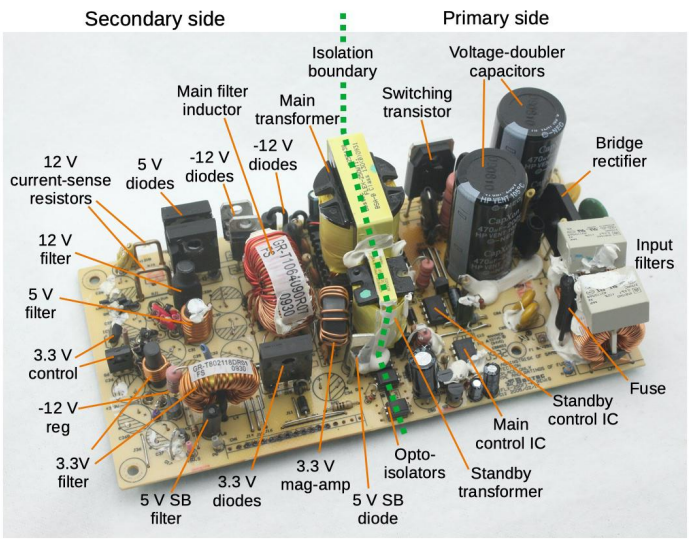
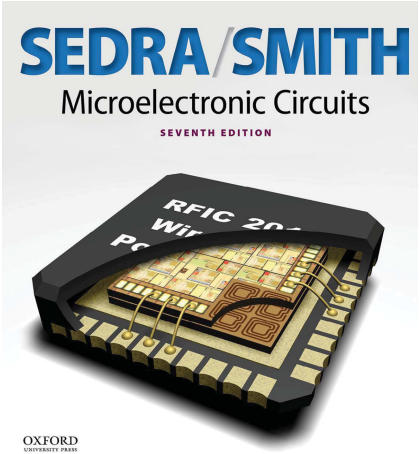


The Ideal Diode

Kizito NKURIKIYEYEZU, Ph.D.

Readings

- **Read section 4.1 on pages 175- 184**
- **Do and understand example 4.2 on page 181**
- Do exercises 4.1, 4.2 and 4.3 on page 179
- Do exercises 4.4 and 4.5 and 4.3 on page 183



[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

- There exist some signal processing functions that can be only implemented by nonlinear circuit
  - generation of dc voltages from the ac power supply
  - signal generations (e.g., square waves, ninusoids waves)
  - digital logic
  - memory circuits
- A diode is a fundamental nonlinear circuit element.

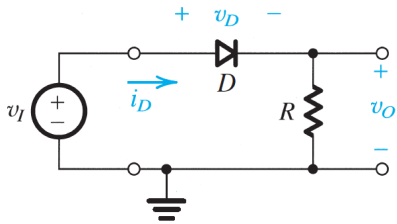


FIG 1. A diode rectifier

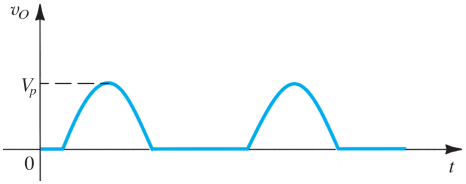


FIG 2. output of the rectifier

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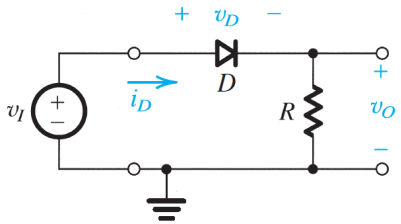

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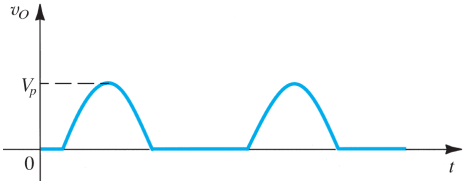

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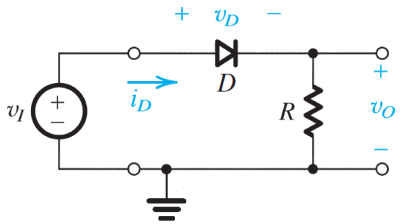

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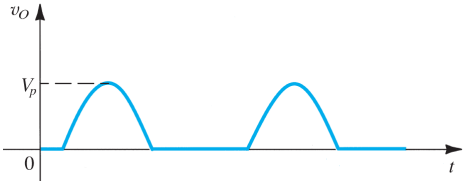

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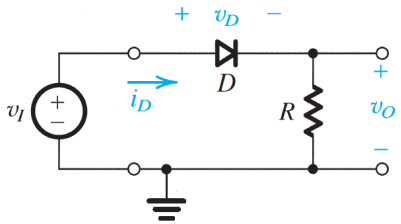

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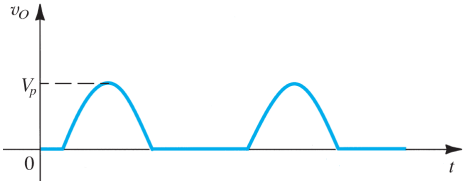

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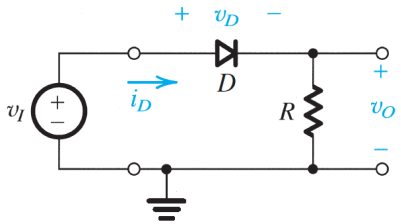

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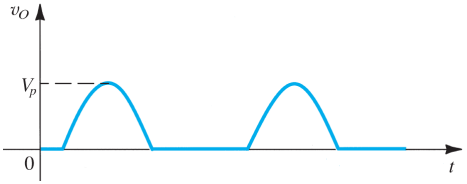

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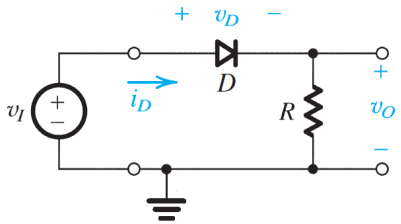

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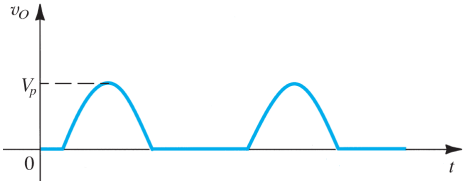

FIG 2. output of the rectifier

What is a diode

- Diodes are essentially one-way current gates
- Diodes are made of semiconductors —usually silicon—that consist of stack of p-doped and n-doped silicon to form a p-n junction
- A diode has two terminals and typically allows the flow of current in one direction only.

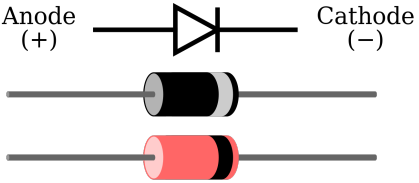

FIG 3. Typical diode packages in same alignment as diode symbol. Thin bar depicts the cathode[1]

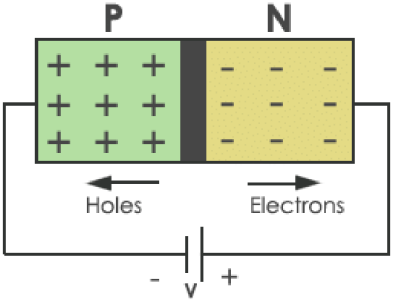

FIG 4. n-types and p-type arrangement in a diode

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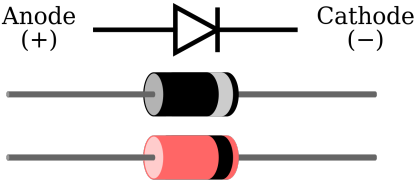

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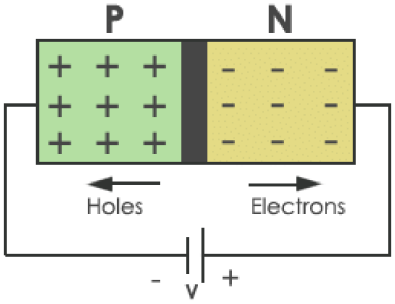

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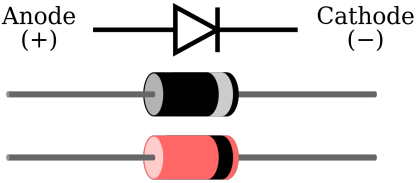

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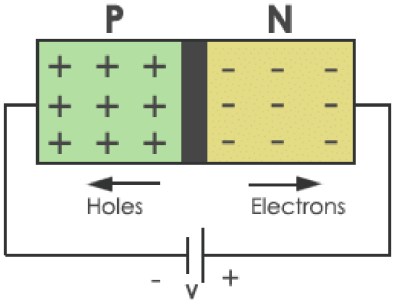

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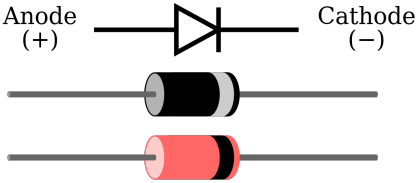

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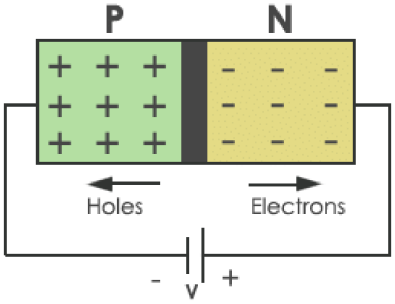

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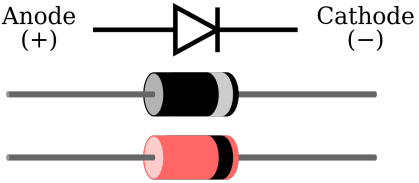

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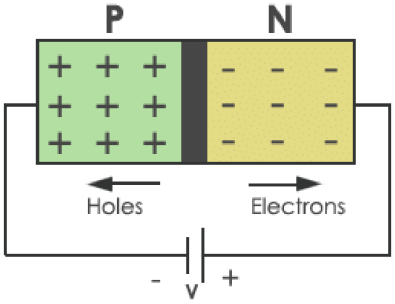

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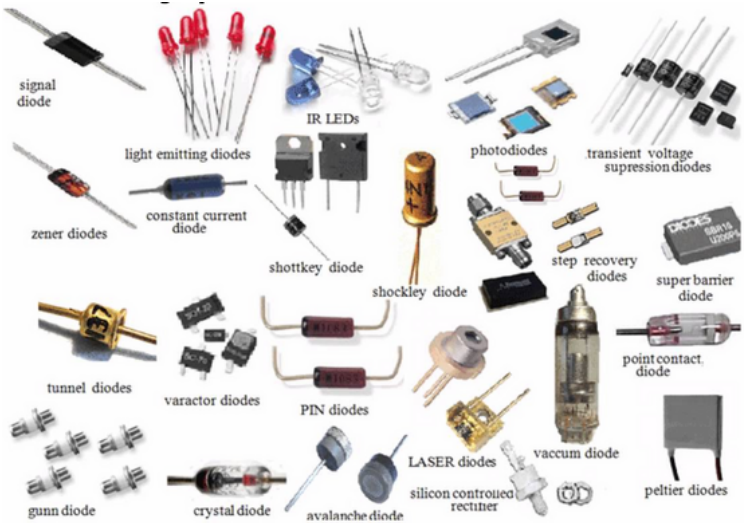

FIG 7. Various types of diodes[1]

[1] Gupta, K. M., & Gupta, N. (2015). Different Types of Diodes, Ideal and Real Diodes, Switching Diodes, Abrupt and Graded Junctions. Engineering Materials, 235–259

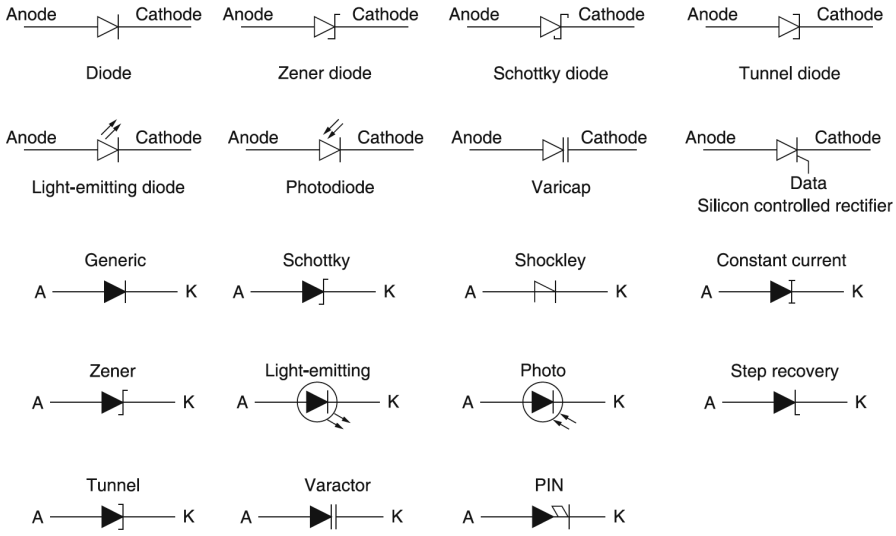

FIG 8. Various types of diodes and their schematic symbols[2]

[2]Gupta, K. M., & Gupta, N. (2015). Different Types of Diodes, Ideal and Real Diodes, Switching Diodes, Abrupt and Graded Junctions. Engineering Materials, 235–259

Characteristics of Ideal Diode

- An ideal diode would be a perfect diode without any flaws (Fig. 9)
- Characteristics of ideal diode when forward biased
  - Zero resistance
  - Infinite amount of current
  - Zero threshold voltage, V_T
- Characteristics of an ideal diode when reverse biased
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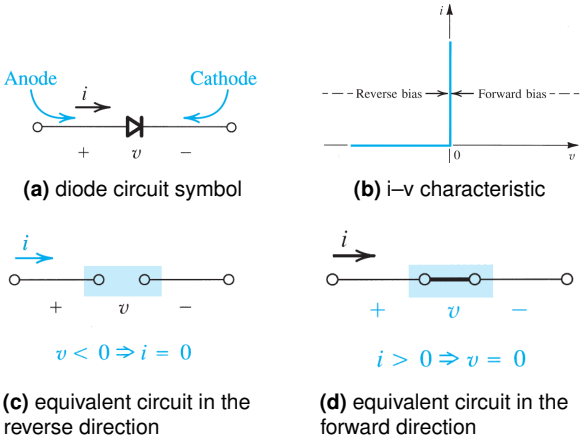
- **NOTE**: As Murphy's law would predict, no ideal diode exists.



(a) diode circuit symbol

(b) i–v characteristic

(c) equivalent circuit in the reverse direction

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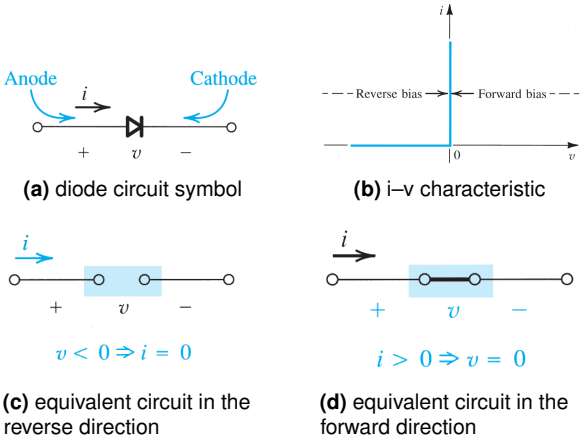

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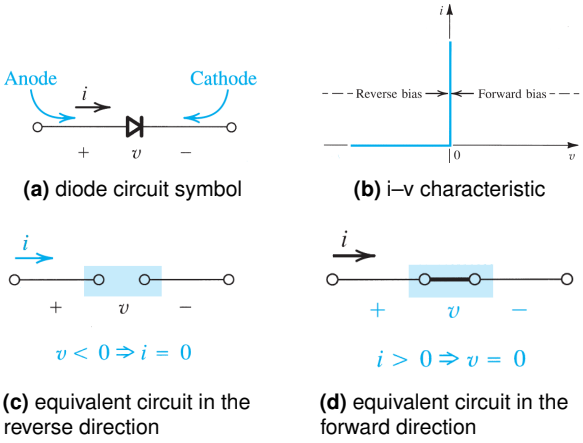

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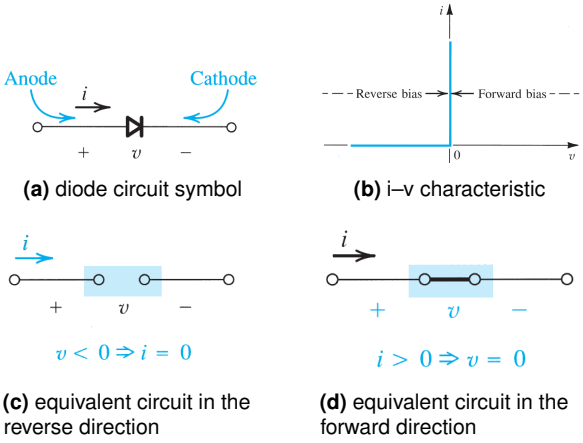

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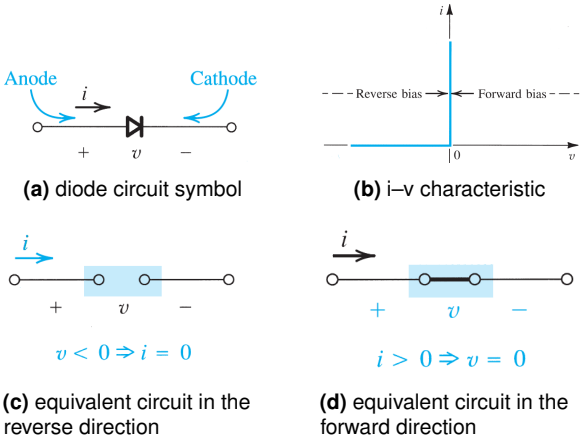

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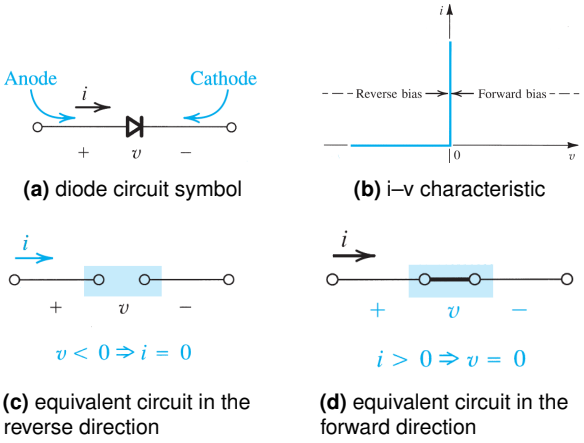

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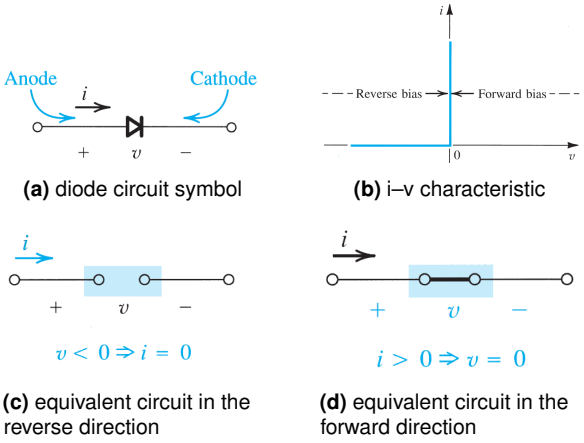

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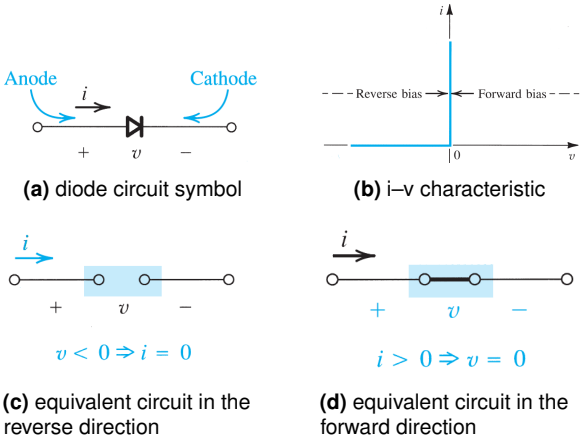

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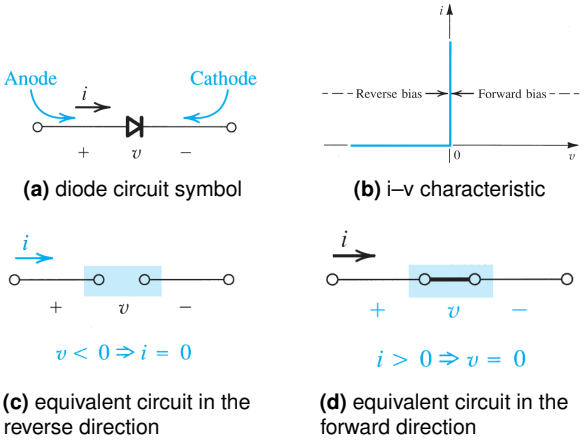

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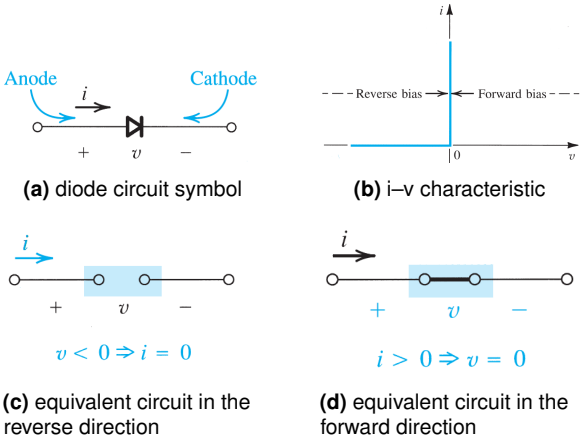

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Real diode

Real diodes do not follow the ideal diode equation because of physical limitations of device fabrication or design techniques. In a real diode:

- R_F is of the order of a few ohms.
- $V_F \approx 0.7$ for silicon and $V_F \approx 0.3$ for germanium based diodes.
- Reverse bias resistance R_r is of the order of a few kilo ohms.

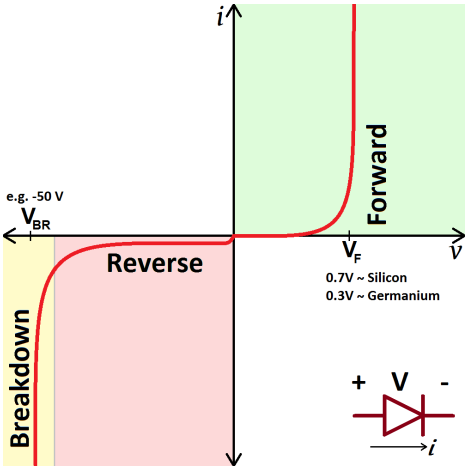

FIG 10. The I-V relationship of a real diode[2]

[2] https://learn.sparkfun.com/tutorials/diodes/real-diode-characteristics

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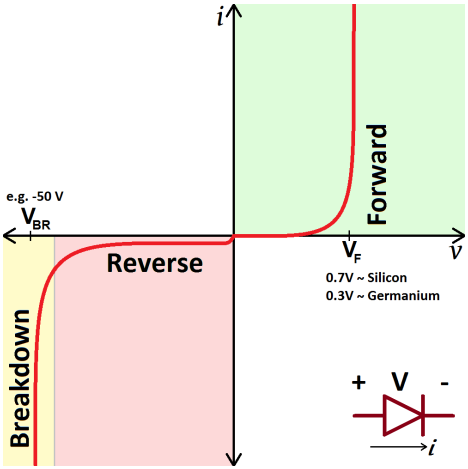


FIG 10. The I-V relationship of a real diode[2]

[2] https://learn.sparkfun.com/tutorials/diodes/real-diode-characteristics

Real diode

Real diodes do not follow the ideal diode equation because of physical limitations of device fabrication or design techniques. In a real diode:

- R_F is of the order of a few ohms.
- $V_F \approx 0.7$ for silicon and $V_F \approx 0.3$ for germanium based diodes.
- Reverse bias resistance R_r is of the order of a few kilo ohms.

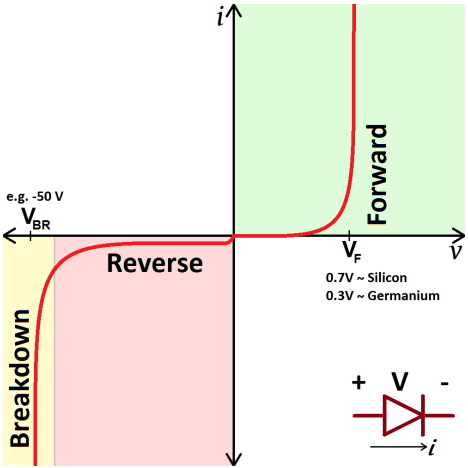


FIG 10. The I-V relationship of a real diode[2]

[2] https://learn.sparkfun.com/tutorials/diodes/real-diode-characteristics

TAB 1. Ideal diode versus real diode

Ideal diode	**Real diode**
No reverse leakage current	There exists some leakage current
Can behave as a perfect conductor (R=0)	No such perfection exists in the real-world
Can behave as a perfect insulator ($R = \infty$)	No such perfection exists in the real-world
Draws no current when reverse biased	Normally draws very low current in reverse bias
Have infinite resistance	Have high resistance, but not infite
No voltage drops when forward biased.	very low voltage drop when forward biased.
Acts like a short circuit in the forward-bias mode	$V_T \neq 0$ when current flows through it
Acts like an open circuit in a reverse-bias mode	Reverse-bias resistance is of a few kilo-ohms
It cannot be manufactured.	it is manufactored, duh!

EXAMPLE—1N4148 diode characteristics

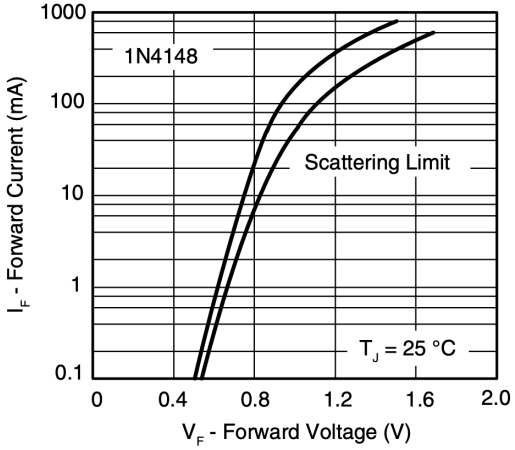
ELECTRICAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)						
PARAMETER	**TEST CONDITION**	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Forward voltage	I_F = 10 mA	V_F			1	V
Reverse current	V_R = 20 V	I_R			25	nA
	V_R = 20 V, T_j = 150 °C	I_R			50	µA
	V_R = 75 V	I_R			5	µA
Breakdown voltage	I_R = 100 µA, t_p/T = 0.01, t_p = 0.3 ms	$V_{(BR)}$	100			V
Diode capacitance	V_R = 0 V, f = 1 MHz, V_{HF} = 50 mV	C_D			4	pF
Rectification efficiency	V_{HF} = 2 V, f = 100 MHz	η_r	45			%
Reverse recovery time	I_F = I_R = 10 mA, i_R = 1 mA	t_{rr}			8	ns
	I_F = 10 mA, V_R = 6 V, i_R = 0.1 x I_R, R_L = 100 Ω	t_{rr}			4	ns

FIG 11. Electrical characteristics of a 1N4148 diode

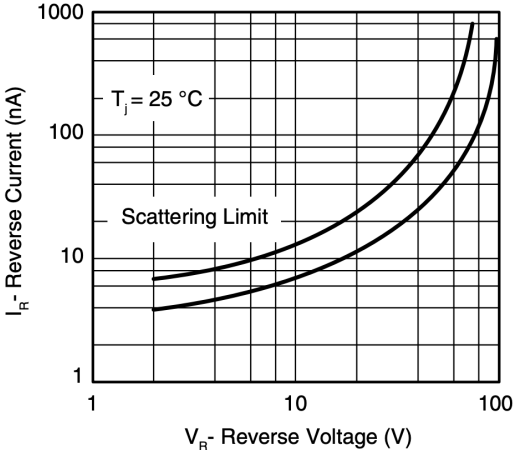
The 1N4148 diode is a standard silicon switching signal diode. The 1N4148 was first developed 1960 by Texas Instruments and is useful in switching applications up to about 100 MHz with a reverse-recovery time of no more than 4*ns*

[2]The 1N4148's datashet is available at https://www.vishay.com/docs/81857/1n4148.pdf

EXAMPLE—1N4148 diode characteristics



(a) Forward current vs. Forward voltage



(b) Reverse Current vs. Reverse Voltage

FIG 12. Typical behaviors of 1N4148 diode at $T = 25\,^{\circ}\mathrm{C}$

Application—the rectifier circuit

- Rectifier—A circuit which converts AC waves in to DC.
- The diode blocks reverse current flow, preventing negative voltage across the resistor *R*.

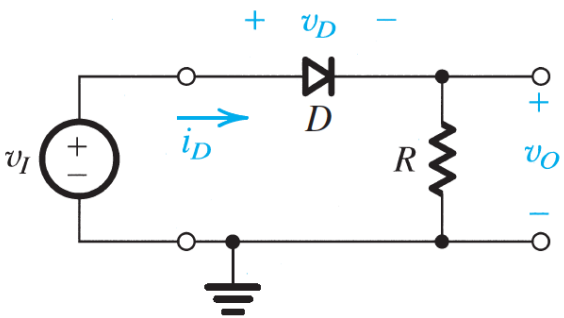
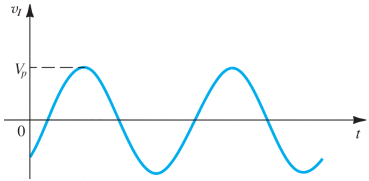


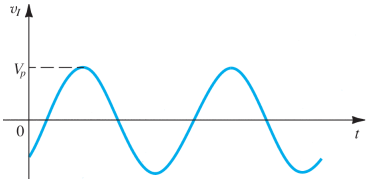
FIG 13. A rectifier circuit

Application—the rectifier circuit

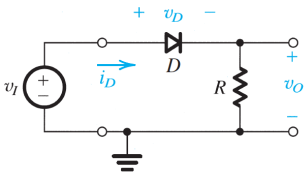


(a) input waveform

Application—the rectifier circuit

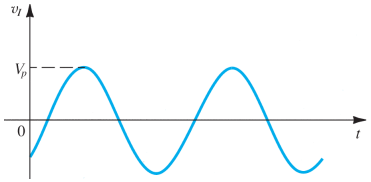


(a) input waveform

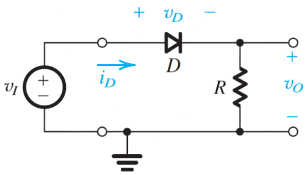


(b) The rectifier circuit.

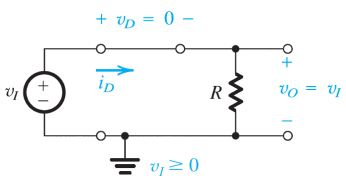
Application—the rectifier circuit



(a) input waveform

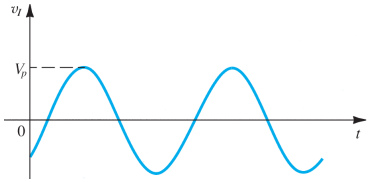


(b) The rectifier circuit.

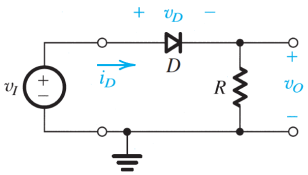


(c) Equivalent circuit when $v_I \geq 0$

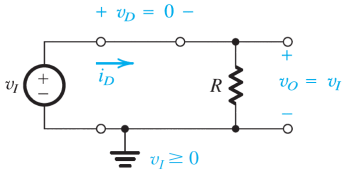
Application—the rectifier circuit



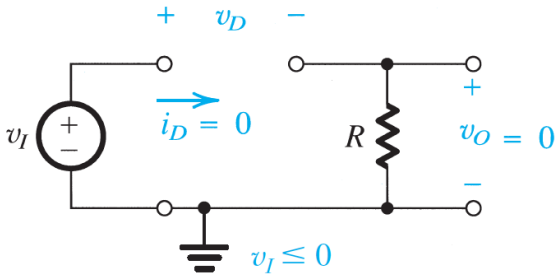
(a) input waveform



(b) The rectifier circuit.

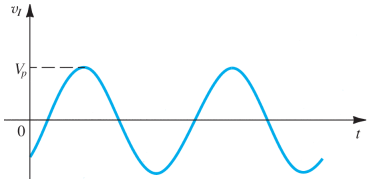


(c) Equivalent circuit when $v_I \geq 0$

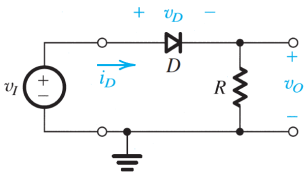


(d) Equivalent circuit when $v_I \leq 0$

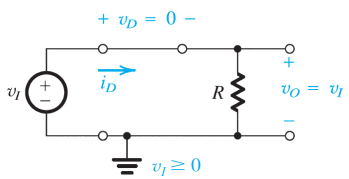
Application—the rectifier circuit



(a) input waveform



(b) The rectifier circuit.



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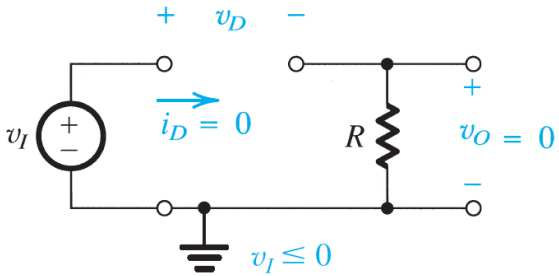

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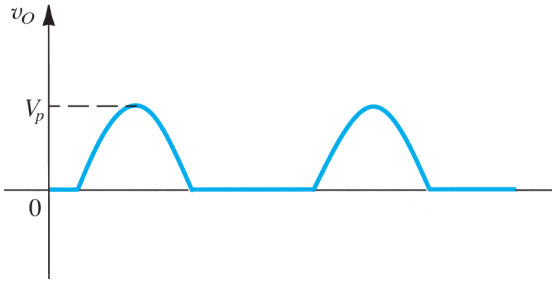
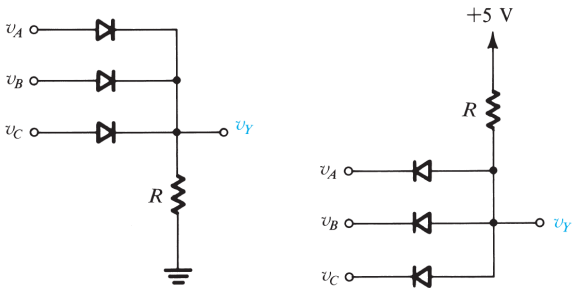


(e) output waveform

FIG 14. A half wave rectifier allows one half-cycle of an AC voltage waveform to pass, blocking the

Application—diode logic gates

- OR logic gate (Fig. 15a)
  - If $v_A = 5V$, then the diode D_A will conduct and $v_Y = v_A = 5V$
  - Similary, if any diode conducts, then $v_Y = 5V$
  - The output $v_Y = v_A + v_B + v_C$
- AND gate (Fig. 15b)
  - If $v_A = 0V$ then diode D_A will conduct and $v_Y = v_A = 0V$
  - If all diodes block then $v_Y = 5V$
  - The output $v_Y = v_A \cdot v_B \cdot v_C$



(a) OR logic gate **(b)** AND logic gate

FIG 15. Diode logic gates

[2]This analysis, of course, assumes we are using ideal diodes

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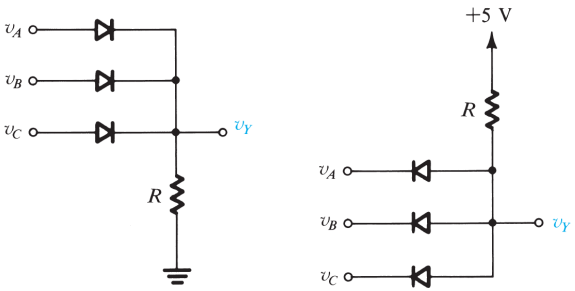

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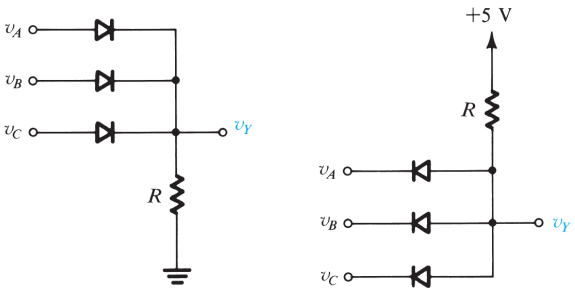

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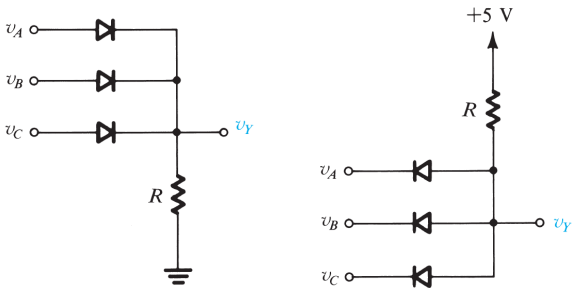

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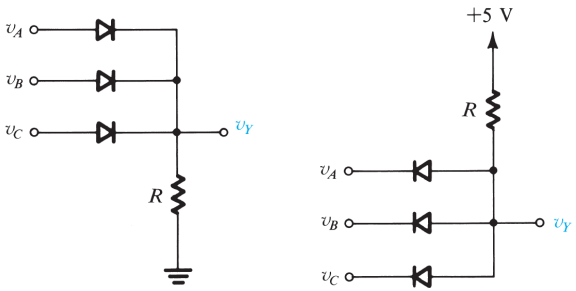

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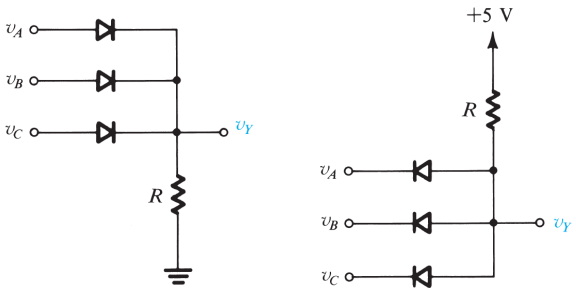

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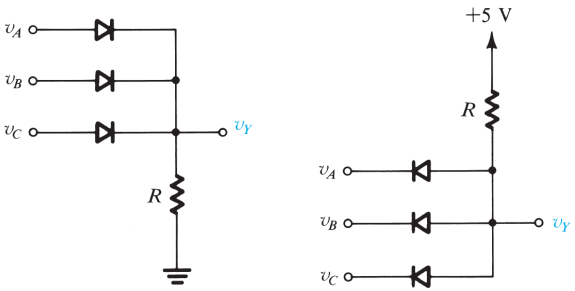

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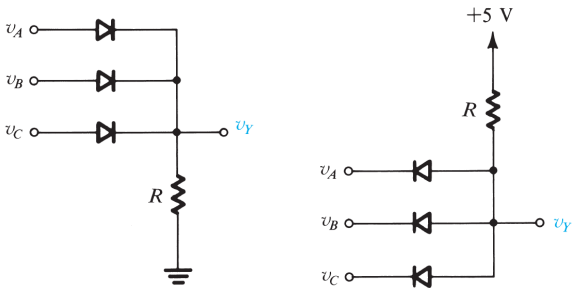

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The end