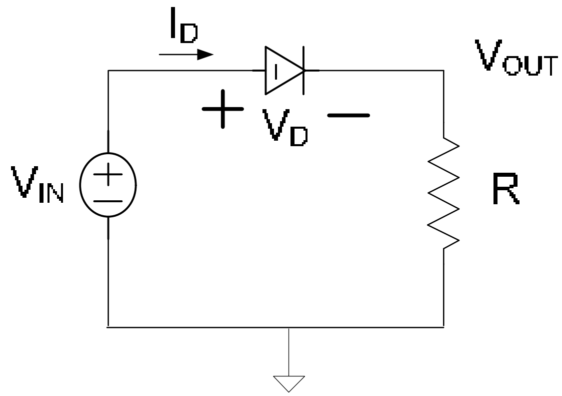
$$I_d = 0 \qquad V_d < 0.6V$$

$$V_d = 0.6V \qquad I_d > 0$$

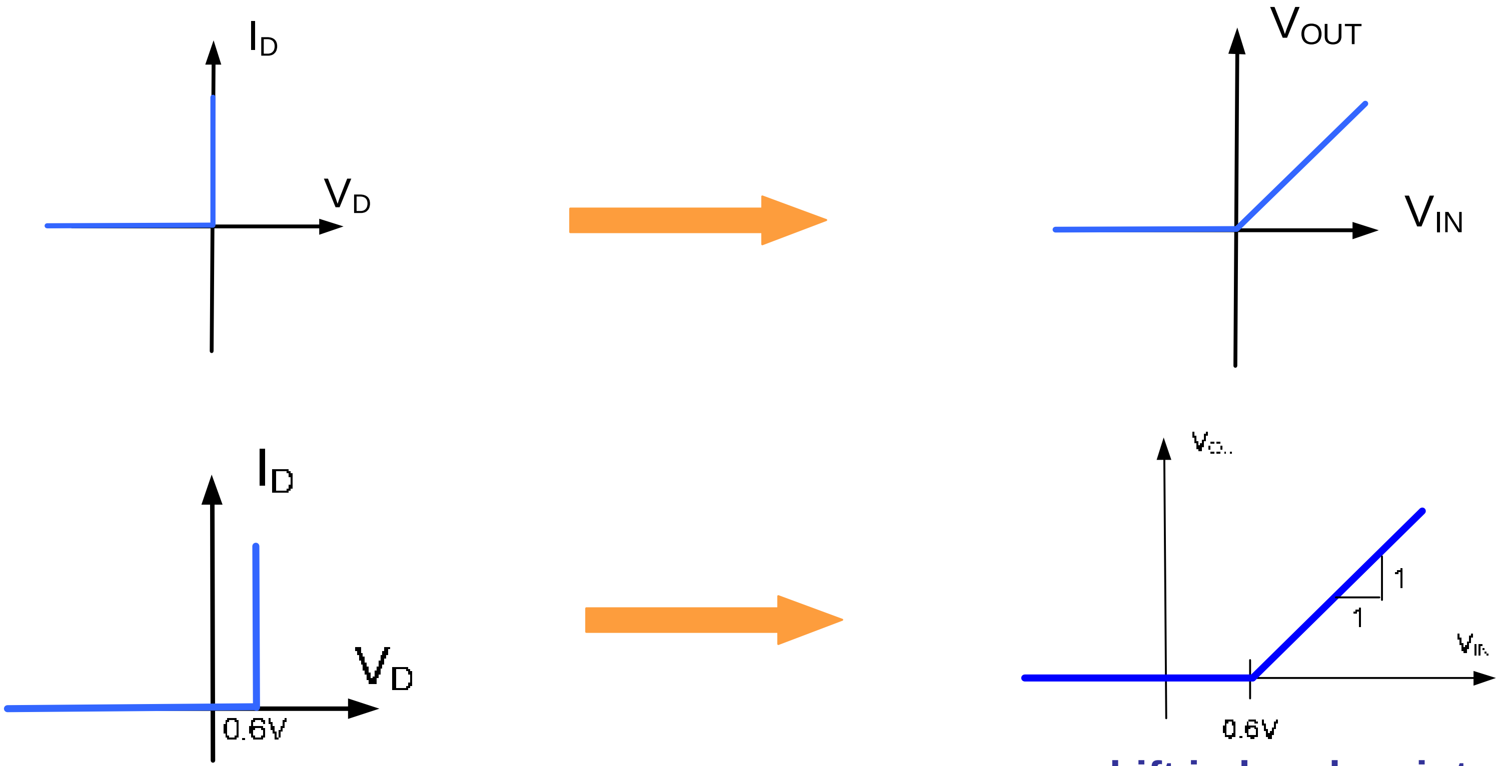
Equivalent Circuit



Performance Limitations of Diode Rectifier Circuit

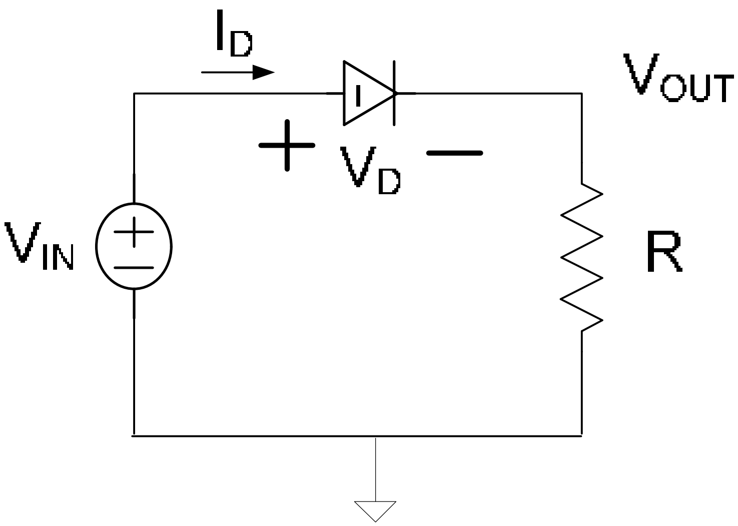


Diode rectifier circuit

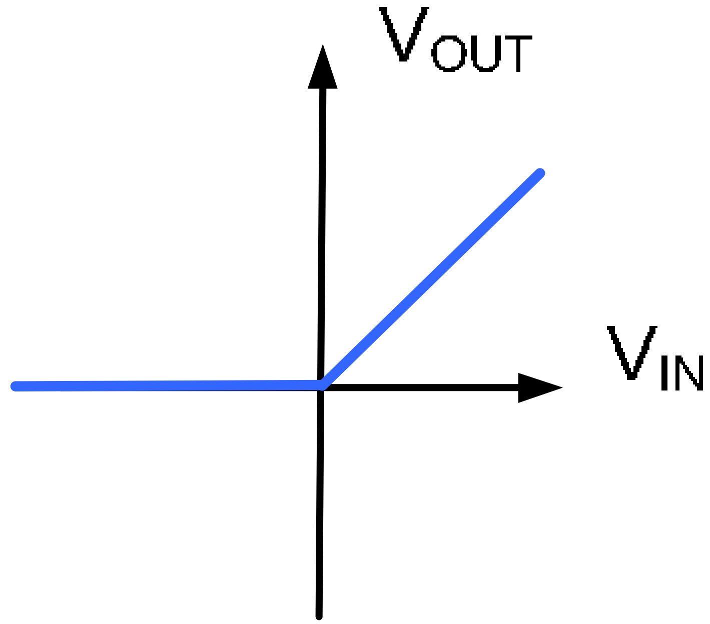


shift in break point

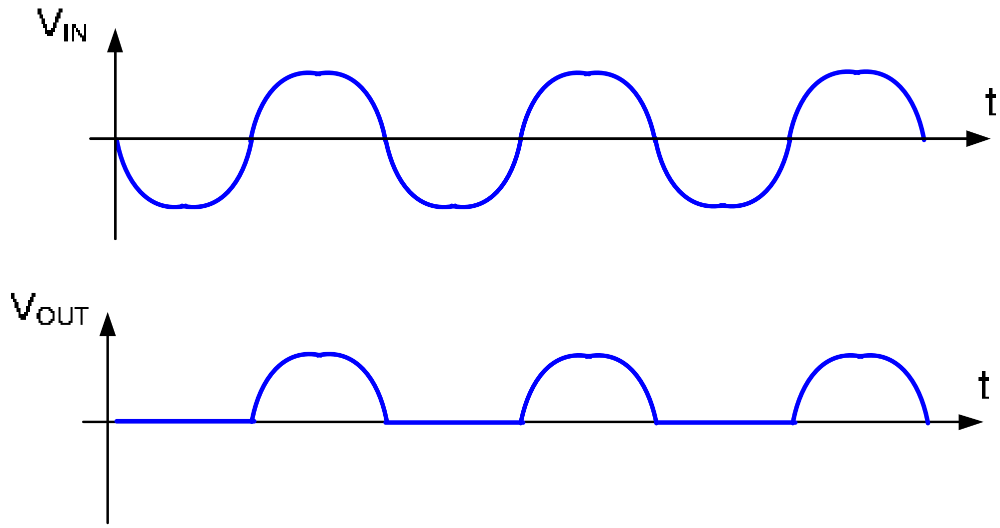
Review from Last Time:



Diode rectifier circuit

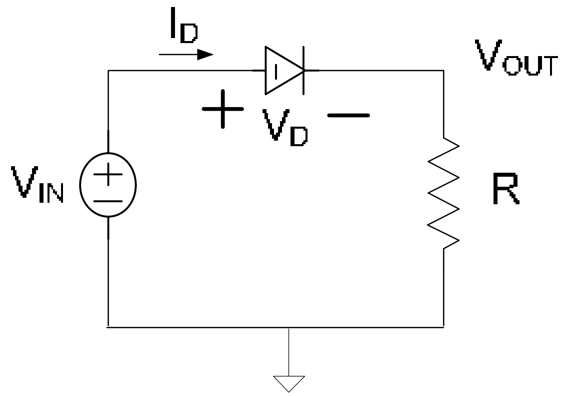


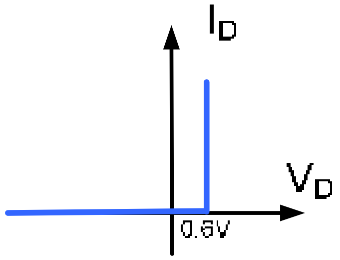
If $V_{IN}=V_M \sin\omega t$



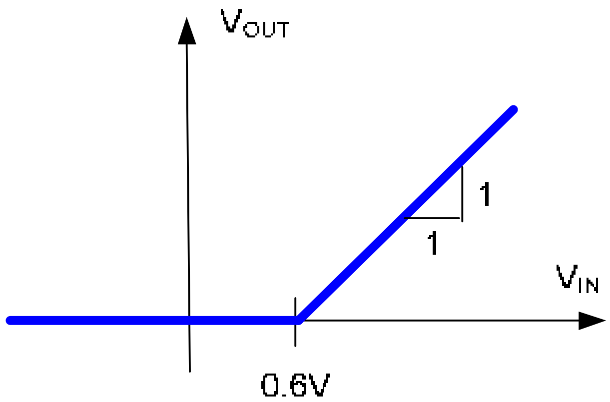
Serves as a rectifier – very useful function !

Performance Limitations of Diode Rectifier Circuit



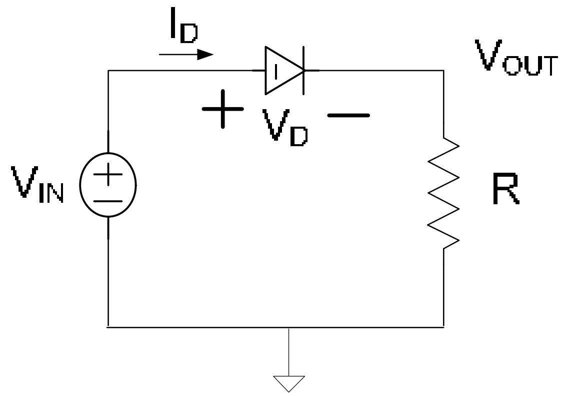


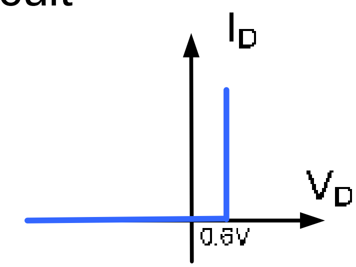
Diode rectifier circuit



$$V_{OUT} = \begin{cases} 0 & V_{IN} \leq 0.6V \\ V_{IN} - 0.6V & V_{IN} > 0.6V \end{cases}$$

Performance Limitations of Diode Rectifier Circuit



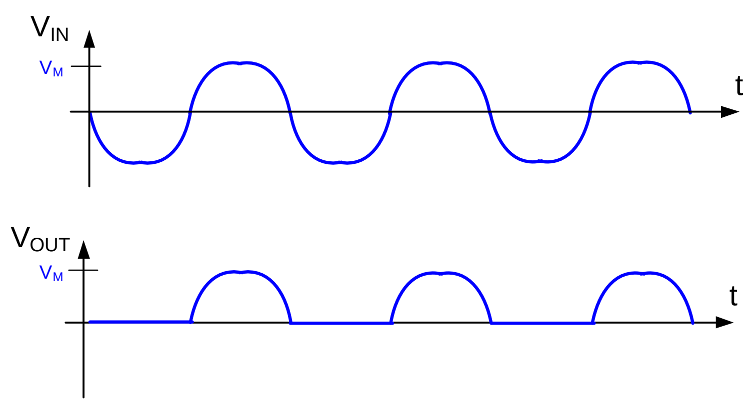


Diode rectifier circuit

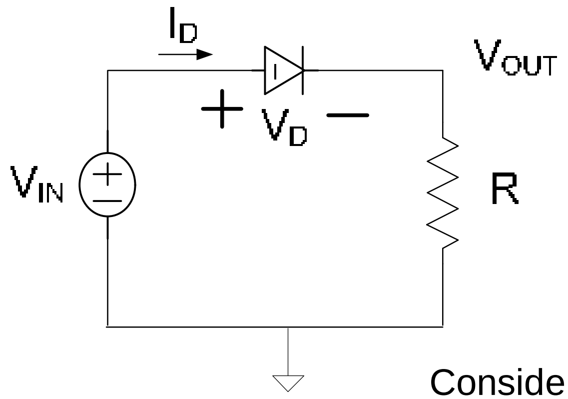
$$V_{OUT} = \begin{cases} 0 & V_{IN} \leq 0.6V \\ V_{IN} - 0.6V & V_{IN} > 0.6V \end{cases}$$

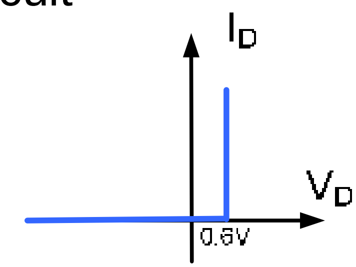
Consider $V_{IN} = V_M \sin\omega t$ for $V_M = 50V$, $V_M = 1V$ and $V_M = 0.5V$

Desired output:

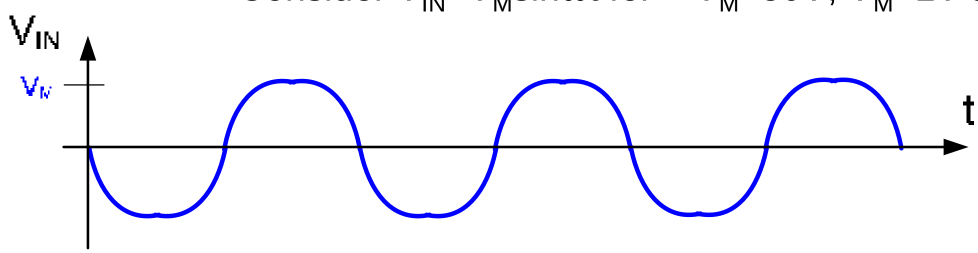


Performance Limitations of Diode Rectifier Circuit

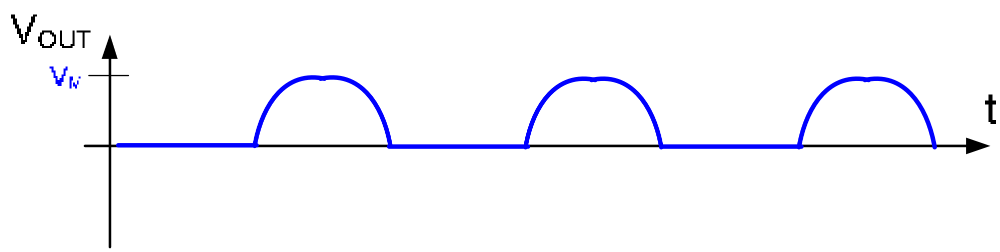


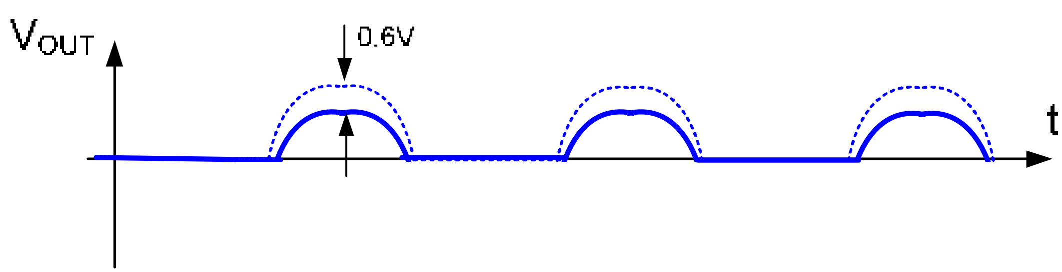


Consider $V_{IN}=V_M \sin\omega t$ for $V_M=50V$, $V_M=1V$ and $V_M=0.5V$

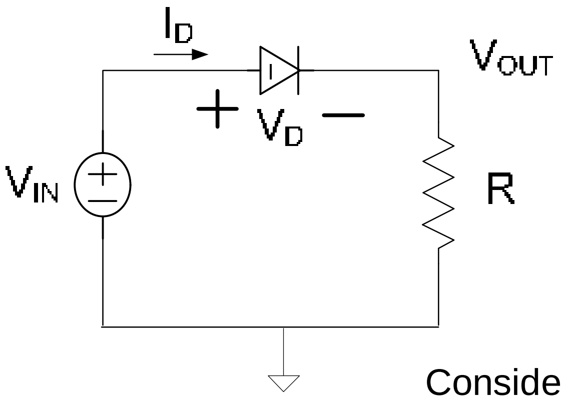


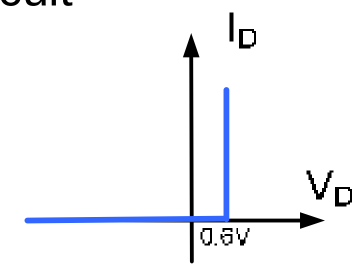
Desired output:



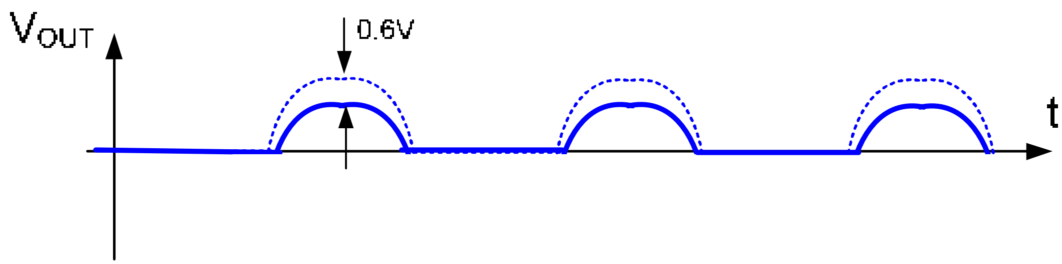


Performance Limitations of Diode Rectifier Circuit



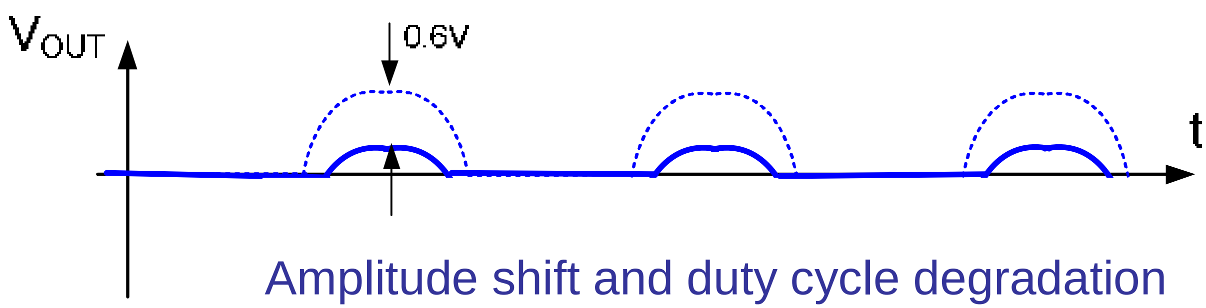


Consider $V_{IN}=V_M\sin\omega t$ for V_M=50V, V_M=1V and V_M=0.5V



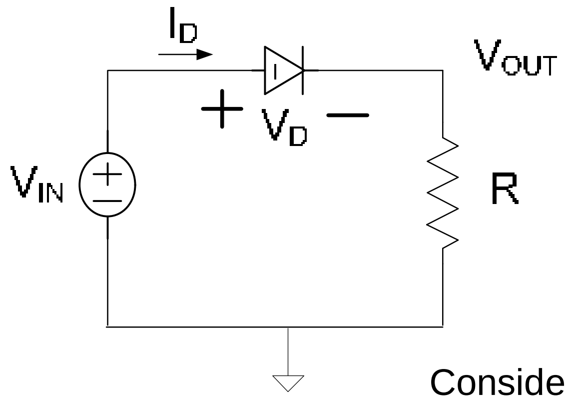
If V_M=50V, the 0.6V drop causes very little degradation in performance

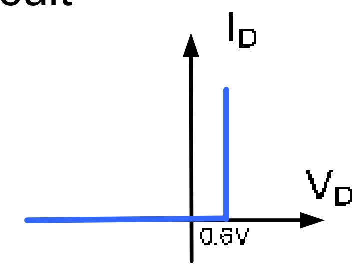
If V_M=1V, the 0.6V drop causes dramatic degradation in performance



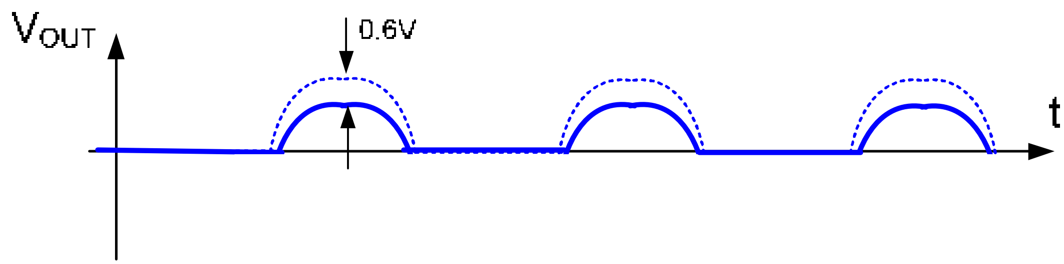
Amplitude shift and duty cycle degradation

Performance Limitations of Diode Rectifier Circuit

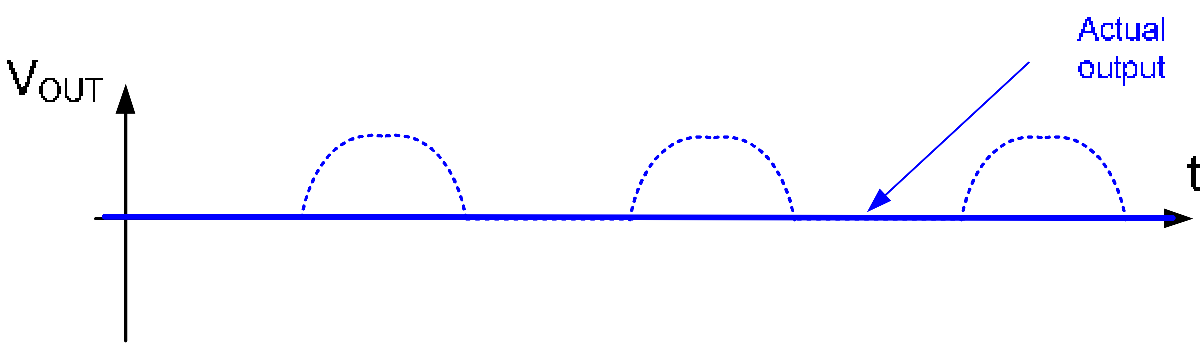




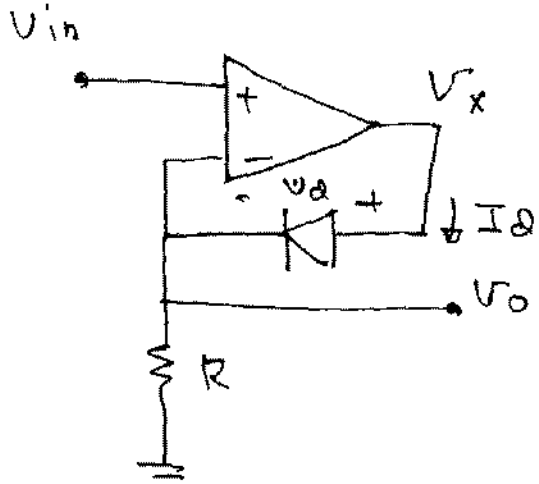
Consider $V_{IN}=V_M\sin\omega t$ for $V_M=50V$, $V_M=1V$ and $V_M=0.5V$



If $V_M=0.5V$, the 0.6V drop provides no output !



Precision Rectifier



Case 1 D1 conducting

$v_x = v_i + .6V$

$v_o = v_i$

Valid for $I_d > 0$

$\frac{V_{in}}{R} > 0$

$V_{in} > 0$

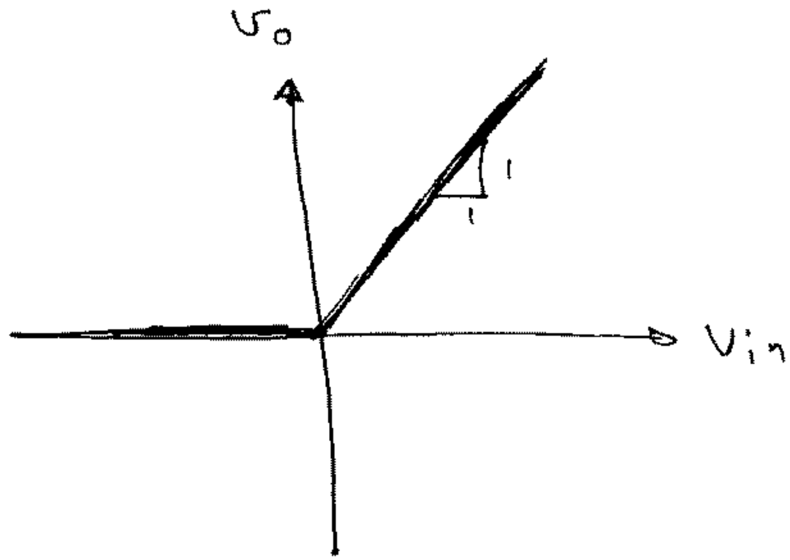
Case 2 D1 cutoff

$v_x = V_{ss}$

$v_o = 0$

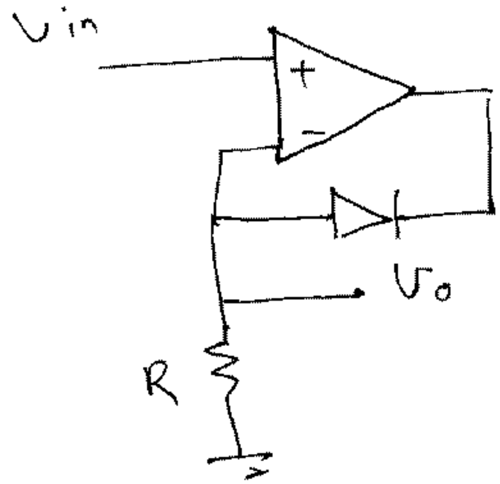
Valid for $v_d < 0$ & $V_{in} < V^-$

$v_{ss} < 0$ & $v_{in} < 0$

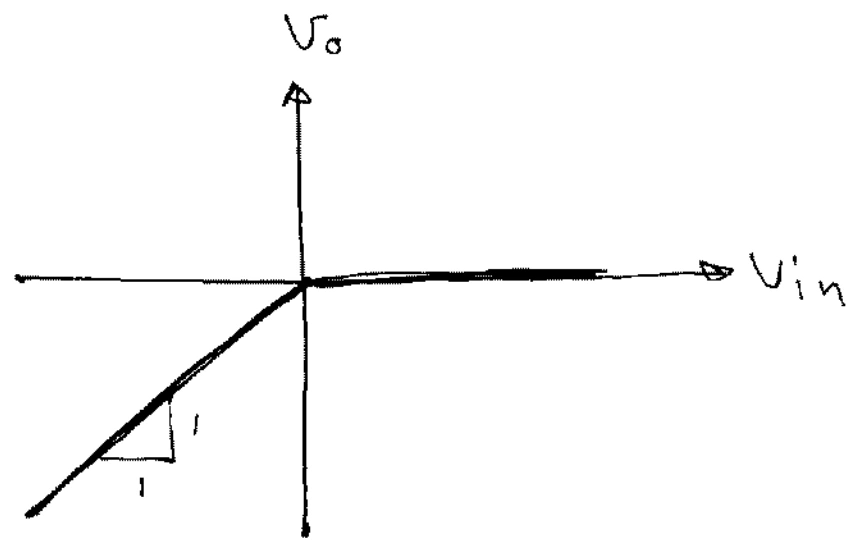


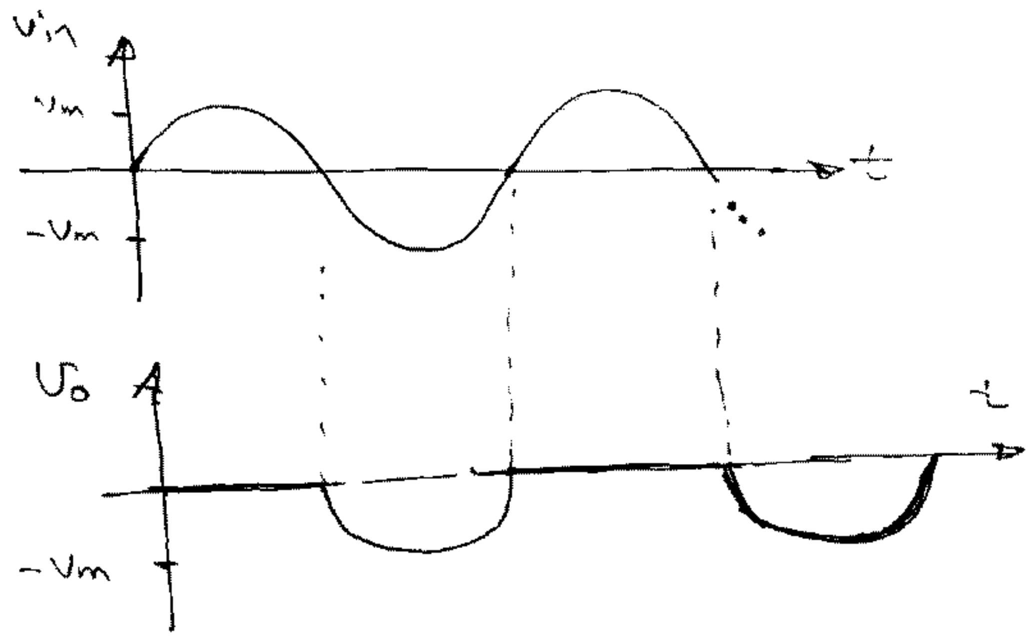
$$v_o = \begin{cases} v_{in} & v_{in} > 0 \\ 0 & v_{in} < 0 \end{cases}$$

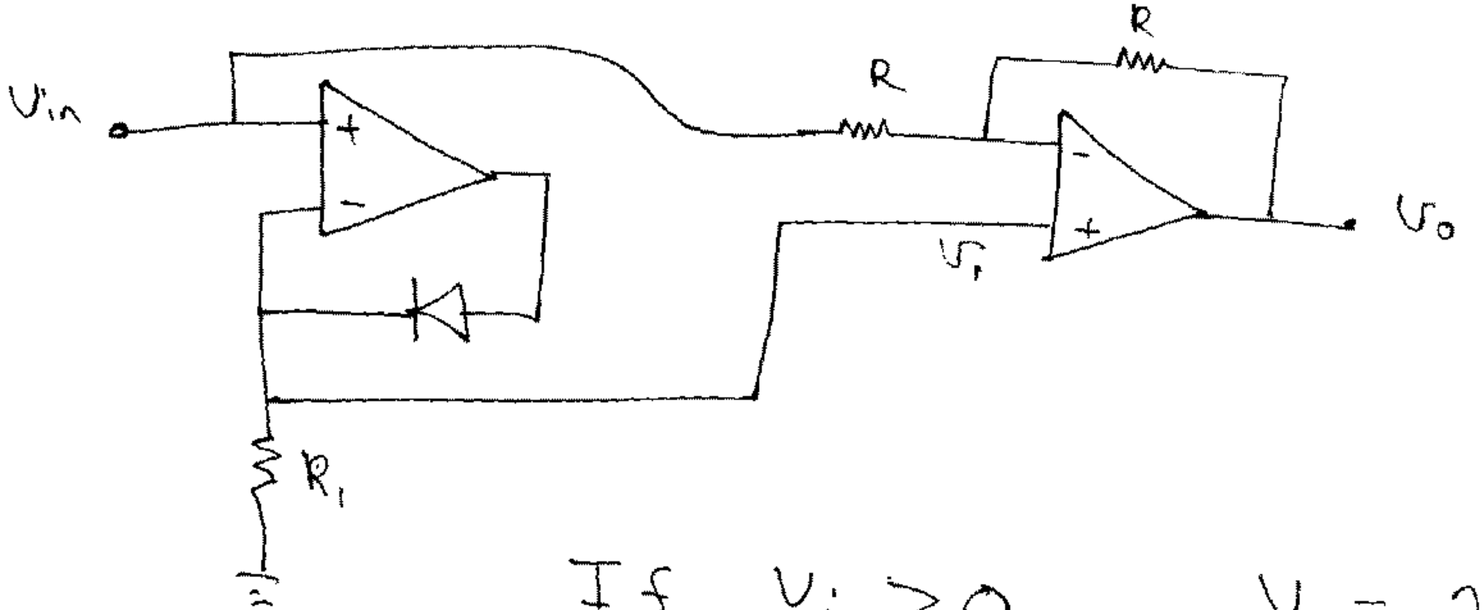
This is termed precision rectifier because diode drop is not present in transfer characteristics



Precision Inverting Rectifier



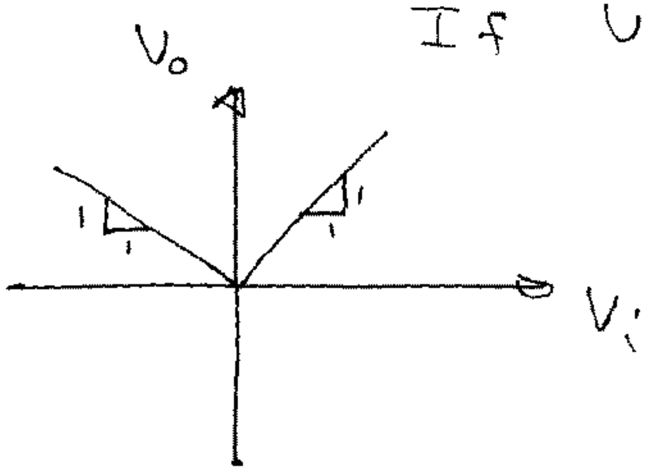




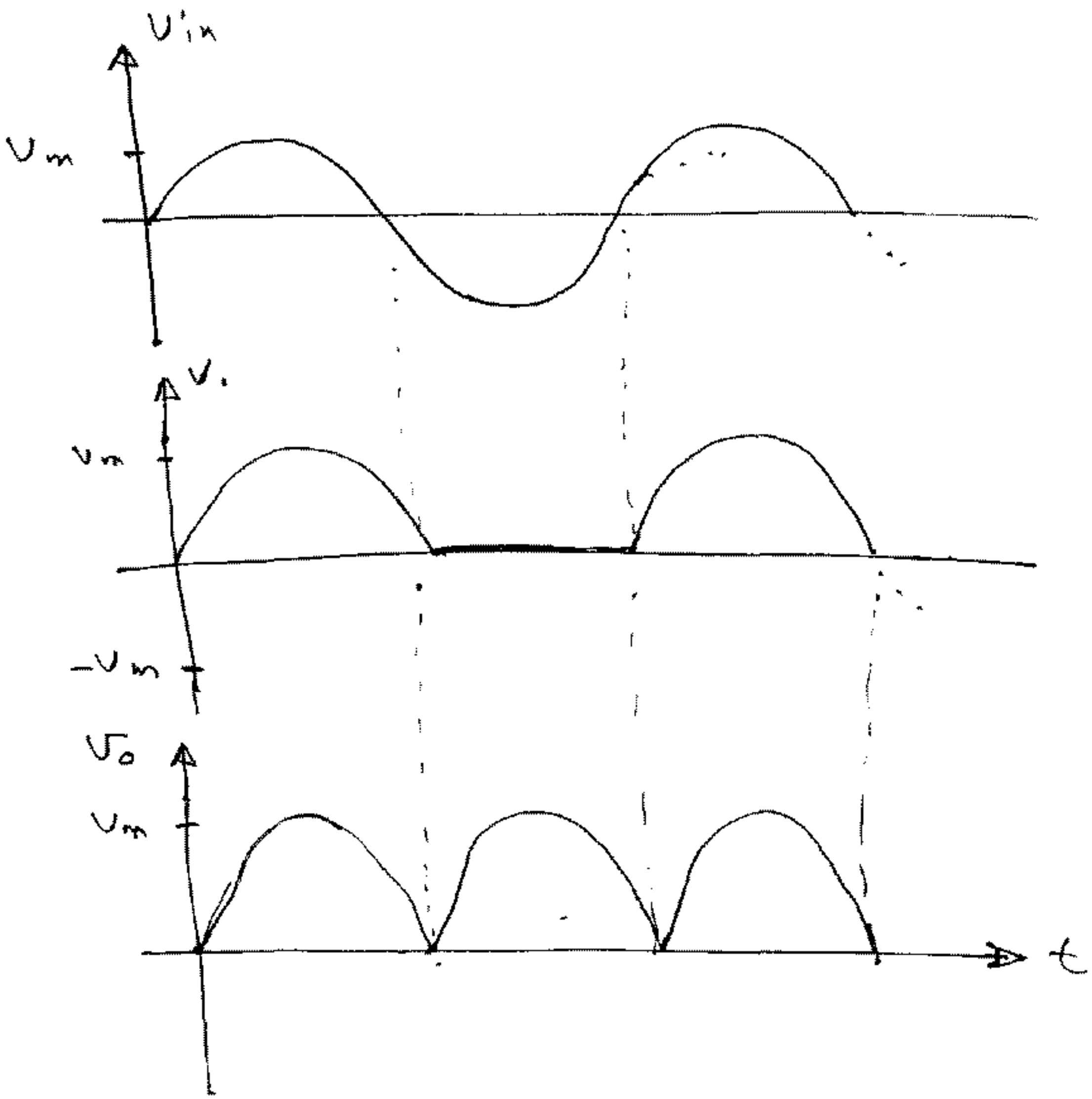
If $V_i > 0$ $\quad V_o = 2V_i - V_i$

$V_o = V_i$

If $V_i < 0$ $\quad V_o = -V_i$



Precision Full-Wave Rectifier



$$V_i = V_m \sin \omega t$$

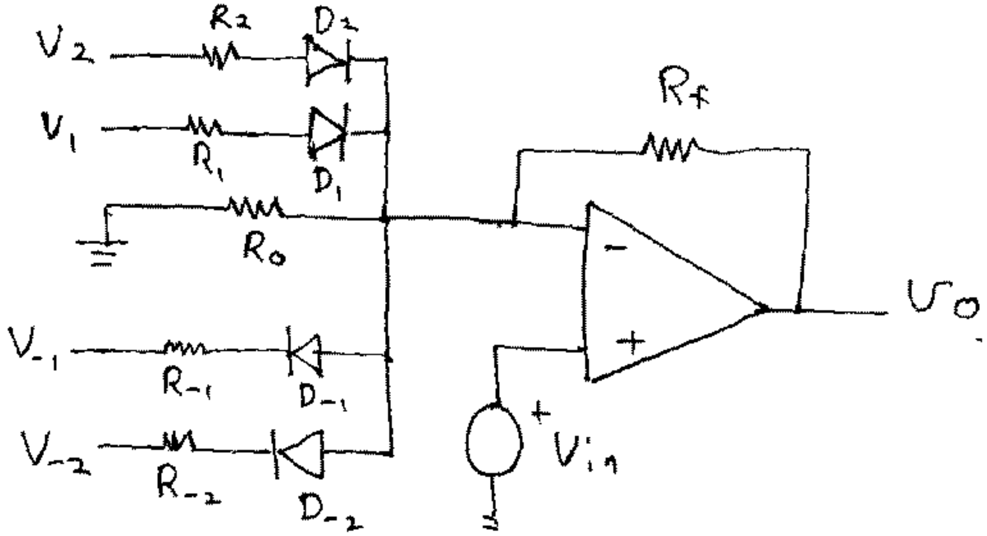
$$V_1 = \begin{cases} V_m \sin \omega t & V_i > 0 \\ 0 & V_i < 0 \end{cases}$$

$$V_o = 2V_1 - V_i$$

$$V_o = \begin{cases} (2V_m - V_m)\sin \omega t & V_i > 0 \\ -V_m \sin \omega t & V_i < 0 \end{cases}$$

$$V_o = \begin{cases} V_m \sin \omega t & V_i > 0 \\ -V_m \sin \omega t & V_i < 0 \end{cases}$$

Nonlinear Function Generator.



Assume ideal diodes (actually may work better with nonideal diodes)

$$V_2 > V_1 > 0 > V_{-1} > V_{-2}$$

For $V_i > V_2$, D_1 & D_2 off, D_{-1}, D_{-2} ON

$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_0 \,//\, R_{-1} \,//\, R_{-2}}$$

For $V_1 < V_i < V_2$ D_1 off, D_2, D_{-1}, D_{-2} on

$$\frac{v_o}{v_i} = 1 + \frac{R_f}{R_o /\!/ R_2 /\!/ R_{-1} /\!/ R_{-2}}$$

For $V_{-1} < V_i < V_1$ D_1, D_2, D_{-1}, D_{-2} ON

$$\frac{v_o}{v_i} = 1 + \frac{R_f}{R_o /\!/ R_1 /\!/ R_2 /\!/ R_{-1} /\!/ R_{-2}}$$

For $V_{-2} < V_i < V_{-1}$ D_{-1} off, D_1, D_2, D_{-2} ON

$$\frac{v_o}{v_i} = 1 + \frac{R_f}{R_o /\!/ R_1 /\!/ R_2 /\!/ R_{-2}}$$

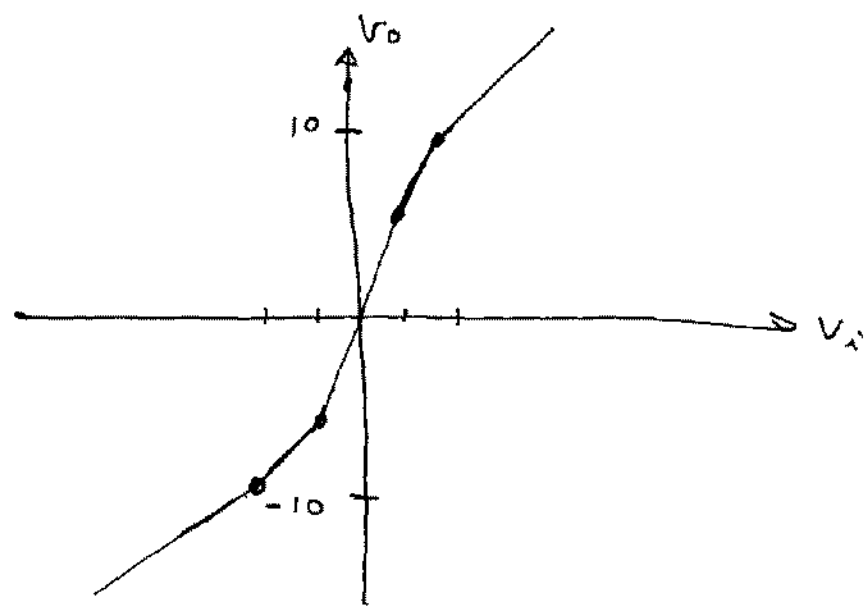
For $V_i < V_{-2}$ D_1, D_2 ON

$$\frac{v_o}{v_i} = 1 + \frac{R_f}{R_o /\!/ R_1 /\!/ R_2}$$

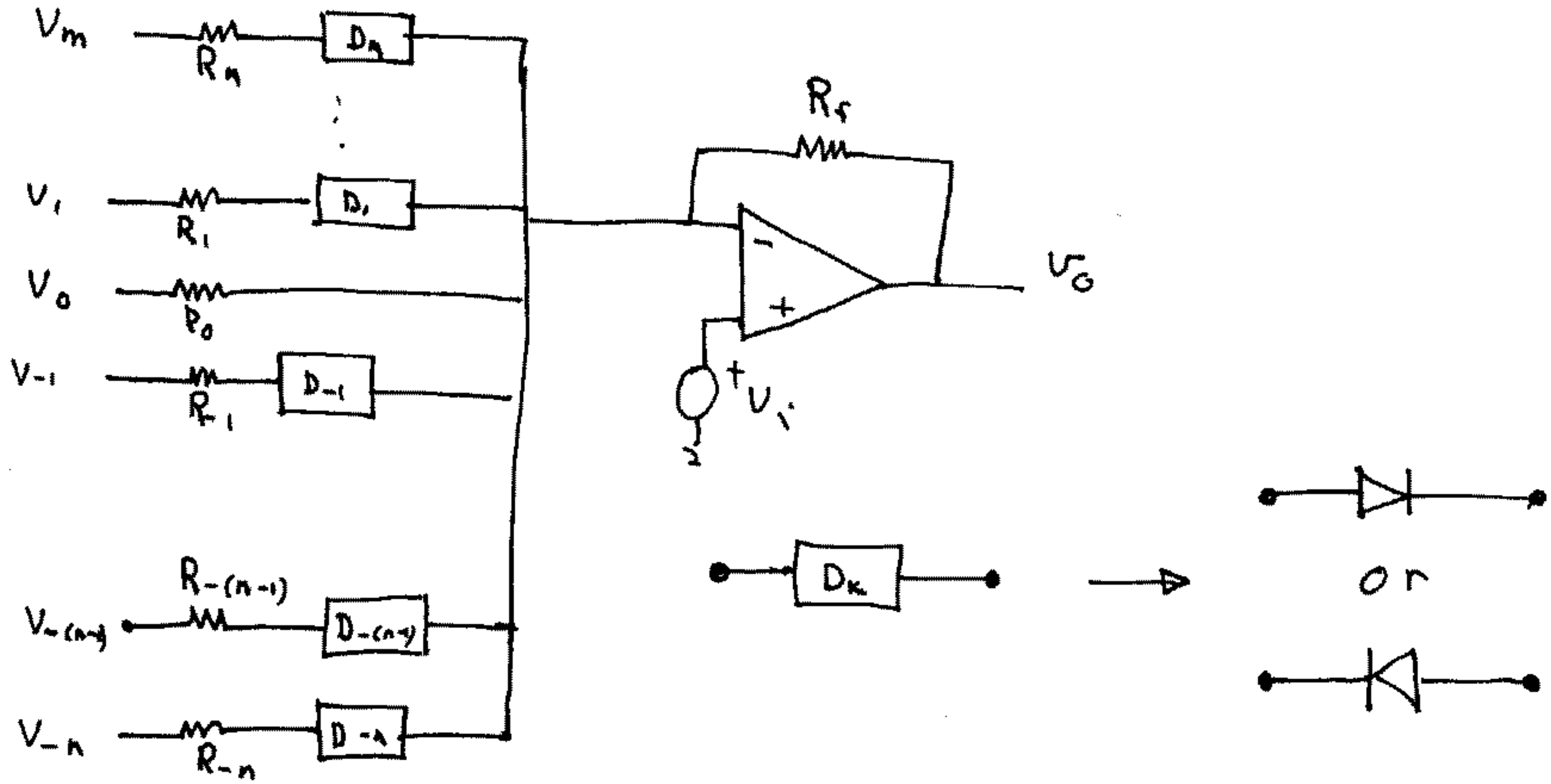
Example: $V_1 = 1V$, $V_2 = 2V$, $V_{-1} = -1V$, $V_{-2} = -2V$

$R_0 = R_1 = R_2 = R_{-1} = R_{-2} = R_F$

$$
V_o = \begin{cases} 4V_i + 3 & 2 < V_i \\ 5V_i + 1 & 1 < V_i < 2 \\ 6V_i & -1 < V_i < 1 \\ 5V_i - 1 & -2 < V_i < -1 \\ 4V_i - 3 & V_i < -2 \end{cases}
$$



Generalized Nonlinear Function Generator



$$V_{-n} < V_{-(n-1)} < \cdots < V_{-1} < V_0 < V_1 < \cdots < V_m$$

Each diode can be oriented either to the left or to the right.

Slope of V_o vs V_i always positive and larger than 1

- This circuit can generate an arbitrary nonlinear transfer characteristic depending only upon how the diodes are oriented and how the voltages are selected.

- The slope of the transfer characteristic at a voltage V_i will depend upon which diodes are conducting and will be given by

$$1 + \frac{R_f}{\text{(Parallel Combination of Resistors for branches with conducting diodes)}}$$

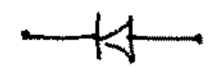
A mathematical expression will now be given for V_o. The notation is tedious. Define the Boolean variable $b_k(V_i)$ for $-n \le k < 0$ and $0 < k \le m$ as

$b_k(V_i) = 1$ if $V_i > V_k$ and diode_k oriented

or if $V_i < V_k$ and diode_k oriented

$b_k(V_i) = 0$ if $V_i > V_k$ and diode_k oriented

or if $V_i < V_k$ and diode_k oriented



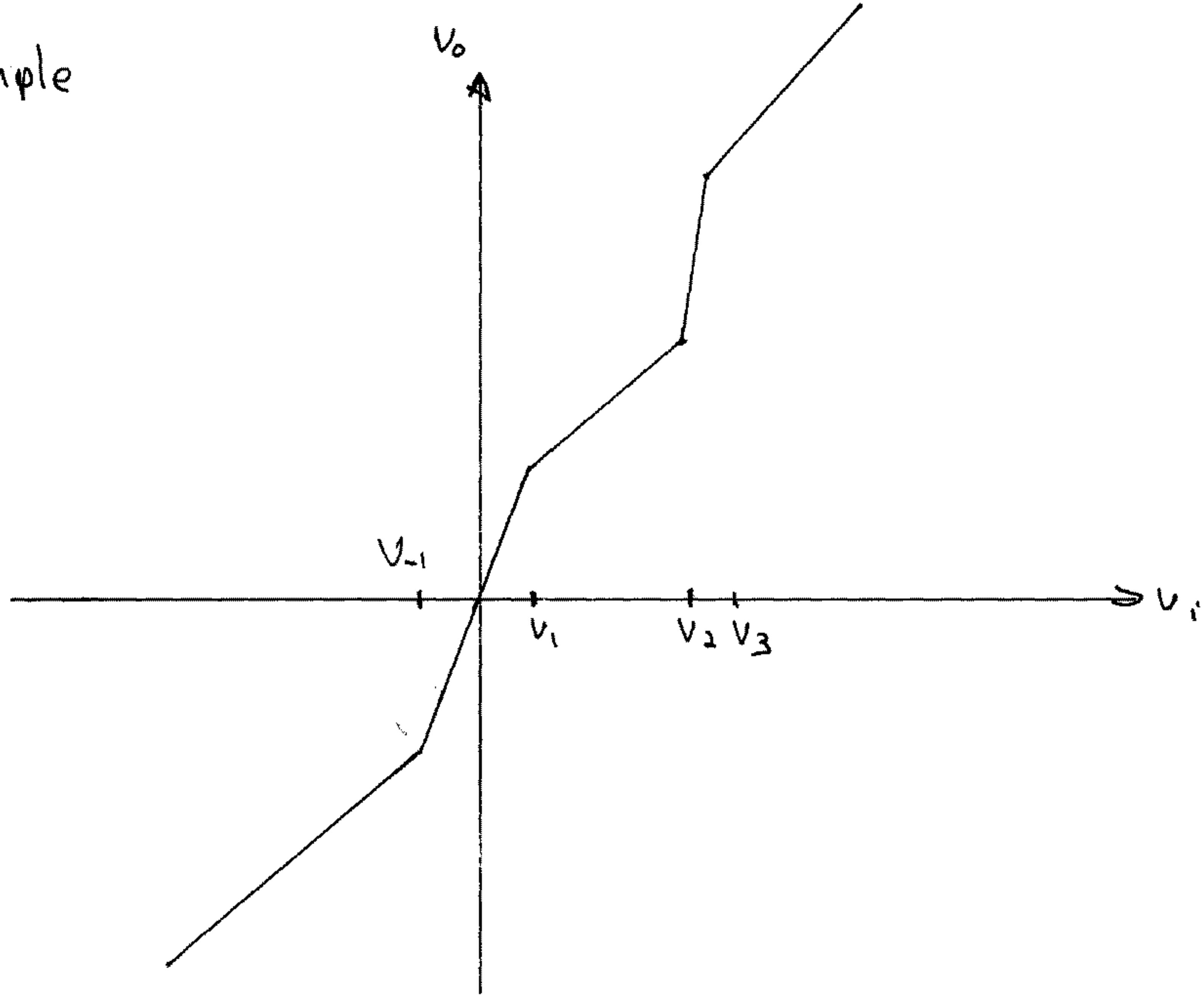
and define

$$b_0 = 1$$

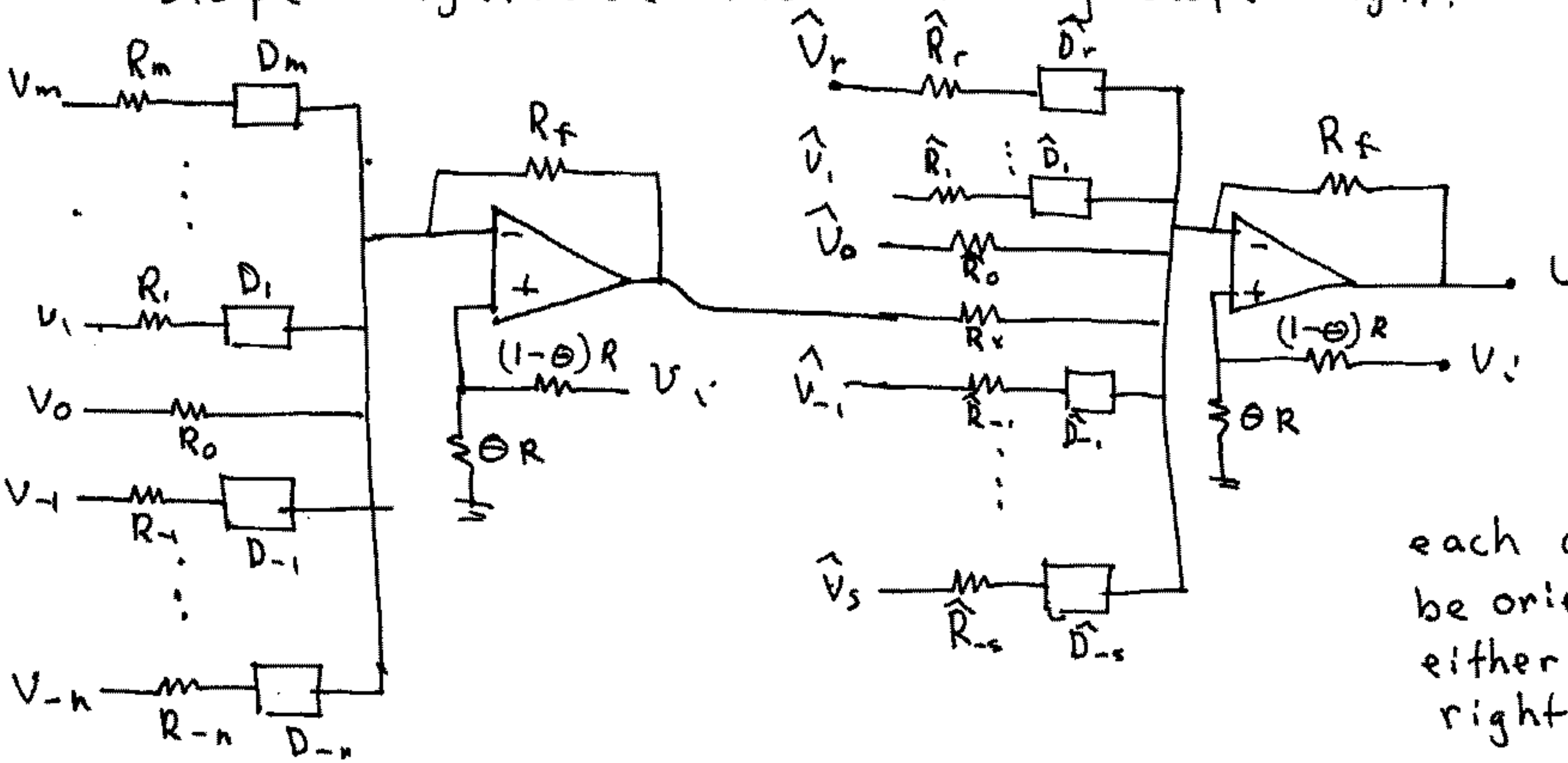
It follows from KCL by summing currents at the "−" terminal of the op amp that the output at a given v_i can be expressed as

$$v_o = v_i\left[1 + R_F \sum_{k=-n}^{m} \frac{b_k(v_i)}{R_k}\right] - \sum_{k=-n}^{m} v_k\left(\frac{R_F}{R_k}\right) b_k(v_i)$$

Example



Generalized Nonlinear Function Generator with arbitrary slope magnitude and arbitrary slope sign.



each diode can be oriented to either left or right

The formulation of an expression for V_0 is quite tedious but operation and design is straightforward.

Example