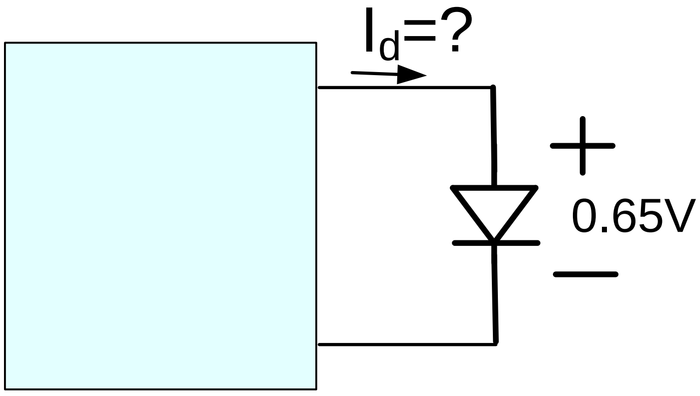
EE 230
Lecture 28

Nonlinear Circuits using Diodes

- Rectifiers
- Precision Rectifiers
- Nonlinear function generators

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 4

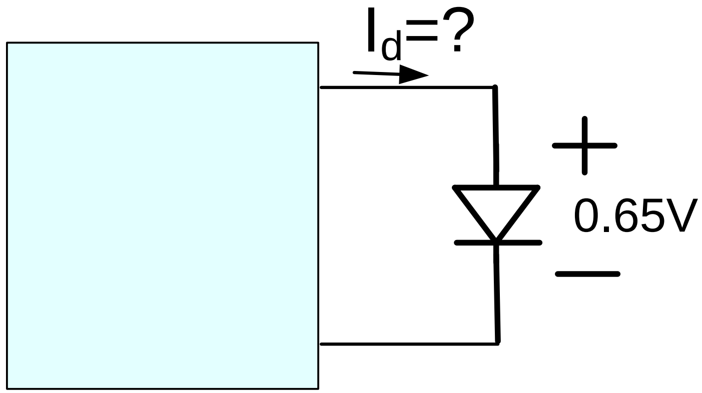
3

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?



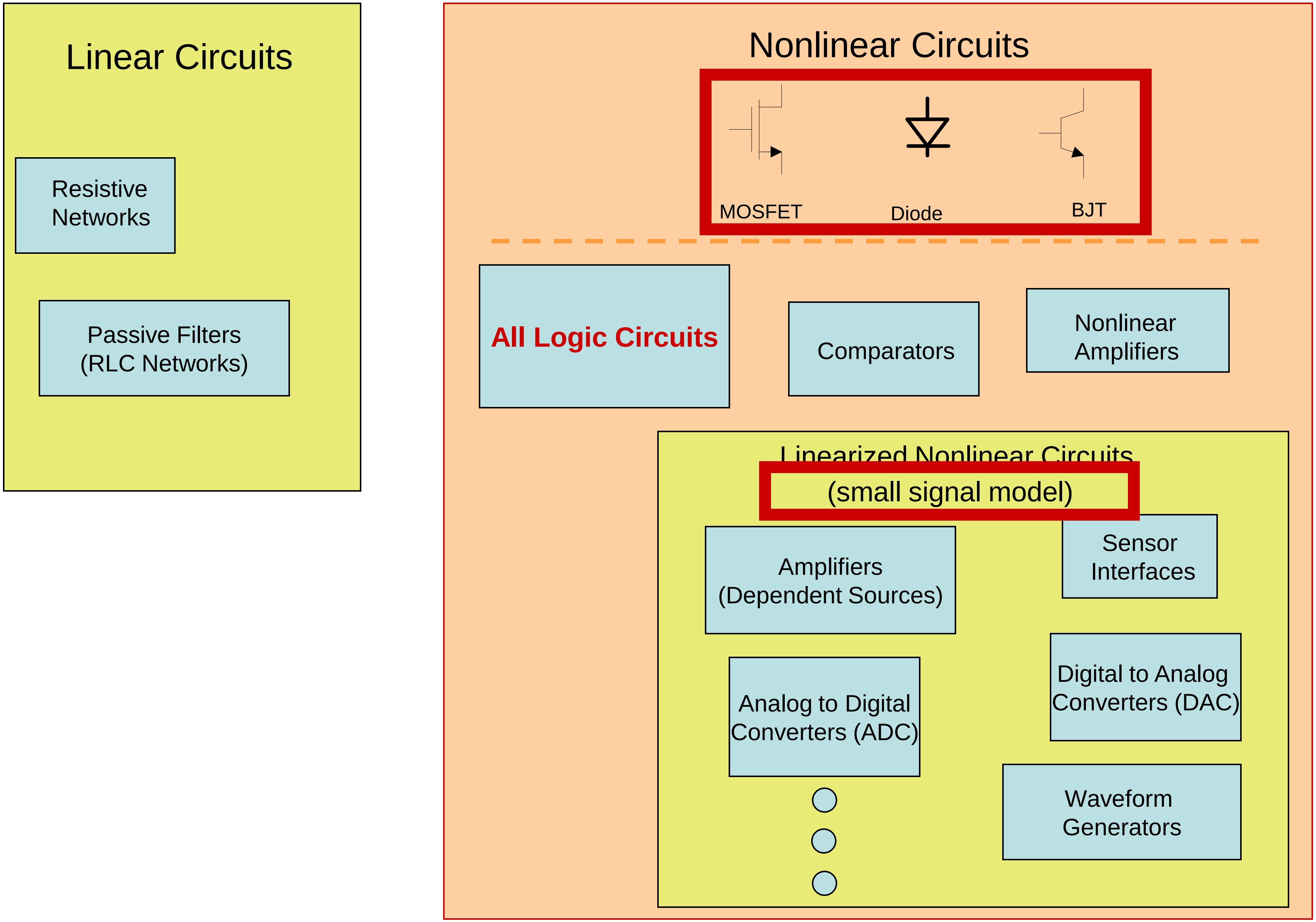
Solution:

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

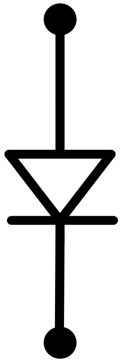
$$I_d = 1E\text{-}14\left(e^{\frac{0.65}{300 \bullet 8.63E-5}}\right) = 1E\text{-}14 \bullet 8E10 = 800uA$$

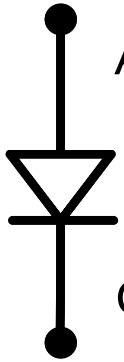
Review from Last Time:

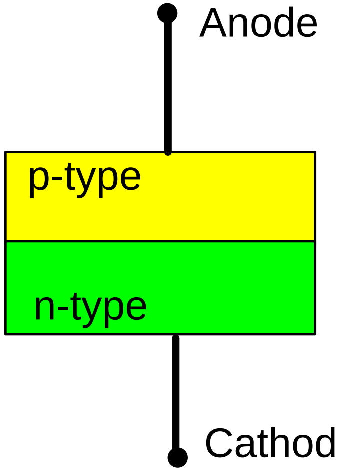
The Real Electronics World

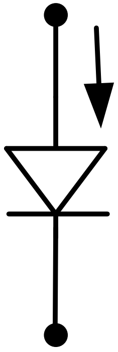


The Diode





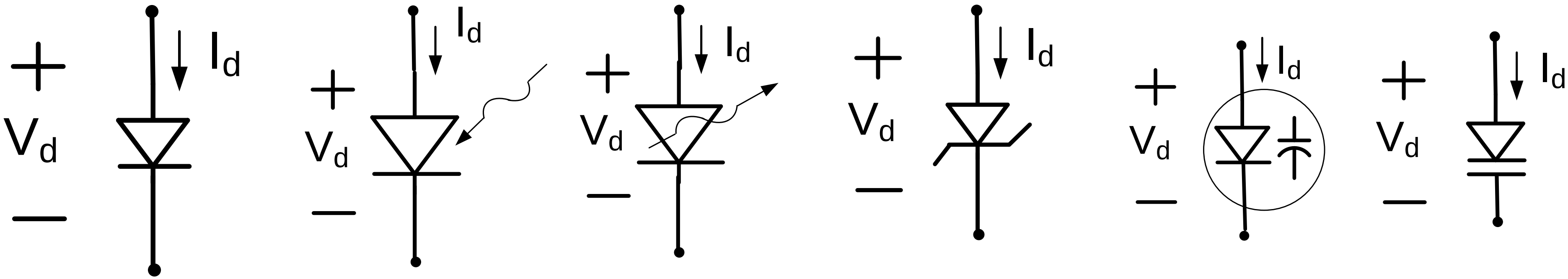




Review from Last Time:

Types of Diodes

pn junction diodes



Signal or Rectifier

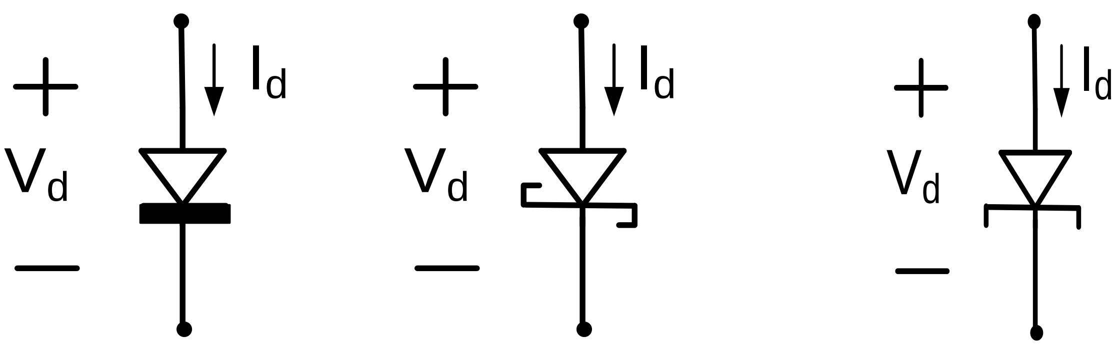
Pin or Photo

Light Emitting
LED
Laser Diode

Zener

Varactor or Varicap

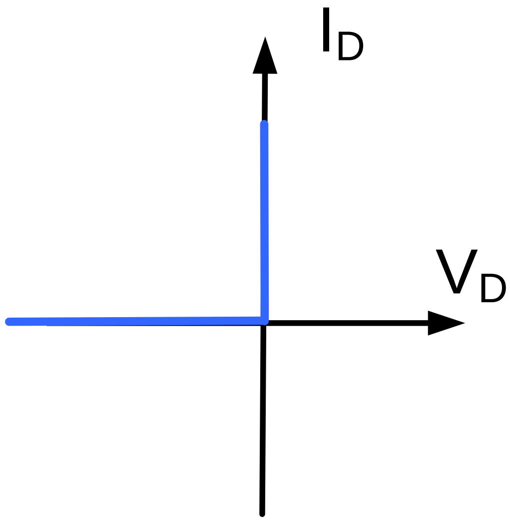
Metal-semiconductor junction diodes

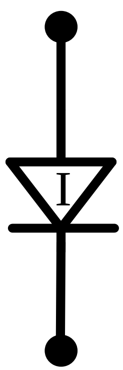


Schottky Barrier

Review from Last Time:

The Ideal Diode





$I_D = 0$ if $V_D \le 0$ "OFF"

$V_D = 0$ if $I_D > 0$ "ON"

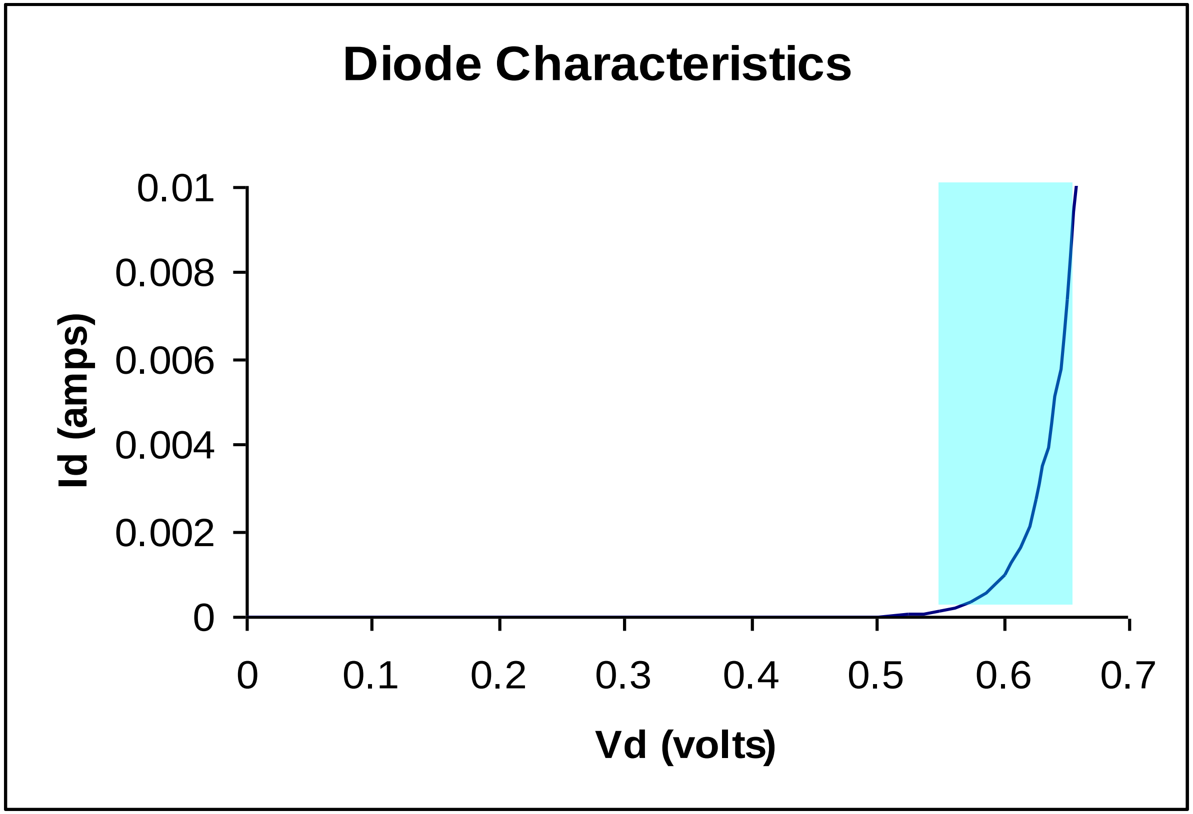
"ON" "OFF"

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

Review from Last Time:

Diode equation (silicon pn junction diodes)

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

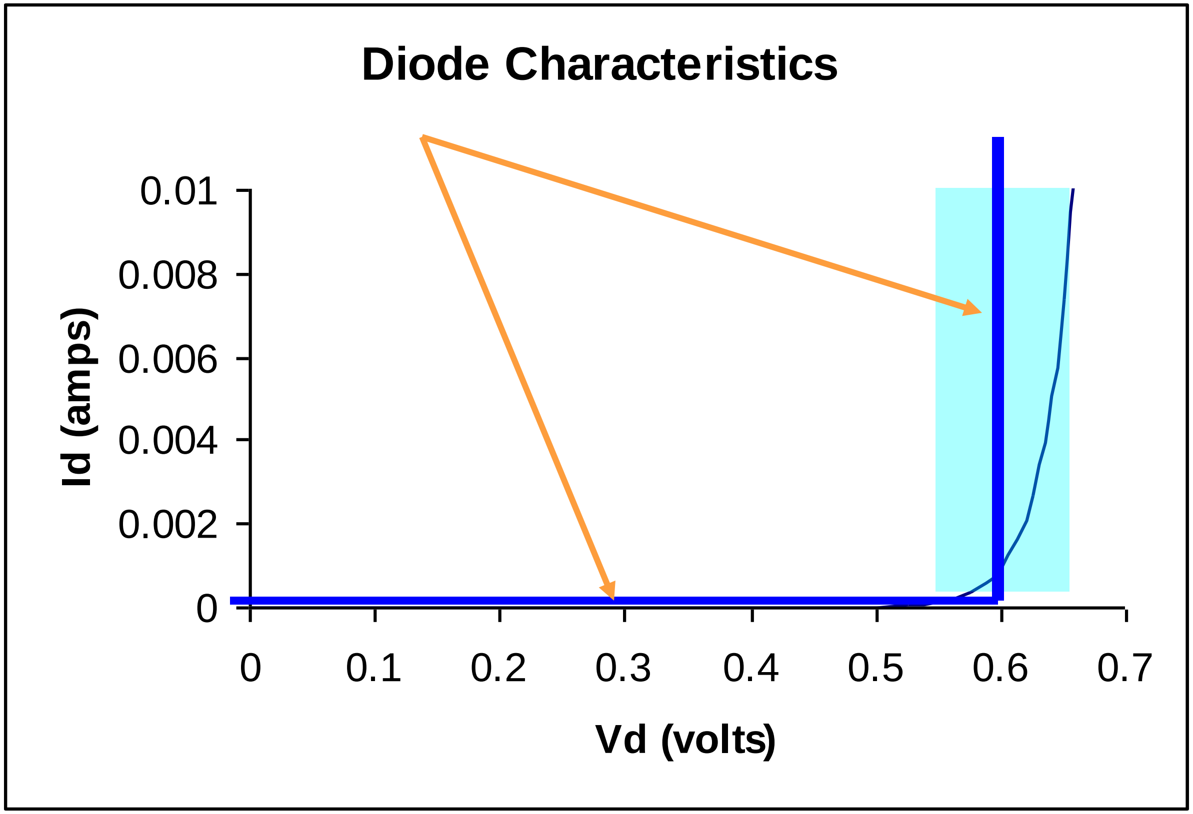


Widely Used Piecewise Linear Model

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:

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

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

A more accurate approximation to the diode equation

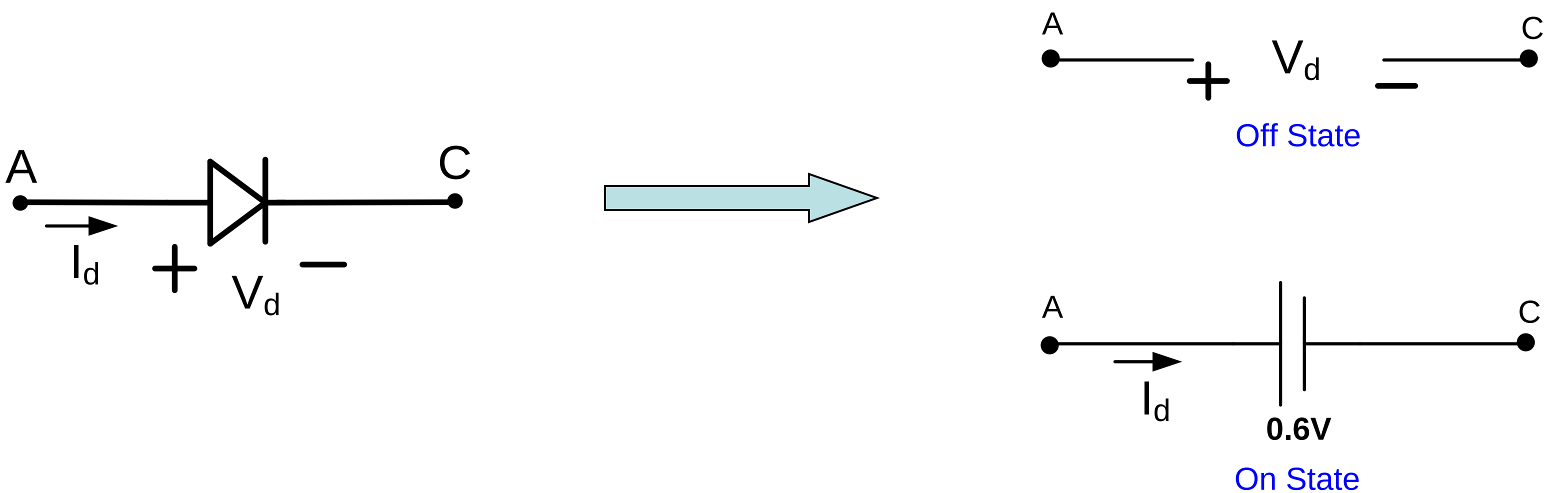
$$I_d = I_S\left(e^{\frac{V_d}{V_t}} - 1\right)$$

Piecewise Linear Model

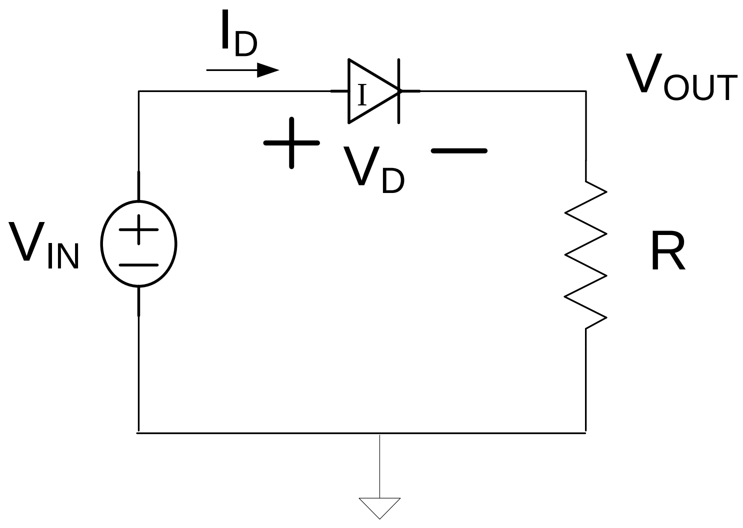
$$I_d = 0 \qquad V_d < 0.6V$$

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

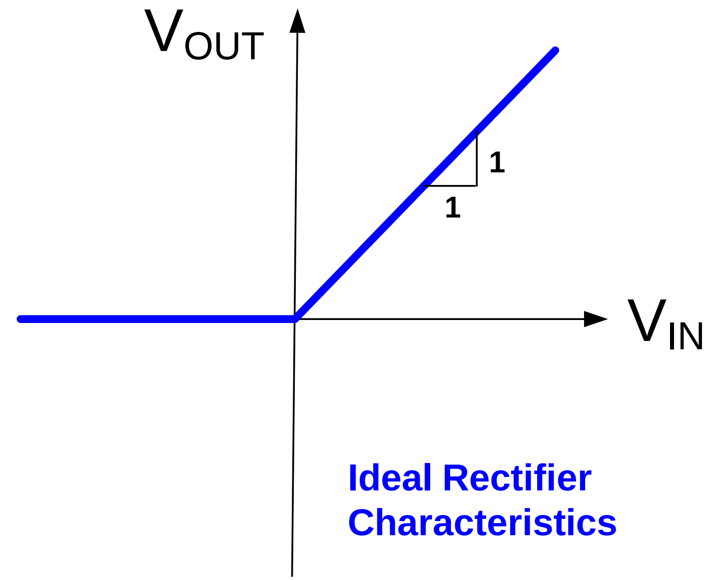
Equivalent Circuit



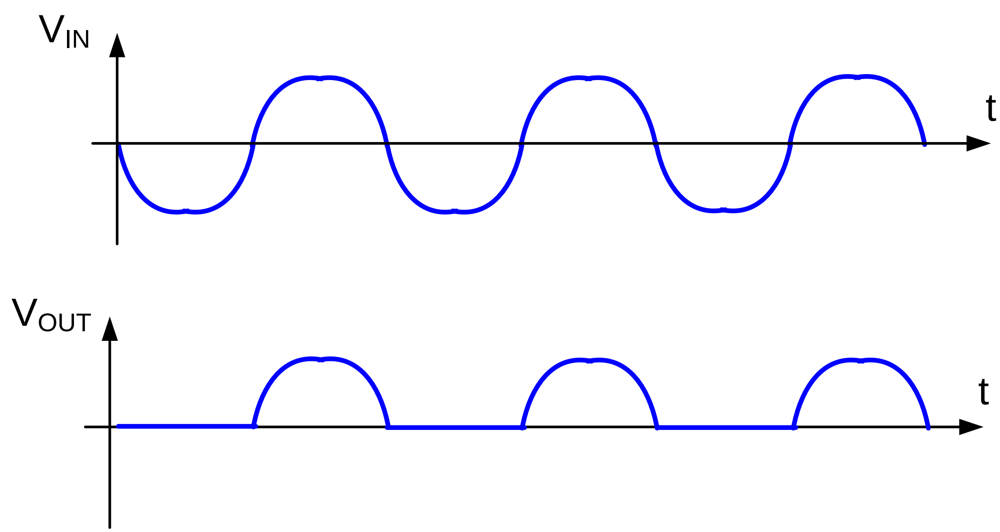
Review from Last Time:



Diode rectifier circuit

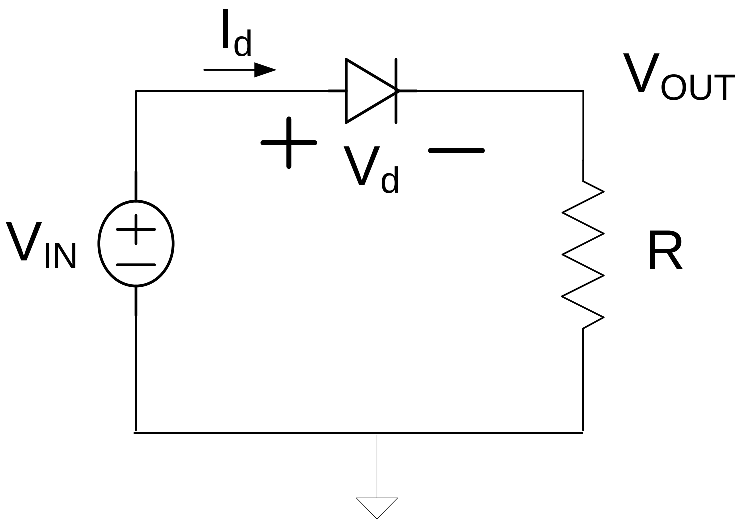


If $V_{IN}=V_M \sin\omega t$



Serves as a rectifier – very useful function !

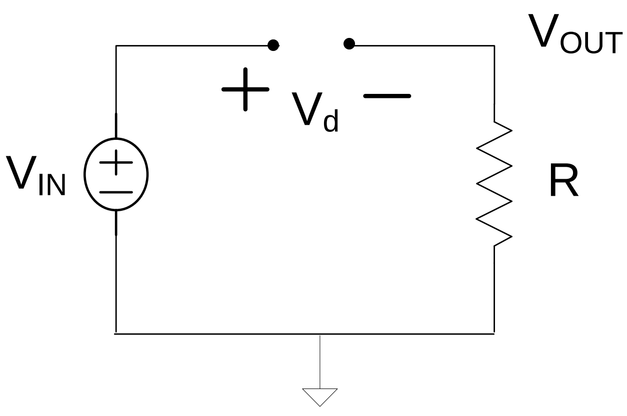
Consider again the basic rectifier circuit



Analyze with piecewise linear model $I_d = 0 \qquad V_d \leq 0.6V$

$V_d = 0.6V \qquad I_d > 0$

Case 1 $\qquad I_d = 0$



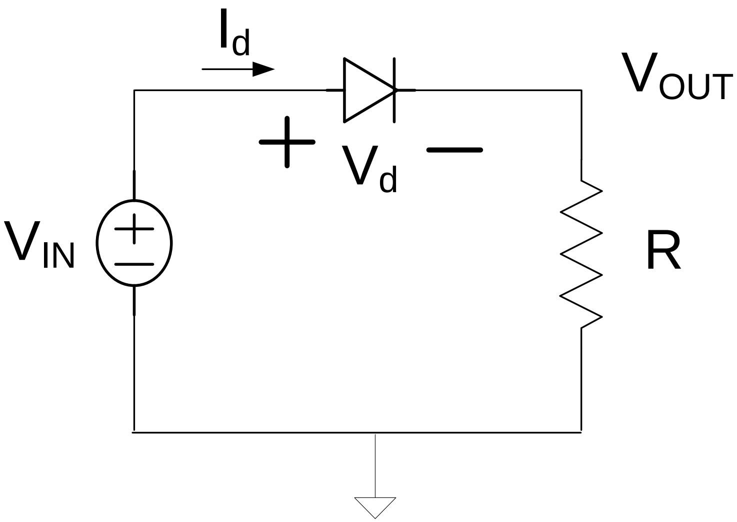
$V_{OUT}=0$

valid for $V_d \leq 0.6V$

but $V_d = V_{IN}$

$\therefore$ valid for $V_{IN} \leq 0.6V$

Consider again the basic rectifier circuit



Analyze with piecewise linear model

$I_d = 0 \qquad V_d < 0.6V$

$V_d = 0.6V \qquad I_d > 0$

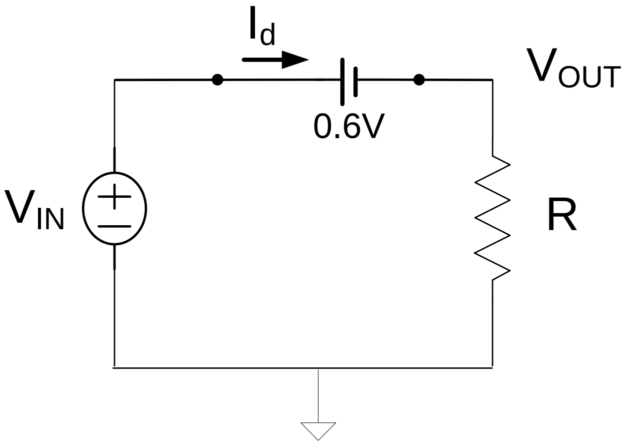
Case 2 $\qquad V_d = 0.6V$

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

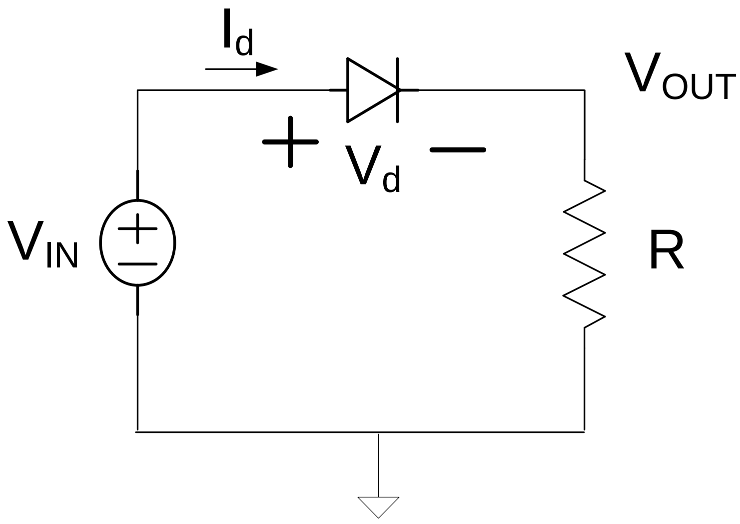
valid for $I_d > 0$

but $\quad I_d = \dfrac{V_{IN} - 0.6V}{R}$

$\therefore$ valid for $\quad V_{IN} > 0.6V$



Consider again the basic rectifier circuit



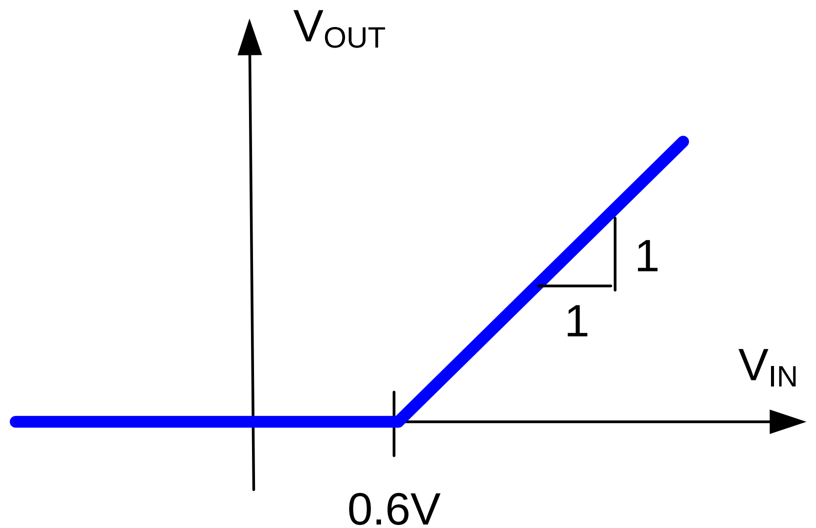
Analyze with piecewise linear model

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

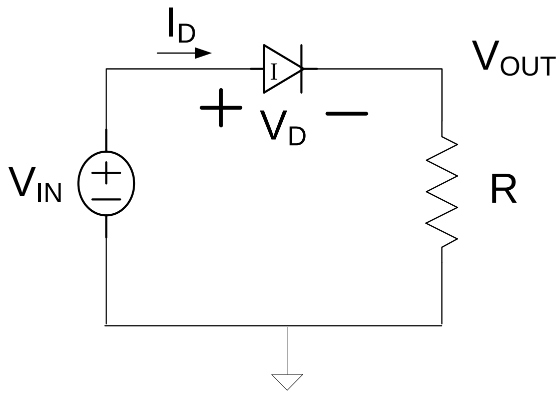
$$V_d = 0.6V \qquad I_d > 0$$

Solution summary:

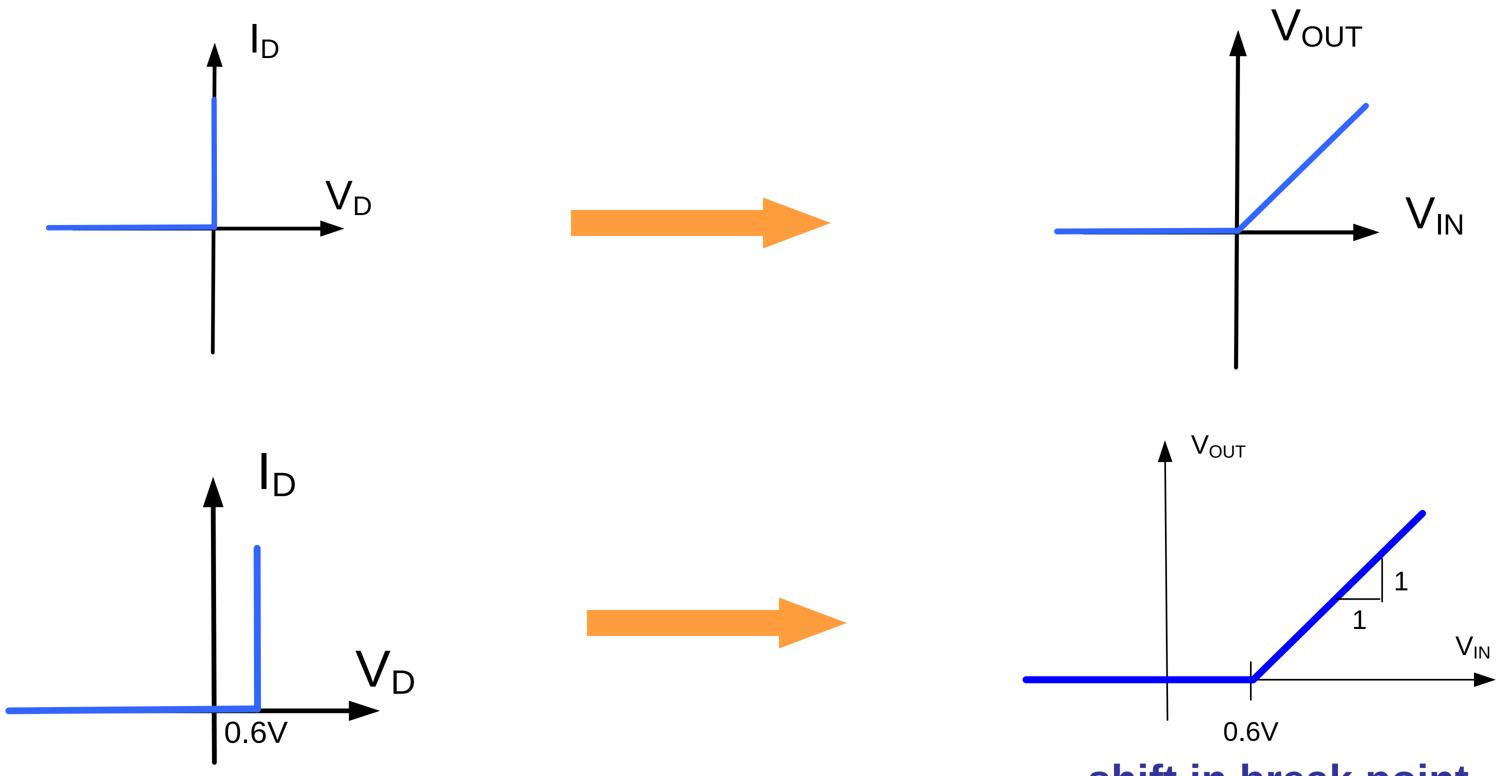
$$V_{OUT} = \begin{cases} 0 & V_{IN} \leq 0.6V \\ V_{IN} - 0.6V & V_{IN} > 0.6V \end{cases}$$



Performance Limitations of Diode Rectifier Circuit

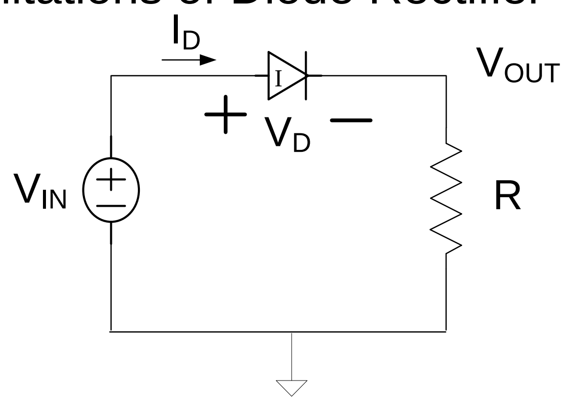


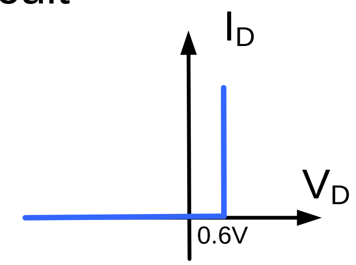
Diode rectifier circuit



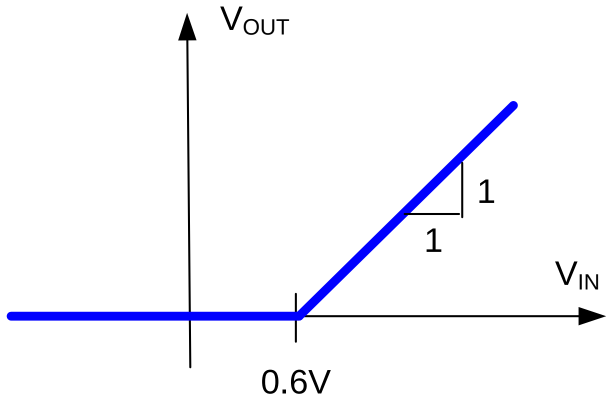
shift in break point

Performance Limitations of Diode Rectifier Circuit



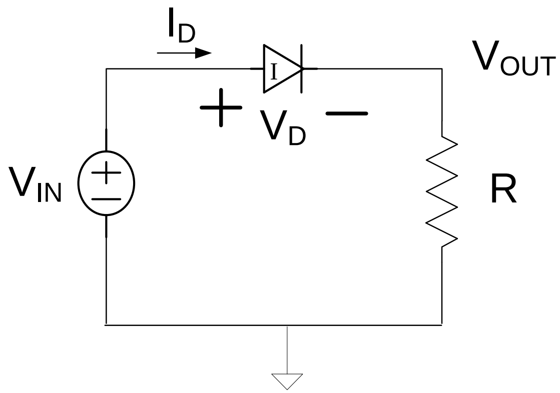


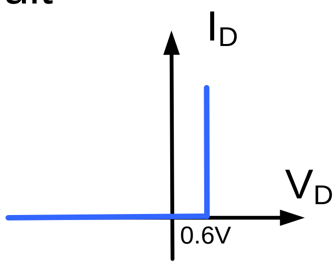
Diode rectifier circuit



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

Performance Limitations of Diode Rectifier Circuit



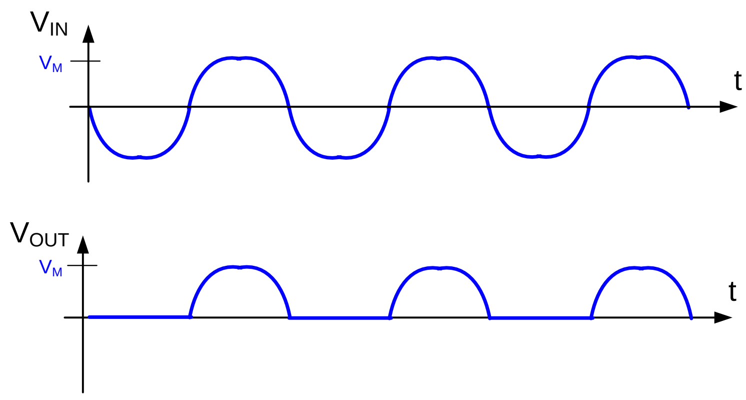


Diode rectifier circuit

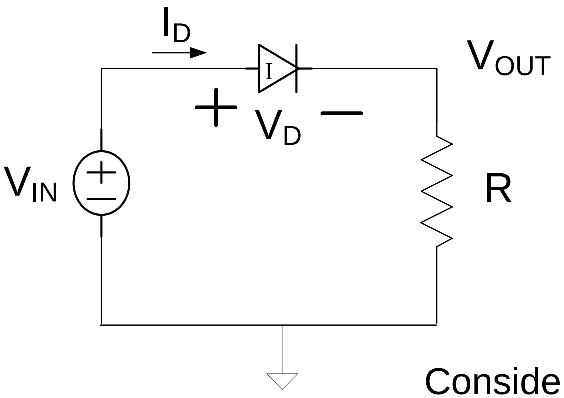
$$V_{OUT} = \begin{cases} 0 & V_{IN} \leq 0.6V \\ V_{IN} - 0.6V & V_{IN} > 0.6V \end{cases}$$

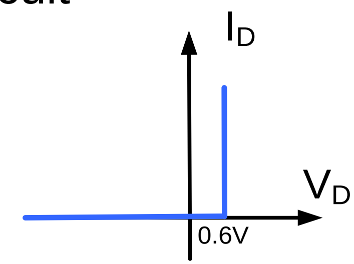
Consider $V_{IN} = V_M \sin\omega t$ for $V_M = 50V$, $V_M = 1V$ and $V_M = 0.5V$

Desired output:

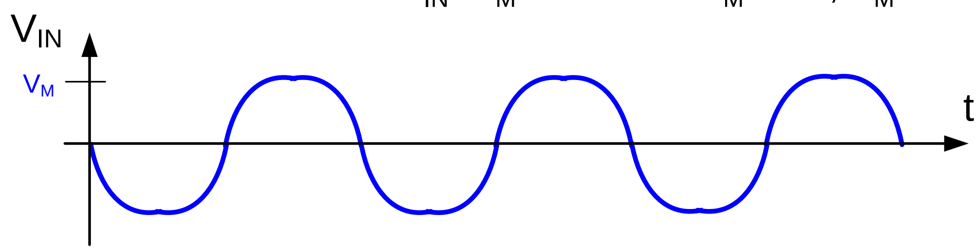


Performance Limitations of Diode Rectifier Circuit

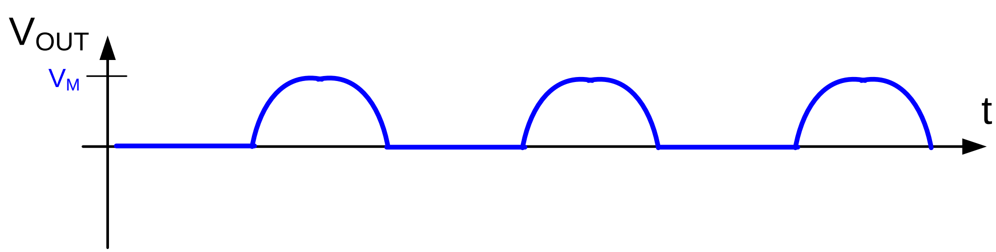


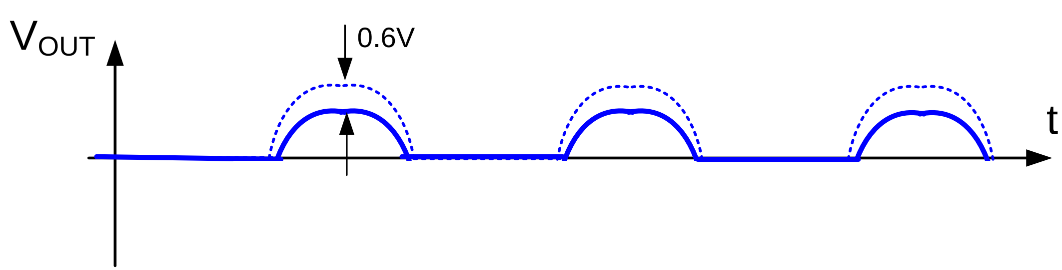


Consider $V_{IN}=V_M \sin\omega t$ for V_M=50V, V_M=1V and V_M=0.5V

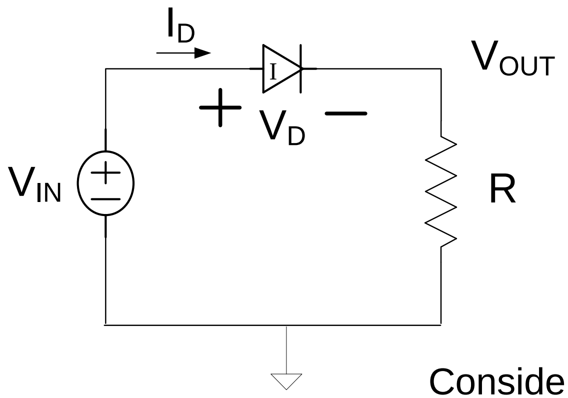


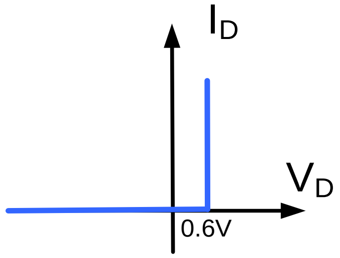
Desired output:



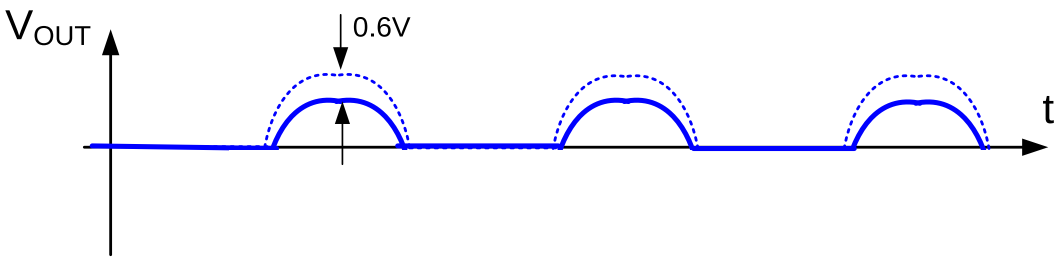


Performance Limitations of Diode Rectifier Circuit



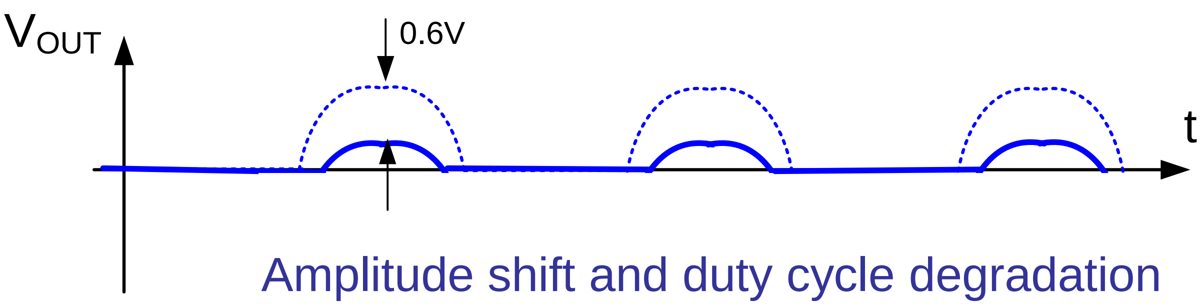


Consider $V_{IN}=V_M\sin\omega t$ for V_M=50V, V_M=1V and V_M=0.5V



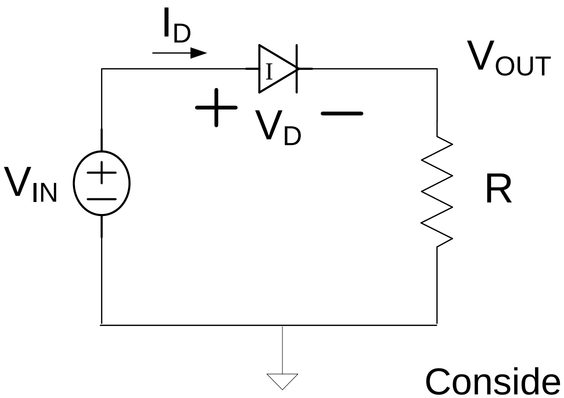
If V_M=50V, the 0.6V drop causes very little degradation in performance

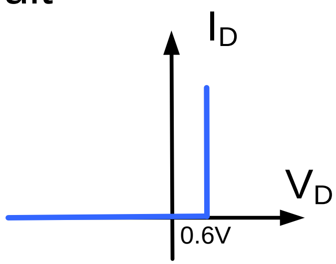
If V_M=1V, the 0.6V drop causes dramatic degradation in performance



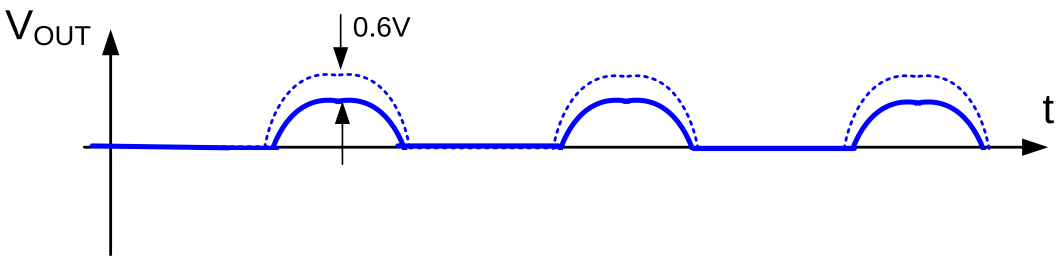
Amplitude shift and duty cycle degradation

Performance Limitations of Diode Rectifier Circuit

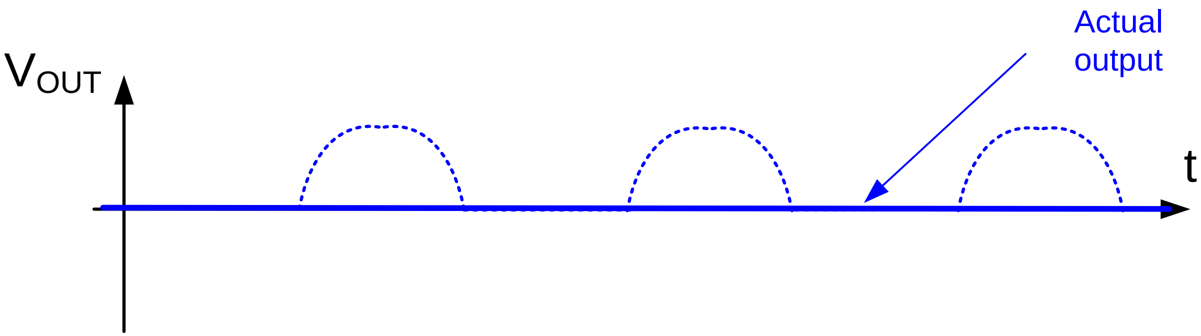




Consider $V_{IN}=V_M \sin\omega t$ for $V_M=50V$, $V_M=1V$ and $V_M=0.5V$

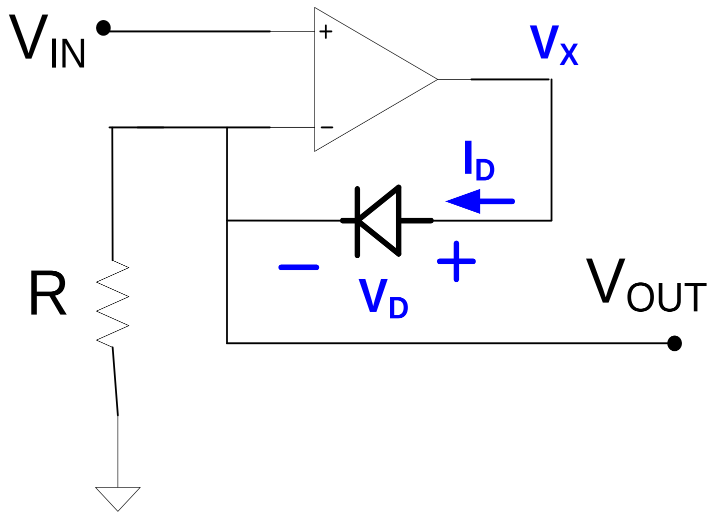


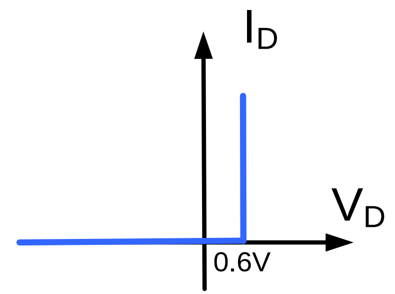
If $V_M=0.5V$, the 0.6V drop provides no output !



Precision Rectifier Circuit

(with nonideal diode)





$I_D = 0 \quad V_D < 0.6V$

$V_D = 0.6V \quad I_D > 0$

Case 1 D_1 Conducting, Op Amp operating linearly

$V_{OUT} = V_{IN}$

Valid for $I_D>0$ and $V_{SATL}<V_X<V_{SATH}$

$I_D=V_{IN}/R$

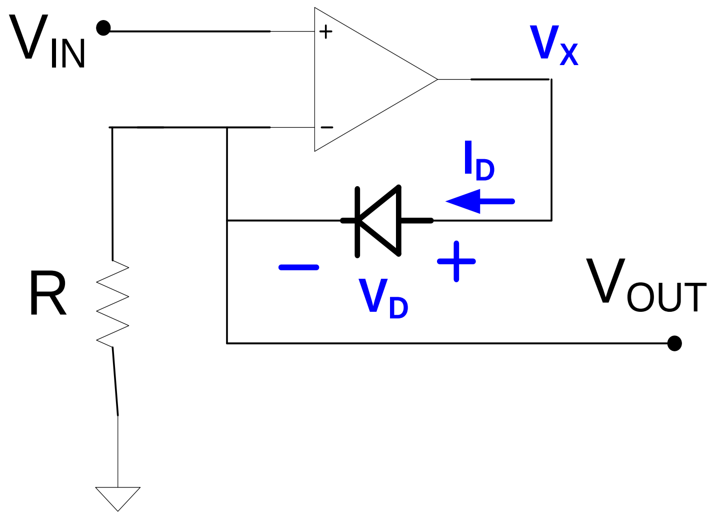
$V_X=V_{OUT}+0.6V$

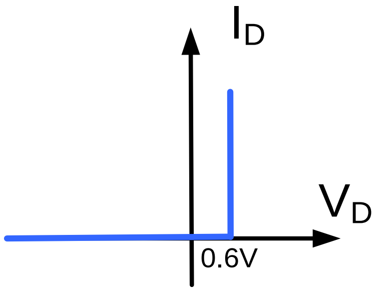
$I_D > 0$ when $V_{IN}>0$ and $V_{SATL}-0.6 < V_{IN} < V_{SATH} - 0.6$

$0 < V_{IN} < V_{SATH} - 0.6$

Precision Rectifier Circuit

(with nonideal diode)





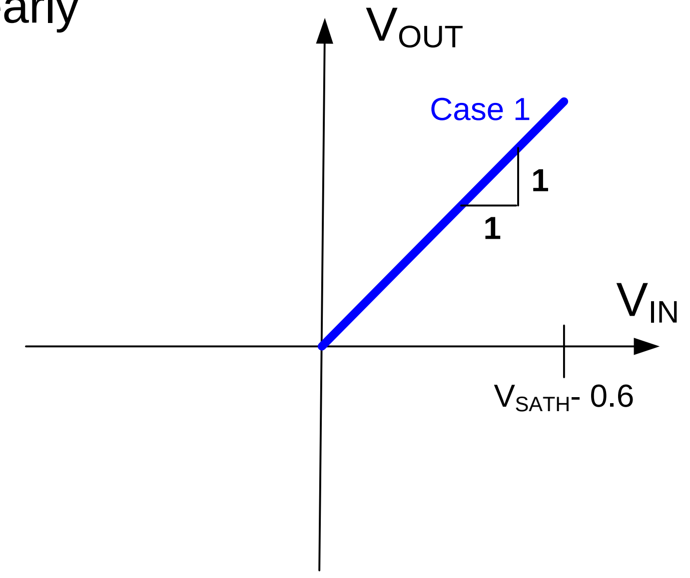
$I_D = 0$ $V_D < 0.6V$

$V_D = 0.6V$ $I_D > 0$

Case 1 D_1 Conducting, Op Amp operating linearly

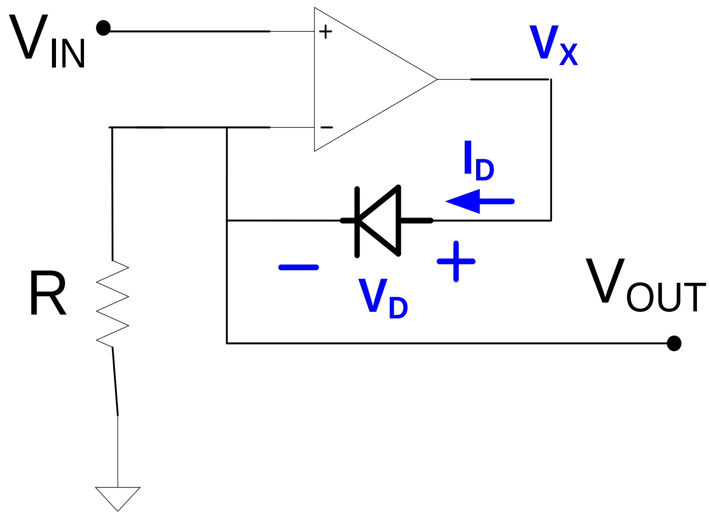
$V_{OUT} = V_{IN}$

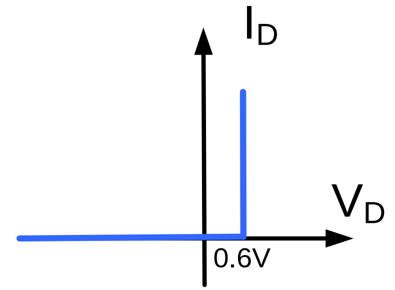
$0 < V_{IN} < V_{SATH} - 0.6$



Precision Rectifier Circuit

(with nonideal diode)





$I_D = 0 \quad V_D < 0.6V$

$V_D = 0.6V \quad I_D > 0$

Case 2 D_1 Not Conducting, Op Amp saturated low

$V_{OUT} = 0$ (since no current flowing through R)

Valid for $V_D<0.6V$ and $V^+ < V^-$

$V_X = V_{SATL}$

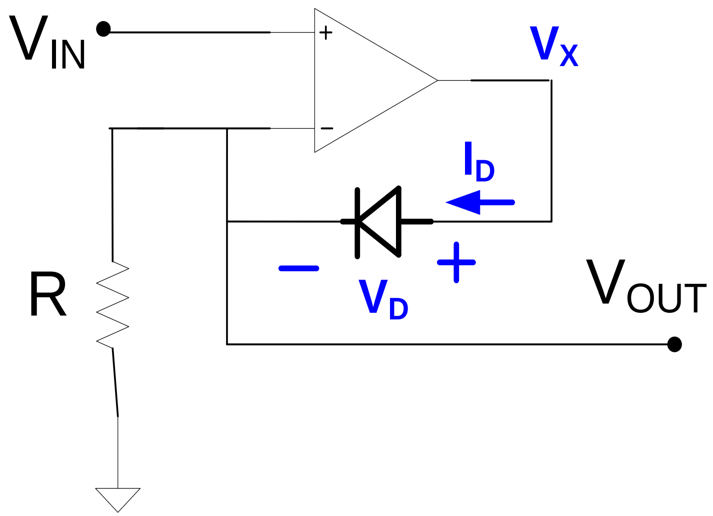
$V_D = V_X - 0$

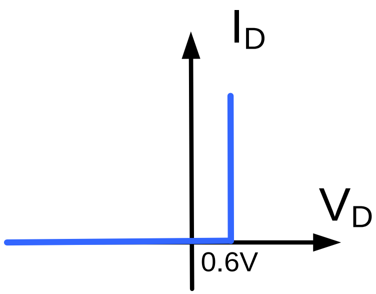
$V_{IN} < V_{OUT}$

$V_{SATL} < 0.6V$ and $V_{IN} < 0$

Precision Rectifier Circuit

(with nonideal diode)



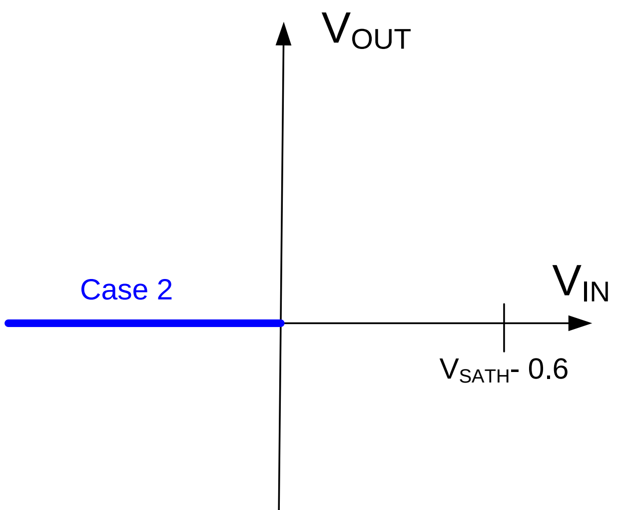


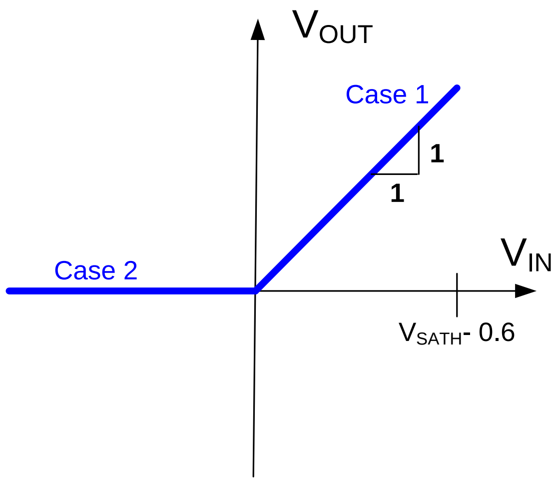
$I_D = 0 \qquad V_D < 0.6V$

$V_D = 0.6V \qquad I_D > 0$

Case 2 D_1 Not Conducting, Op Amp saturated low

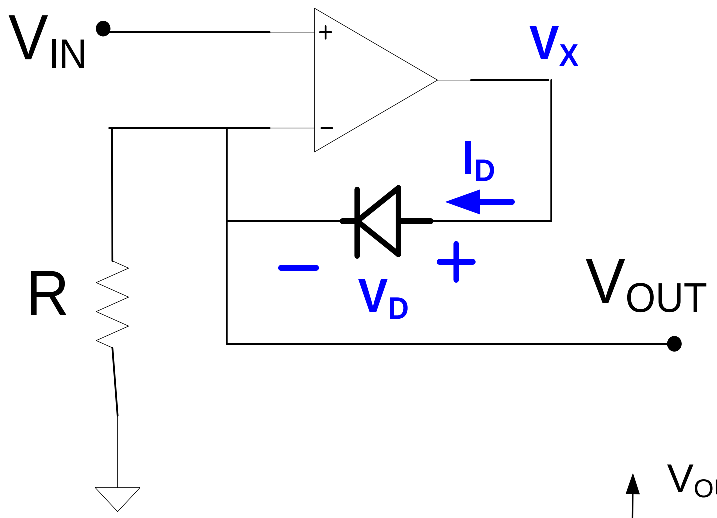
$V_{OUT} = 0$ valid for $V_{IN} < 0$

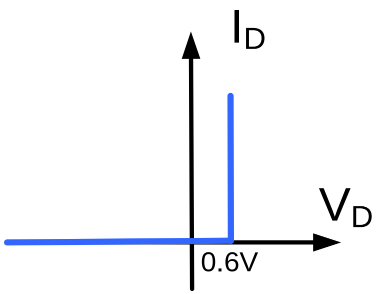




Precision Rectifier Circuit

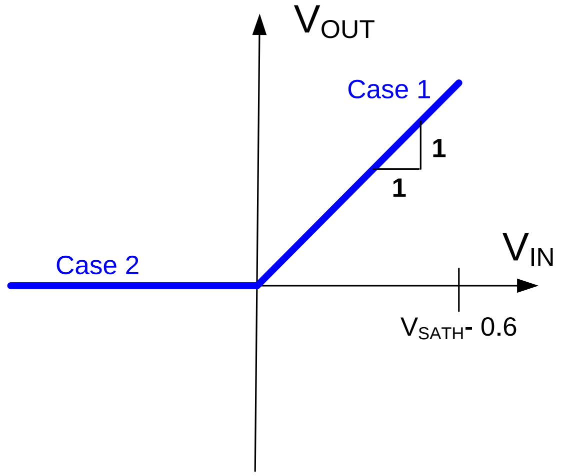
(with nonideal diode)





$I_D = 0$ $V_D < 0.6V$

$V_D = 0.6V$ $I_D > 0$

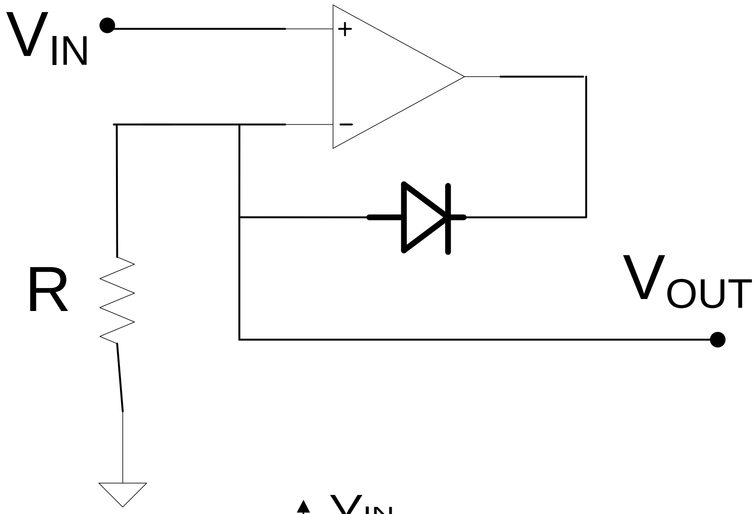


This is the transfer characteristics of an ideal rectifier!

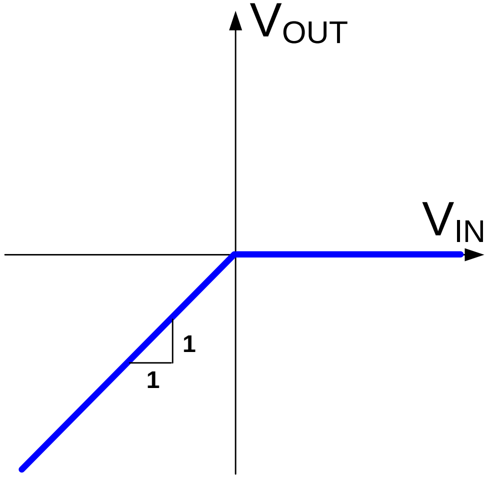
Can be used to rectify very small signals !

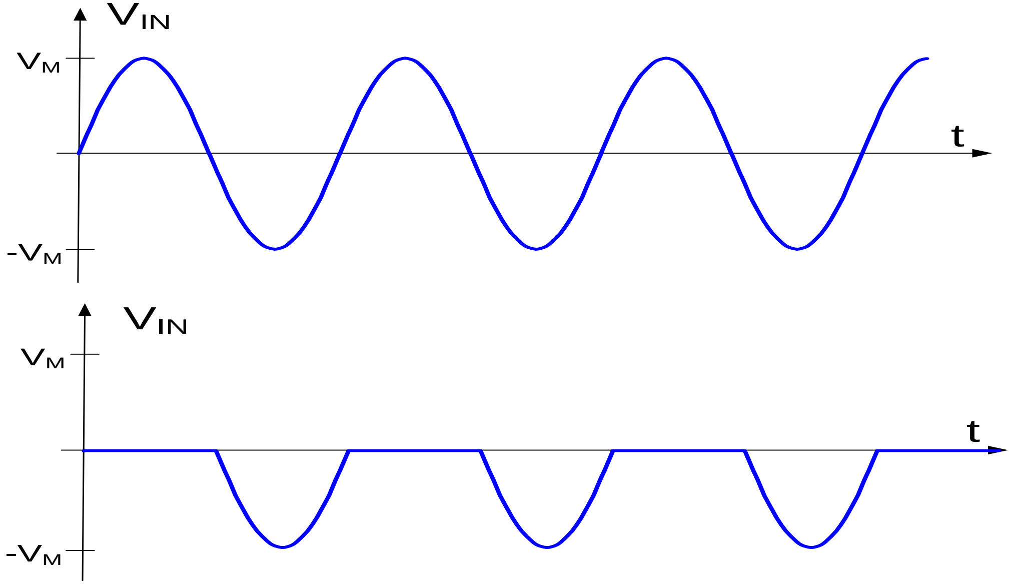
Need a buffer on V_{OUT} if any current is to be provided to a load !

Consider this circuit



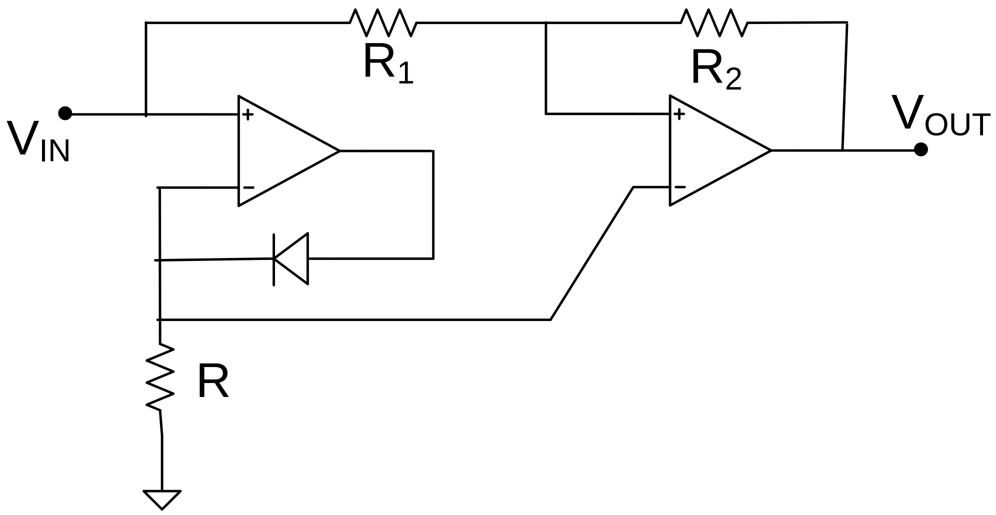
Following an almost identical analysis, can show

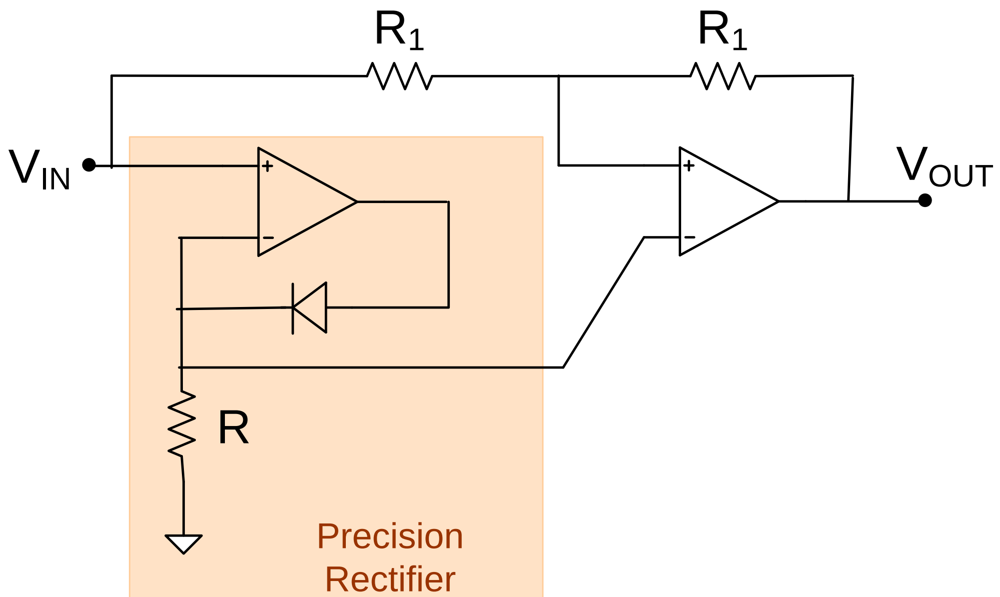




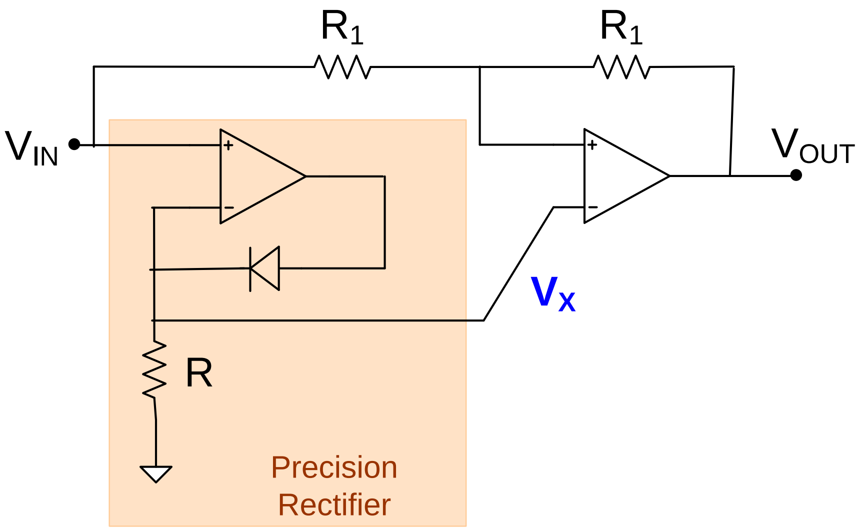
This serves as a precision negative rectifier (not inverting rectifier)

Consider this circuit





Consider this circuit

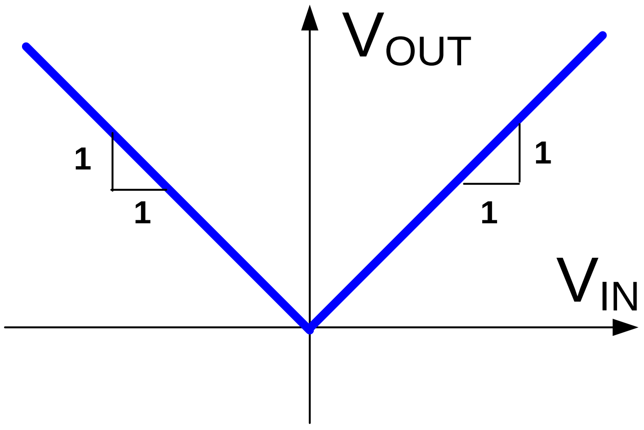


If $V_{IN}>0$

$V_X=V_{IN}$ so $V_{OUT}=V_{IN}$

If $V_{IN}<0$

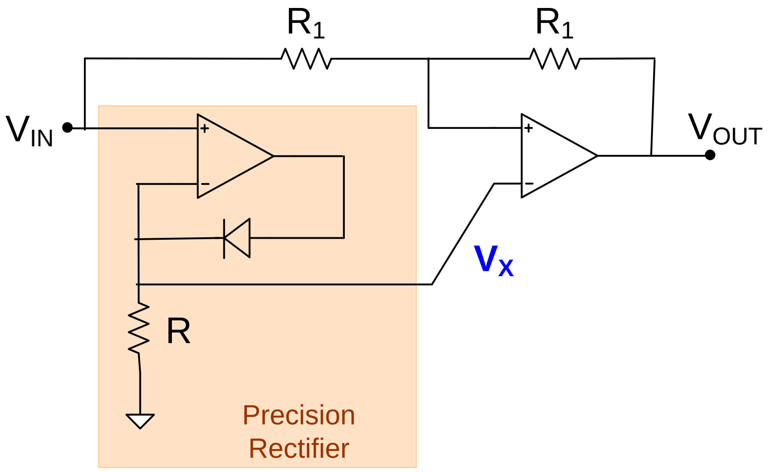
$V_X=0$ so $V_{OUT}= -V_{IN}$

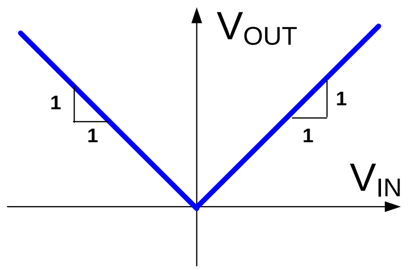


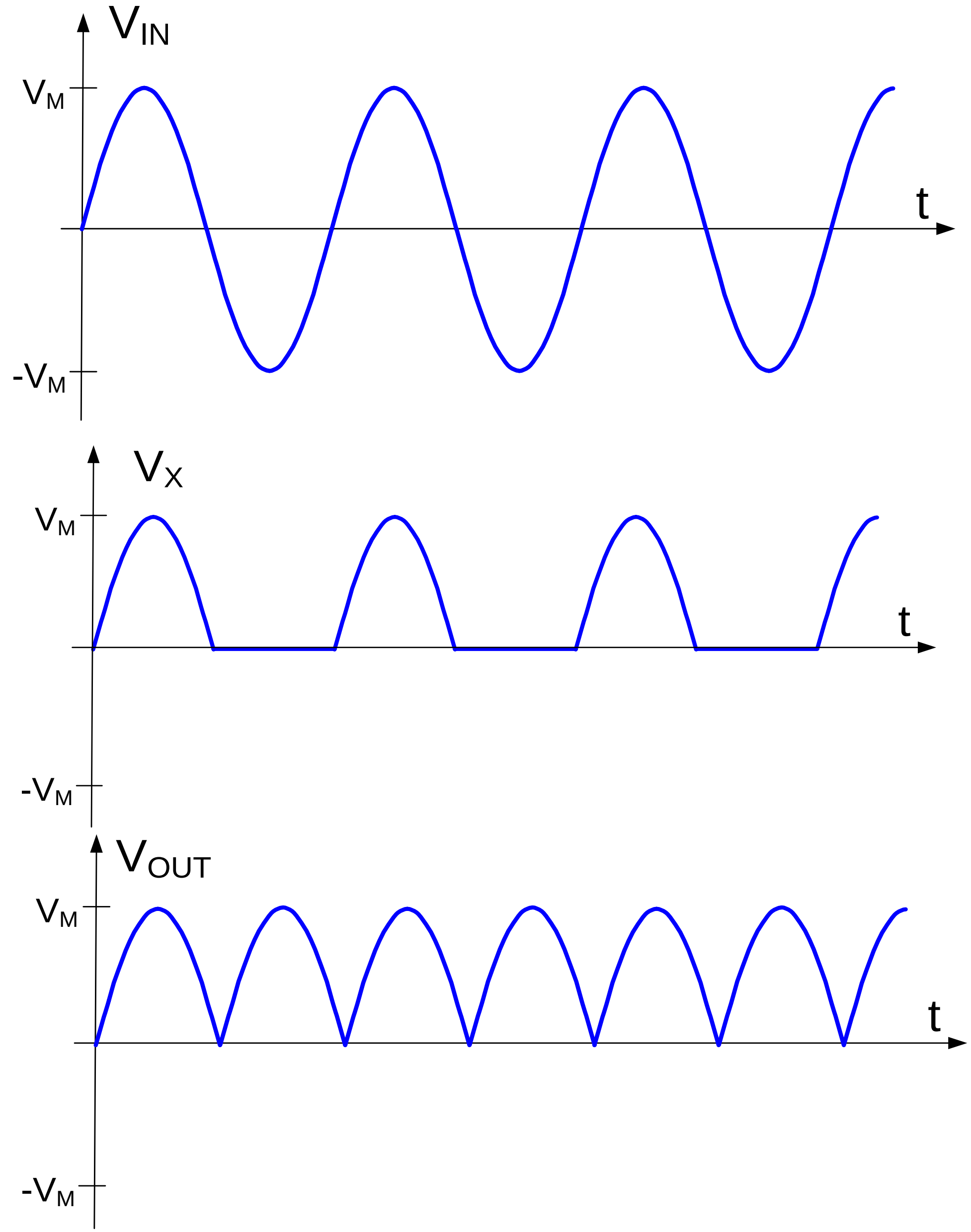
This is a precision full-wave rectifier

(rectifies positive signals, inverts and rectifies negative signals)

Precision Full-Wave Rectifier

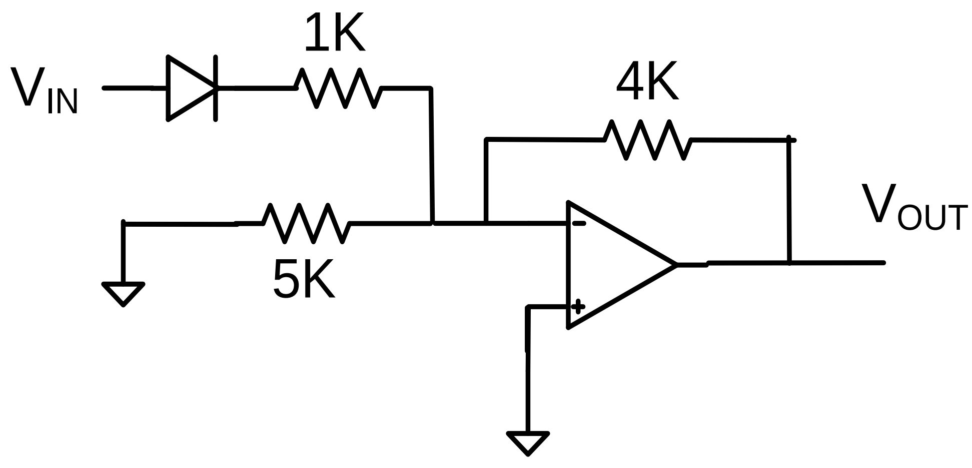






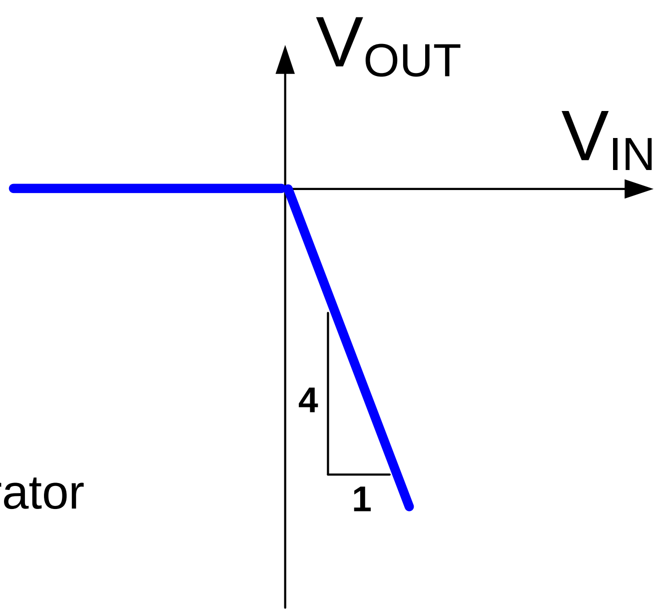
Consider this circuit

(assume diode is ideal)



If diode is OFF, $V_{OUT}=0$

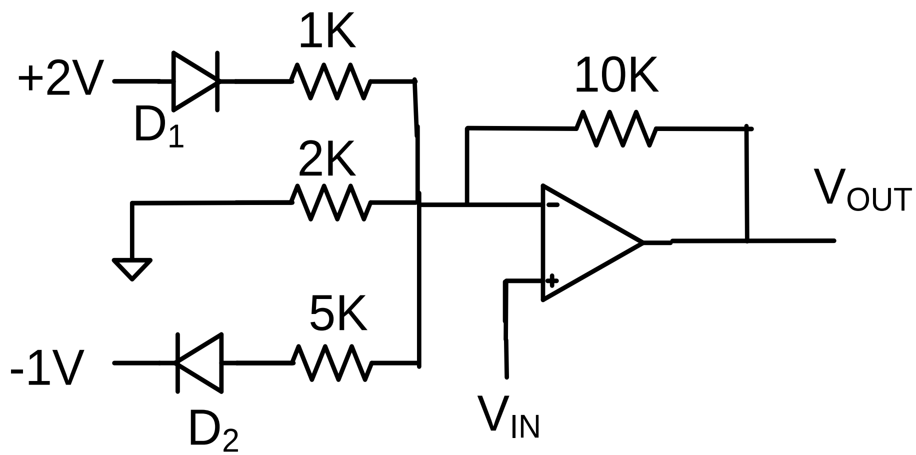
If diode is ON, $V_{OUT}= -10V_{IN}$



- Serves as a two-segment function generator
- But no control of the first slope

Consider this circuit

(assume diodes are ideal)



If $V_{IN} < -1V$, D_1 ON, D_2 OFF

$$V_{OUT} = V_{IN}\left(1+\frac{10K}{1K//2K}\right)+2\left(-\frac{10K}{1K}\right)$$

$$V_{OUT} = V_{IN}\ 16\ \ -20$$

If $2V > V_{IN} > -1V$, D_1 ON, D_2 ON

$$V_{OUT} = V_{IN}\left(1+\frac{10K}{1K//2K//5K}\right)+2\left(-\frac{10K}{1K}\right)-1V\left(-\frac{10K}{5K}\right)$$

$$V_{OUT} = V_{IN}\ 18\ \ -18$$

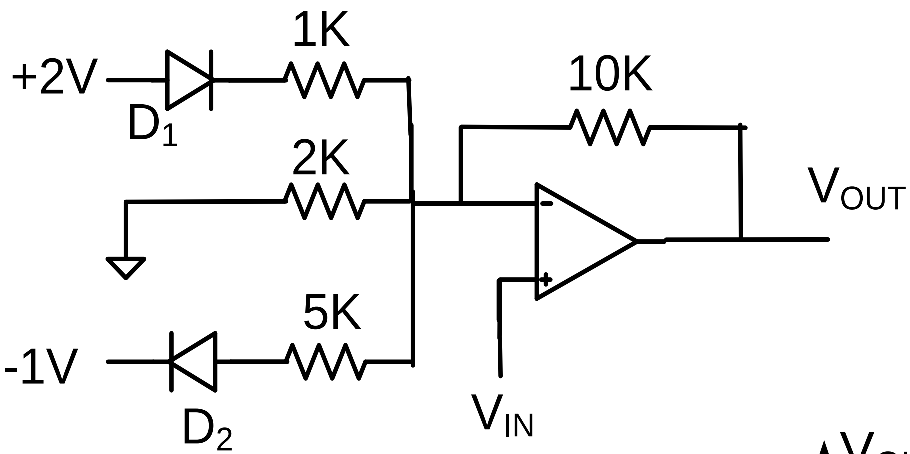
If $V_{IN} > 2V$, D_1 OFF, D_2 ON

$$V_{OUT} = V_{IN}\left(1+\frac{10K}{2K//5K}\right)+-1V\left(-\frac{10K}{5K}\right)$$

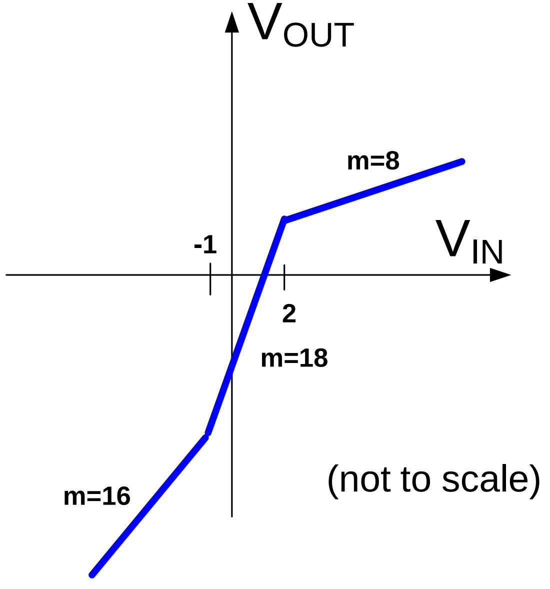
$$V_{OUT} = V_{IN}\ 8\ \ +2$$

Consider this circuit

(assume diodes are ideal)



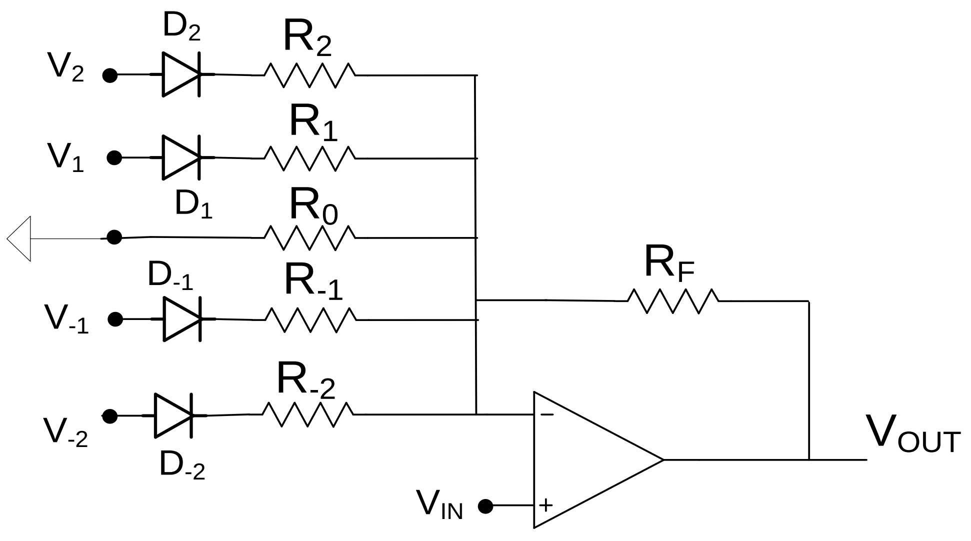
$$V_{OUT} = \begin{cases} 16V_{IN}-20 & V_{IN}<-1 \\ 18V_{IN}-18 & -1<V_{IN}<2 \\ 8V_{IN}+2 & V_{IN}>2 \end{cases}$$



This is a nonlinear function generator

Nonlinear Function Generator

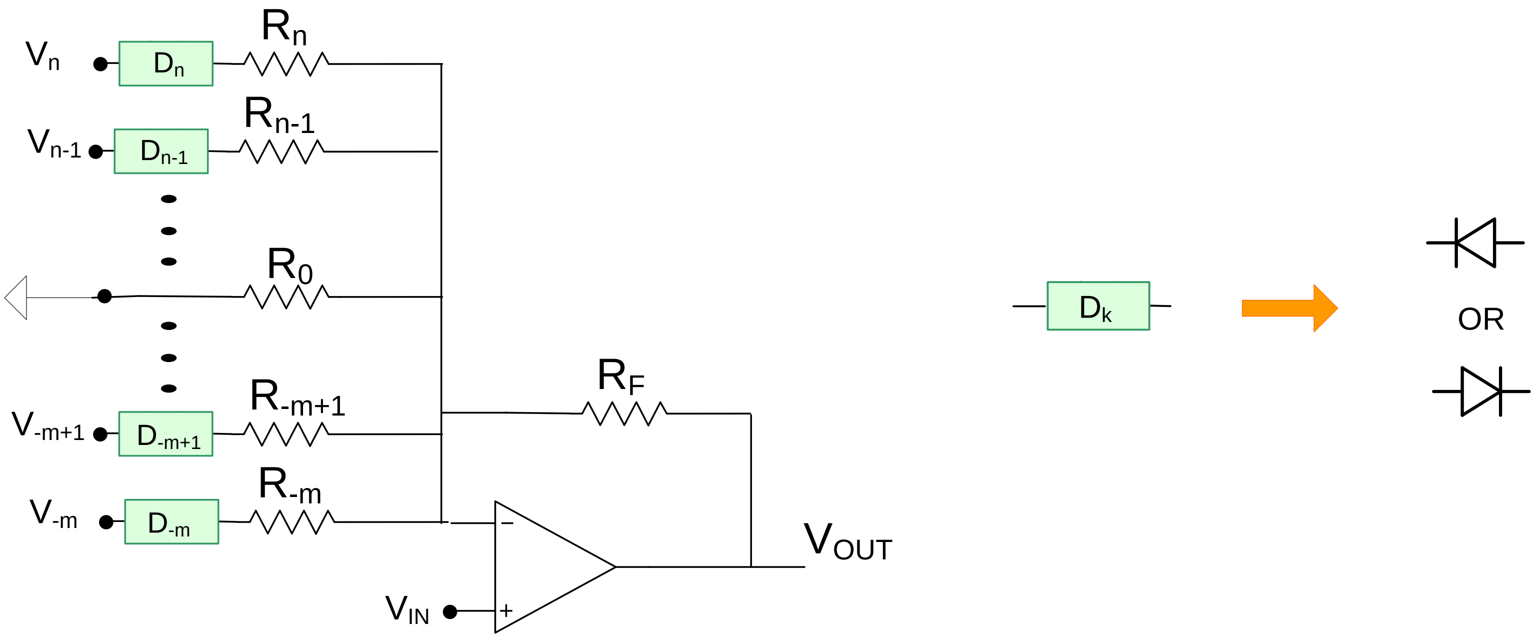
(assume diodes are ideal)



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

- Provides a 5-segment nonlinear function generator
- Analysis straightforward but tedious
- Diode function generators like this can be used to convert a triangle wave to a very good sine wave
- Performance actually usually better with actual diodes since transition between regions is smoother

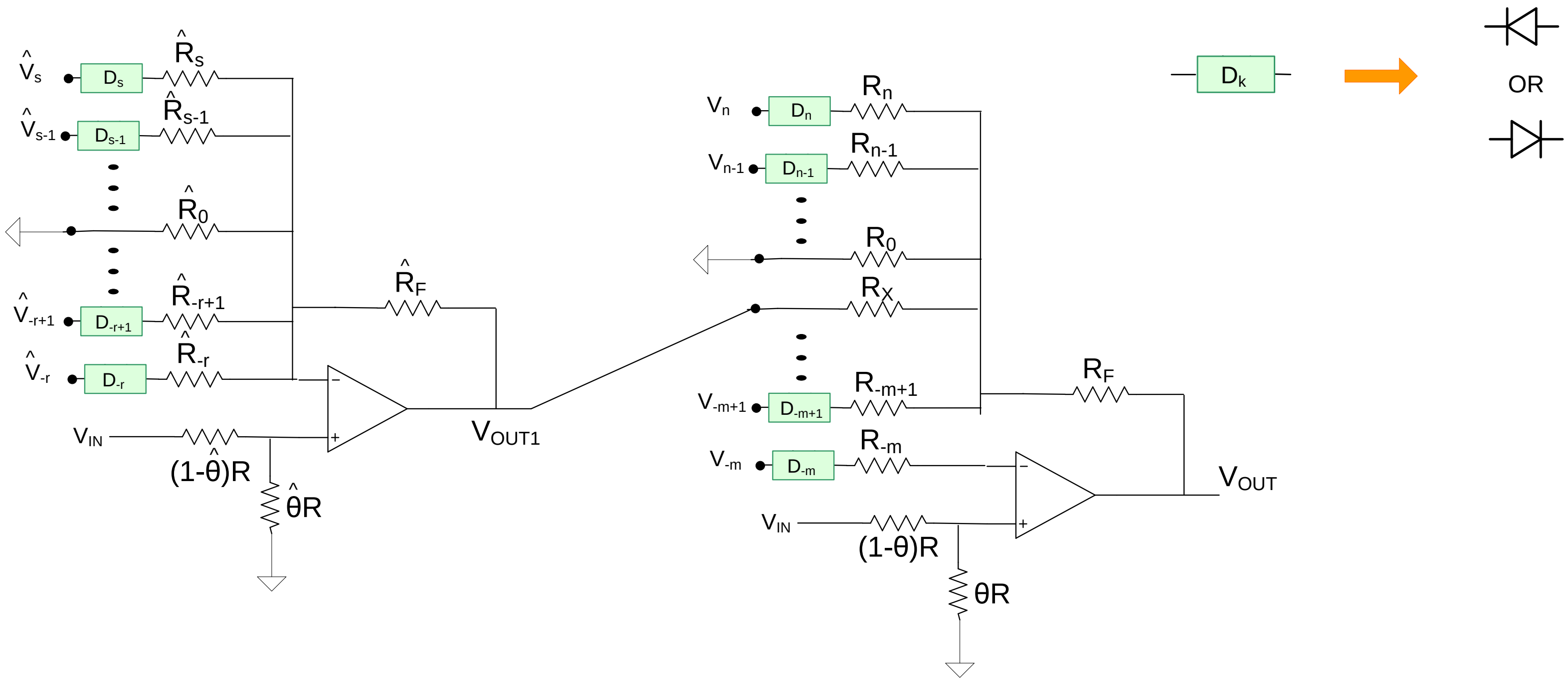
Generalized Nonlinear Function Generator



Assume $V_n > V_{n-1} > \ldots V_1 > 0 > V_{-1} > \ldots > V_{-m}$

- Provides m+n+1 segment nonlinear function
- Slopes are always positive and greater than 1
- Can generate arbitrary nonlinear transfer characteristic
- Actually works better with nonideal diodes
- Can be extended to provide slopes less than 1
- Can be further extended to provide slopes of arbitrary sign and arbitrary magnitude

Generalized Nonlinear Function Generator



- Provides m+n+r+s+2 segment nonlinear function
- Slopes can be positive or negative of any magnitude
- Analysis and design tedious but straight forward

End of Lecture 28