

- Rectifier circuits are useful in battery-charging circuits and for converting ac into nearly constant dc to power electronic circuits such as amplifiers. Transformers are used to adjust the ac voltage to the value needed. Half-wave and several full-wave circuits can be used.
- The reverse-breakdown voltage of the diodes used in a rectifier must exceed the expected PIV of the circuit.
- Waveshaping circuits transform one waveform into another. Examples are clipping and clamp circuits.
- AND and OR logic gates can be constructed from diodes, resistors, and voltage sources. However, diode logic gates have two drawbacks: First, they produce output levels that are not as well separated as the input voltage levels; second, a practical diode logic inverter does not exist.
- Operating from variable supplies, voltage regulators supply nearly constant voltages to loads. Percentage source regulation and load regulation are important specifications for a voltage regulator.
- The analysis of nonlinear electronic circuits is often accomplished in two steps: First, the dc operating point is determined, and a linear small-signal equivalent circuit is found for the nonlinear devices; second, the equivalent circuit is analyzed.
- At low frequencies, The small-signal equivalent circuit of a diode is its dynamic resistance, which is equal to the inverse slope of the diode characteristic, evaluated at the operating point.
- The Shockley equation relates the voltage and current in a pn junction. Secondary effects result in higher reverse current than that predicted by the equation. For large forward current, the equation becomes inaccurate due to ohmic drop across the series resistance.
- Silicon forms a crystal in which each atom develops covalent bonds with its four nearest neighbors. At normal temperatures, a small fraction of the bonds are broken, producing holes and free electrons that can carry current. The hole and free-electron concentrations are equal in pure silicon. As temperature increases, the carrier concentrations and the conductivity increase.
- Adding donor (valence-five) impurities to silicon produces an n -type material, in which conduction is due mainly to free electrons. Holes (minority carriers) are produced by thermal generation and eventually recombine with electrons.
- Adding acceptor (valence-four) impurities to silicon produces p -type material, in which conduction is due mainly to holes.
- According to the mass-action law, the product of the free-electron concentration and the hole concentration is a constant that is independent of the doping. Thus, as the concentration of one type of carrier increases, the concentration of the other type decreases.
- Silicon can be cycled from n -type to p -type and back several times by alternately adding donor and acceptor impurities. This is necessary in the fabrication of inte-

grated circuits. For material with both types of impurities, we can write

$$p + N_D = n + N_A$$

- Carriers move through a semiconductor by diffusion when a concentration gradient exists. Carriers move from regions of high concentration, to regions of low concentration.
- When an electric field is applied, the carriers move by drift.
- Electrons diffuse and drift more rapidly in silicon than holes do. Hence, for rapid response, devices in which current is carried by free electrons are preferred.
- In a pn junction, a depletion region appears at the junction, with a layer of net positive charge just inside the n -side and a layer of negative charge on the p -side. These charge layers set up an electric field barrier that tends to hold the majority carriers on their respective sides of the junction. Equal and opposite currents cross the junction. One component is due to minority, the other to majority, carriers.
- Under reverse bias, the junction barrier becomes larger, stopping the majority carrier current. The reverse current is due to minority carriers and second-order effects.
- Under forward bias, the junction barrier becomes smaller, and the majority carrier current increases dramatically.
- The current in a pn junction is given by the Shockley equation,

$$i_D = I_s \left[\exp \left(\frac{v_D}{nV_T} \right) - 1 \right]$$

- Depletion capacitance is associated with charge storage in the depletion region. Diffusion capacitance results from minority carriers stored on opposite sides of the junction under forward bias. Both capacitances are nonlinear. The high-frequency equivalent circuit for the pn junction is illustrated in Figure 3.50.
- Charge-storage effects slow diode switching. If a junction has been forward biased, it conducts well in the reverse direction until the minority carrier concentration is depleted on the two sides of the junction.
- Computer-aided analysis is a powerful tool for circuit design.

PROBLEMS

Section 3.1: Diode Characteristics

- 3.1.** Draw the circuit symbol for a diode. Label the anode and cathode.
- 3.2.** Draw the volt–ampere characteristic of a typical small-signal diode to scale, and label the various regions.
- 3.3.** What is a Zener diode? For what is it typically used? What are two other names for it? Sketch the volt–ampere

characteristic to scale for a 5.6-V Zener diode (i.e., a Zener diode having a reverse-breakdown voltage of 5.6 V).

3.4. Recall that the forward voltages of small-signal silicon diodes decrease about 2 mV/K. Such a diode has a voltage of 0.600 V, with a current of 1 mA at a temperature of 25°C. Find the diode voltage at 1 mA and a temperature of 175°C.

3.5. Sketch i against v to scale for the circuits shown in Figure P3.5. The diodes are typical small-signal silicon devices at 300 K. The reverse-breakdown voltages of the Zener diodes are shown. Assume 0.6 V for all diodes (including Zeners) in

the forward-bias region.

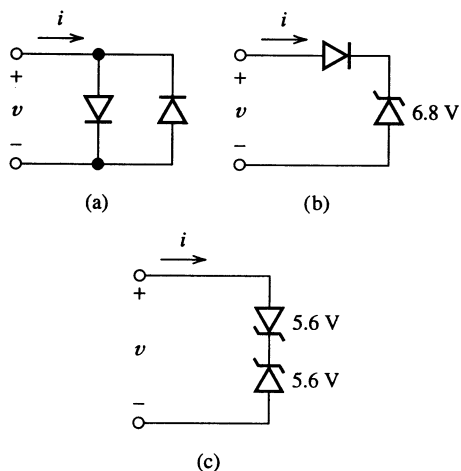


Figure P3.5

3.6. Consider the circuit shown in Figure P3.6. Assume that the reverse diode current is independent of the reverse voltage. If $v_o = 0.5$ V at a temperature of 70°C , estimate its values at 50°C and at 100°C . (Hint: A rule of thumb is that the reverse current doubles for each 10-K increase in temperature.)

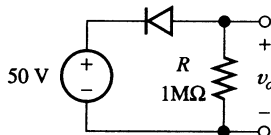


Figure P3.6

3.7. A certain diode is at a temperature of 25°C . Suddenly, a forward current of 100 mA is applied, and the voltage becomes 0.65 V. After several minutes, the diode warms due to its power dissipation, and the voltage is 0.45 V. Estimate the diode temperature.

3.8. Sometimes we may want to obtain a reference voltage by combining ordinary diodes in series, rather than using a Zener diode. How many diodes must be placed in series to obtain a 3-V reference voltage? Assume that each diode has a forward drop of 0.6 V. By what percentage does this voltage change when the temperature increases by 10°C ?

Section 3.2: Load-Line Analysis

3.9. Use graphical load-line analysis to find the currents and voltages labeled in the circuits shown in Figure P3.9. The device characteristics are illustrated in Figures P3.9d and e.

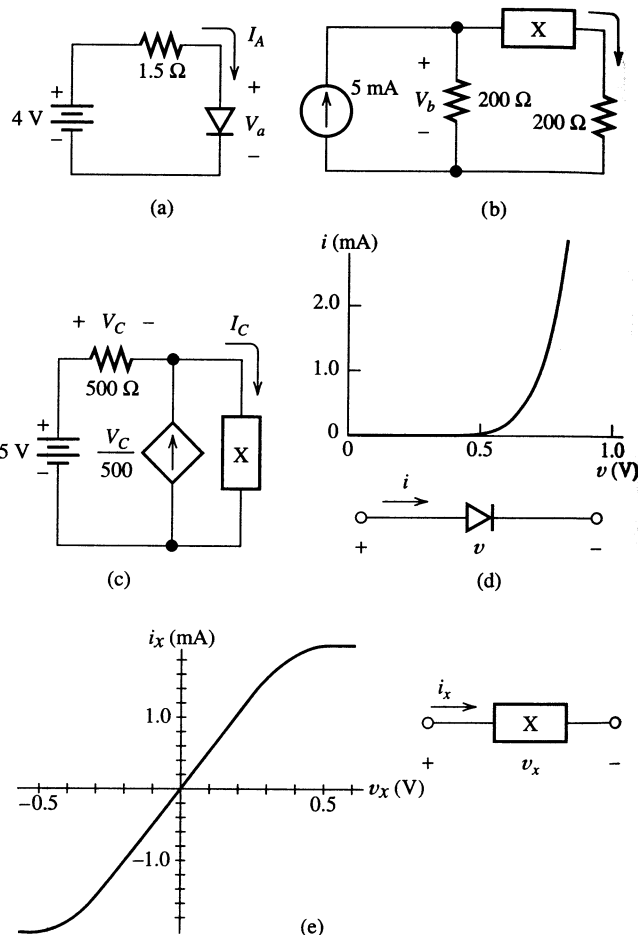


Figure P3.9

3.10. Consider the circuit of Figure 3.4. Draw the load line for the circuit for a 1-V source and $R = 500 \Omega$. Repeat for a 0.5-V source and $R = 500 \Omega$. Does the slope of the load line change when the source voltage changes? Find an expression for the slope of the load line in terms of the circuit resistance R .

3.11. Sketch the load line to scale on the i_D - v_D axes for the circuit illustrated in Figure P3.11a. Repeat for Figure P3.11b.

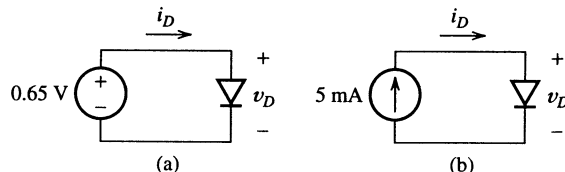


Figure P3.11

3.12. Sketch i against v to scale for the circuits displayed in Figure P3.12. The individual device characteristics are shown in Figures P3.9d and e.

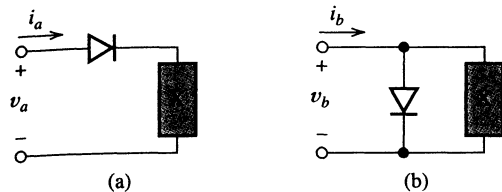


Figure P3.12

Section 3.3: The Ideal-Diode Model

3.13. Describe the ideal-diode model. Draw its i - v characteristic.

3.14. After solving a circuit with ideal diodes, what check is necessary for diodes initially assumed to be on? Off?

3.15. Assuming that the diodes are ideal, find the values of I and V for the circuits of Figure P3.15.

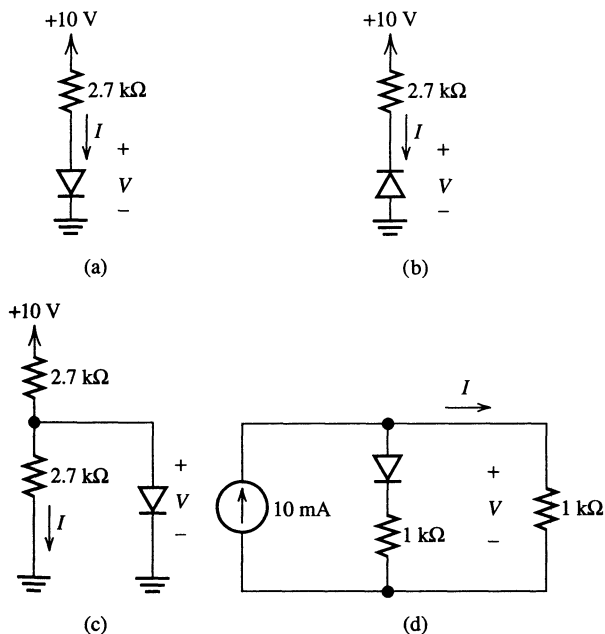


Figure P3.15

3.16. Assuming that the diodes are ideal, find the values of I and V for the circuits of Figure P3.16.

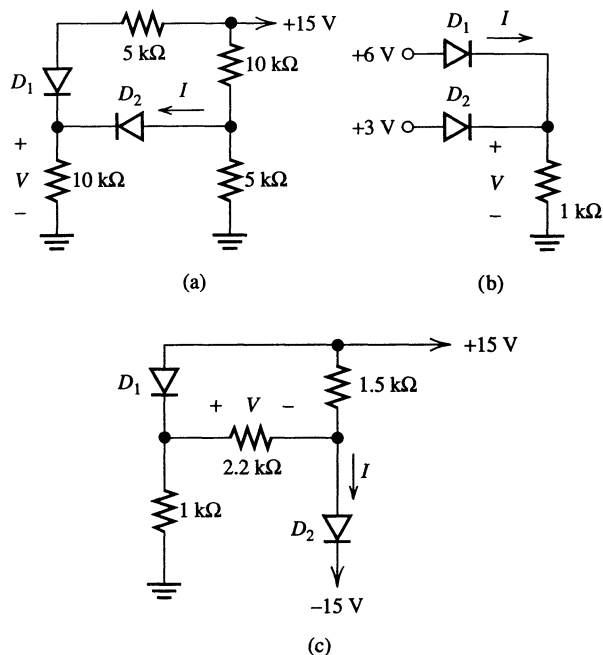


Figure P3.16

3.17. Assuming that the diodes are ideal, find the values of I and V for the circuits of Figure P3.17. For part (b), consider $V_{in} = 0, 2, 6,$ and 10 V. Then plot V against V_{in} for $-10 \leq V_{in} \leq 10$.

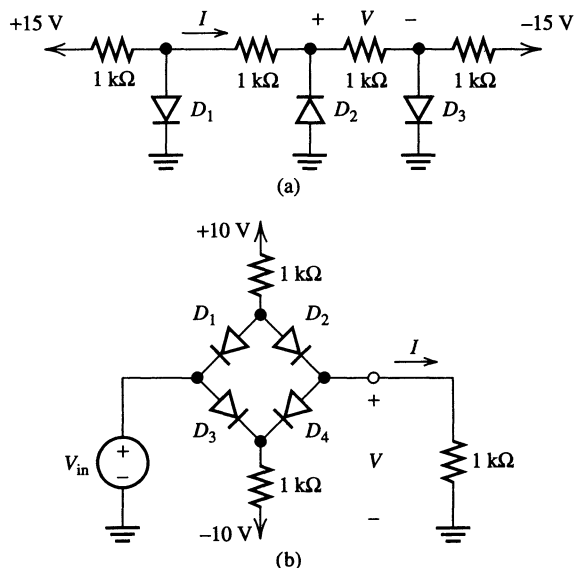


Figure P3.17

3.18. Two ideal diodes are connected in series, pointing in opposite directions. What is the equivalent circuit? Repeat if the diodes are in parallel.

D3.19. Reverse-polarity-protection circuit. An expensive electronic circuit is to be powered by a battery. If the battery is accidentally connected with the wrong polarity, the circuit will be damaged. Show how to connect a fuse and diode to protect the circuit and to avoid short-circuiting the battery. (*We do not want to place the diode in series with the battery, because, under normal operating conditions, that would reduce the voltage supplied to the circuit.*)

Section 3.4: Rectifier Circuits

3.20. Sketch the transfer functions (v_o versus v_{in}) for the circuits displayed in Figure P3.20. Also, plot v_o to scale against time for $v_{in}(t) = 10 \sin(200\pi t)$. Assume ideal diodes.

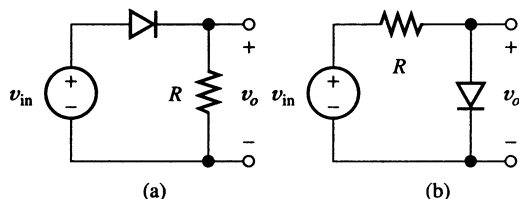


Figure P3.20

3.21. (a) Show that the average value of a half-wave rectified sine wave is the peak value divided by π .

(b) Determine the average value of a full-wave rectified sine wave. (*Hint: The average value of a periodic voltage $v(t)$ is given by*

$$V_{\text{avg}} = \frac{1}{T} \int_0^T v(t) dt$$

where T is the period.)

3.22. Figure P3.22 shows an ac voltmeter. Assume that the diode is ideal. Suppose that the meter reads full scale when the average current is 5 mA. Assume that the resistance of the meter is negligible. For what value of R will full scale correspond to an ac voltage of 10 V rms? (*Hint: The average value of a half-wave rectified sine wave is the peak value divided by π .*)

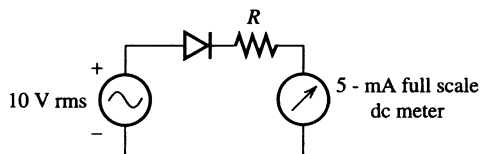


Figure P3.22

3.23. Draw the circuit diagram of a half-wave rectifier that will deliver a nearly steady dc voltage to a load from an ac source. Include a transformer to adjust the voltage level. Draw two different full-wave circuits.

3.24. Consider the battery-charging circuit of Figure P3.24 with $V_m = 20$ V, $R = 10 \Omega$, and $V_B = 14$ V. Find the peak current, assuming an ideal diode. Also, find the percentage of each cycle for which the diode is in the on state. Sketch $v_s(t)$ and $i(t)$ to scale against time.

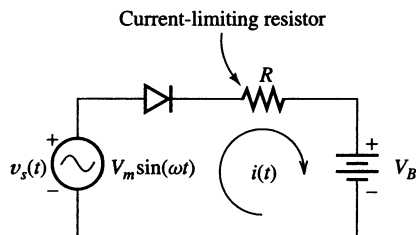


Figure P3.24 Half-wave battery charger.

D3.25. Half-wave rectifier design. Power is available from a 110-V rms, 60-Hz ac source. Design a half-wave rectifier power supply that will deliver an average voltage of 9 V with a peak-to-peak ripple of 2 V to a load. The average load current is 100 mA. Assume that ideal diodes and transformers are available. Draw the circuit diagram for your design. Specify the values of all components used. Be sure to give the turns ratio for the transformer.

1. Determine the peak load voltage needed to achieve the desired average load voltage with the specified ripple.
2. Determine the turns ratio.
3. Then compute the capacitance required.

D3.26. Full-wave bridge rectifier design. Repeat Problem D3.25 using a full-wave bridge rectifier.

D3.27. Full-wave rectifier design. Repeat Problem D3.25 using two diodes and a center-tapped secondary winding to form a full-wave rectifier.

D3.28. Rectifier design with nonideal diodes. Repeat Problem D3.25, assuming that the diodes have forward drops of 0.8 V.

1. Determine the peak voltage needed to achieve the desired average load voltage with the specified ripple.
2. Allow for the diode drops and determine the peak secondary voltage required.
3. Determine the turns ratio.
4. Then compute the capacitance required.

3.29. A full-wave rectifier is to be used to convert 400-Hz ac to dc. The dc output voltage is 15 V and the load current is 1 A. The ripple voltage is required to have a peak-to-peak value of 0.5 V or less. Estimate the capacitance required. Repeat for a 60-Hz source. Comment.

Section 3.5: Wave-Shaping Circuits

3.30. What is a clipper circuit? Draw a sample circuit diagram, including component values, an input waveform, and the corresponding output waveform.

3.31. Repeat Problem 3.30 for a clamp circuit.

3.32. Voltage-doubler circuit. Consider the circuit of Figure P3.32. The capacitors are very large, so that they discharge only a very small amount per cycle. (Thus, no ac voltage appears across the capacitors, and the ac input plus the dc voltage of C_1 must appear at point A.) Sketch the voltage at point A against time. Find the voltage across the load. Why is this circuit called a voltage doubler? Determine the peak inverse voltage across each diode in terms of V_m .

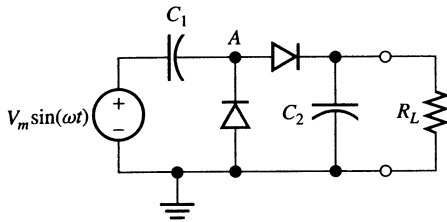


Figure P3.32

D3.33. Clipper design. Design a clipper circuit to clip off the portions of an input voltage that fall above 3 V or below -5 V. The input voltage ranges from -10 to +10 V. Assume that diodes having a forward drop of 0.7 V are available. Ideal Zener diodes of any breakdown voltage required are available. Use standard 5%-tolerance resistor values, and design for a peak current of about 1 mA in the diodes. The power-supply voltages that are available are ± 15 V. Try the circuit configuration shown in Figure 3.16a.

D3.34. Clipper design. Repeat Problem D3.33, assuming that the clipping levels are +2 V and +5 V (i.e., every part of the input waveform below +2 or above +5 is clipped off). Try a circuit configuration like that shown in Figure 3.16a but add a resistor connected to the positive power supply to keep one of the Zener diodes in the breakdown region.

3.35. Consider the circuit shown in Figure P3.35. Allow 0.6 V for the forward drops of the diodes. Sketch the transfer characteristic to scale. (Combining the bridge rectifier with a Zener diode is a neat way to obtain nearly identical characteristics for both polarities of the input voltage.)

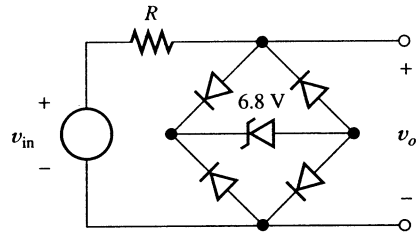
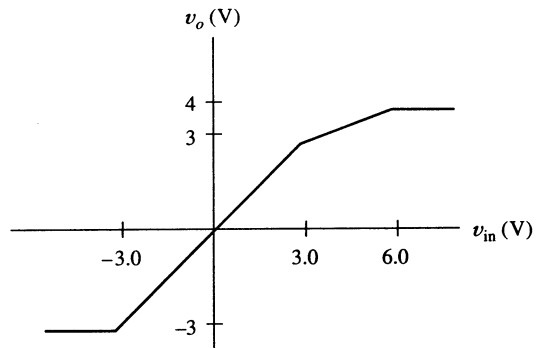
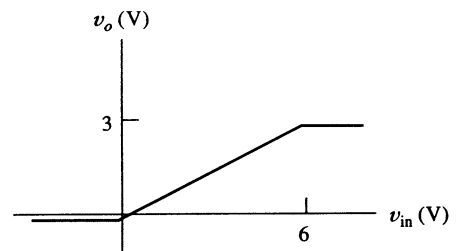


Figure P3.35

D3.36. Nonlinear transfer characteristics. Design circuits that have the transfer characteristics shown in Figure P3.36. Assume that v_{in} ranges from -10 to +10 V. Use diodes, Zener diodes, and standard 5%-tolerance resistor values. Assume a 0.6-V forward drop for all diodes, and suppose that the Zener diodes have an ideal characteristic in the breakdown region. Power-supply voltages of ± 15 V are available. Look at Exercise 3.17 and Figure 3.7 to get some ideas for the circuit configurations. For part b you may need to add a resistor connected to the positive power supply to keep some of the diodes forward biased with $v_o = 0$.



(a)



(b)

Figure P3.36

D3.37. Clamp-circuit design. Design a clamp circuit to clamp the negative extreme of a periodic input waveform to -5 V . Use diodes, Zener diodes, and standard 5%-tolerance resistor values. Assume a 0.6-V forward drop for all diodes, and suppose that the Zener diodes have an ideal characteristic in the breakdown region. Power-supply voltages of $\pm 15\text{ V}$ are available. Look at Figure 3.20a for ideas.

D3.38. Clamp-circuit design. Repeat Problem D3.37 to clamp the positive extreme to $+5\text{ V}$. Look at Figure 3.20a for ideas.

D3.39. (a) Consider the electronic switch shown in Figure P3.39. Assume ideal diodes, $R = R_L = 1\text{ k}\Omega$, $V_{C1} = +5\text{ V}$, and $V_{C2} = -5\text{ V}$. Plot the transfer characteristic (v_o versus v_{in}) for v_{in} ranging from -5 V to $+5\text{ V}$. (b) Repeat for $V_{C1} = -5\text{ V}$ and $V_{C2} = +5\text{ V}$.

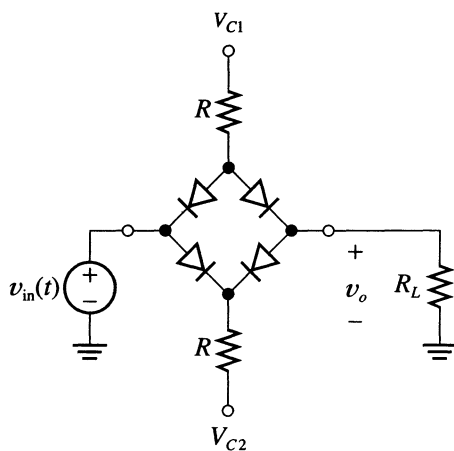


Figure P3.39 Electronic switch.

Section 3.6: Diode Logic Circuits

3.40. Draw the circuit diagram of a two-input diode AND gate. Repeat for a two-input OR gate.

3.41. Briefly discuss two problems that prevent diode logic circuits from having widespread application.

D3.42. Diode logic design. Given three input logic signals v_A , v_B , and v_C that assume values of 0 V (low) or 5 V (high), design a circuit consisting of ideal diodes, resistors, and voltage sources for which the output voltage is high (i.e., $v_o > 3\text{ V}$) if v_A and v_B are high or if v_C is high. The output should be low (i.e., $v_o < 1\text{ V}$) for other combinations of the inputs. Combine diode gates like those illustrated in Figure 3.23.

3.43. Assuming real diodes with forward drops of 0.6 V and input logic levels of 0 V and 5 V , how many diode OR gates can be cascaded if the output voltage for the high state is required to be greater than 3.5 V ?

Section 3.7: Voltage-Regulator Circuits

3.44. Draw the circuit diagram of a simple voltage regulator. Give the definitions of source regulation and load regulation.

3.45. A 6-V Zener diode regulator circuit operates from a source that varies from 10 to 14 V , the series resistance is $100\ \Omega$, and the load draws a current that varies from 0 to 30 mA . Determine the power dissipation in the Zener diode under worst-case conditions (i.e., the highest power dissipation).

3.46. We want to design a simple 5-V Zener diode voltage regulator that operates from a source that varies from 10 to 14 V . The load current varies from 0 to 10 mA . Determine the value of the series resistance so that the minimum magnitude of the Zener-diode current is 5 mA .

D3.47. Voltage-regulator design. Design a voltage regulator circuit that will provide a constant voltage of 5 V to a load from a variable supply voltage. The load current varies from 0 to 100 mA , and the source voltage varies from 8 to 10 V . You may assume that ideal Zener diodes are available. Resistors should be standard 5%-tolerance values. Draw the circuit diagram of your regulator and specify the value of each component. Also, find the worst-case (maximum) power dissipated in each component of your regulator. Try to use good judgment in your design. Look at Figure 3.28 for ideas.

D3.48. Voltage-regulator design. Repeat Problem D3.47, assuming that the supply voltage ranges from 6 to 10 V .

D3.49. Voltage-regulator design. Repeat Problem D3.47, assuming that the load current varies from 0 to 1 A .

Section 3.8: Linear Small-Signal Equivalent Circuits

3.50. An ideal Zener diode has a vertical volt-ampere characteristic in the breakdown region. What is the value of the dynamic resistance of the ideal Zener diode in the breakdown region?

3.51. A small-signal diode conducts 1 mA for a forward voltage of 0.6 V at a temperature of 300 K . Determine I_s , assuming that $n = 1$. Repeat for $n = 2$.

3.52. Solve the Shockley equation for v_D .

3.53. Consider the circuit illustrated in Figure P3.53. The source voltage consists of a dc component plus an ac ripple. The diode has a forward drop of approximately 0.6 V and $n = 1$. Find an approximate expression for the output voltage $v_D(t)$, including both the dc term and a small ac term.

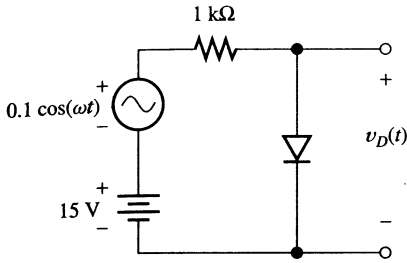


Figure P3.53

3.54. A certain integrated circuit *pn*-junction diode has $n = 1$ and a forward voltage of 0.6 V for a forward current of 1 mA. Another junction on the same chip has identical structure and doping as the first diode, except that the junction area is 10 times larger. Find the forward voltage of the second diode for a forward current of 1 mA. (Hint: I_s is proportional to the junction area.)

3.55. The circuit displayed in Figure P3.55 is used to provide an output voltage of approximately 2.4 V. The diodes have $n = 1$. (a) With the load disconnected, determine the change in v_o when the source voltage changes from 10 V to 12 V. Compute the percentage source regulation for this circuit. (b) For $V_s = 12$ V, determine the change in v_o when the load is connected, and find the percentage load regulation.

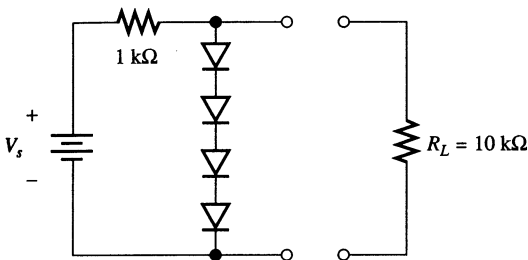


Figure P3.55

3.56. Suppose that a certain diode has $n = 1$ and carries a forward current of 2 mA. Assume that $V_T = 26$ mV. Determine the dynamic resistance of the diode. Now suppose that an identical diode is placed in parallel with the first diode and the current splits equally between them. Determine the dynamic resistance of the parallel combination. Compare the results and comment.

3.57. Consider the voltage regulator circuit shown in Figure 3.28a. Suppose that the dynamic resistance of the Zener diode is denoted as r_z . Derive expressions for the source and load regulations in terms of R , r_z , and R_L . Assume that the no-load current is zero (i.e., R_L is disconnected from the circuit).

3.58. A certain diode has $I_s = 10^{-14}$ A and $n = 1$. Assume that $V_T = 26$ mV.

- Determine the dynamic resistance if the forward current is 1 mA.
- Use the dynamic resistance to find the change in the diode voltage if the current changes to 1.1 mA.
- Use the Shockley equation to determine the diode voltages for 1 mA and 1.1 mA. Compare the difference between these values with the change computed in part (b). What is the percentage error?

3.59. A breakdown diode has

$$i_D = \frac{-10^{-6}}{(1 + v_D/5)^3} \text{ for } -5 \text{ V} < v_D < 0$$

where i_D is in amperes. Plot i_D against v_D in the reverse-bias region. Find the dynamic resistance of this diode at $I_{DQ} = -1$ mA and at $I_{DQ} = -10$ mA.

3.60. Consider the voltage regulator circuit illustrated in Figure P3.60. The ac ripple voltage is 1 V peak to peak. The dc load voltage is 5 V. What is the Q -point current in the Zener diode? What is the maximum dynamic resistance allowed for the Zener diode if the output ripple is to be less than 10 mV peak to peak?

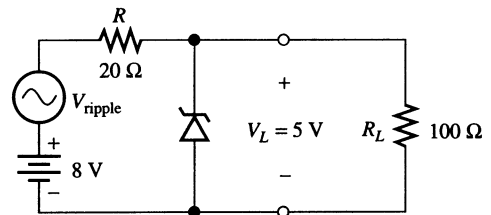


Figure P3.60

Section 3.9: Basic Semiconductor Concepts

3.61. Sketch the crystal lattice structure of intrinsic silicon, and label the important features.

3.62. What is the relationship between hole concentration and free-electron concentration in an intrinsic semiconductor?

3.63. Briefly discuss the generation and recombination of charge carriers in a semiconductor.

3.64. How does the conductivity of intrinsic silicon depend on temperature? Why?

3.65. Sketch the crystal lattice structure for *n*-type silicon. Repeat for *p*-type. Label the important features on the sketches.

3.66. Write an equation relating the donor-atom concentration, the acceptor-atom concentration, the free-electron concentration, and the hole concentration for a doped semiconductor.

3.67. Briefly discuss the mass-action law.

3.68. Briefly discuss conduction due to drift. Define mobility.

3.69. Briefly discuss conduction due to diffusion.

3.70. Given that silicon has about 5×10^{22} atoms/cm³, find the volume occupied by each silicon atom and an (order-of-magnitude) estimate of the center-to-center spacing between nearest atoms.

3.71. Doped silicon at 300 K contains 10^{16} acceptor atoms/cm³. Find the hole concentration and the free-electron concentration.

3.72. Find the hole concentration and free-electron concentration of silicon at 300 K if

(a) The acceptor concentration is 10^{15} cm⁻³ and the donor concentration is 10^{17} cm⁻³.

(b) The acceptor concentration is 10^{15} cm⁻³ and the donor concentration is 10^{15} cm⁻³.

Section 3.10: Physics of the Junction Diode

3.73. Sketch a *pn* junction, showing the charge stored in the depletion region. Also, sketch the hole and electron concentrations against distance across the junction.

3.74. With no external bias applied, two equal, but opposite, currents flow across a *pn* junction. Briefly explain.

3.75. Discuss how the saturation current I_s of a *pn* junction varies with temperature. With junction area. With doping.

3.76. Sketch the hole and electron concentration against distance across a *pn* junction, under forward-bias conditions. Also, sketch the hole and electron current against distance. Assume equal doping levels on both sides of the junction.

3.77. Consider the circuit displayed in Figure P3.77. The diodes are identical and have $n = 1$. The temperature of each diode is 300 K. Before the switch is closed, the voltage v is 600 mV. Find v after the switch is closed. Repeat for $n = 2$.

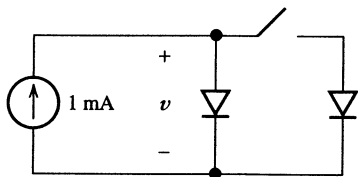


Figure P3.77

3.78. A junction diode has $n = 1$ and is operating at 300 K, with a current of 1 mA and a voltage of 600 mV. By how much must the voltage be increased (a) to double the current? (b) to

increase the current by one order of magnitude? Repeat parts (a) and (b) if $n = 2$.

3.79. Current hogging. Consider the diodes shown in Figure P3.79. The diodes are identical and have $n = 1$. For each diode, a forward current of 100 mA results in a voltage of 700 mV at a temperature of 300 K. (a) If both diodes are at 300 K, what are the values of I_A and I_B ? (b) If diode *A* is at 300 K and diode *B* is at 305 K, again find I_A and I_B . Assume that I_s doubles in value for every 5-K increase in temperature. [Hint: Answer part (a) by the use of symmetry. For part (b), a transcendental equation for the voltage across the diodes can be found. Solve by trial and error.] An important observation to be made from this problem is that, starting at the same temperature, the diodes should theoretically each conduct half of the total current. However, if one diode conducts slightly more, it becomes warmer, resulting in even more current. Eventually, one of the diodes hogs most of the current. Hogging is particularly noticeable with large currents for which significant heating occurs.

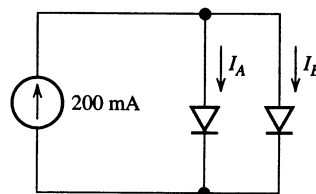


Figure P3.79

3.80. A certain diode has $n = 1$. At 300 K, $v_D = 650$ mV when $i_D = 1$ mA. Plot i_D against v_D for this diode at 300 K on semilog graph paper. (Use the linear axis for v_D and the logarithmic axis for i_D .) Allow i_D to range from 0.1 to 100 mA. Repeat if a resistance of $R_s = 10 \Omega$ is placed in series with the diode.

3.81. A certain p^+n -junction diode is known to have an emission coefficient $n = 1$. For a forward voltage of 0.6 V, the current is 1 mA. A second diode is identical, except that the dopant concentrations on both sides of the junction are twice as great as for the first diode. What is the forward voltage of the second diode for a current of 1 mA? Assume a temperature of 300 K. (Hint: The saturation current I_s is proportional to the minority carrier concentration on the *n*-side of the junction. Increased doping reduces the minority carrier concentration.)

3.82. A certain *pn* junction has $N_A = 10^{15}$ cm⁻³ on the *p*-side and $N_D = 10^{15}$ cm⁻³ on the *n*-side. Plot the hole and free-electron concentrations to scale against distance across the junction. Use a logarithmic scale for the concentrations. Label the *p*-side, the depletion region, and the *n*-side. Assume zero bias and a temperature of 300 K.

Section 3.11: Switching and High-Frequency Behavior

3.83. Name the two capacitances associated with a pn -junction diode. Which is most important under reverse bias? Under forward bias?

3.84. Draw the small-signal equivalent circuit for a pn -junction diode under forward-bias conditions.

3.85. A junction diode is connected in series with a resistance and a voltage source. Prior to $t = 0$, the source forward biases the diode, and the current is I_F . At $t = 0$, the polarity of the source reverses. Sketch the diode current against time. Label the storage interval, the transition interval, and the reverse recovery time on the sketch.

3.86. A capacitor is formed by a square plate of aluminum separated from a silicon substrate by a layer of silicon dioxide that has a thickness of 1000 angstroms (1 angstrom = 10^{-10} m). Find the dimensions of the aluminum plate for a capacitance of 30 pF. The relative dielectric constant of silicon dioxide is approximately 3.97.

3.87. A pn junction has $C_{j0} = 100$ pF, $\phi_0 = 1.0$ V, and $m = 1/2$. Find the depletion capacitance for a reverse-bias voltage of 1 V and for 10 V. Repeat for $m = 1/3$.

3.88. A certain diode has a saturation current $I_s = 10^{-12}$, an emission coefficient $n = 1$, and a transit time $\tau_T = 1$ μ s. Plot the diffusion capacitance against forward voltage for $0 < v_D < 0.7$ V. Assume a temperature of 300 K.

3.89. A certain diode has the following parameters:

$$I_s = 10^{-15} \text{ A};$$

$$n = 1;$$

$$C_{j0} = 5 \text{ pF};$$

$$\phi_0 = .9 \text{ V};$$

$$m = 0.333;$$

$$R_s = 20 \Omega;$$

$$\tau_T = 6 \text{ ns}.$$

Find the small-signal equivalent circuit for the diode, including values, if the diode is

- Reverse biased with $V_{DQ} = -20$ V.
- Forward biased with $I_{DQ} = 1$ mA.
- Forward biased with $I_{DQ} = 10$ mA.

3.90. Consider the circuit shown in Figure P3.90. Prior to $t = 0$, the source voltage is +5 V. At $t = 0$, it switches

abruptly to -5 V. The voltage across the diode is observed on an oscilloscope having an input capacitance of 7 pF. The voltage waveform is shown in the figure. For the diode, find

- The ohmic resistance R_s .
- The zero-bias junction capacitance C_{j0} . Neglect the effect of R_s for this part of the problem. [Hint: $dQ/dv_D = (dQ/dt)/(dv_D/dt)$. Also, $dQ/dt = i_D$.]
- The transit time τ_T .

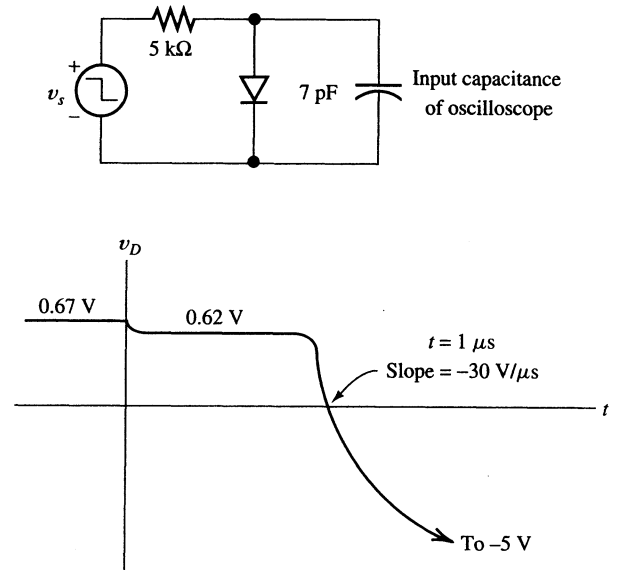


Figure P3.90

Section 3.12: Computer-Aided Analysis of Diode Circuits

D3.91. Electronic thermometer design. A diode can be used as a temperature sensor because its forward voltage decreases by about 2 mV/°C. Design an electronic thermometer that produces $v_o = T/10$, where T is the diode temperature in °C and v_o is the output voltage of the circuit in volts. Design for temperatures ranging from 0 to 50°C. Use power-supply voltages of ± 15 V, any diodes or op amps for which you have SPICE models, and 5%-tolerance discrete resistors. Include two adjustable resistances in your design, so that the zero and full-scale outputs can be adjusted. Verify your design using SPICE. *Suggestions: Use a Zener-diode regulator to obtain a constant reference voltage to supply current to the sensor diode(s). Use several diodes in series for the sensor to obtain a larger voltage change with temperature. Use amplifiers and a summer (see Figure 2.7) to derive the desired output voltage from the reference voltage and the sensor voltage.*

3.92. Perform a SPICE transient analysis of the half-wave rectifier with a smoothing capacitor shown in Figure 3.12. Use a 1N4002 diode or any other diode for which you have a SPICE model. The source voltage is a 10-V peak 60-Hz sine wave. The load is a 100- Ω resistor, and $C = 1000\ \mu\text{F}$. Obtain plots of the load voltage and the diode current against time for about 5 cycles. Determine the average load current, the peak diode

current, and the peak-to-peak ripple. Repeat for $C = 2000\ \mu\text{F}$, and compare results. Comment on the results.

3.93. Use SPICE to plot the volt–ampere characteristics of the 1N4148 diode for temperatures of 0, 50, and 100°C. Also, obtain plots of the dynamic resistance versus current at each temperature.