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Diode Circuit

VE311 Electronic Circuits (Fall 2020)

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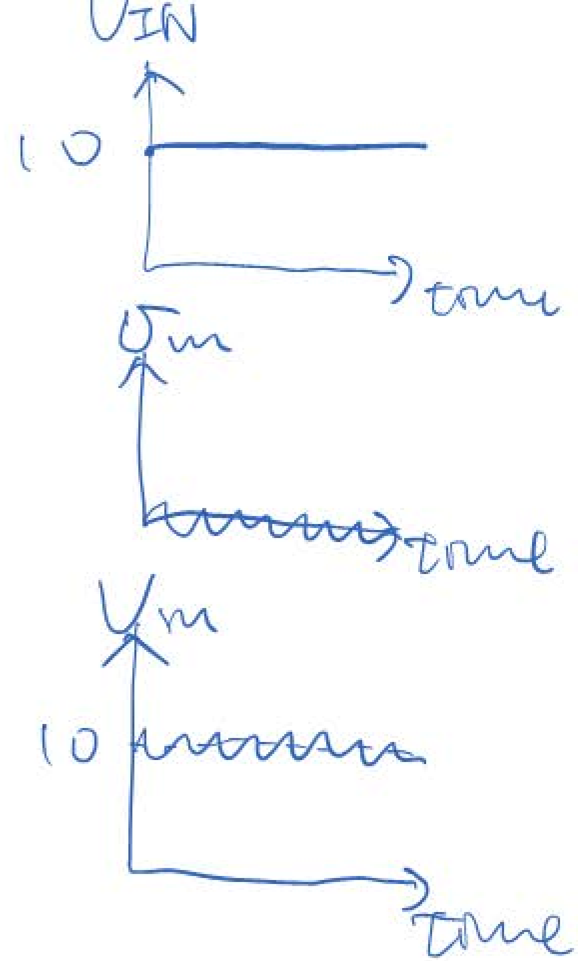
$$V_{IN} = 10V$$

$$v_{in} = 0.01 \sin \omega t$$

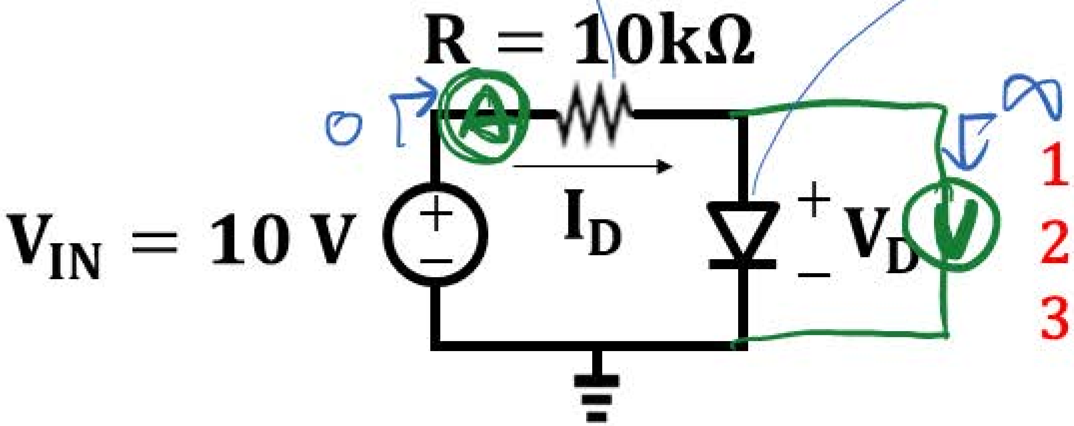
$$V_{in} = 10 + 0.01 \sin \omega t$$



Solving Techniques

$$I_D = \frac{10 - V_D}{10k}$$

$$I_D = I_S\left(e^{\frac{qV_D}{kT}} - 1\right)$$



1. Graphical analysis
2. Mathematical analysis
3. Simplified analysis (ideal diode)
4. Simplified analysis (constant voltage drop)

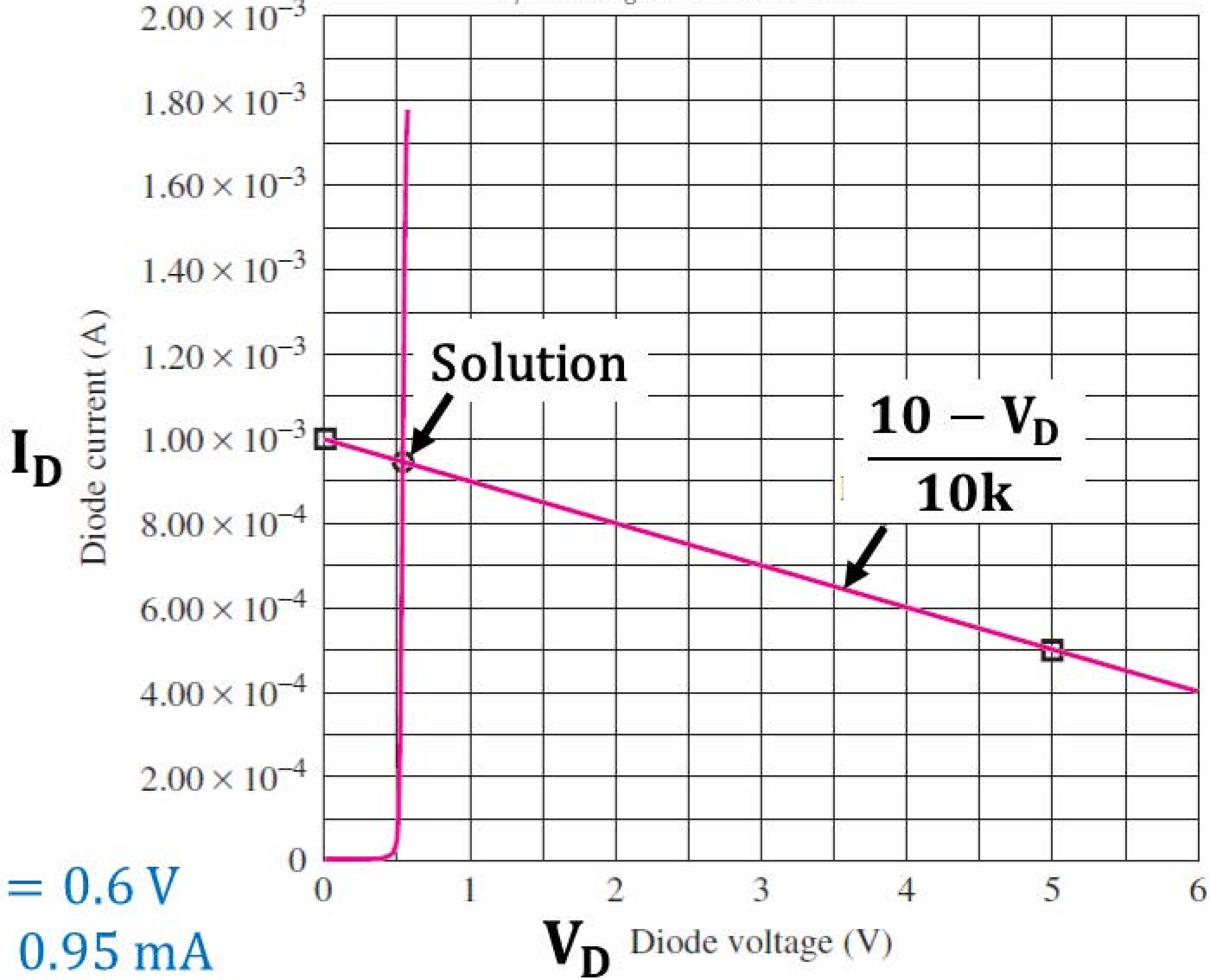
$$V_{IN} = I_D R + V_D$$

$$I_D = ?$$

$$V_D = ?$$

Graphical Analysis

Source: Microelectronic Circuit Design, 4th Edition, by R. C. Jaeger and T. N. Blalock



$V_D = 0.6\ \text{V}$

$I_D = 0.95\ \text{mA}$

Mathematical Analysis

$$V_{IN} = I_D R + V_D$$

$$V_{IN} = \left[I_S\left(e^{\frac{qV_D}{kT}} - 1\right)\right] R + V_D$$

$$10 = \left[10^{-13}\left(e^{\frac{V_D}{0.0258}} - 1\right)\right] 10^4 + V_D$$

Above is a transcendental equation which does not have a close-form **analytical solution**. So, through trial and error, we seek a **numerical solution**.

function xd = diode(vd)

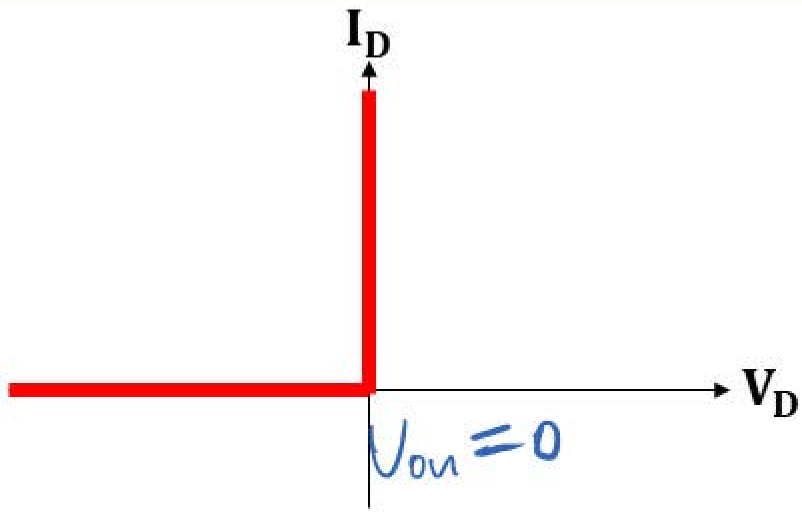
$$xd = 10 - (10^{-9}) * \left(\exp\left(\frac{vd}{0.0258}\right) - 1\right) - vd$$

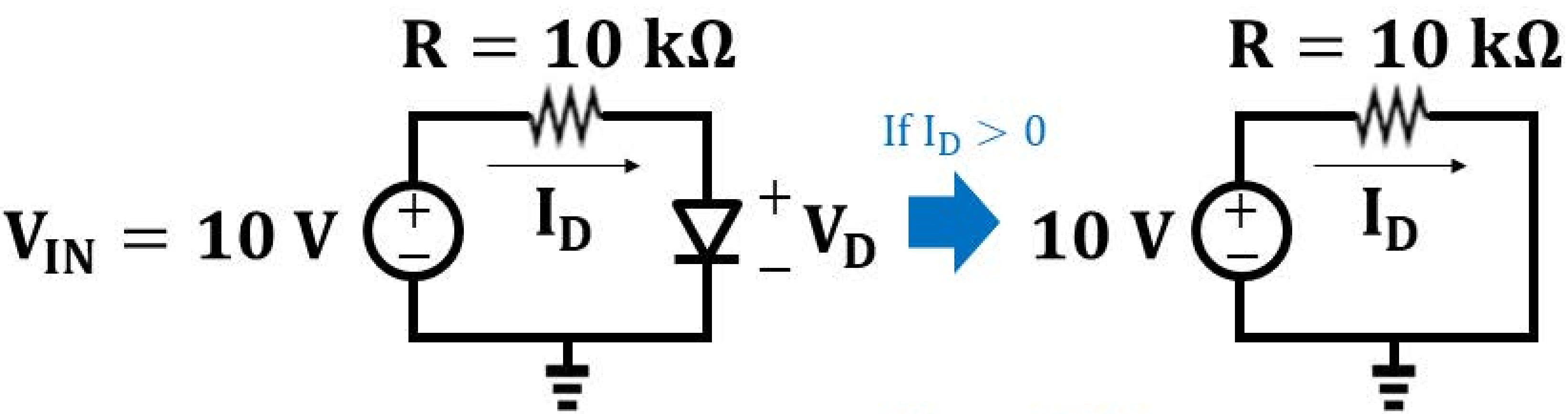
Use MATLAB to plot xd as a function of vd, and find out a vd that makes xd closest to zero.

$$V_D = 0.5742\ \text{V}$$

$$I_D = 0.944\ \text{mA}$$

Simplified Analysis (Ideal Diode)

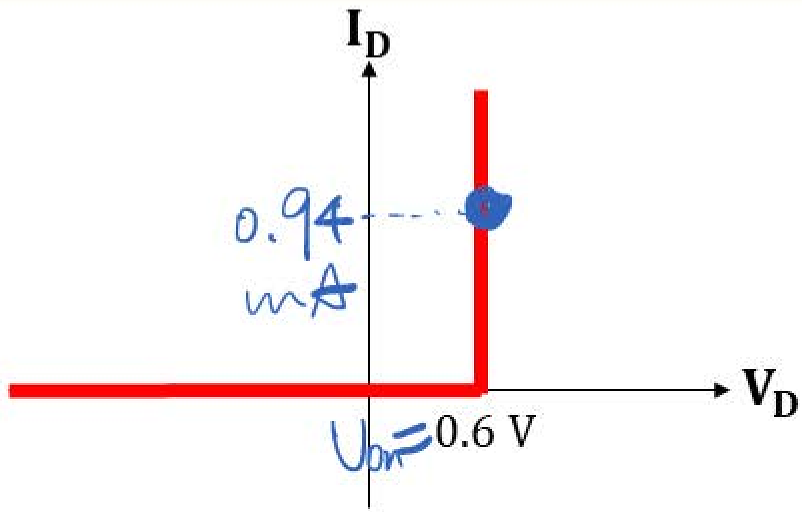


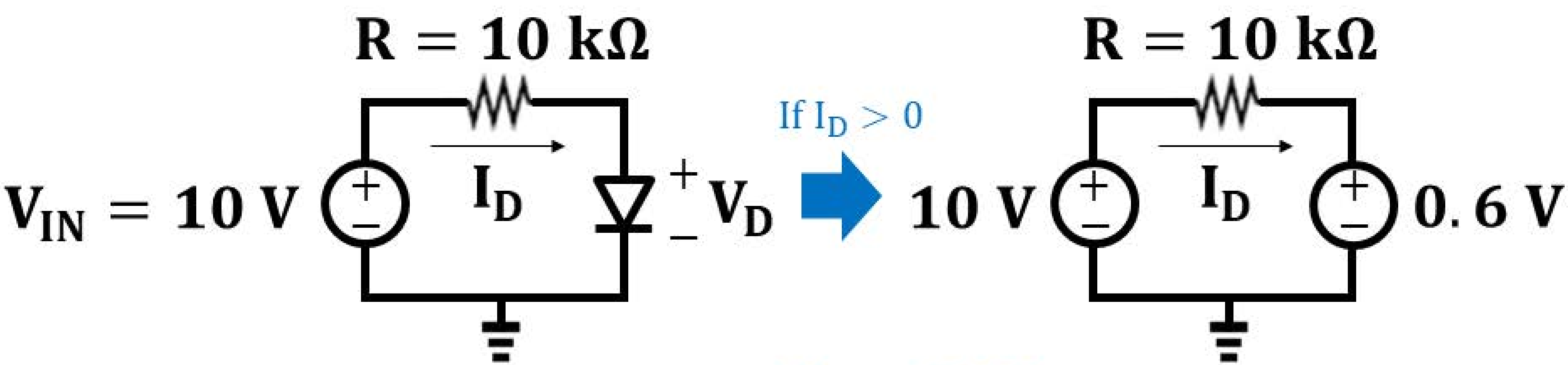


$$V_D = 0\ V$$

$$I_D = \frac{(10 - 0)\ V}{10\ k\Omega} = 1\ mA$$

Simplified Analysis (Constant Voltage Drop)



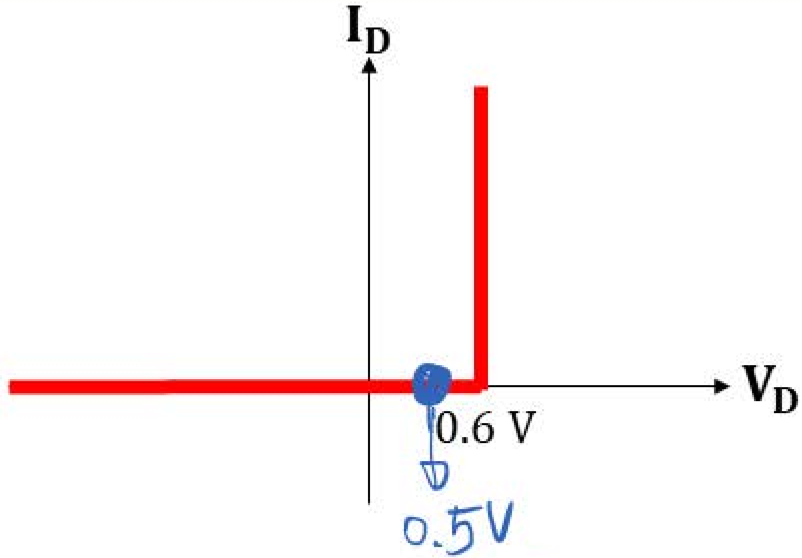


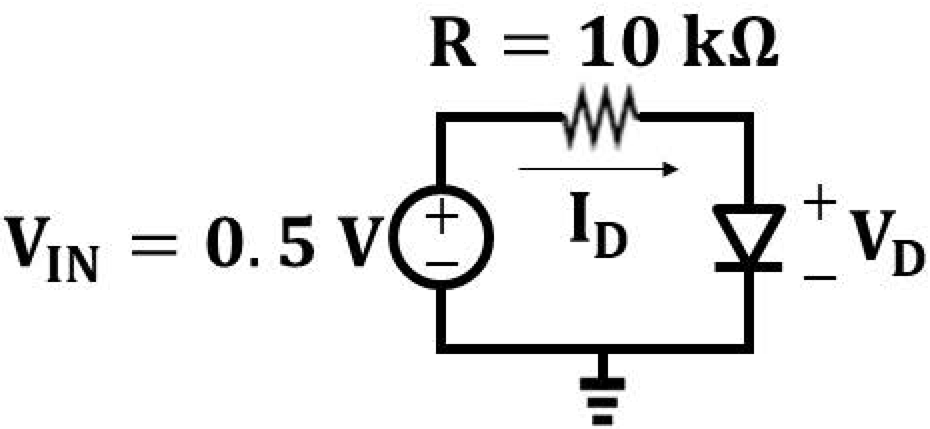
$$V_D = 0.6\ V$$

$$I_D = \frac{(10 - 0.6)\ V}{10\ k\Omega} = 0.94\ mA$$

V_D a power supply?
What happens if $V_{IN} = 0.5\ V$?

Simplified Analysis (Constant Voltage Drop)

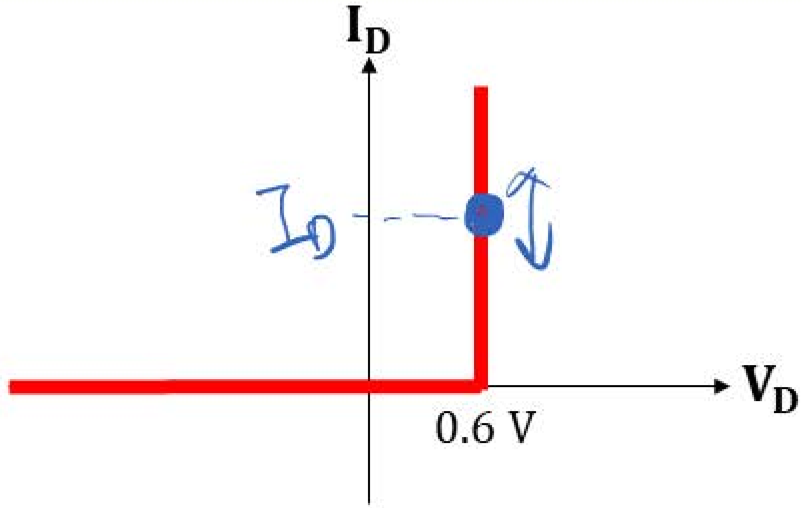




$I_D = 0\ A$

$V_D = 0.5\ V$

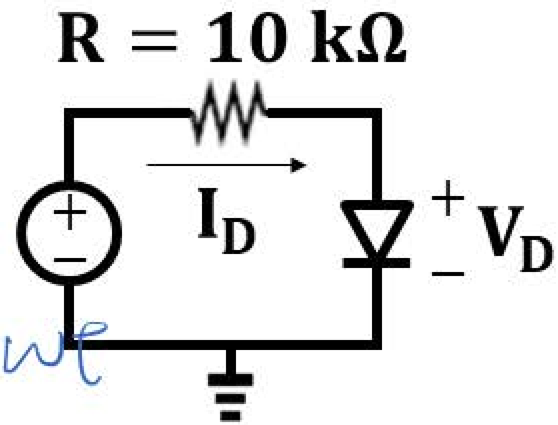
Simplified Analysis (Constant Voltage Drop)



$2 + 0.01\sin\omega t$

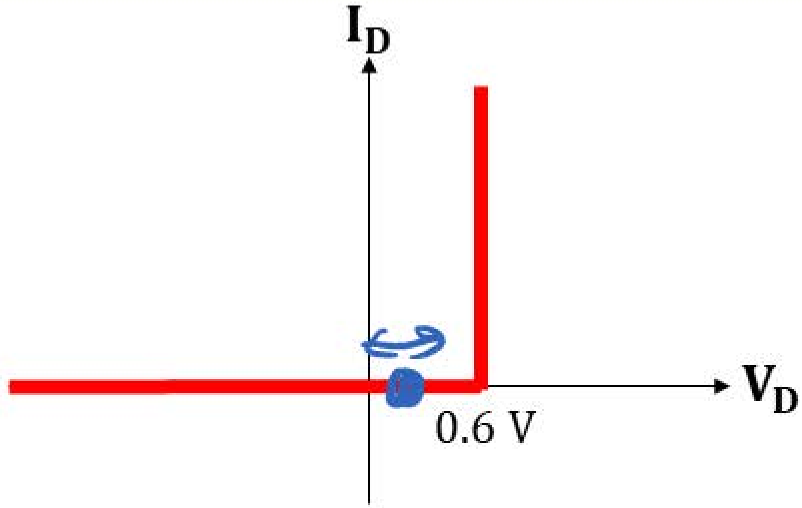
$$I_d = I_D + i_d = \frac{V_{in} - 0.6}{10K}$$

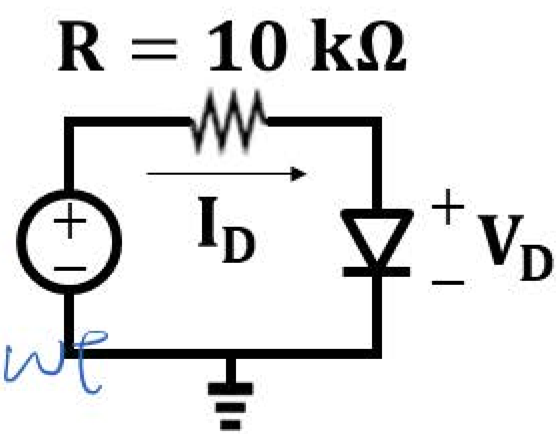
$V_D = 0.6\ V$



$V_{in} =$ $2 + 0.01\sin\omega t$

Simplified Analysis (Constant Voltage Drop)



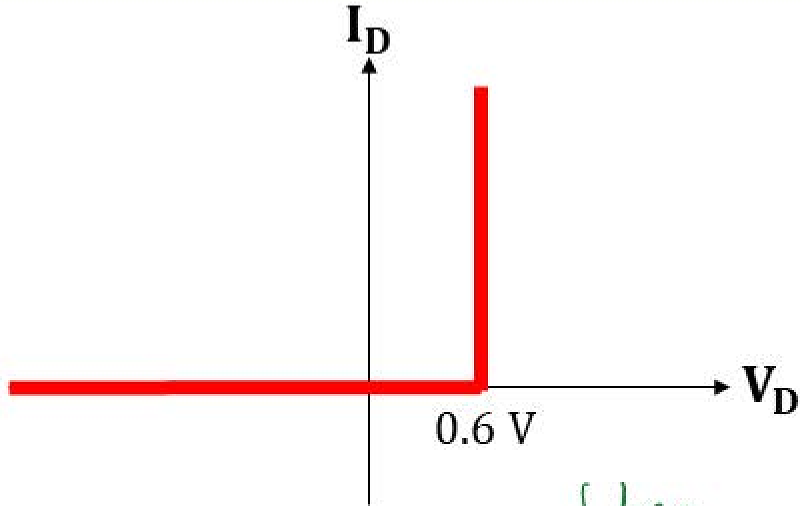


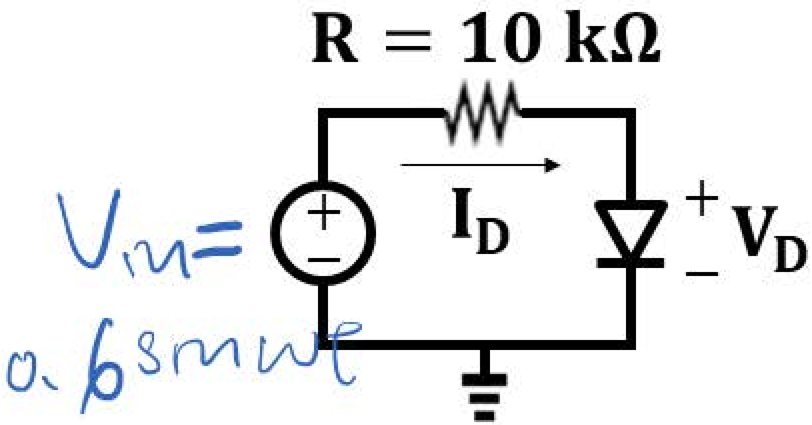
$V_{in} = 0.2 + 0.01 \sin \omega t$

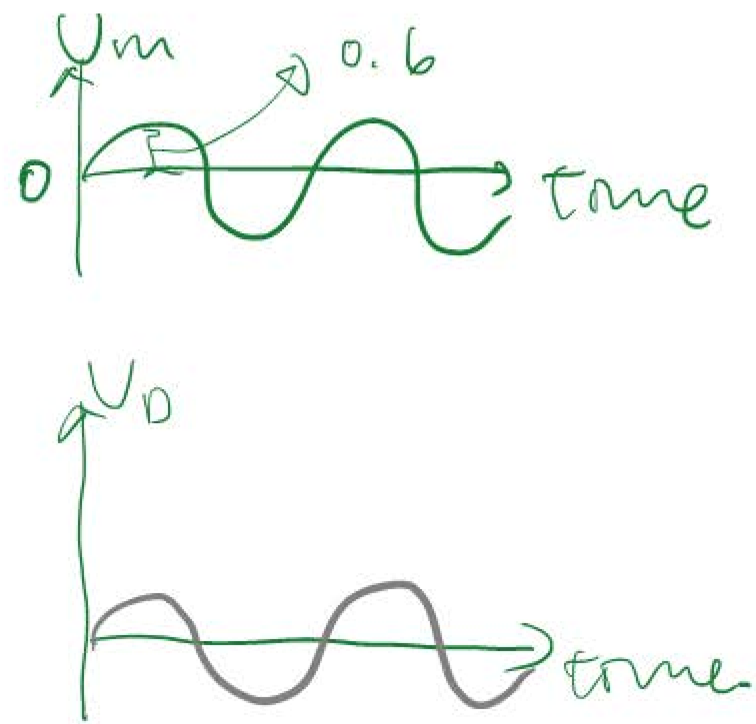
$I_d = 0$ A

$V_D = 0.2 + 0.01 \sin \omega t$

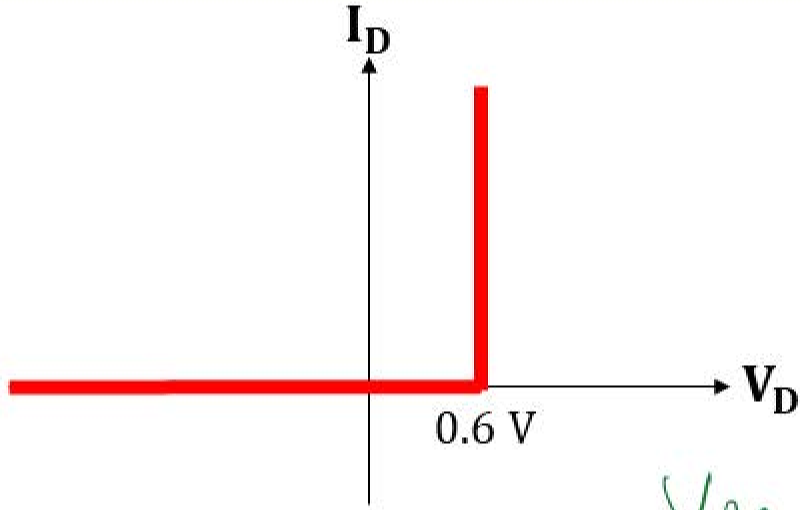
Simplified Analysis (Constant Voltage Drop)

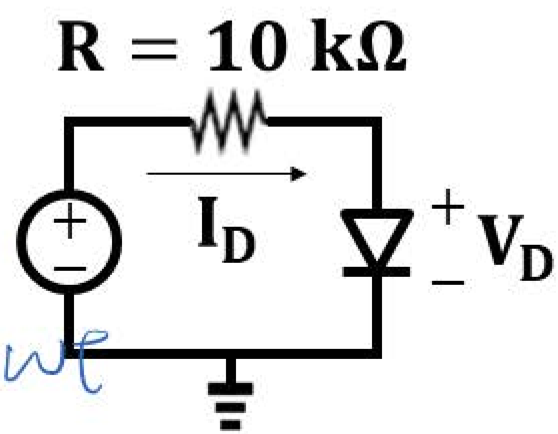




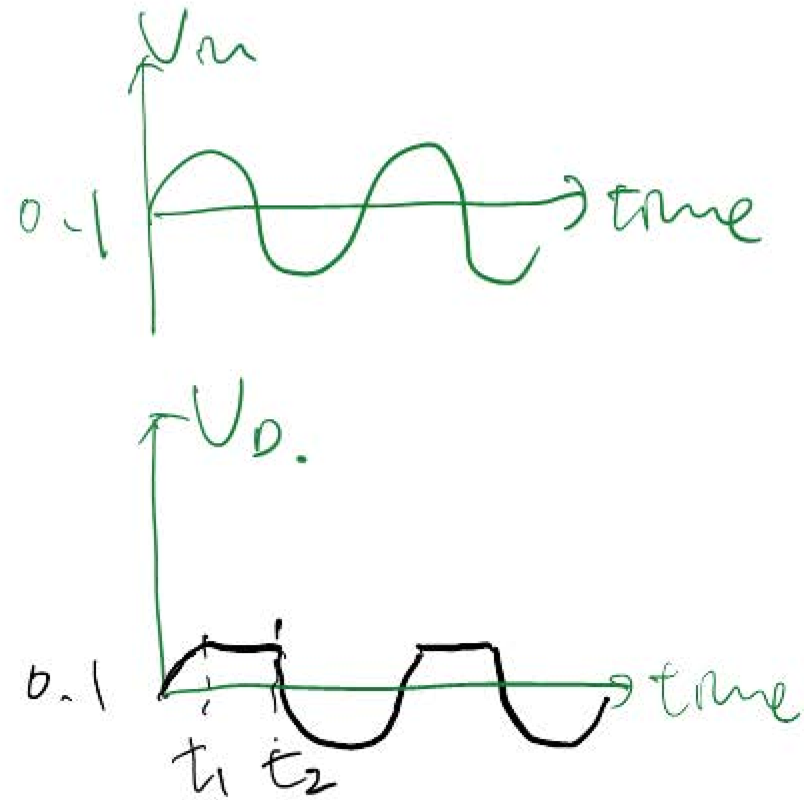


Simplified Analysis (Constant Voltage Drop)

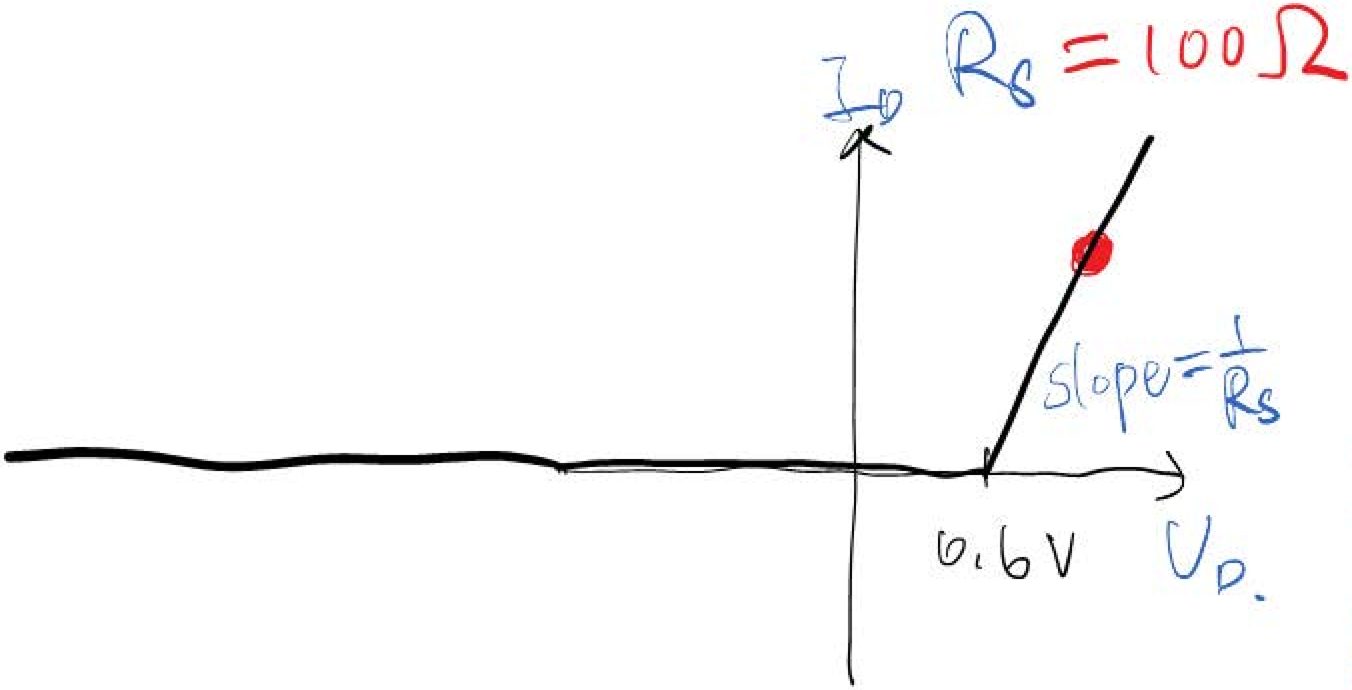




$V_{in} = 0.1 + 0.6 \sin \omega t$

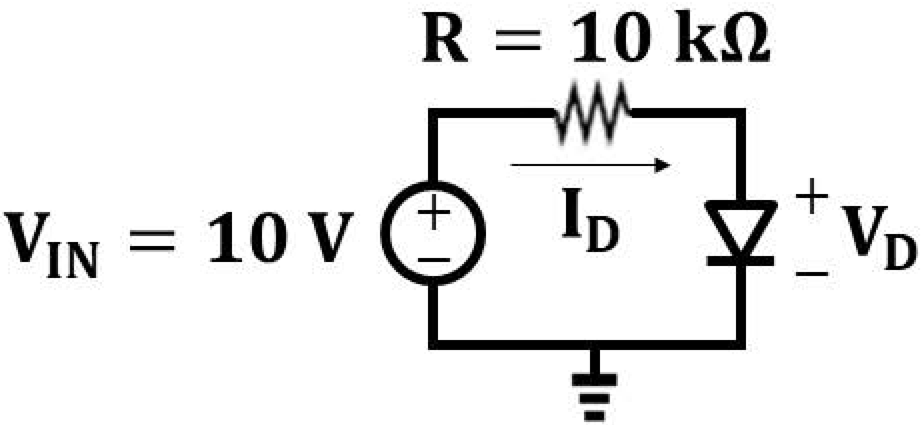


Simplified Analysis (Constant Voltage Drop)

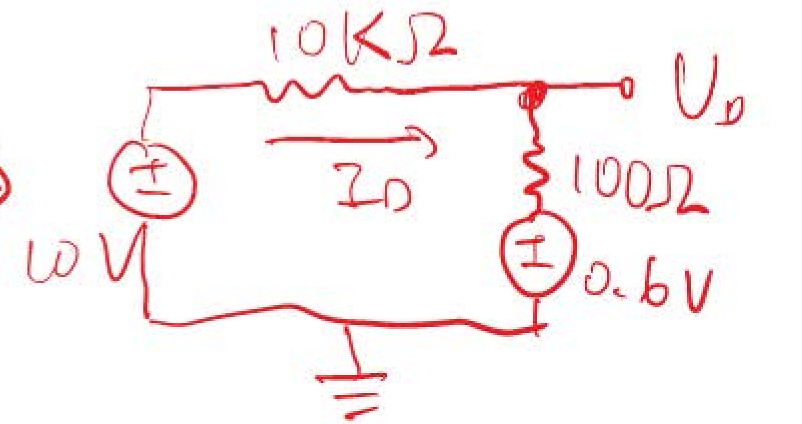


$$I_D = \frac{10 - 0.6}{10k + 100}$$

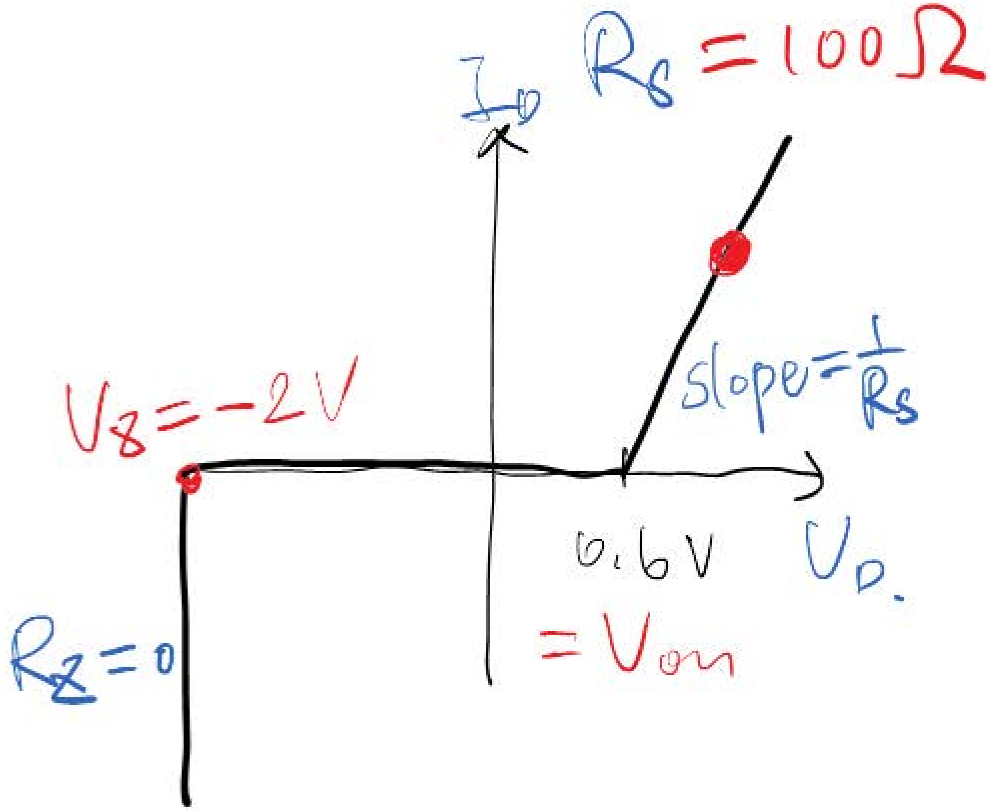
$$U_D = 0.6 + I_D 100$$



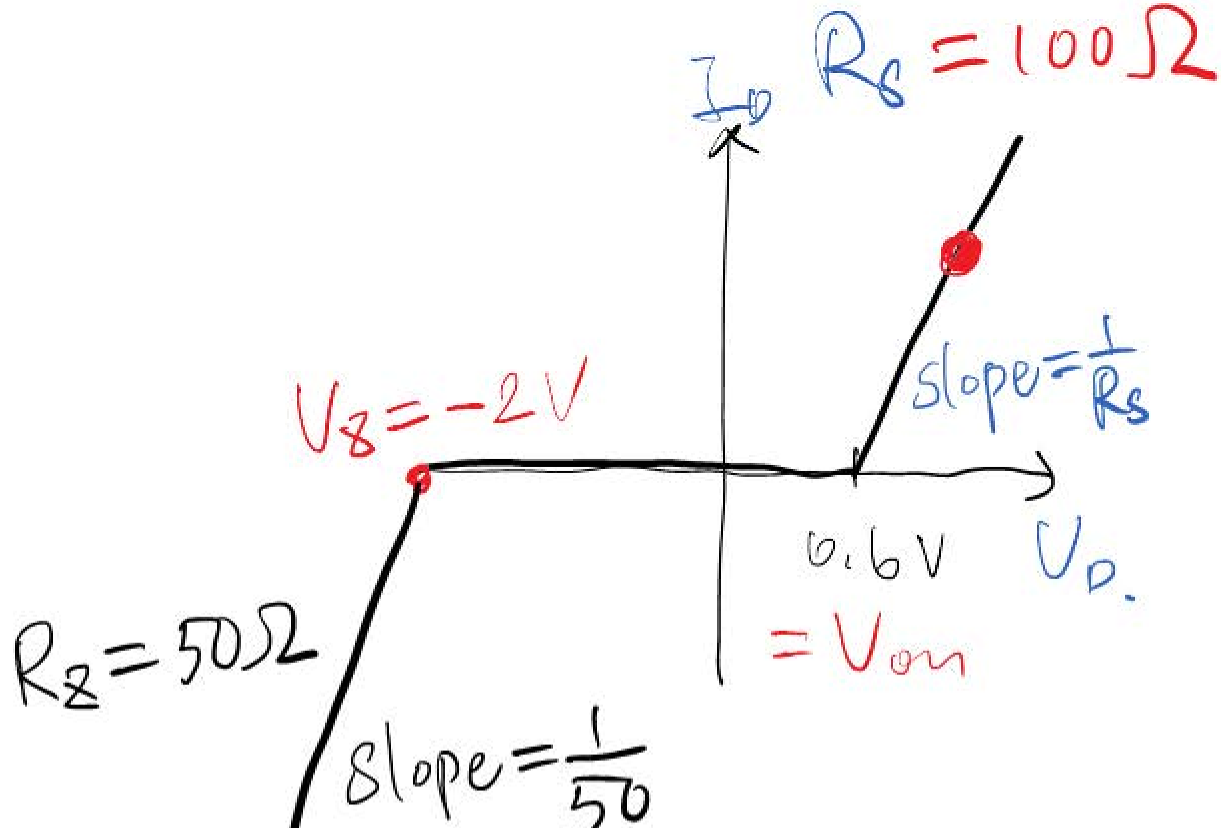
$\Rightarrow$



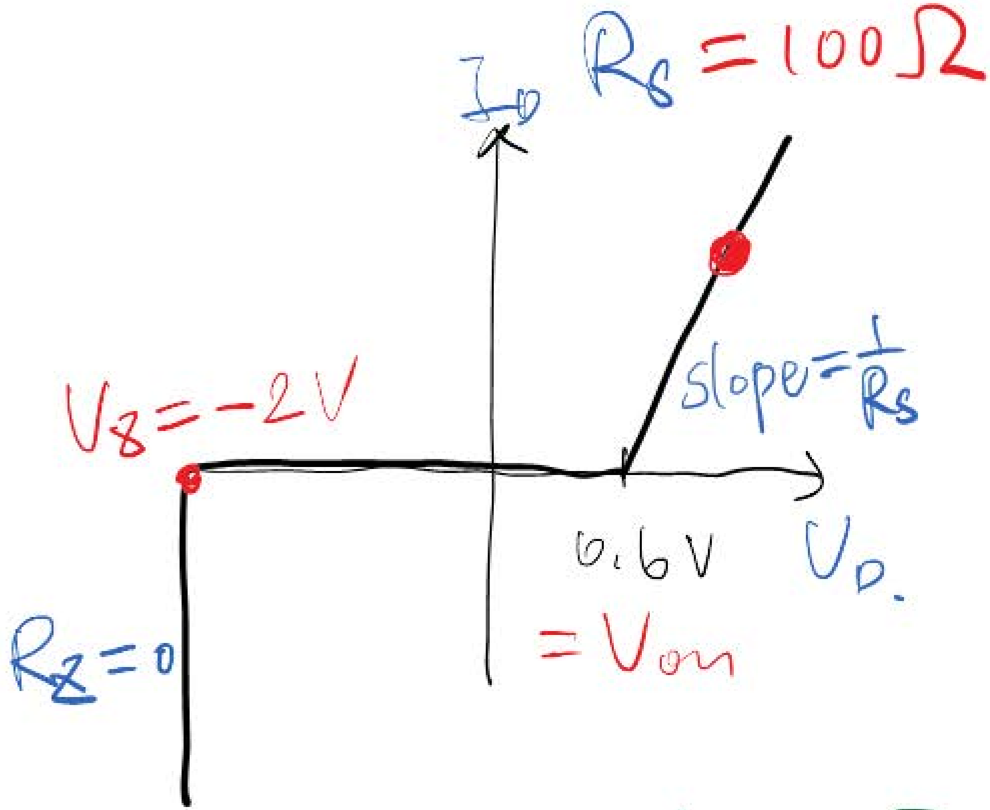
Simplified Analysis (Constant Voltage Drop)

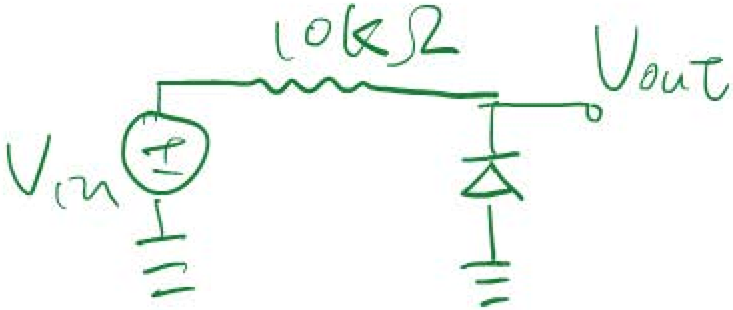


Simplified Analysis (Constant Voltage Drop)



Simplified Analysis (Constant Voltage Drop)





$V_{in} = 5 + 0.01 \sin(2\pi 60 t)$

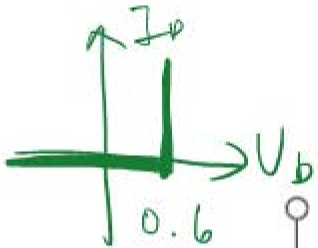
$V_{out} = 2$

Comparison

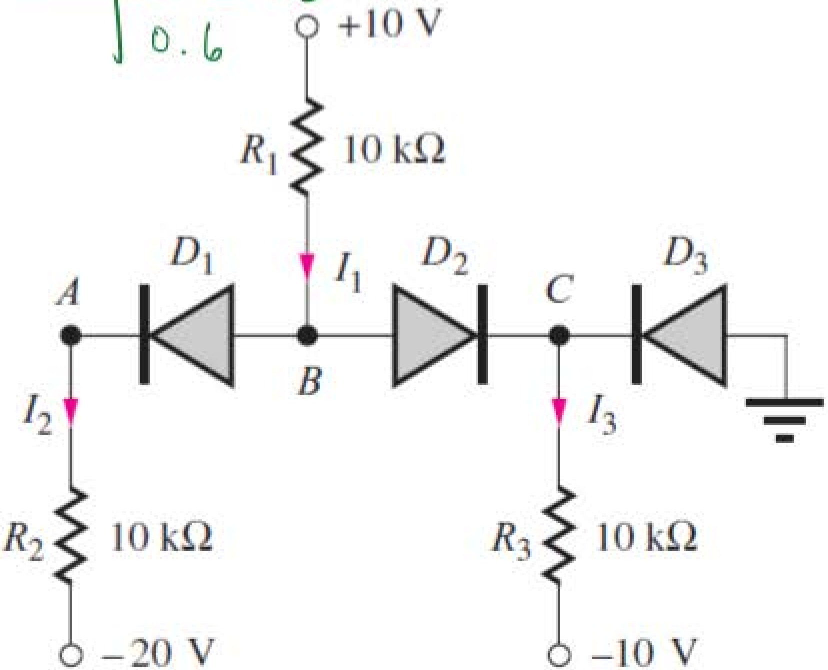
	V_D	I_D
Graphical Analysis	0.6 V	0.95 mA
Mathematical Analysis	0.5742 V	0.944 mA
Ideal Diode Model	0 V	1 mA
Constant Voltage Drop Model	0.6 V	0.94 mA

Example

Use constant voltage drop model ($V_{on} = 0.6$ V) to calculate V_D and I_D of each diode.



$R_S = 0$



D_1 on, D_2 on, D_3 off

- Assume no current flowing through D_3

$$\frac{10 - V_B}{10k} = \frac{V_B - 0.6 + 20}{10k} + \frac{V_B - 0.6 + 10}{10k}$$

$$V_B = -6.27 \text{ V}$$

$$V_C = -6.87 \text{ V} \Rightarrow D_3 \text{ in forward bias}$$

Assumption NOT valid

D_1 on, D_2 off, D_3 on

- Assume no current flowing through D_2

$$\frac{10 - V_B}{10k} = \frac{V_B - 0.6 + 20}{10k}$$

$$V_B = -4.7 \text{ V}$$

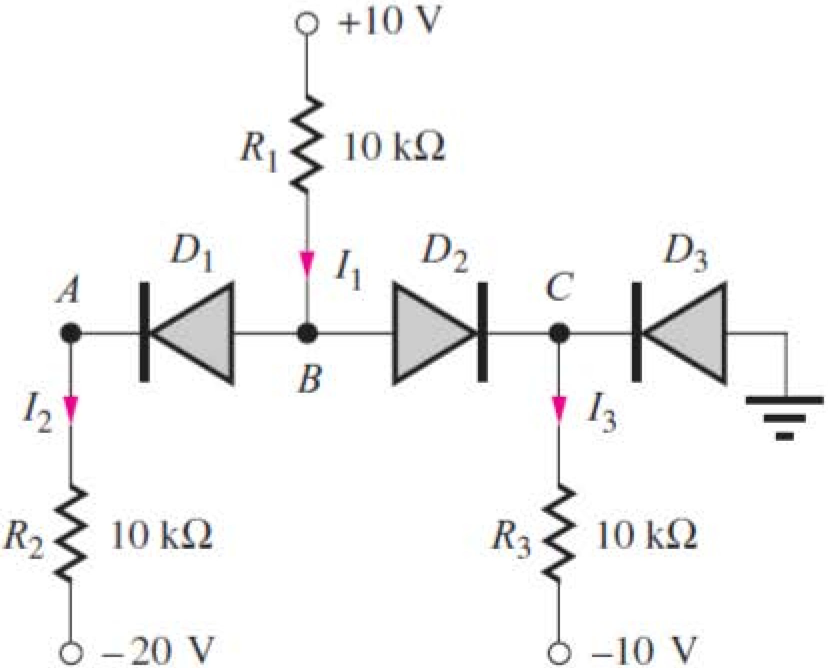
$$V_C = -0.6 \text{ V} \Rightarrow D_2 \text{ indeed in reverse bias}$$

Assumption valid

$V_{D1} = 0.6$ V	$V_{D2} = -4.1$ V	$V_{D3} = 0.6$ V
$I_{D1} = 1.47$ mA	$I_{D2} = 0$ mA	$I_{D3} = 0.94$ mA

Example

Use ideal diode model ($V_{on} = 0$ V) to calculate V_D and I_D of each diode.



- Assume D_3 in reverse bias

$$\frac{10 - V_B}{10k} = \frac{V_B + 20}{10k} + \frac{V_B + 10}{10k}$$

$$V_B = -6.67 \text{ V}$$

$$V_C = -6.67 \text{ V} \quad \Rightarrow \quad D_3 \text{ in forward bias}$$

Assumption NOT valid

- Assume D_2 in reverse bias

$$\frac{10 - V_B}{10k} = \frac{V_B + 20}{10k}$$

$$V_B = -5 \text{ V}$$

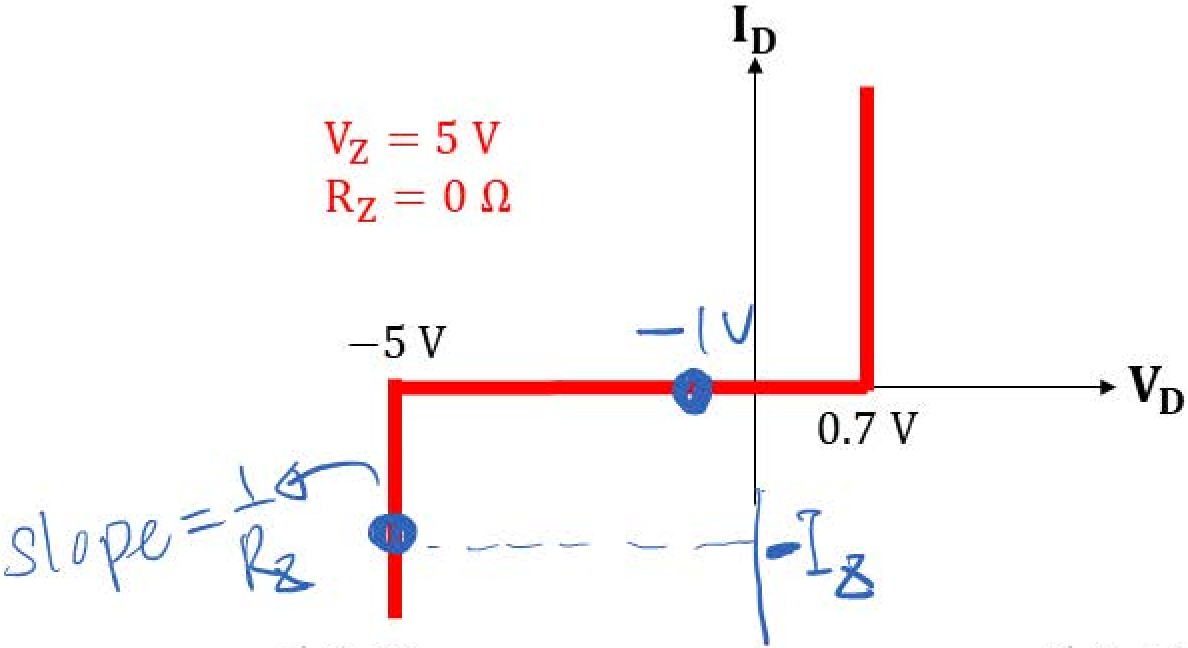
$$V_C = 0 \text{ V} \quad \Rightarrow \quad D_2 \text{ indeed in reverse bias}$$

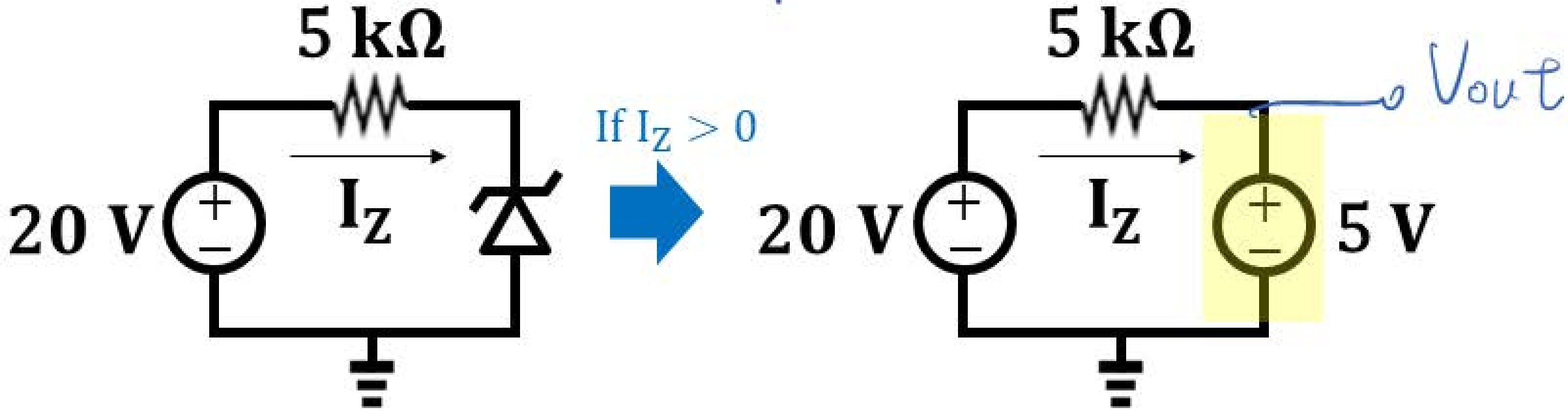
Assumption valid

$V_{D1} = 0$ V	$V_{D2} = -5$ V	$V_{D3} = 0$ V
$I_{D1} = 1.5$ mA	$I_{D2} = 0$ mA	$I_{D3} = 1$ mA

Zener Diode Circuit

Simplified Analysis for Zener Diode ($R_Z = 0$)

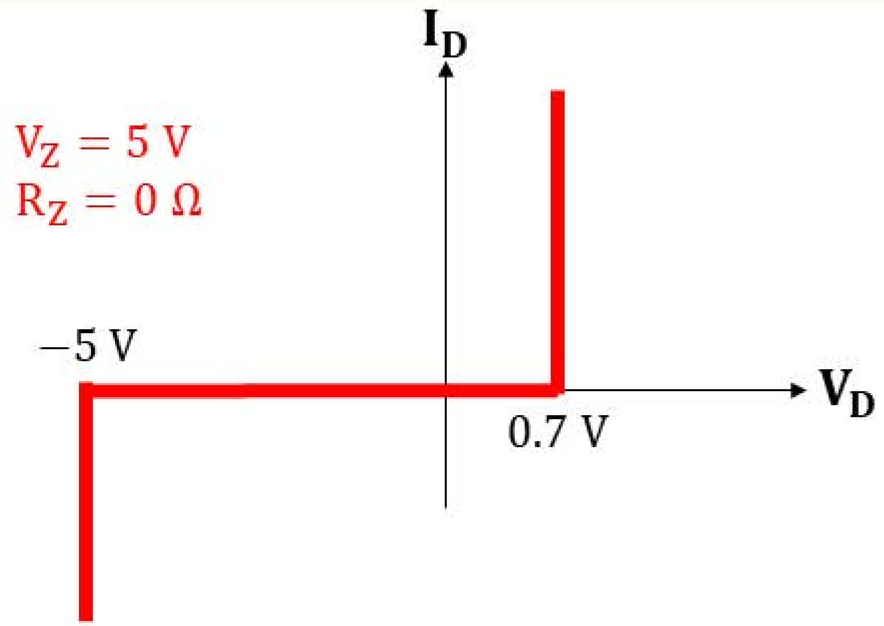


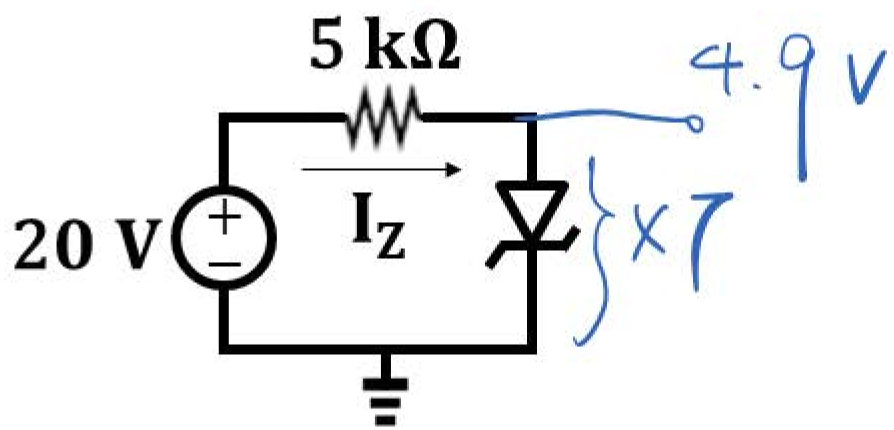


$$I_Z = \frac{20 - 5}{5000} = 3 \times 10^{-3}\ \text{(A)}$$

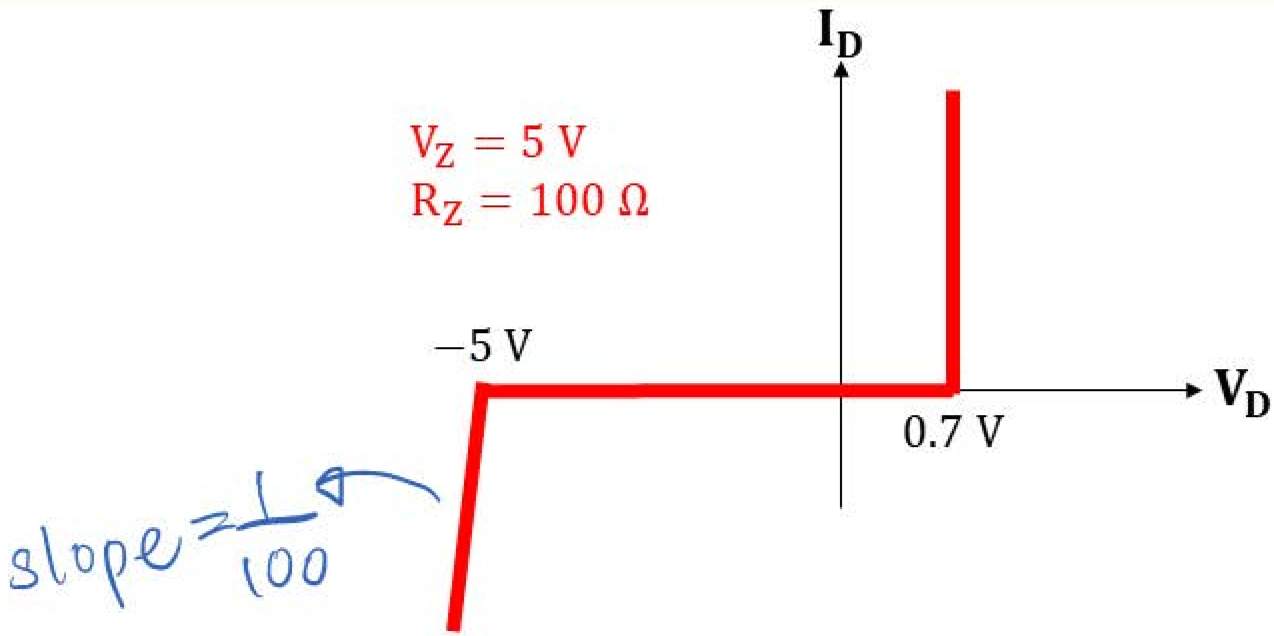
What happens if $V_{IN} = 1$ V?

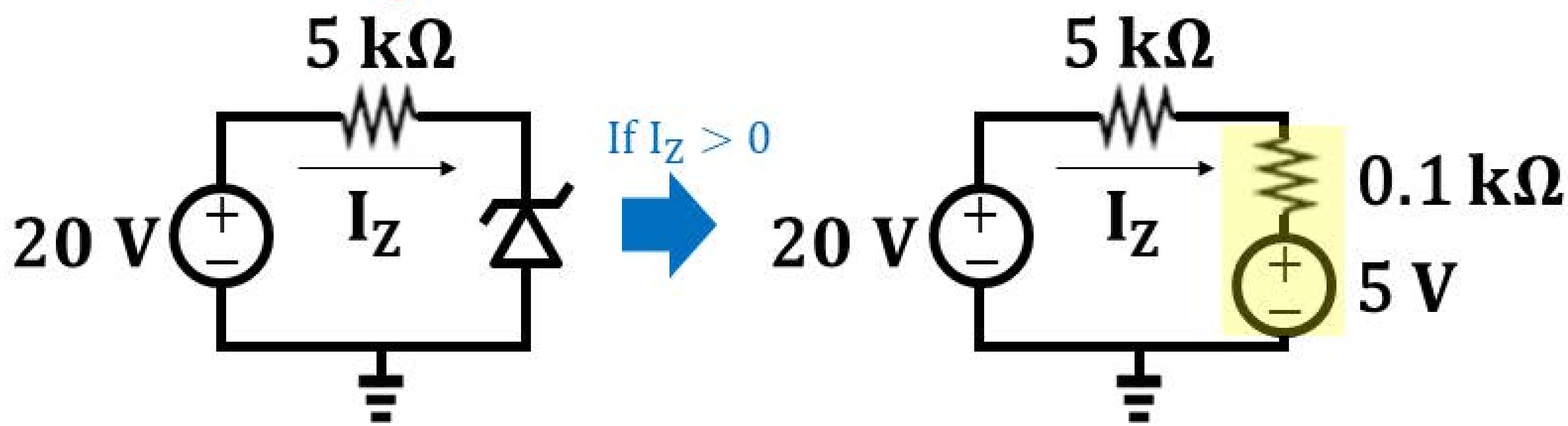
Simplified Analysis for Zener Diode ($R_Z = 0$)





Simplified Analysis for Zener Diode ($R_Z \neq 0$)

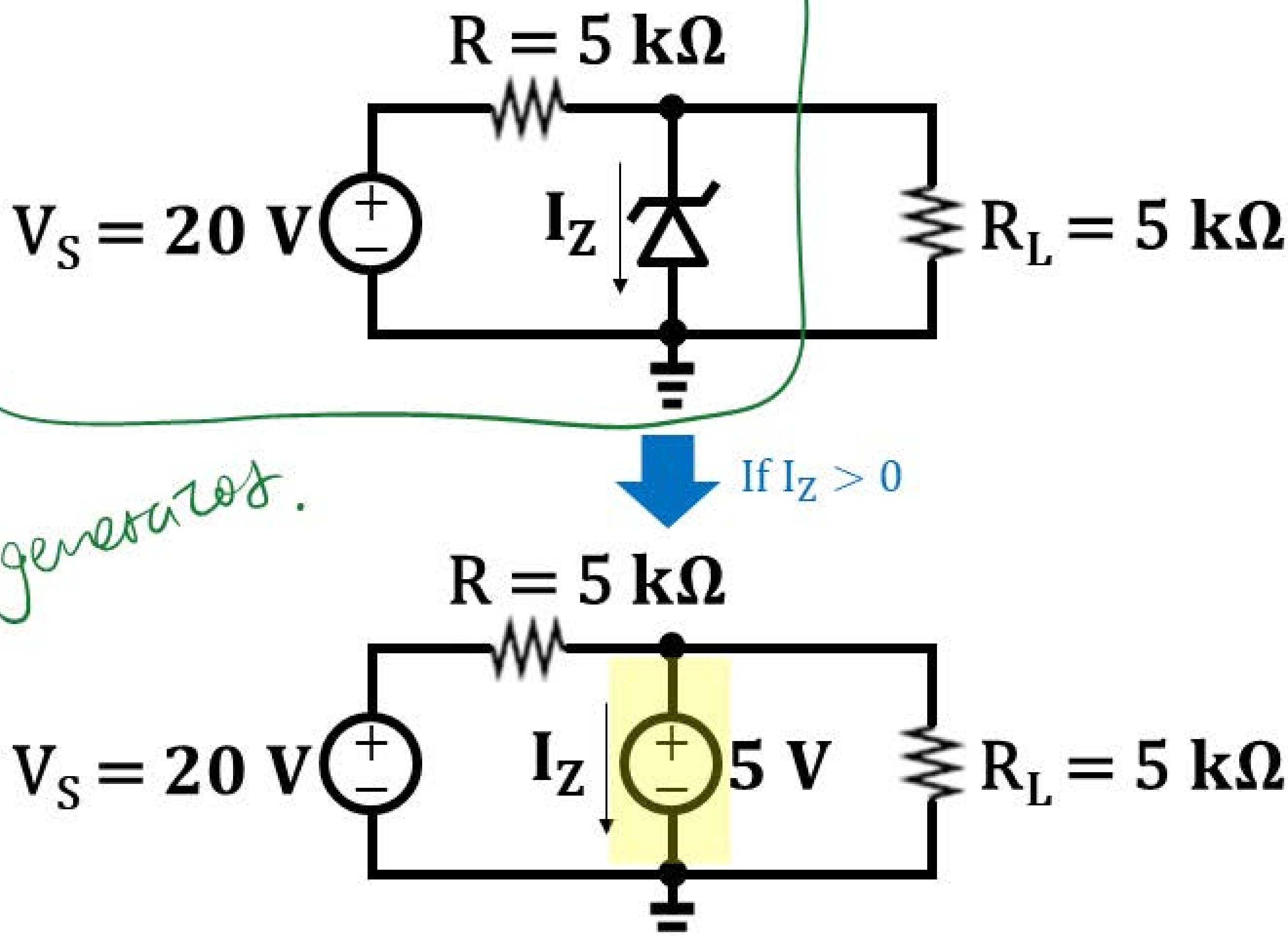




$$I_Z = \frac{20 - 5}{5100} = 2.94 \times 10^{-3}\ (\text{A})$$

Voltage Regulator Using Zener Diode ($R_Z = 0$)

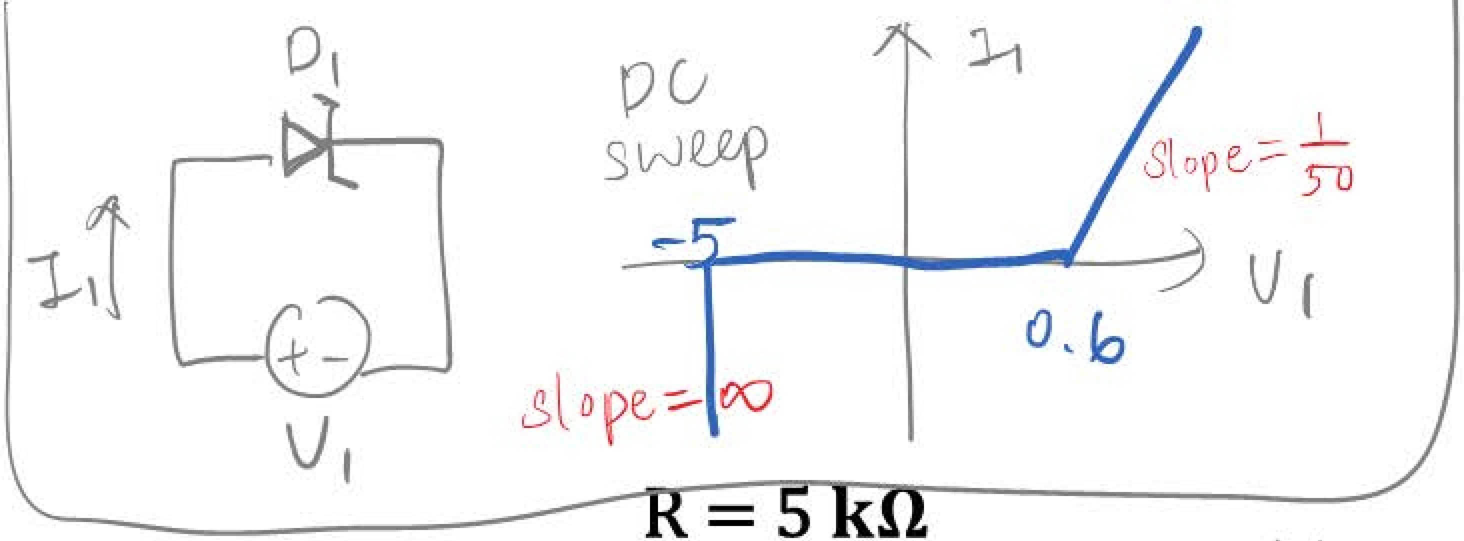
power supply or DC 5V generator.

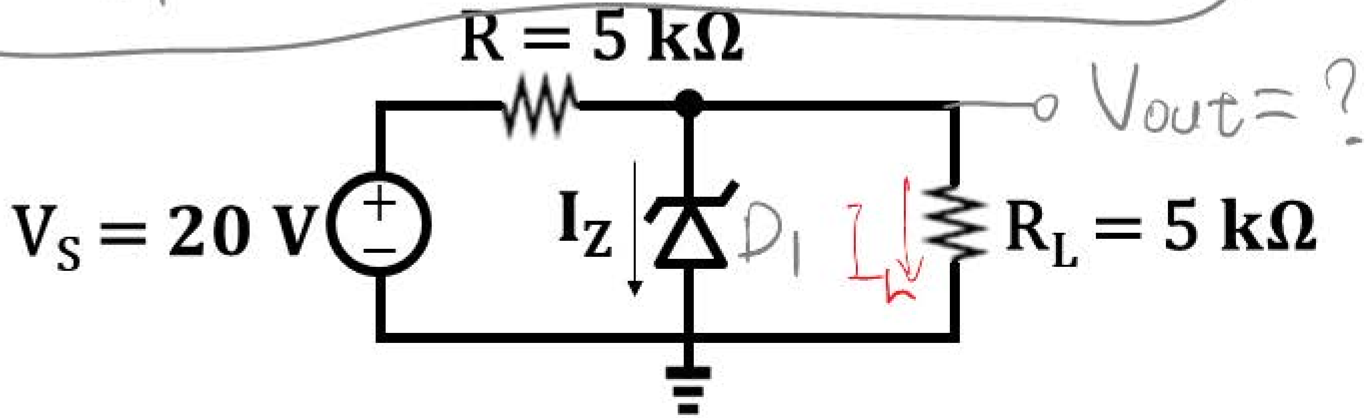


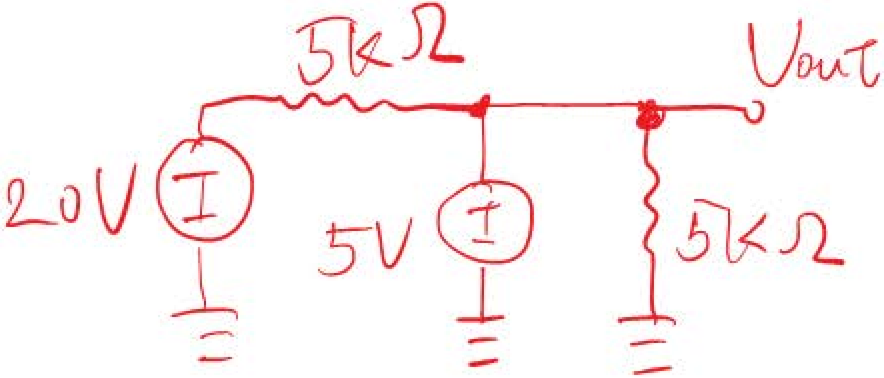
$$I_Z = \frac{20-5}{5k} - \frac{5}{5k} = 2\ \text{mA} > 0$$

As long as the zener diode operates in reverse breakdown region ($I_Z > 0$), a constant voltage (5 V) appears across R_L.

What is the smallest R_L for reverse breakdown to happen? Answer: $R_{L,min} = 1.67\ k\Omega$



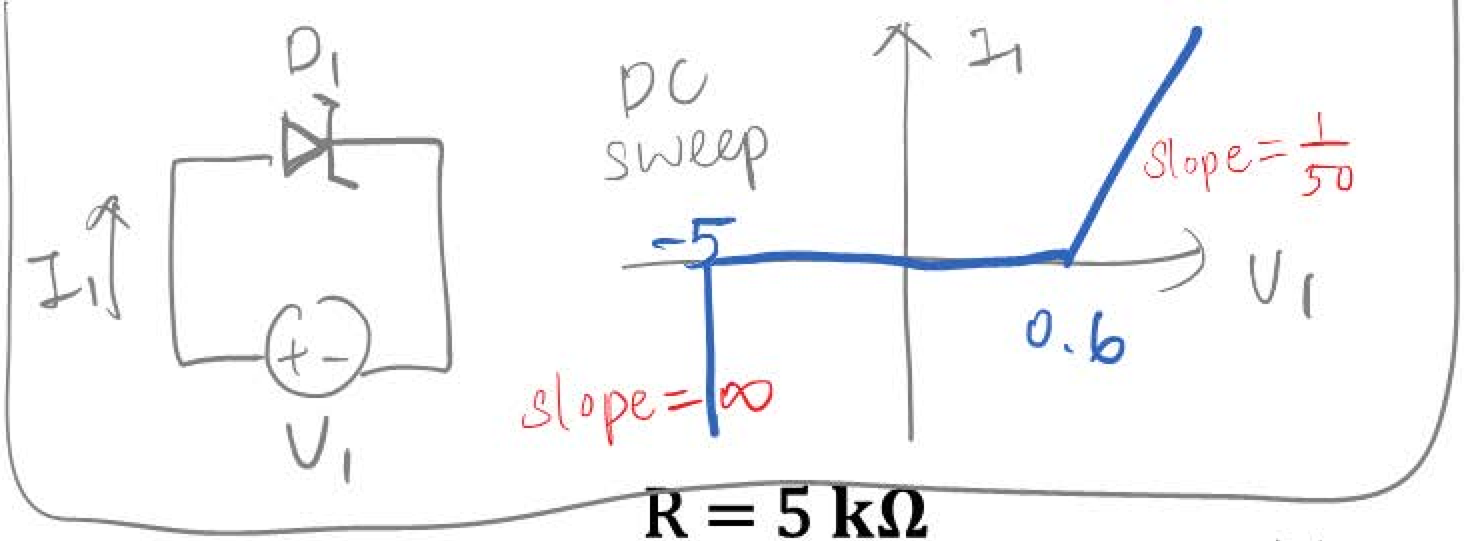


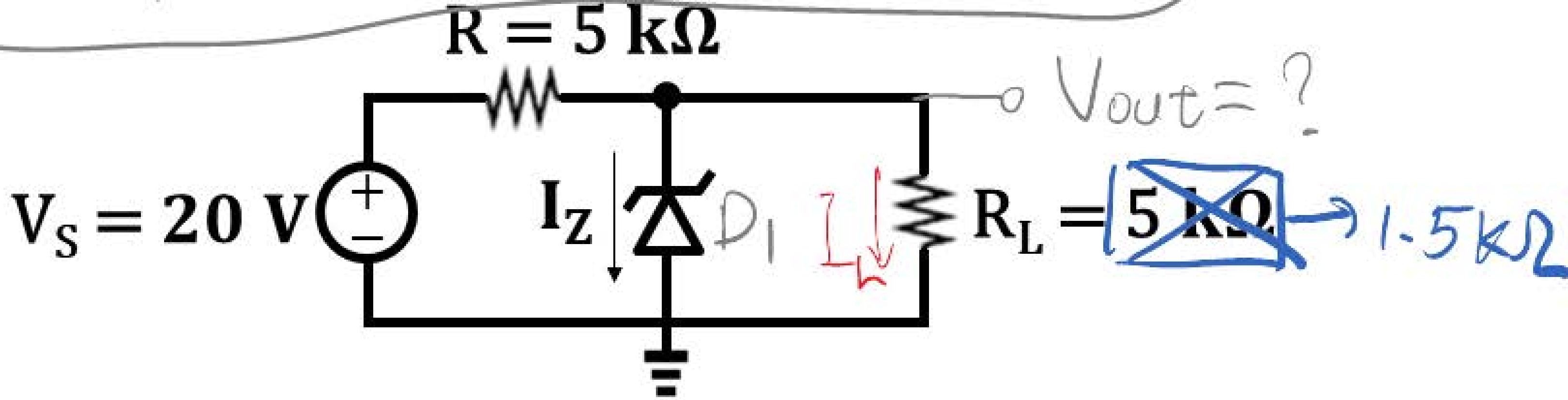


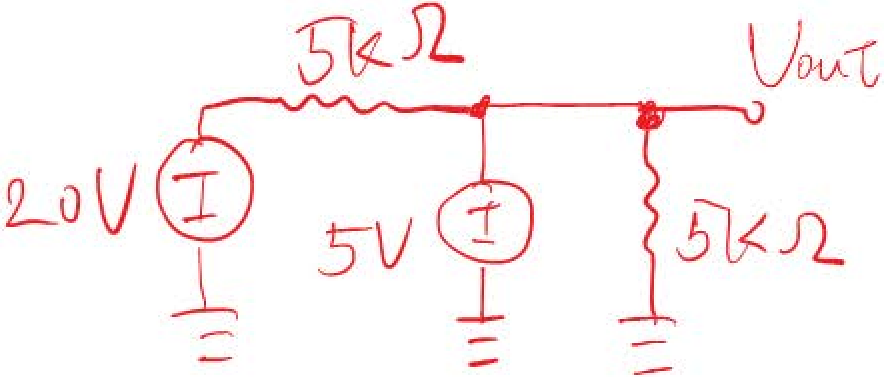
$V_{out} = 5\text{ V}$

$$\frac{20-5}{5k} - I_L = I_Z$$

$$\frac{5}{5k} = I_L$$







$$20 \cdot \frac{1.5k}{1.5k+5k} = V_{out}$$

$$\boxed{\frac{5}{1.5k} = I_L > \frac{20-5}{5k}}$$