ENEE236

Analog Electronics

T2 Semiconductor Diodes

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Diode Operating Conditions

A diode has three operating conditions:

1) **No bias**
2) **Reverse bias**
3) **Forward bias**

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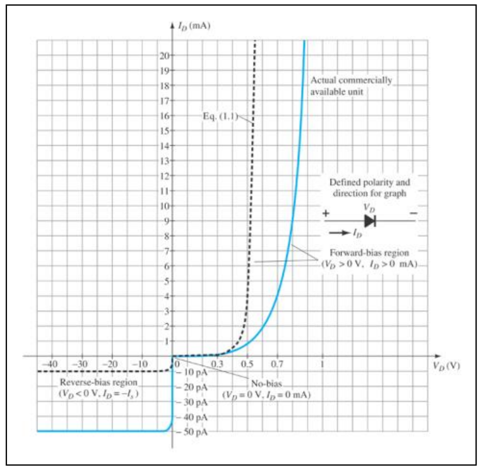
Actual Diode Characteristics

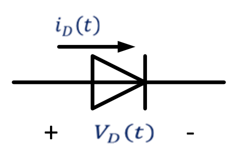
Note the regions for no bias, reverse bias, and forward bias conditions.

Carefully note the scale for each of these conditions.



Diode Equation

$$i_D(t) = I_S(e^{\frac{V_D(t)}{\eta V_T}} - 1)$$



Is: Reverse saturation current

Is= 10^{-12}, 10^{-14}A

η : eta

$$\eta = \begin{Bmatrix} 1\ for\ Ge \\ 2\ for\ Si\ (small\ current) \\ 1\ for\ Si\ (large\ current) \end{Bmatrix}$$

V_T= Thermal Voltage

$V_T = \frac{T}{11600}$;T in kelvin

At Room Temp. T=300 k

∴ V_T = 25.69 mv at Room Temp.

$$i_D(t) = I_S(e^{\frac{V_D(t)}{\eta V_T}} - 1)$$

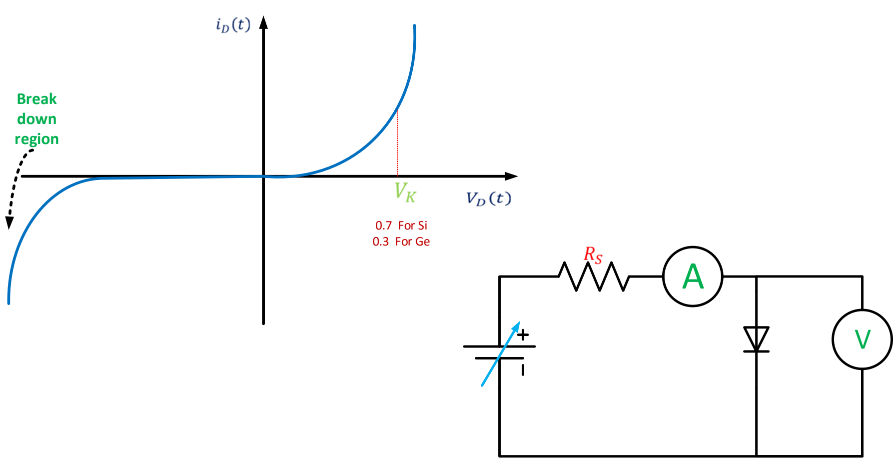
- The equation is a non linear equation

∴ The Diode is non linear Device

- For positive $V_D(t)$, $i_D(t) = I_S(e^{\frac{V_D(t)}{\eta V_T}})$

- **For negative $V_D(t)$** $i_D(t) = -I_S$

Diode V-I Characteristic curve



Approaches to Diode Circuit Analysis

The rectifier diode is a non linear device .

There are essentially three basic approaches to the solution of such problem :

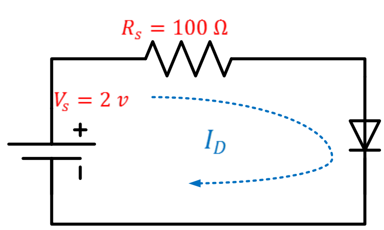
1- The use of non linear mathematics

2- The use of graphical techniques

3- The use of equivalent circuit (models) (piecewise linear models)

1)The use of non linear mathematic (shown , but not required)

- For the circuit shown, find I_D and V_D



Silicon:
η=1.1
I_S= 10^{-14} A

- KVL : $V_S = R_S I_D + V_D$

$$I_D = I_S(e^{\frac{V_D}{\eta V_T}} - 1)$$

- Since the diode is forward biased , we could approximate

$$I_D = I_S(e^{\frac{V_D}{\eta V_T}})$$

- Solving for $V_D = \eta\, V_T \ln\frac{I_D}{I_S}$

∴ **We have two equations and two unknowns**

$V_S = R_S I_D + V_D$ 1

$V_D = \eta V_T \ln \frac{I_D}{I_S}$ 2

$\therefore \quad V_S = R_S I_D + \eta V_T \ln \frac{I_D}{I_S}$

- **non linear equation**

Iterative Analysis

$I_D = \frac{V_S - V_D}{R_S}$

$V_D = \eta V_T \ln \frac{I_D}{I_S}$

1) Let $V_D = 0.7$v

$I_D = \frac{2-0.7}{0.1k}$ = 13 mA

$V_D = 0.7882392$v The error is large

2) Let $V_D = 0.7882392$v

I_D = 12.117608 mA

$V_D = 0.7862529$v The error is small

3) Let $V_D = 0.7862529$v

$I_D = 12.137471$ mA

$V_D = 0.7862991$ V   The error getting smaller

4) Let $V_D = 0.7862991$ V

$V_D = 0.786298066$ V

$I_D = 12.137009$mA

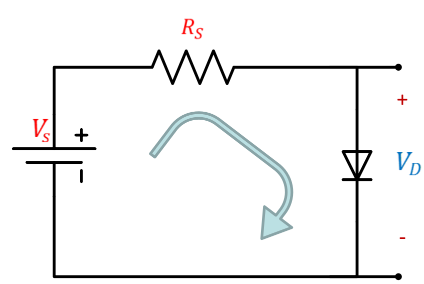
$I_D = 12.137$ mA
$V_D = 0.7863$v

2) The use of graphical techniques

(Requires the V-I exact plot)

$V_S = R_S I_D + V_D$ ……………1

$I_D = I_S\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$ …………2

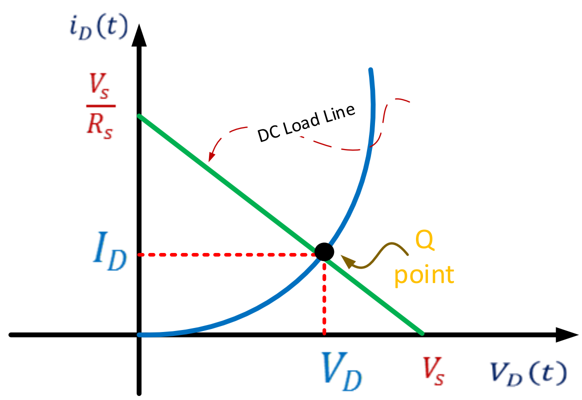


- Using equation 1

$$I_D = -\frac{1}{R_S}V_D + \frac{V_S}{R_S}$$

Dc Load Line Equation

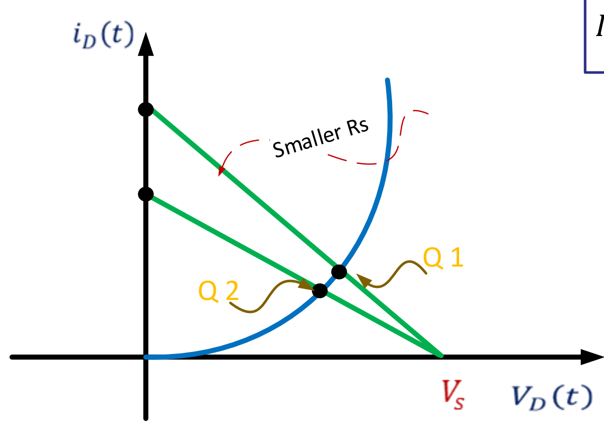
Drawing the two equations



$I_D = -\frac{1}{R_S} V_D + \frac{V_S}{R_S}$

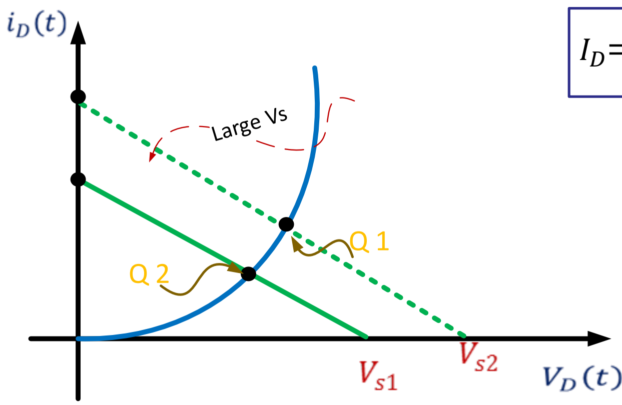
- Q$_{point}$ = (V_{DQ}, I_{DQ}) = Q$_{uiescent\ point}$

The effect of Rs on the Qpoint



$I_D = -\frac{1}{R_S} V_D + \frac{V_S}{R_S}$

The effect of Vs on Qpoint



$$I_D = -\frac{1}{R_S}V_D + \frac{V_S}{R_S}$$

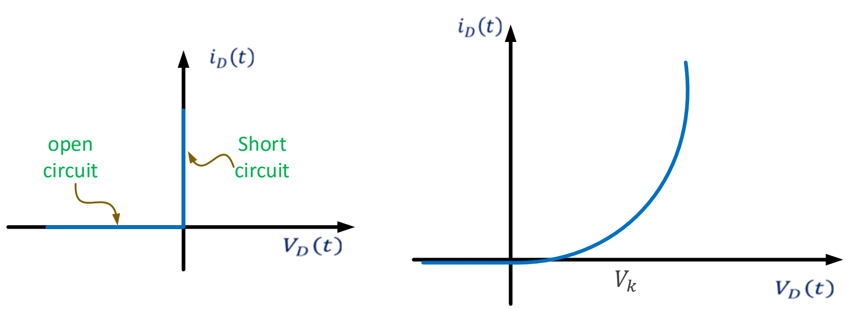
The Use of Diode Model

The use of Diode Models

- A piece wise linear models is an electrical equivalent circuit of a nonlinear electronic device

- **It is composed of linear circuit elements arranged to approximate the characteristics of the electronic device .**

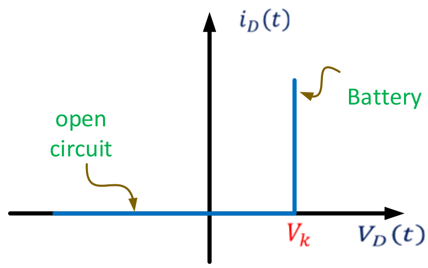
a) ideal diode model

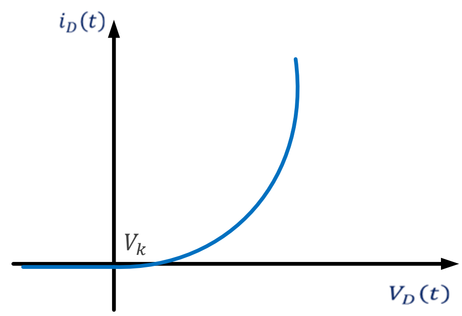


- When $V_s < 0$; the Diode is off, and replaced with open circuit

- When $V_s \geq 0$; the Diode is on, and replaced with short circuit

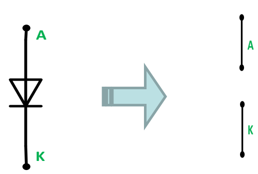
b) Knee Voltage model (simplified/practical model)

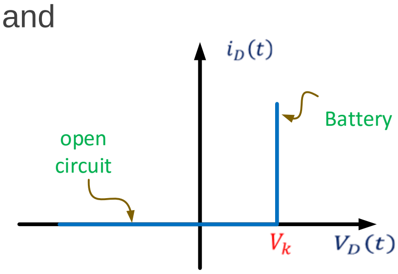




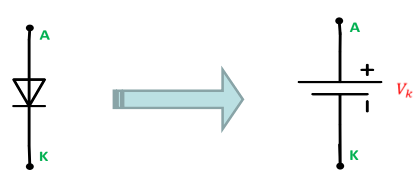
b) Knee Voltage model (simplified/practical model)

- When $V_s < V_k$; the Diode is off, and replaced with open circuit

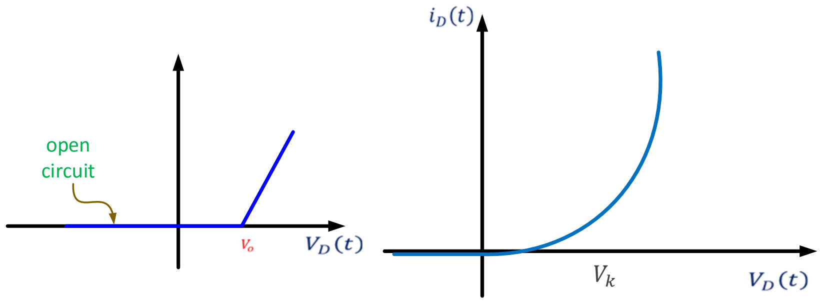




- When $V_s \geq V_k$; the Diode is on, and replaced with a constant voltage source



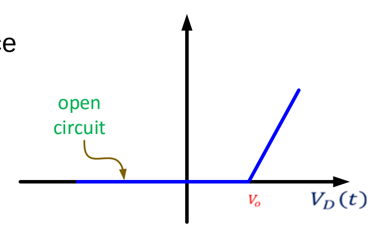
c) Dynamic resistance model (complete model)

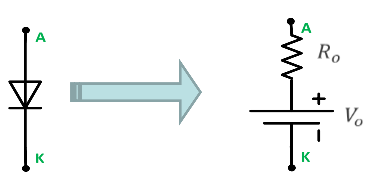


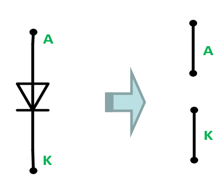
- When $V_s \geq V_o$; the Diode is on, and replaced with a constant voltage source V_o and resistance R_o
- When $V_s < V_o$; the Diode is off, and replaced with open circuit

c) Dynamic resistance model

- When $V_s \geq V_o$; the Diode is on, and replaced with a constant voltage source V_o and resistance R_o

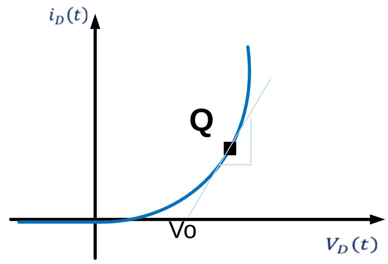






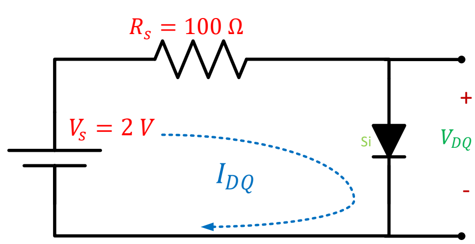
- When $V_s < V_o$; the Diode is off, and replaced with open circuit

To determine Vo and Ro

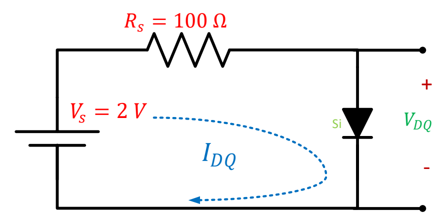


Example

- Find the Q point (I_{DQ} , V_{DQ}) using
  - a) ideal diode model
  - b) knee voltage model



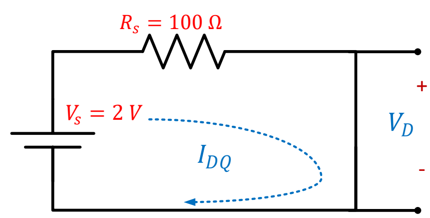
a) using ideal diode model



since $V_S \geq 0$, the diode is on and replaced with short circuit .

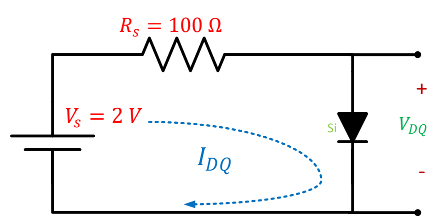
$\therefore\ I_{DQ} = \frac{2}{100} = 20\ mA$

$\therefore\ V_{DQ} = 0\ V$



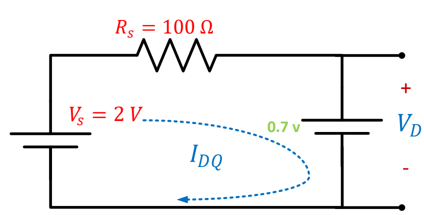
b) Using knee voltage model

since $V_S \geq 0.7$, the diode is on and replaced with $V_k = 0.7$.



$\therefore\ I_{DQ} = \frac{2-0.7}{100} = 13\ mA$

$\therefore\ V_{DQ} = 0.7\ V$



c) using nonlinear mathematic

$I_{DQ} = 12.137\ mA$

$V_{DQ} = 0.7863\ V$

Taking the knee voltage into a count

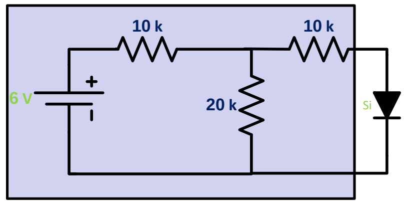
- If $V_S \geq 10\ V_k$, we could use ideal diode model .

$$I_{DQ} = \frac{\boldsymbol{Vs} - V_k}{\mathbf{100}} \approx \frac{\boldsymbol{Vs}}{\mathbf{100}}$$

- If $V_S < 10\ V_k$, we must use knee voltage model .

Note: If applied voltage is much higher than VAK (at least 10 times) , then ideal diode model is recommended

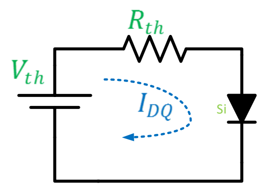
Example



- Find the Q point

Using thevenin's theorem , the circuit is simplified to

$R_{th} = 10k + 10k \,||\, 20k = 16.7k$

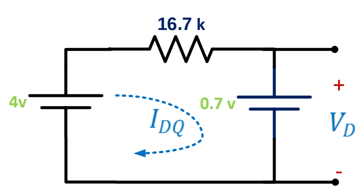


$V_{th} = \frac{20k}{20k+10k} * 6 \; = 4\,V$

since $V_{th} \geq \; V_k$, the diode is on

since $V_{th} < 10\,V_k$, we must use the knee voltage model

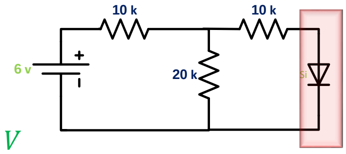
Knee voltage model



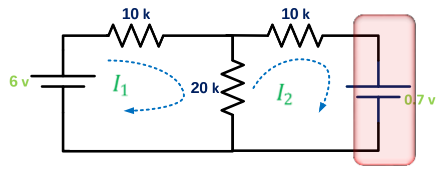
$I_{DQ} = \frac{4-0.7}{16.7K} = 0.198\,mA$

$V_{DQ} = \; V_K = 0.7\,V$

Second method



assume the diode is on , replace it with $V_K = 0.7\ V$



KVL:

$$6 = 30\, I_1 - 20\, I_2$$
$$-0.7 = -20\, I_1 + 30\, I_2$$

Solve for:

$$I_2 = 0.198\ mA$$

$$\therefore\ I_D = I_2 = 0.198\ mA$$

Since $I_D > 0$, $\therefore$ our assumption is ok

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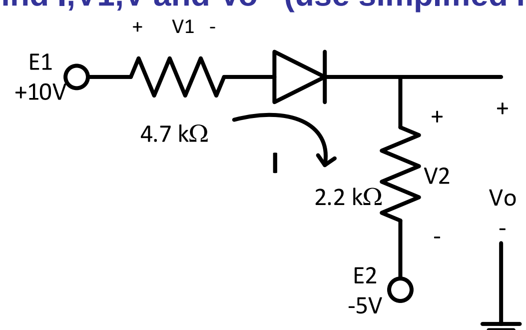
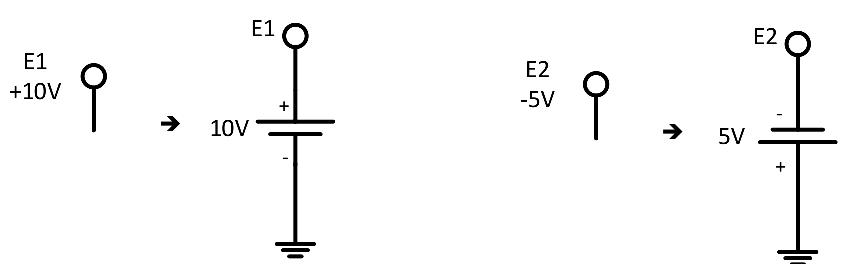
Example: **Find I,V1,V and Vo (use simplified model)**



Solution:



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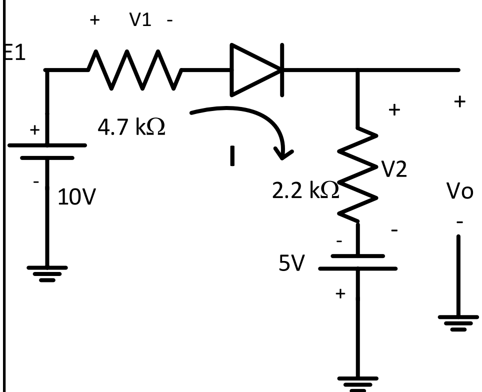
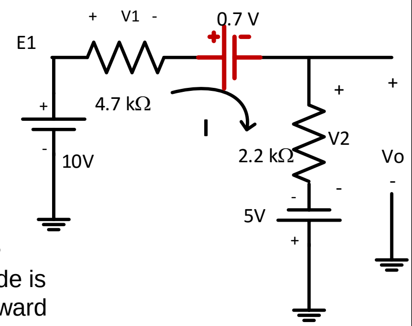


==>
Diode is
Forward
biased



I=(10+5-0.7)V/(4.7+2.2) kΩ
=2.07 mA

V1=I . R1= 9.73 V

V2=I . R2= 4.55 V

Vo= V2- 5 = -0.45 V

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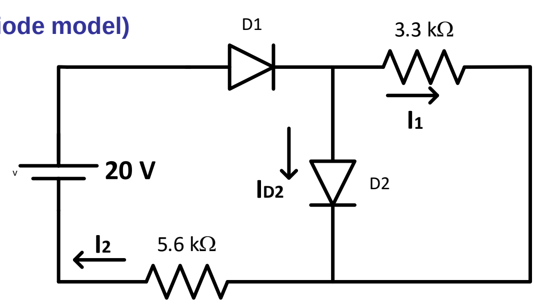
Find I1, I2, ID2 (use practical diode model)

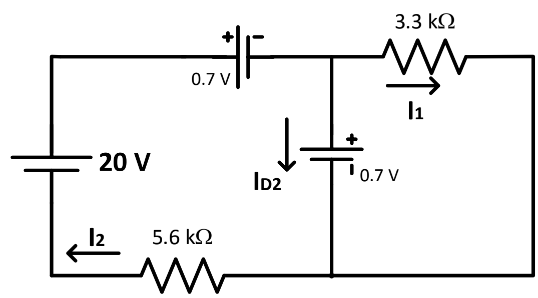


Solution:

Applied voltage is suitable for forward biasing both diodes

I_1= 0.7 V/3.3 kΩ
=0.212 mA

I_2= (20-0.7-0.7)/5.6 kΩ
=3.32 mA



$I_2=I_1+I_{D2}$

$I_{D2}=I_2-I_1$= 3.32– 0.212
=3.11 mA