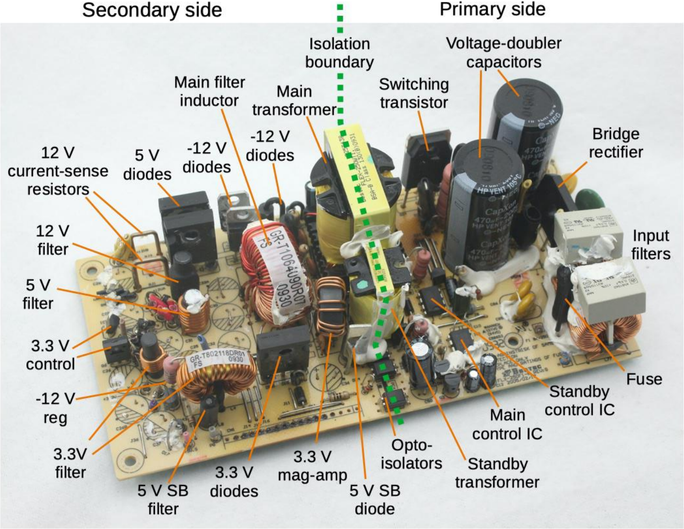
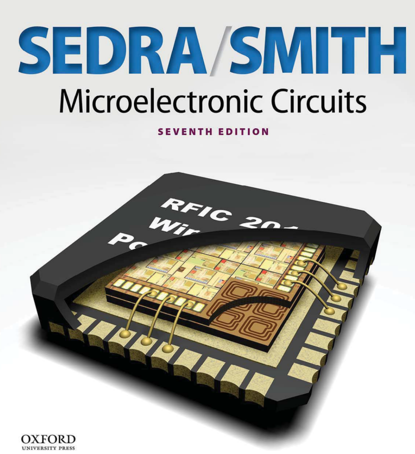


Diode models

Kizito NKURIKIYEYEZU, Ph.D.

Readings

- Section 4.3 on pages 193-195



[1] Readings are based on Sedra & Smith (2014), Microelectronic Circuits 7th edition.
[2] Bold reading section are mandatory. Other sections are suggested but not required readings

Background

How would you find I_D and V_D for the circuit in Fig. 2

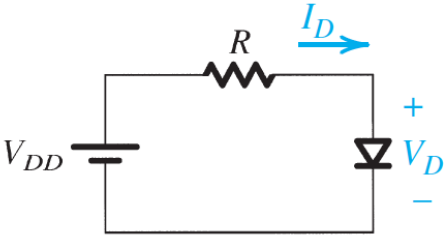
- The current through the diode is the same as the current through the resistor

$$I = \frac{V_{DD} - V_D}{R} \quad (1)$$

- Similarly, from our previous lecture

$$I = I_s\left(e^{v/V_T} - 1\right) \quad (2)$$

- Combining Equation (1) and Equation (2) allows to solve for the unknowns
- This approach is complex and not practical for real-world circuits



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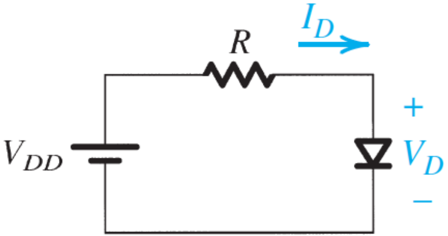

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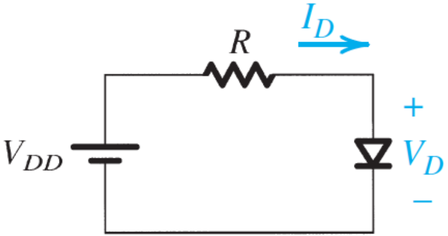

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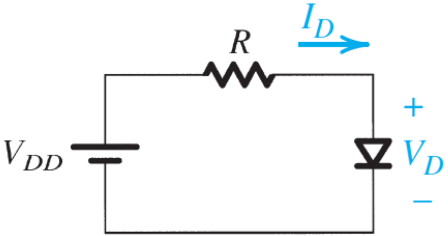

FIG 1. Illustrative diode circuit

Background

- model —a mathematical description or electrical equivalent circuit that represents the behavior of a device or system
- In this lecture, we shall learn simplified diode models that are suited for circuit analysis:
  - Exponential model
  - Constant voltage-drop model
  - ideal diode model
  - small-signal model

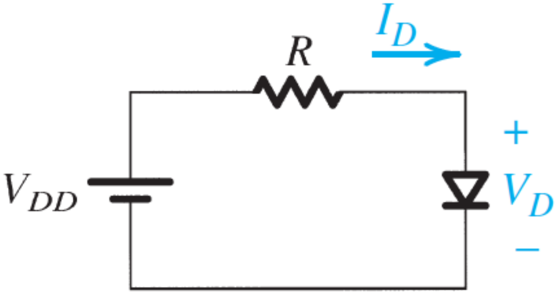

FIG 2. Illustrative diode circuit

The exponential diode model

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- Most accurate model
- However, also most difficult to use:
  - For $V_{DD} > 0.5V$, Equation (3) holds true

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  - Since $I_D = I_R$, then

$$I_s \cdot e^{V_D/V_T} = \frac{V_{DD} - V_D}{R} \qquad (4)$$

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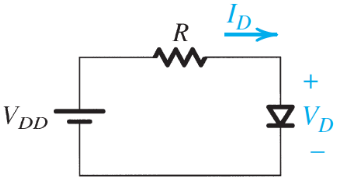

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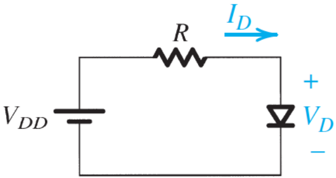

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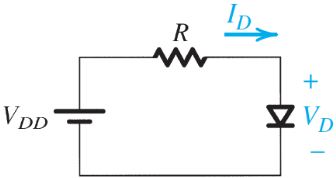

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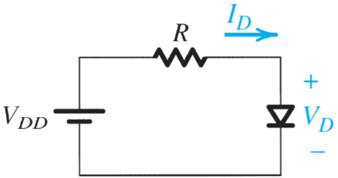

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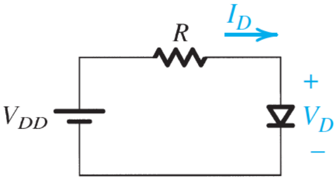

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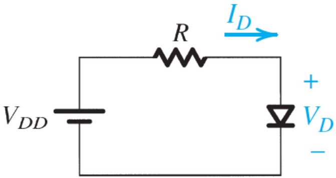


Graphical analysis

- Plot the relationships of Equation (3) and Equation (4) on an *i*-*v* plane.
- The solution is the Q-point—which is the coordinates of the point of intersection of the two graphs
- The Q point is also known as the operating point, the bias point, or quiescent point[1]
- The Q-point is the steady-state voltage or current at a specified terminal of an active diode with no input signal applied [2]

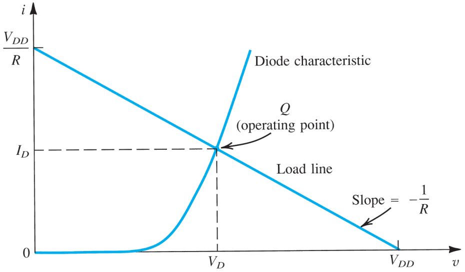


FIG 3. Illustration of the graphical analysis method using the exponential diode model

[1] The graphical analysis is only used for visualization of simple circuit but it is tedious for complex circuit; thus, is seldomly used in practice

[2] For details, please refer to the The Importance of the Q Point of a Diode to Circuit Functionality

[3] https://en.wikipedia.org/wiki/Biasing

Iterative analysis[1]

EXAMPLE—Find I_D and V_D for the circuit in Section 1 when $V_{DD} = 5V$ and $R = 1k$. Assume that the diode has a current of $I_D = 1mA$ at a voltage of $V_D = 0.7V$.

- I_D is found by KVL

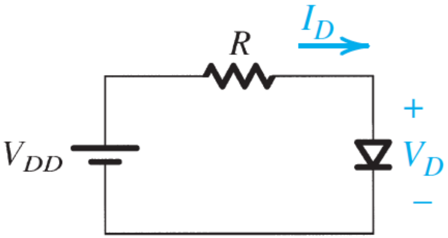
$$I_D = \frac{V_{DD} - V_D}{R} = \frac{5V - 0.5V}{1k} = 4.3mA \quad (5)$$

- V_D is deducted from

$$V_2 - V_1 = 2.3V_T \cdot log(I_2/I_1) \quad (6)$$

Since $2.3V_T = 60mV$, then

$$V_2 = V_1 + 0.06 \cdot log(I_2/I_1) \quad (7)$$



[1] See detailed algebraic solution at https://en.wikipedia.org/wiki/Diode_modelling#Iterative_solution

Iterative analysis[1]

- The first iteration assumes $V_1 = 0.7V$, $I_1 = 1mA$ and $I_2 = 4.3mA$ that we calculated earlier. Thus, $V_D = 0.738V$
- The second iteration goes through the same process

$$I_D = \frac{V_{DD} - V_D}{R} = \frac{5V - 0.738V}{1k} = 4.262mA \tag{8}$$

$$\begin{aligned} V_2 &= V_1 + 0.06 \cdot log\left({}^{I_2}/{}_{I_1}\right) \\ &= 0.738V + 0.06 \cdot log\left({}^{4.262}/{}_{4.3}\right) \\ &= 0.738V \end{aligned} \tag{9}$$

- The iteration can continue but the second iteration yielded values close to the first iteration, there is no reason to continue any further.
- Thus, $I_D \approx 4.262mA$ and $V_D \approx 0.738V$

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Iterative analysis—Practicality

- This method is simple and very accurate
- However, it is very slow and not practical. Circuit design requires evaluating various possibility before making a suitable design
- In practice, analog circuit design is something of an art. Although it is possible to predict the behavior of a very simple circuit mathematically, there are so many factors to consider in a more complicated circuit that the calculations become impossibly convoluted
- It is best to use less accurate methods and verify the design with computer analysis tools such as SPICE

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- The simplest and most widely used diode model in the initial phases of analysis and design
- Since the forward-conducting diode has a voltage drop that varies in a relatively narrow range (usually between 0.6 to 0.8 V), assumes that that the slope of the i-v curve is vertical at $V_D = 0.7V$

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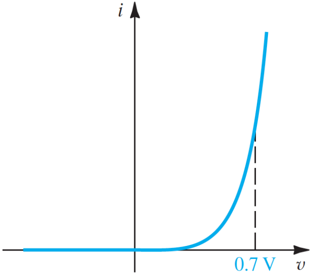

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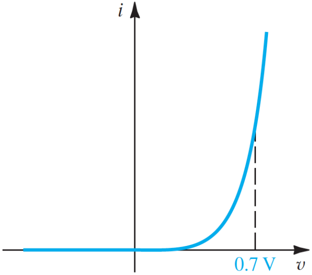

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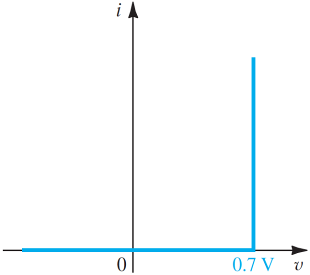

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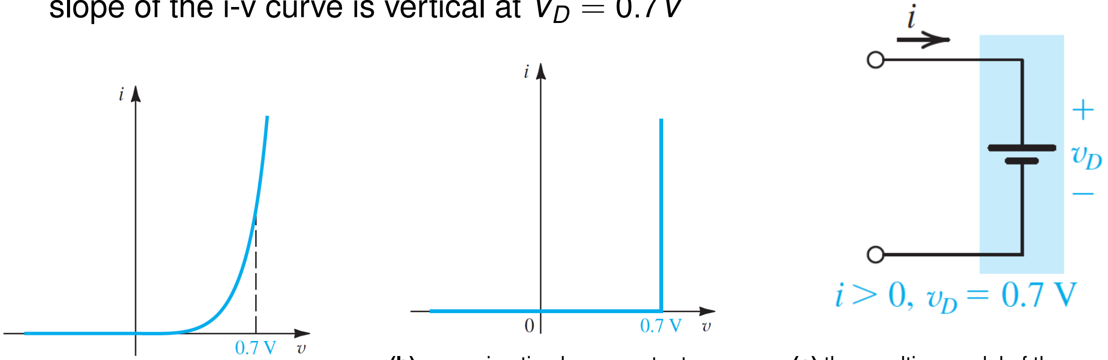

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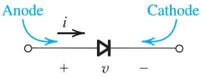
(c) the resulting model of the forward-conducting diodes

FIG 4. Development of the diode constant-voltage-drop model:

The Ideal-Diode Model

- Useful for applications that involve voltages much greater than the diode voltage drop
- In this case, we may neglect the diode voltage drop altogether while calculating the diode current.
- In summary, the ideal diode model assumes that the slope of i-v curve is vertical at $V_D = 0\,V$



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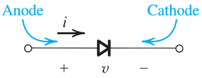

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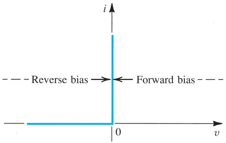

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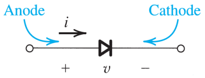

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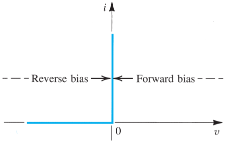

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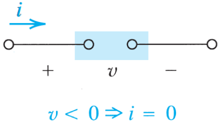

(c) equivalent circuit in the reverse direction

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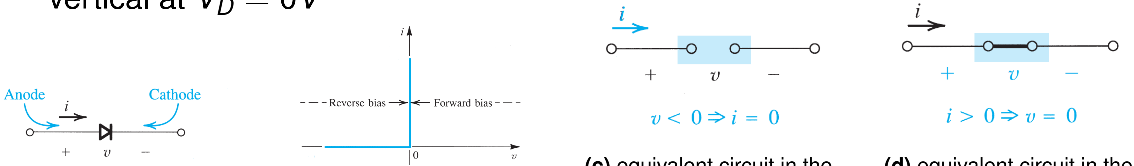

(a) diode circuit symbol

(b) i–v characteristic

(c) equivalent circuit in the reverse direction

(d) equivalent circuit in the forward direction

FIG 5. The ideal diode model

Summary —When to use these models

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  - Coming soon!