FP4-1

Analog Electronics & Actuators

Objectives:

To enable students to **apply basic knowledge of analog electronics and actuators for constructing** hardware systems.

Contents:

Analog Electronics

o Diodes, PN-junction, small-signal model
o Rectifiers, filtering and stabilization
o Practical operational amplifier circuits, common-mode rejection ratio, slew-rate
o Bipolar junction transistor basics, DC-analysis, signal amplification, small-signal model
o Properties of the transistor
o Frequency response of the transistor amplifier
o MOSFET transistor

Electrical Actuators

o Electromechanical energy conversion. General principle, Work, forces, torque, efficiency etc. for electric machines.
o DC-motors. DC-machine construction, characteristics, dynamic models and applications. Motor drivers

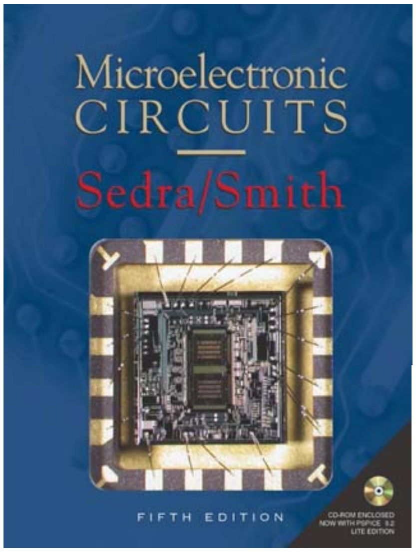
---

Course Web Page

- ☐ Contents
- ☐ Schedule
- ☐ Slides
- ☐ Useful Links
- ☐ Any other Matter & Related Material

Microelectronic Circuits 5/e

Sedra/Smith



Oxford University Press

Oxford New York
Auckland Bangkok Buenos Aires Cape Town Chennai
Dar es Salaam Delhi Hong Kong Istanbul Karachi Kolkata
Kuala Lumpur Madrid Melbourne Mexico City Mumbai Nairobi
São Paulo Shanghai Taipei Tokyo Toronto

Published by Oxford University Press, Inc.
198 Madison Avenue, New York, New York 10016
www.oup.com

Oxford is a registered trademark of Oxford University Press

ISBN 0–19–517267–1

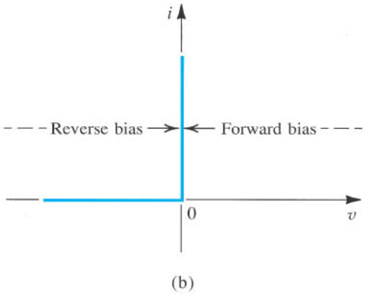
Printing number: 9 8 7 6 5 4 3 2 1

Printed in the United States of America

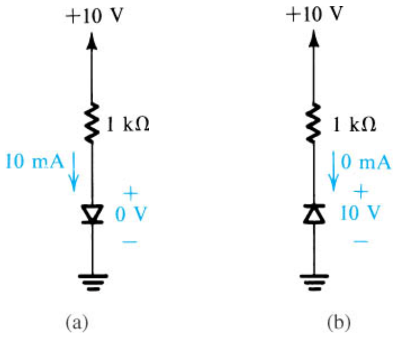
Diodes

Lecture # 1

The Ideal Diode



Forward / Reversed Biased



Dr. D. M. Akbar Hussain

Department of Electronic Systems

The Rectifier

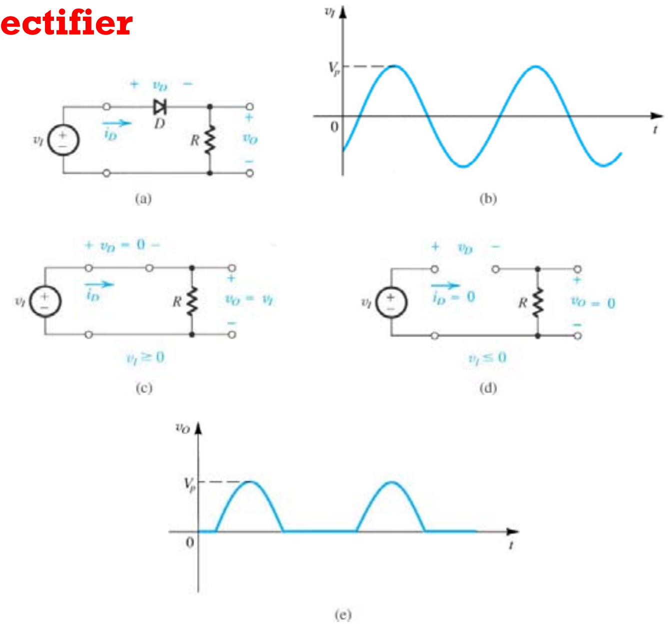


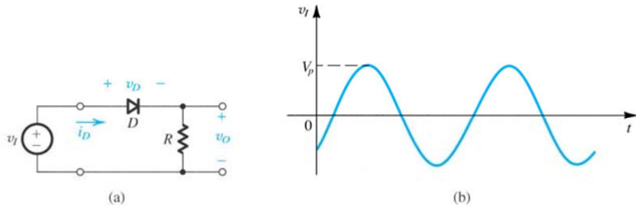
Figure 3.3 **(a)** Rectifier circuit. **(b)** Input waveform. **(c)** Equivalent circuit when $v_I \geq 0$. **(d)** Equivalent circuit when $v_I \leq 0$. **(e)** Output waveform.

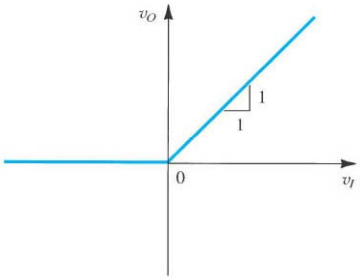
Dr. D. M. Akbar Hussain

Department of Electronic Systems

Exercise 3.1

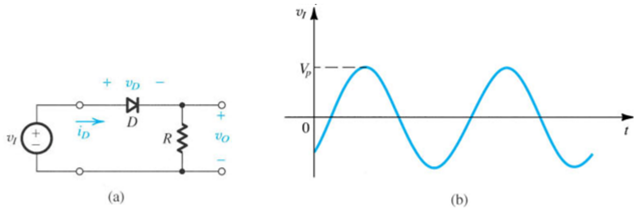
For the circuit (a) sketch the transfer characteristics V_o versus V_i.





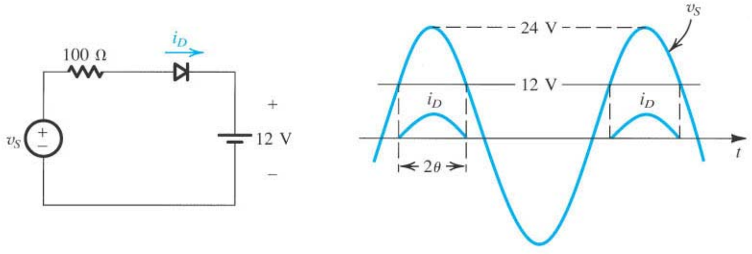
Exercise 3.2 & 3.3

For the circuit (a) sketch the waveform of V_D.



Example 3.1

For the circuit (a) find the fraction of the cycle during which diode conducts, peak value of the diode current and the maximum reverse bias voltage across diode.



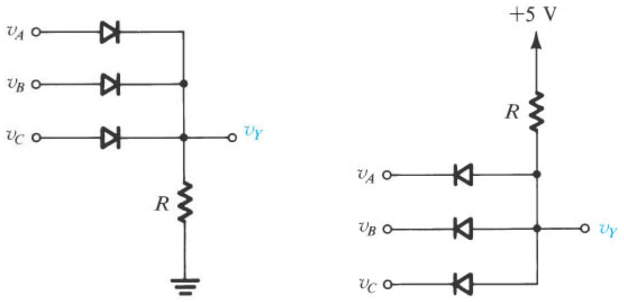
(a)

(b)

Dr. D. M. Akbar Hussain

Department of Electronic Systems

Diode Logic Gates



(a)

(b)

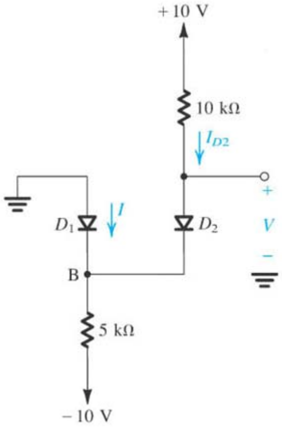
Dr. D. M. Akbar Hussain

Department of Electronic Systems

Example 3.2: Calculate V & I

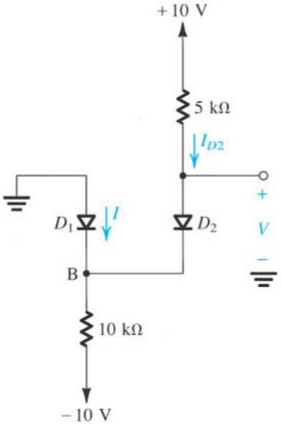
$I_{D2} = (10 - 0)/10 * 10^3$
$= 1\text{ mA}$

$I + 1 = (0 - (-10))/5 * 10^3$
$= 2$
$I = 2 - 1 = 1\text{ mA}$



(a)

Example 3.2: Calculate V & I



(b)

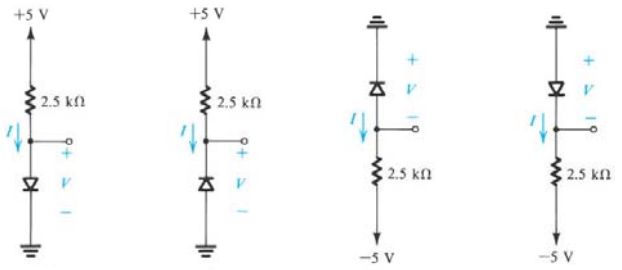
$I_{D2} = (10 - 0)/5 * 10^3$
$= 2\text{ mA}$

$I + 2 = (0 - (-10))/10 * 10^3$
$= 1$
$I = 1 - 2 = -1\text{ mA}$

$I_{D2} = (10 - (-10))/15 * 10^3$
$= 1.33\text{ mA}$

$V_B = -10 + (10 * 10^3 * 1.33 * 10^{-3})$
$V_B = 3.3\text{ V}$

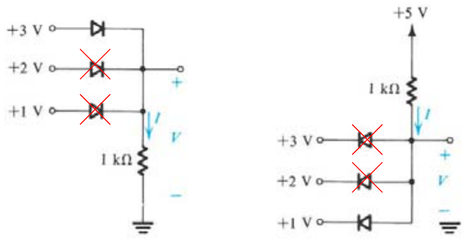
Exercise 3.4: Calculate V & I



(a) (b) (c) (d)

2.0 mA	0.0 mA	0.0 mA	2.0 mA
0 V	5 V	5 V	0 V

Exercise 3.4: Calculate V & I

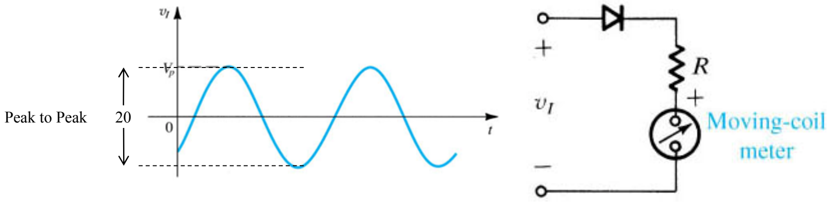


(e) (f)

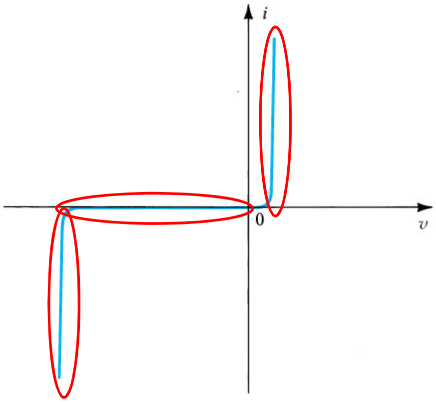
3.0 mA	4.0 mA
3 V	1 V

Exercise 3.5:

Calculate R, that result full scale reading when the input sine wave voltage is 20 V p-p. The meter gives full scale reading when the average current flowing through it is 1 mA, coil has 50 ohm resistance.
(Hint: The average value of half wave rectifier is Vp/π .)

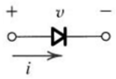


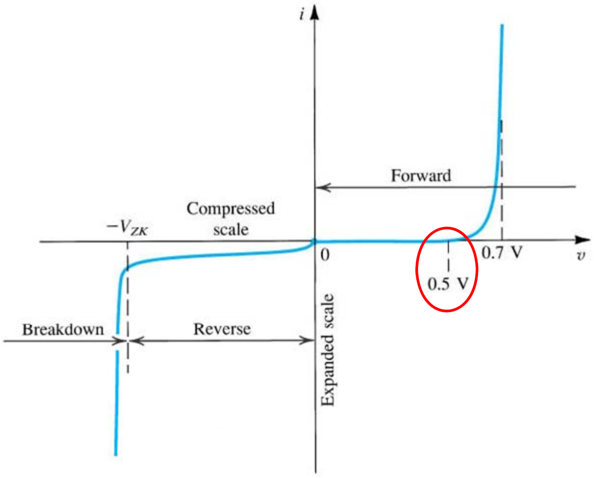
Terminal Behaviour/Characteristics



i-v Characteristics

Forward Bias Region





$$i = I_S(e^{v/nV_T} - 1)$$

$$V_T = \frac{kT}{q}$$

$$i \approx I_S e^{v/nV_T}$$

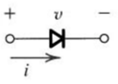
Exercises: 3.6, 3.7 & 3.8

3.6: Consider a silicon diode with n = 1.5, Find the change in voltage if the current changes from 0.1 mA to 10 mA.

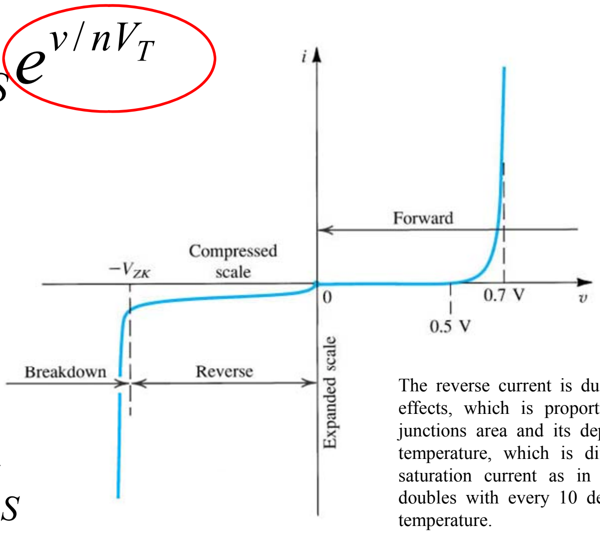
3.7: A silicon junction diode with n = 1 has v = 0.7 V at i=1 mA. Find the voltage drop at i=0.1 mA and i=10mA.

3.8: Using the fact that silicon diode as $I_S=10^{-14}$ A at 25° C and I_S increases by 15 % per °C rise in temperature, find the value of I_S at 125°C.

Reverse Bias Region



$$i \approx I_S e^{v/nV_T}$$

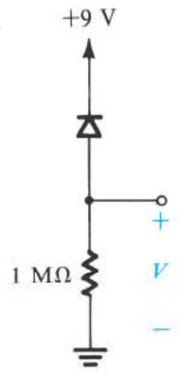


$$i \approx -I_S$$

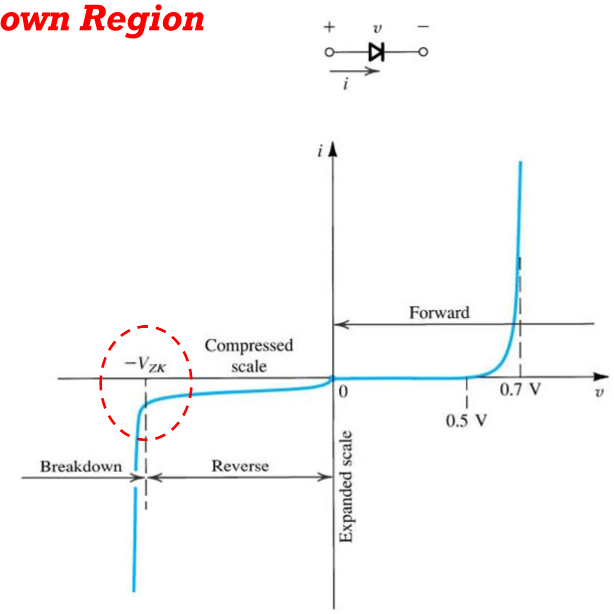
The reverse current is due to leakage effects, which is proportional to the junctions area and its dependence on temperature, which is different from saturation current as in this case it doubles with every 10 degree rise in temperature.

Exercise 3.9

If V = 1 v at 20°C, find the value of V at 40°C and at 0°C.

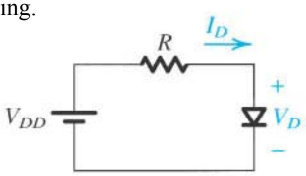


Breakdown Region



Modelling Forward Charcteristics

Following simple circuit used to illustrate the analysis of circuits in which the diode is forward conducting.



Exponential Model is the most accurate, but the trouble is it is severely ?

Assuming V_{DD} greater than cut in voltage 0.5, so

$$I_D = I_S e^{V_D / nV_T}$$

Applying Kirchhoff loop equation: $I_D = \frac{V_{DD} - V_D}{R}$

Both equations have 2 unknown quantities ?

So how to get to the solution ? **Graphical or Iterative**

Graphical Analysis Using Exponential Model

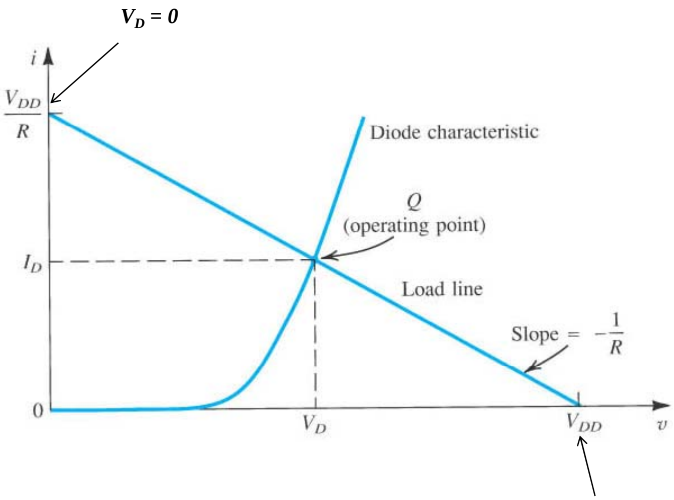
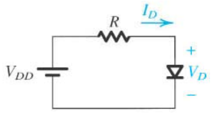


Figure 3.11 Graphical analysis of the circuit in Fig. 3.10 using the exponential diode model.

Iterative Analysis Using Exponential Model

Suppose V_{DD} = 5 V, R = 1 KΩ in the above circuit to determine I_D and V_D using iterative analysis. Assume diode current 1 mA at a voltage of 0.7, which changes by 0.1 V for every decade change in current.



$$\boxed{I_D = \frac{V_{DD} - V_D}{R}}$$

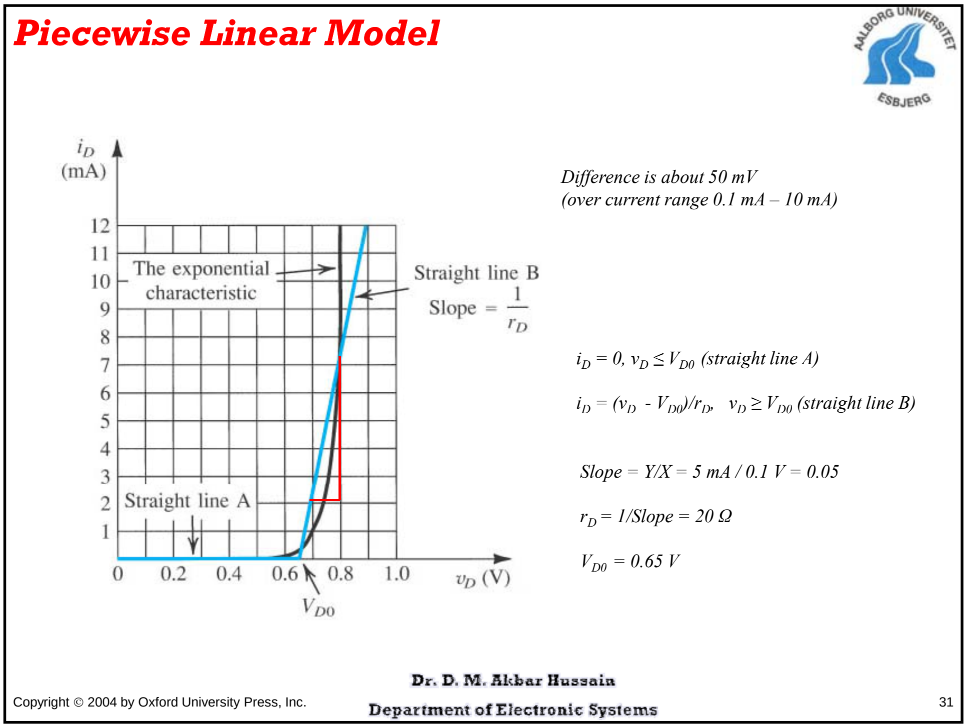
$$V_2 - V_1 = 2.3 * n * V_T \log\left(\frac{I_2}{I_1}\right)$$

$$\boxed{V_2 = V_1 + 0.1 \log\left(\frac{I_2}{I_1}\right)}$$

$$2.3 * n * V_T = 0.1$$

Rapid Analysis

- ☐ ***What is the advantage of Rapid Analysis ?***
- ☐ ***Why we do Rapid Analysis ?***



Piecewise Linear Model

Difference is about 50 mV
(over current range 0.1 mA – 10 mA)

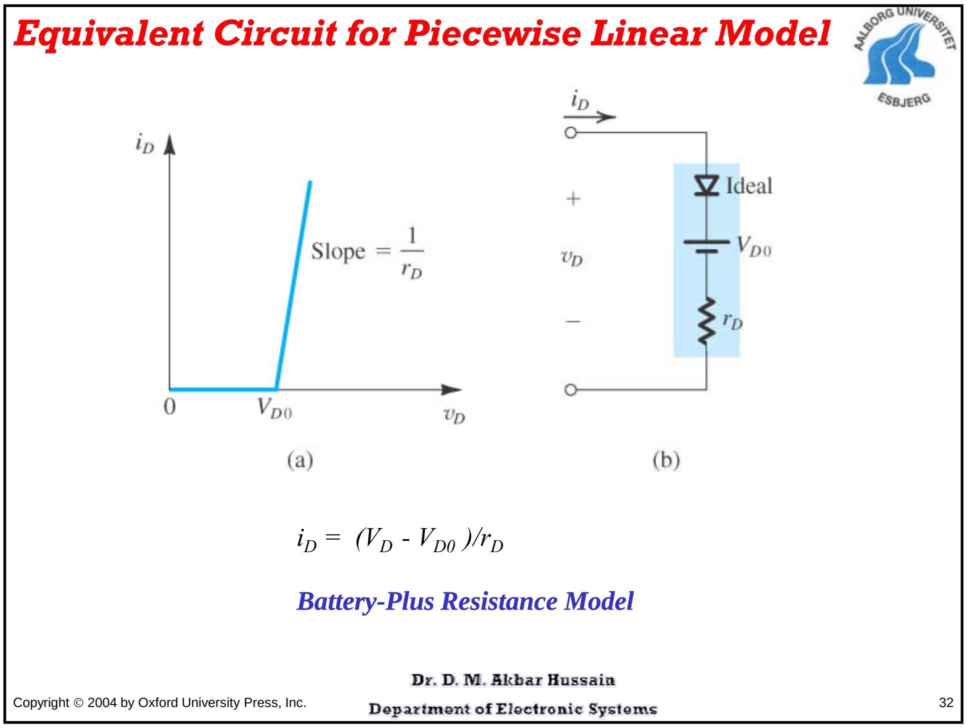
$i_D = 0,\ v_D \le V_{D0}$ *(straight line A)*

$i_D = (v_D - V_{D0})/r_D,\quad v_D \ge V_{D0}$ *(straight line B)*

Slope = Y/X = 5 mA / 0.1 V = 0.05

$r_D = 1/\text{Slope} = 20\ \Omega$

$V_{D0} = 0.65\ V$



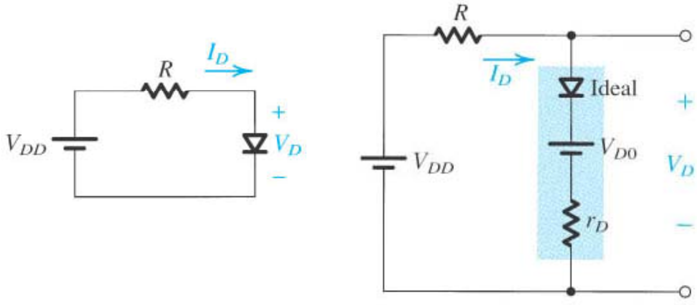
Equivalent Circuit for Piecewise Linear Model

$$i_D = (V_D - V_{D0})/r_D$$

Battery-Plus Resistance Model

Example 3.5

Suppose R = 1 KΩ, V_{DD} = 5 V, V_{D0} = 0.65, r_D = 20 Ω.



$$i_D = (V_{DD} - V_{D0})/R + r_D$$

$$V_D = V_{D0} + I_D\, r_D$$

Constant Voltage Drop Model

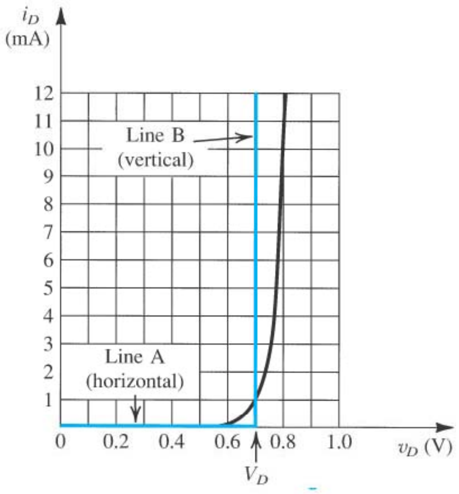
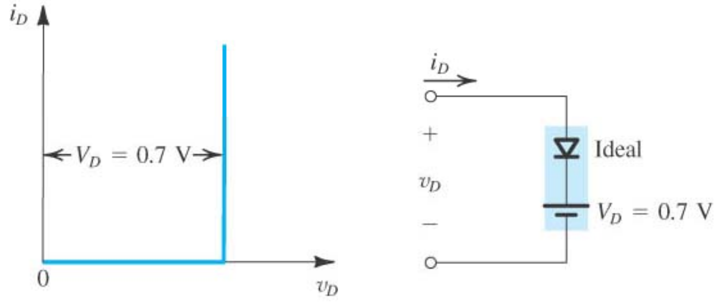
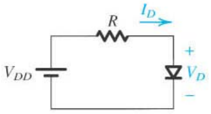


Figure 3.15 Development of the constant-voltage-drop model of the diode forward characteristics. A vertical straight line (B) is used to approximate the fast-rising exponential. Observe that this simple model predicts V_D to within ±0.1 V over the current range of 0.1 mA to 10 mA.

Equivalent Circuit



(a) (b)



$i_D = (V_{DD} - V_{D0})/R$

$= (5.0 – 0.7)/1 = 4.3$ *mA*

(which is not different what we had for piecewise linear model)

Dr. D. M. Akbar Hussain

Department of Electronic Systems

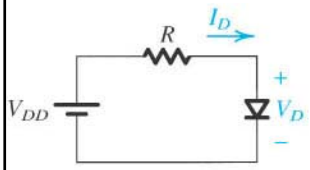
Exercises: 3.10

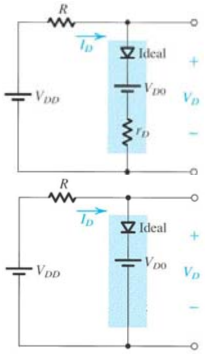
Suppose R = 10 KΩ, V_{DD} = 5 V, Assuming that the diode has a voltage drop of 0.7 V at a current 0.1 mA and the voltage changes by 0.1 V/decade of current change. Use the following to calculate I_D and V_D.

(a): Iteration

(b): Piecewise linear model $V_{D0} = 0.65$, $r_D = 20\ \Omega$.

(c): Constant voltage model with $V_D = 0.7$ V.





Dr. D. M. Akbar Hussain

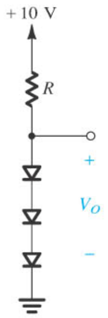
Department of Electronic Systems

Exercises: 3.11

Consider a diode that is 100 times as large (in junction area), if we approximate the characteristics as shown below over a range of current 100 times as large, how would the model parameters V_{D0} and r_D change.

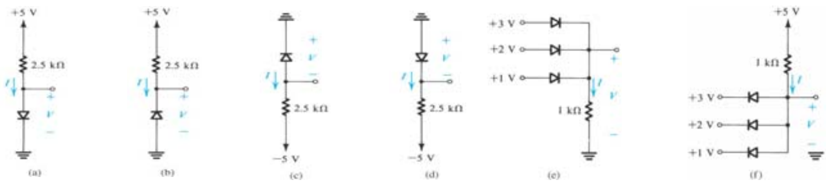
Exercises: 3.12

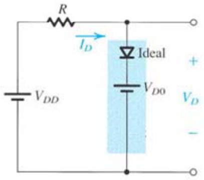
Design the following circuit to provide an output voltage of 2.4 V, assuming the voltage drop across diodes is 0.7 V at 1 mA and that $\Delta V = 0.1$ V/decade change in current.



Exercises: 3.13

Use the constant voltage drop model (0.7 V) on the following circuits to obtain better estimates of current *(I)* and voltage *(V)*.





Home work:

Problem: 3.1, 3.2, 3.3, 3.4, 3.5, 3.7, 3.8