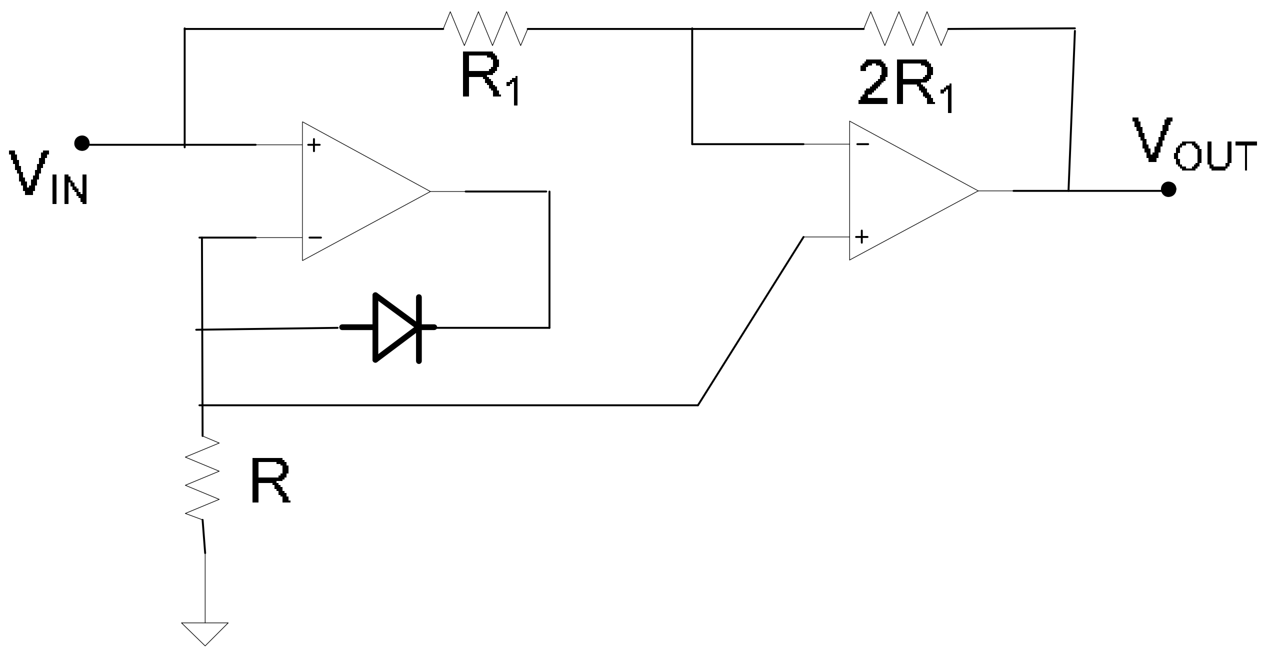
EE 230
Lecture 31

Nonlinear Circuits and Nonlinear Devices

– Diode
– BJT
– MOSFET

Quiz 19

Obtain the transfer characteristics of the following circuit and plot the output if V_{IN}= -5sinωt. Assume the diode is ideal.



And the number is ?

1

3

8

5

4

2

6

9

7

And the number is ?

1 3 8

5 4

3

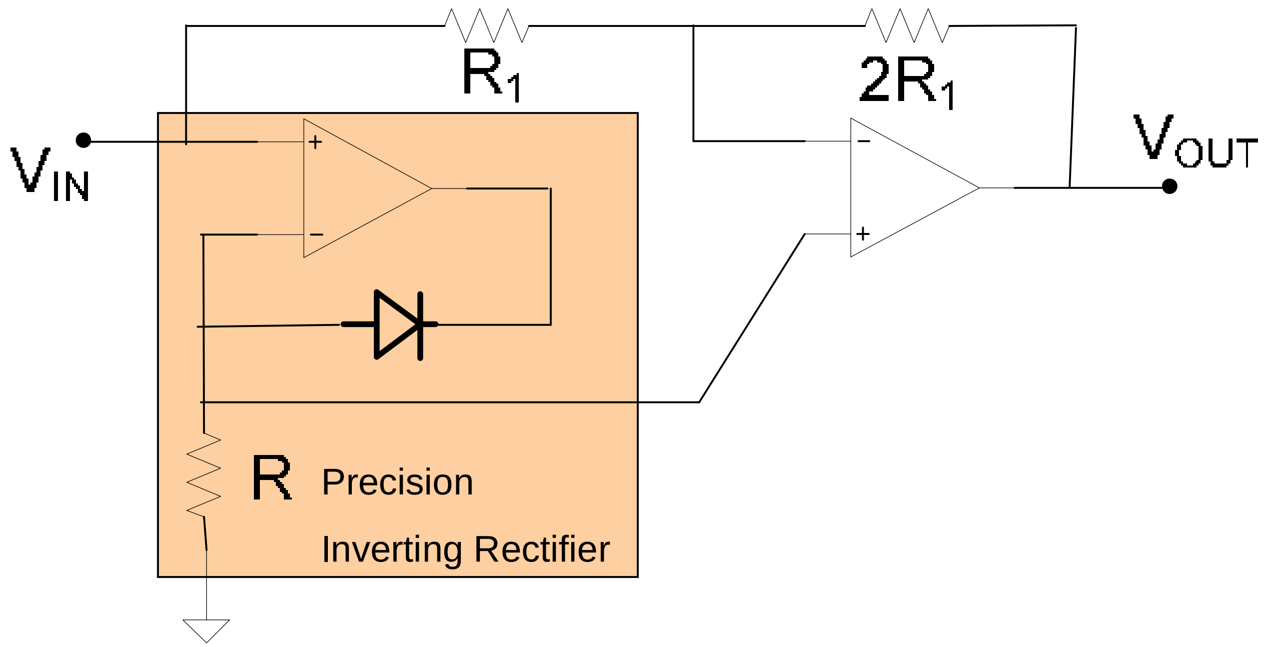
2 6

9

7

Quiz 19

Obtain the transfer characteristics of the following circuit and plot the output if $V_{IN}=5\sin\omega t$. Assume the diode is ideal.



Solution:

Observe D_1 is ON for $V_{IN}<0$ and OFF for $V_{IN}>0$

$\therefore$ for $V_{IN}>0$, $V_{OUT}=-2V_{IN}$

for $V_{IN}\leq 0$, $V_{OUT}=(1+2)V_{IN}-2V_{IN}=V_{IN}$

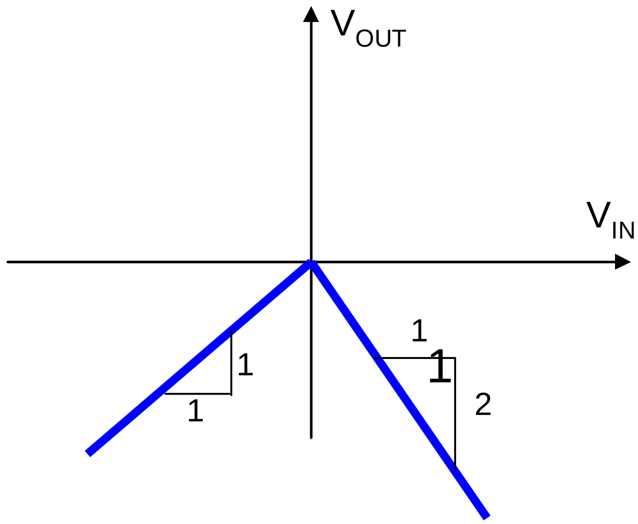
Quiz 19

Obtain the transfer characteristics of the following circuit and plot the output if V_{IN}=5sinωt. Assume the diode is ideal.

Solution:

for $V_{IN}>0$, $V_{OUT}=-2V_{IN}$

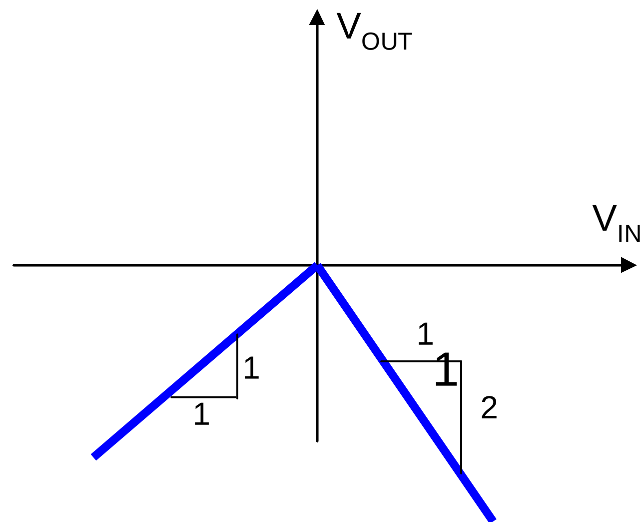
for $V_{IN}\leq 0$, $V_{OUT}=(1+2)V_{IN}-2V_{IN}=V_{IN}$

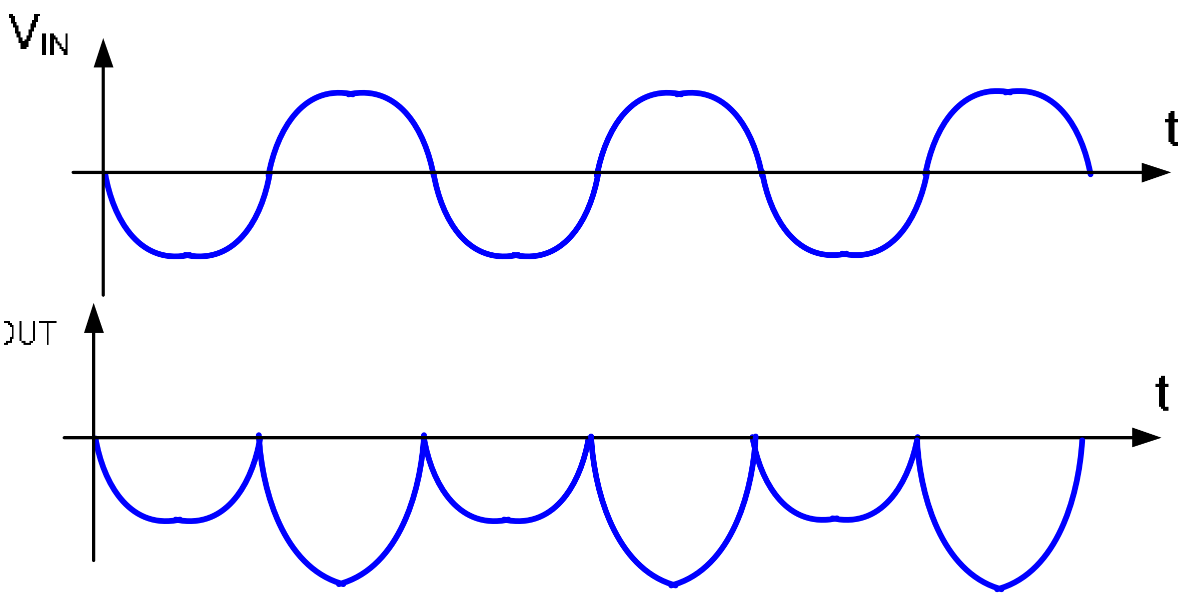


Quiz 19

Obtain the transfer characteristics of the following circuit and plot the output if V_{IN}= - 5sinωt. Assume the diode is ideal.

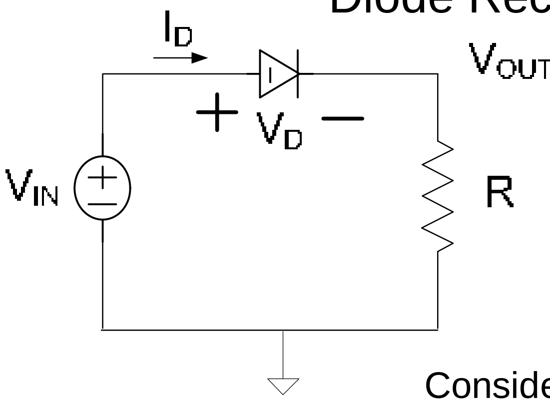
Solution:

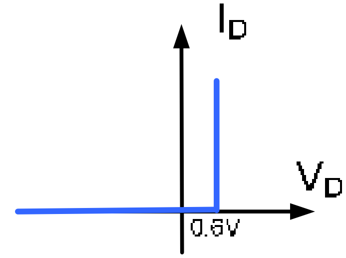




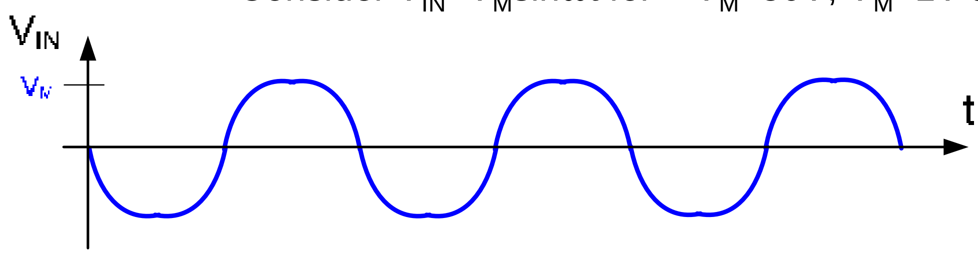
Review from Last Time:

Diode Rectifier Circuit

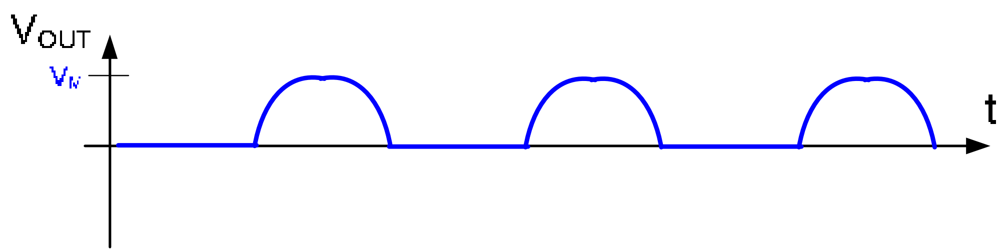


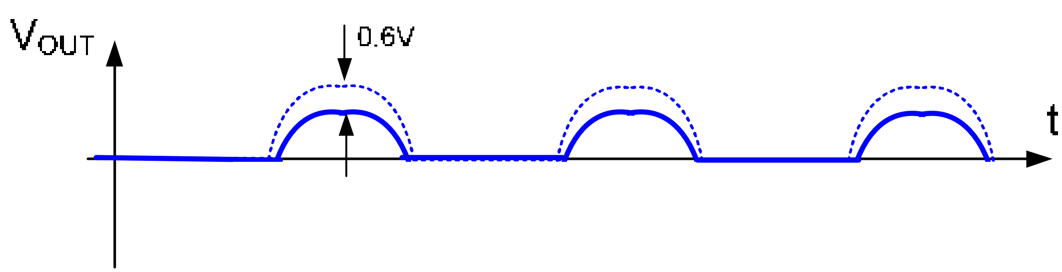


Consider $V_{IN}=V_M\sin\omega t$ for V_M=50V, V_M=1V and V_M=0.5V



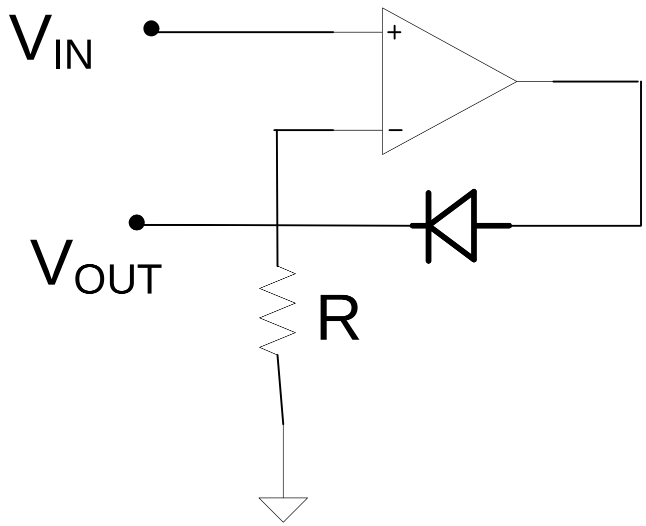
Desired output:

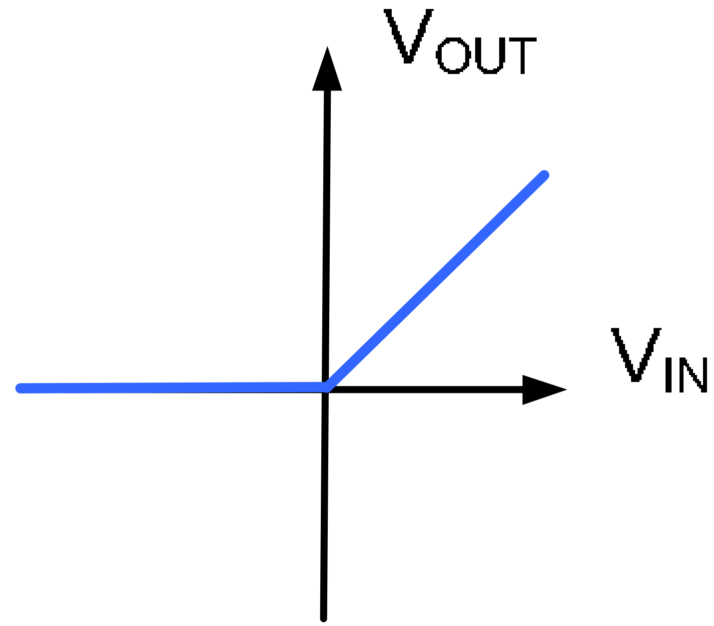




Review from Last Time:

Precision Rectifier Circuit

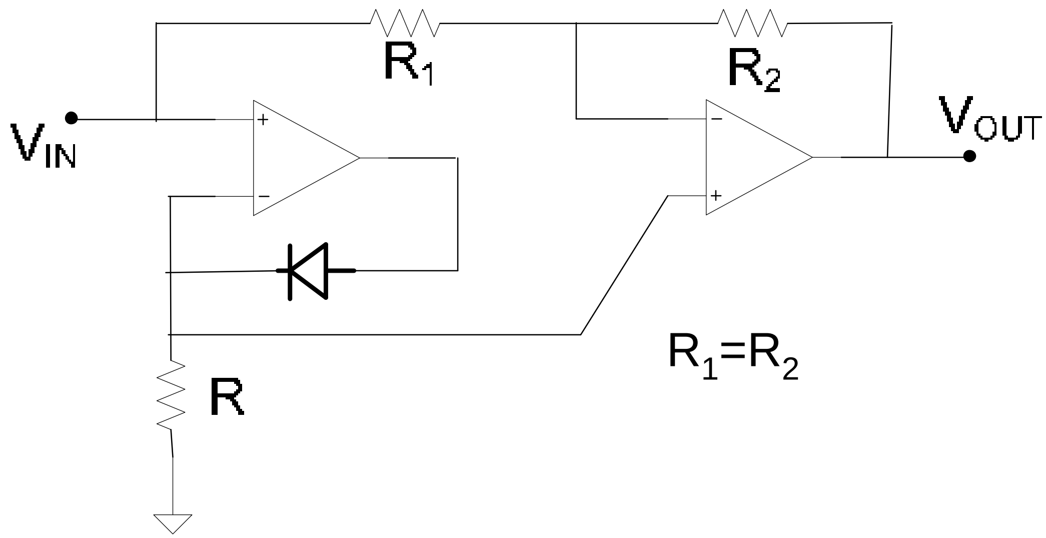


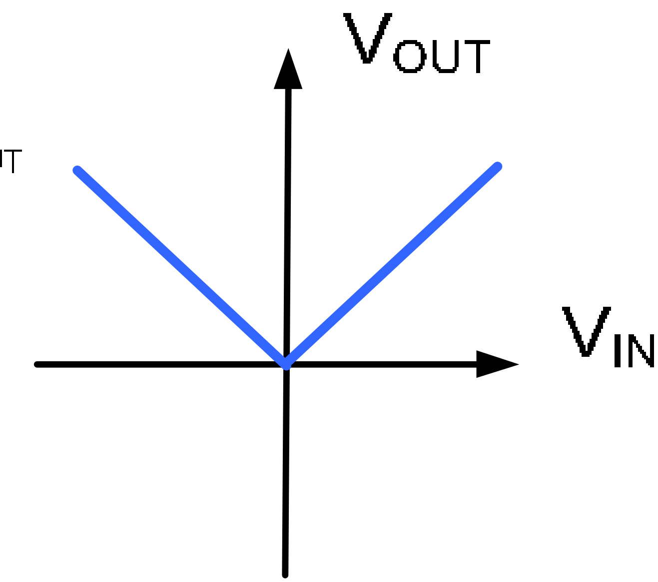


- Buffer may be needed on V_{OUT}
- SR of op amp limits speed of this circuit

Review from Last Time:

Precision Full-Wave Rectifier Circuit

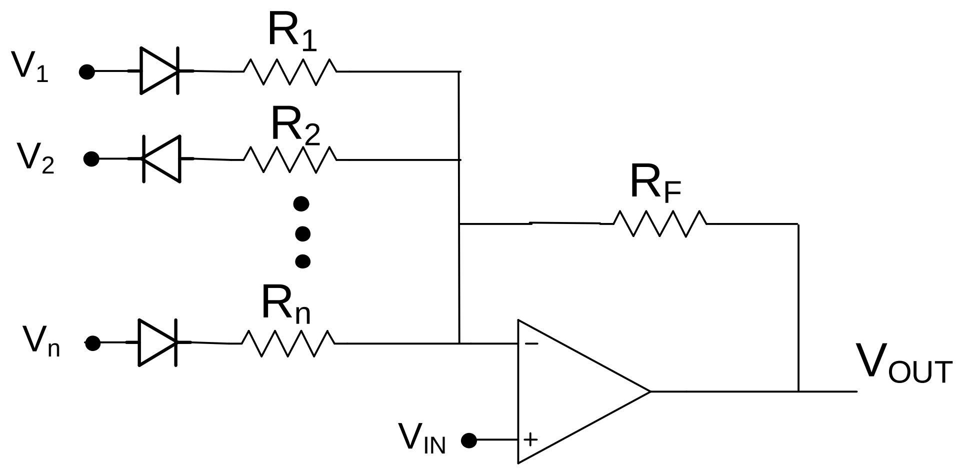




- SR on first op amp limits speed of this circuit

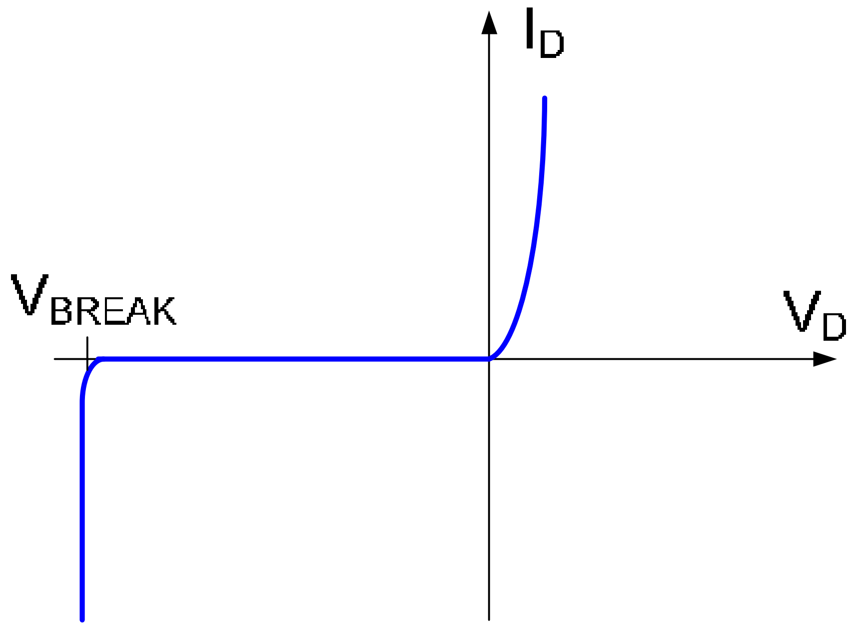
Review from Last Time:

Nonlinear Function Generation



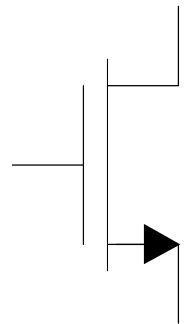
Variants of this approach can be used to generate arbitrary nonlinear functions

Diode Limitations

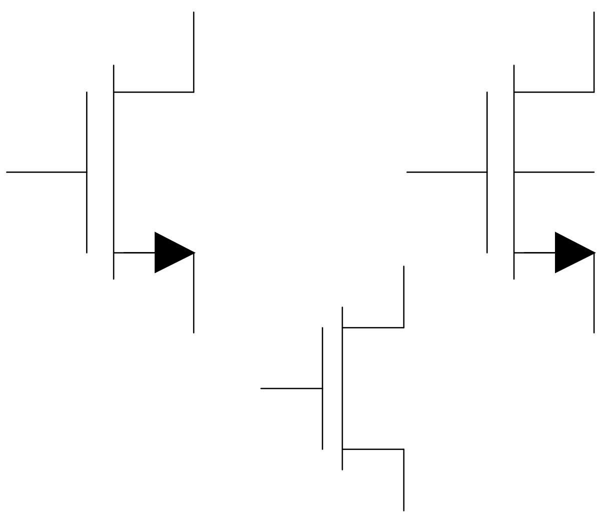


- All diodes will break down if too much reverse bias is applied
- V_{BREAK} can range from a few volts to over 1000V depending upon diode type
- Some are designed to work with modest breakdown voltages (zener diodes)
- Most are not and will be destroyed if allowed to breakdown due to excessive power dissipation

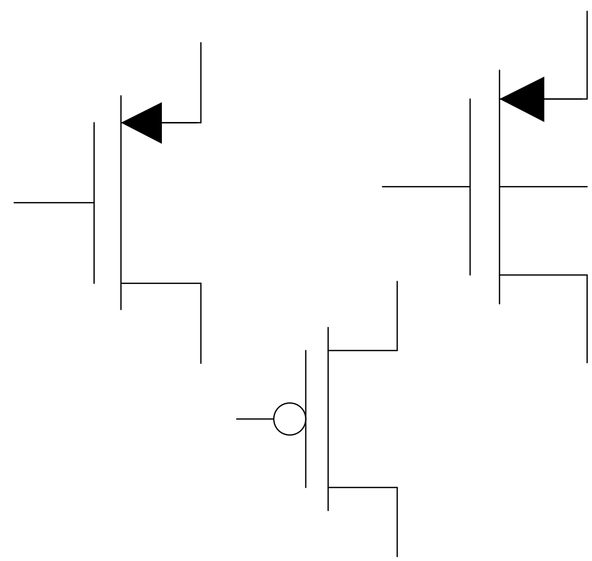
MOS Transistors



MOSFET

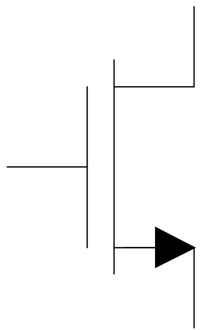


n-channel

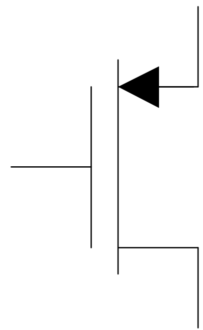


p-channel

MOS Transistors



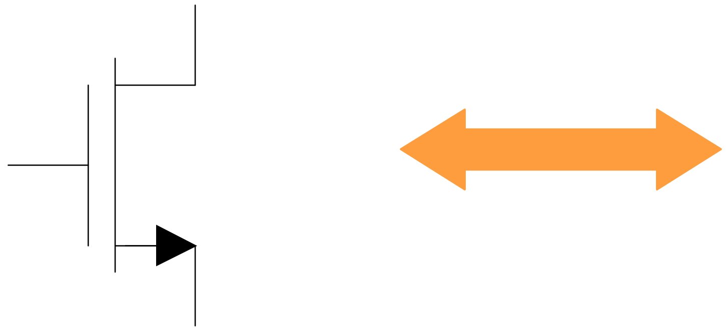
n-channel

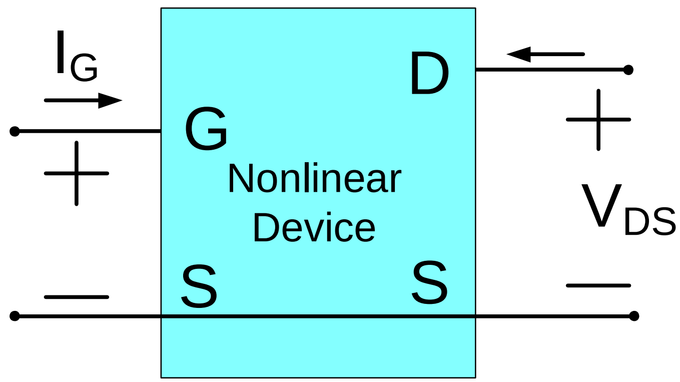


p-channel

- Operation very similar
- Model parameters differ modestly
- Direction of current flow differs

MOS Transistors

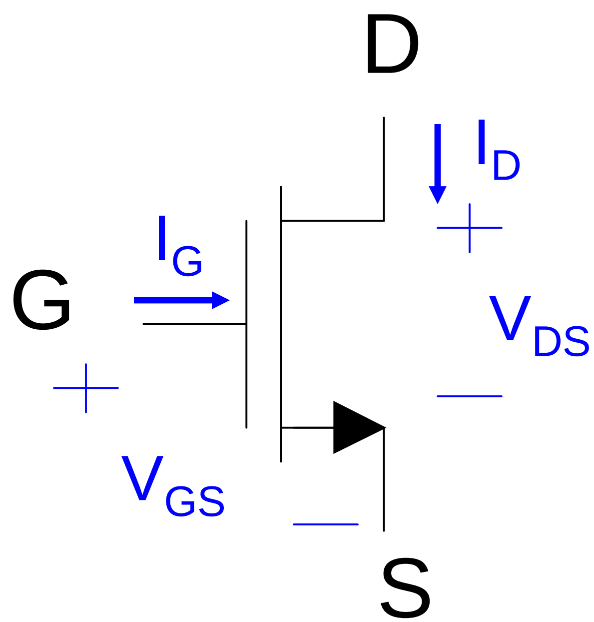




$$I_G = 0$$

$$I_D = \begin{cases} 0 & V_{GS} < 1V \\ 10^{-4}\left(V_{GS} - 1 - \frac{V_{DS}}{2}\right)V_{DS} & V_{GS} > 1V,\ \ V_{DS} < V_{GS} - 1V \\ \frac{10^{-4}}{2}(V_{GS} - 1)^2 & V_{GS} > 1V,\ \ V_{DS} > V_{GS} - 1V \end{cases}$$

MOS Transistors



Model:

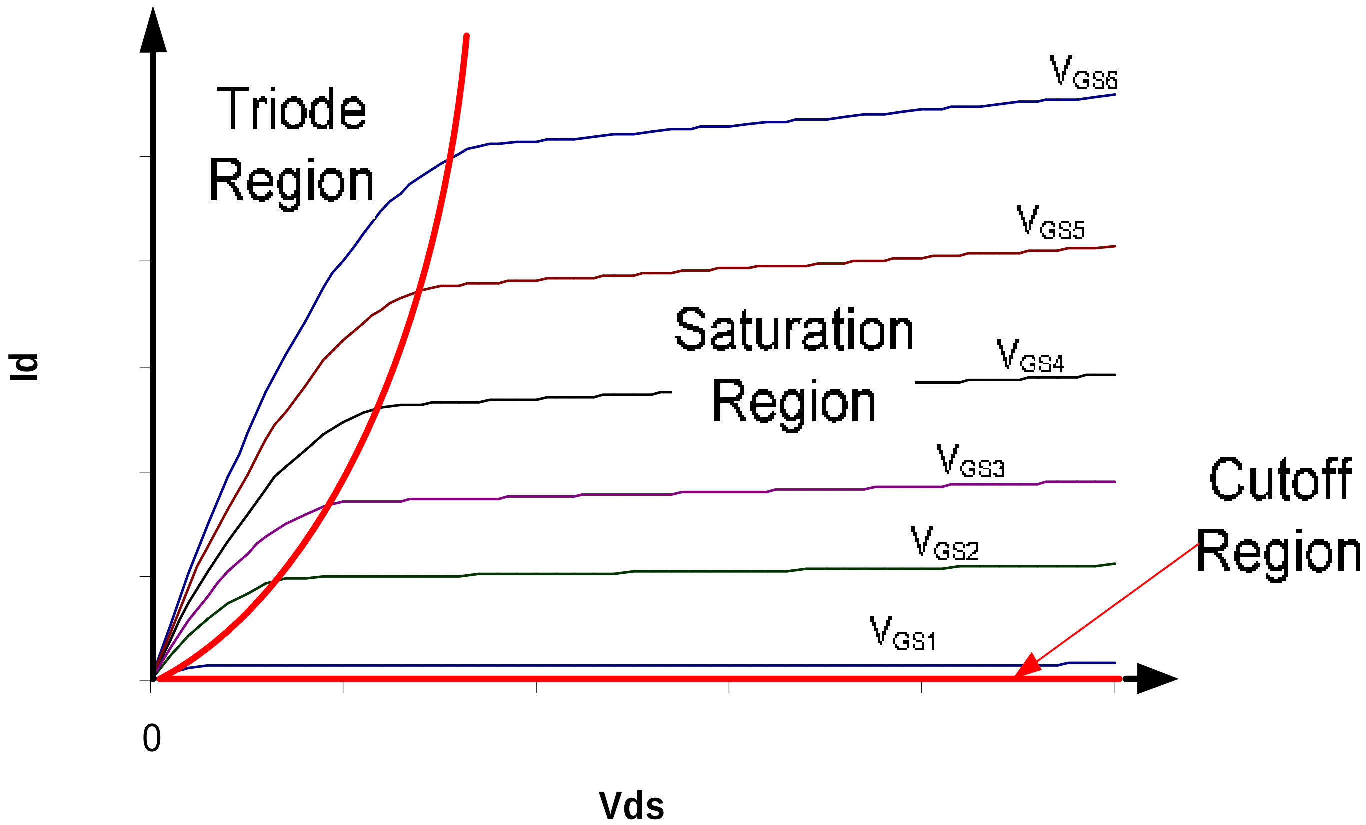
$$I_G = 0$$

$$I_D = f_1(V_{GS}, V_{DS})$$

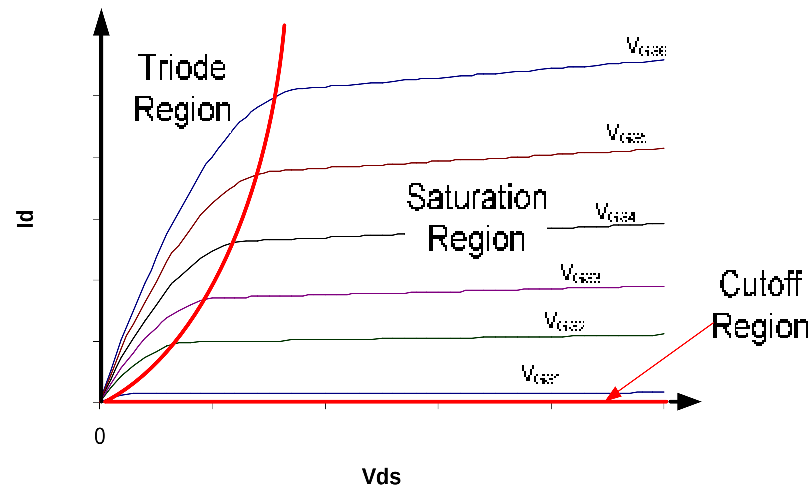
the two-variable function f_1 is quite nonlinear

D: Drain
G: Gate
S: Source

MOS Transistors



MOS Transistors



Popular square-law model for the transistor

$$I_G = 0$$

$$I_D = \begin{cases} 0 & V_{GS} \le V_T \\ \mu C_{OX} \dfrac{W}{L}\left(V_{GS} - V_T - \dfrac{V_{DS}}{2}\right)V_{DS} & V_{GS} \ge V_T \quad V_{DS} < V_{GS} - V_T \\ \mu C_{OX} \dfrac{W}{2L}(V_{GS} - V_T)^2 \bullet (1 + \lambda V_{DS}) & V_{GS} \ge V_T \quad V_{DS} \ge V_{GS} - V_T \end{cases}$$

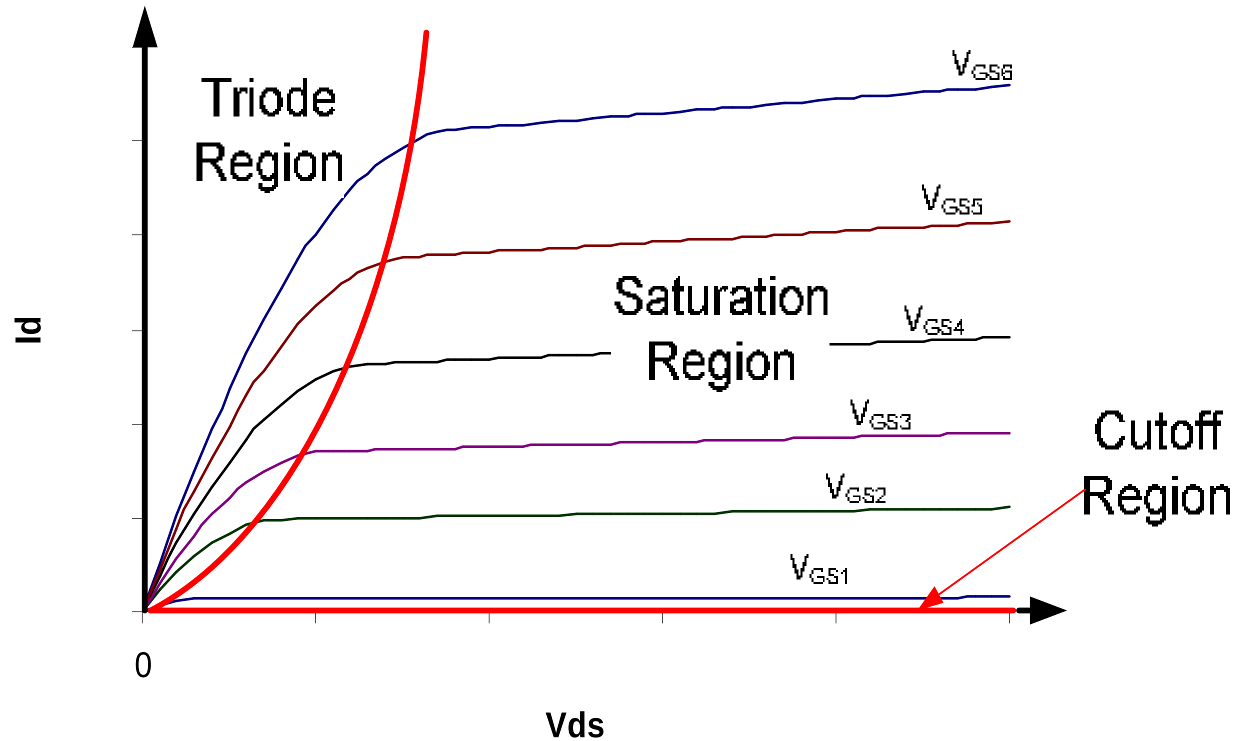
← Cutoff

← Triode

← Saturation

$\{\mu, C_{OX}, V_T, \lambda, W, L\}$ are model parameters

MOS Transistors



In most analog applications, the MOSFET is operated in the saturation region

In most digital applications, the MOSFET is operated in either the cutoff or triode regions and changes between these two regions as the boolean variables change from a “0” to a “1”