ANSWERS

Chapter 1

SECTION CHECKUPS

Section 1–1 The Atom

1. The Bohr model has a central nucleus consisting of protons and neutrons orbited by electrons at varying distances from the nucleus.
2. An electron is the smallest particle of negative electrical charge.
3. Protons and neutrons. A proton is a particle of positive charge and a neutron has no net charge.
4. The atomic number is the number of electrons in the nucleus of an atom.
5. An electron shell contains orbiting electrons at a certain energy level. Each shell of a given atom is at a different energy level.
6. A valence electron is one that is in the outer shell of an atom.
7. A free electron is a valence electron that has broken free of its parent atom.
8. A positive ion is a previously neutral atom that has lost a valence electron and has a net positive charge. A negative ion is one that has gained an extra electron and has a net negative charge.
9. The quantum model is based on the uncertainty principle and wave-particle duality.

Section 1–2 Materials Used in Electronics

1. Conductors have many free electrons and easily conduct current. Insulators have essentially no free electrons and do not conduct current.
2. Semiconductors do not conduct current as well as conductors do. In terms of conductivity, they are between conductors and insulators.
3. Conductors such as copper have one valence electron.
4. Semiconductors have four valence electrons.
5. Gold, silver, and copper are the best conductors.
6. Silicon is the most widely used semiconductor.
7. The valence electrons of a semiconductor are more tightly bound to the atom than those of conductors.
8. Covalent bonds are formed by the sharing of valence electrons with neighboring atoms.
9. An intrinsic material is one that is in a pure state.
10. A crystal is a solid material formed by atoms bonding together in a symmetrical pattern.

Section 1–3 Current in Semiconductors

1. Free electrons are in the conduction band.
2. Free (conduction) electrons are responsible for electron current in silicon.
3. A hole is the absence of an electron in the valence band.
4. Hole current occurs at the valence level.

Section 1–4 *N*-Type and *P*-Type Semiconductors

1. Doping is the process of adding impurity atoms to a semiconductor in order to modify its conductive properties.
2. A pentavalent atom has five valence electrons and a trivalent atom has three valence electrons.
3. A pentavalent atom is called a donor atom and a trivalent atom is called an acceptor atom.
4. An *n*-type material is formed by the addition of pentavalent impurity atoms to the intrinsic semiconductive material.
5. A *p*-type material is formed by the addition of trivalent impurity atoms to the intrinsic semiconductive material.
6. The majority carrier in an *n*-type semiconductor is the free electron.
7. The majority carrier in a *p*-type semiconductor is the hole.

8. Majority carriers are produced by doping.
9. Minority carriers are thermally produced when electron-hole pairs are generated.
10. A pure semiconductor is intrinsic. A doped (impure) semiconductor is extrinsic.

Section 1–5 The *PN* Junction

1. A *pn* junction is the boundary between *p*-type and *n*-type semiconductors in a diode.
2. Diffusion is the movement of the free electrons (majority carriers) in the *n*-region across the *pn* junction and into the *p* region.
3. The depletion region is the thin layers of positive and negative ions that exist on both sides of the *pn* junction.
4. The barrier potential is the potential difference of the electric field in the depletion region and is the amount of energy required to move electrons through the depletion region.
5. The barrier potential for a silicon diode is approximately 0.7 V.
6. The barrier potential for a germanium diode is approximately 0.3 V.

RELATED PROBLEM FOR EXAMPLE

1–1 $1s^2$
$2s^2$ $2p^6$
$3s^2$ $3p^6$ $3d^{10}$
$4s^2$ $4p^2$

TRUE/FALSE QUIZ

1. F **2.** T **3.** T **4.** F **5.** T **6.** T **7.** F **8.** T **9.** F

SELF-TEST

1. (c) **2.** (d) **3.** (a) **4.** (b) **5.** (a) **6.** (d) **7.** (d) **8.** (c)
9. (d) **10.** (d) **11.** (d) **12.** (d) **13.** (c) **14.** (b) **15.** (a) **16.** (d)
17. (e) **18.** (a) **19.** (b) **20.** (c) **21.** (c) **22.** (a) **23.** (c) **24.** (d)
25. (d)

ANSWERS Chapter 2

SECTION CHECKUPS

Section 2–1 Diode Operation

1. When forward-biased, a diode conducts current. The free electrons in the *n* region move across the *pn* junction and combine with the holes in the *p* region.
2. To forward-bias a diode, the positive side of an external bias voltage is applied to the *p* region and the negative side to the *n* region.
3. When reverse-biased, a diode does not conduct current except for an extremely small reverse current.
4. To reverse-bias a diode, the positive side of an external bias voltage is applied to the *n* region and the negative side to the *p* region.
5. The depletion region for forward bias is much narrower than for reverse bias.
6. Majority carrier current is produced by forward bias.
7. Reverse current is produced by the minority carriers.
8. Reverse breakdown occurs when the reverse-bias voltage equals or exceeds the breakdown voltage of the *pn* junction of a diode.
9. Avalanche effect is the rapid multiplication of current carriers in reverse breakdown.

Section 2–2 Voltage-Current Characteristic of a Diode

1. The knee of the characteristic curve in forward bias is the point at which the barrier potential is overcome and the current increases drastically.
2. A forward-biased diode is normally operated above the knee of the curve.
3. Breakdown voltage is always much greater than the barrier potential.
4. A reverse-biased diode is normally operated between 0 V and the breakdown voltage.
5. Barrier potential decreases as temperature increases.

Section 2–3 Diode Models

1. A diode is operated in forward bias and reverse bias.
2. A diode should never be operated in reverse breakdown.
3. The diode can be ideally viewed as a switch.
4. A diode includes barrier potential, dynamic resistance, and reverse resistance in the complete model.
5. The complete diode model is the most accurate diode approximation.

Section 2–4 Half-Wave Rectifiers

1. PIV across the diode occurs at the peak of the input when the diode is reversed biased.
2. There is current through the load for approximately half (50%) of the input cycle.
3. The average value is $10\text{ V}/\pi = 3.18\text{ V}$.
4. The peak output voltage is $25\text{ V} - 0.7\text{ V} = 24.3\text{ V}$.
5. The PIV sating must be at least 60 V.

Section 2–5 Full-Wave Rectifiers

1. A full-wave voltage occurs on each half of the input cycle and has a frequency of twice the input frequency. A half-wave voltage occurs once each input cycle and has a frequency equal to the input frequency.
2. The average value of $2(60\text{ V})/\pi = 38.12\text{ V}$
3. The bridge rectifier has the greater output voltage.
4. The 50 V diodes must be used in the bridge rectifier.
5. In the center-tapped rectifier, diodes with a PIV rating of at least 90 V would be required.

Section 2–6 Power Supply Filters and Regulators

1. The output frequency is 60 Hz.
2. The output frequency is 120 Hz.
3. The ripple voltage is caused by the slight charging and discharging of the capacitor through the load resistor.
4. The ripple voltage amplitude increases when the load resistance decreases.
5. Ripple factor is the ratio of the ripple voltage to the average or dc voltage.
6. Input regulation is a measure of the variation in output voltage over a range of input voltages. Load regulation is a measure of the variation in output voltage over a range of load current values.

Section 2–7 Diode Limiters and Clampers

1. Limiters clip off or remove portions of a waveform. Clampers insert a dc level.
2. A positive limiter clips off positive voltages. A negative limiter clips off negative voltages.
3. 0.7 V appears across the diode.
4. The bias voltage must be $5\text{ V} - 0.7\text{ V} = 4.3\text{ V}$.
5. The capacitor acts as a battery.

Section 2–8 Voltage Multipliers

1. The peak voltage rating must be 100 V.
2. The PIV rating must be at least 310 V.

Section 2–9 The Diode Datasheet

1. 1N4002: 100 V; 1N4003: 200 V; 1N4004: 400 V; 1N4005: 600 V; 1N4006: 800 V
2. No
3. Approximately 0.65 A
4. 12 A

Section 2–10 Troubleshooting

1. 0.5 V to 0.9 V
2. OL
3. An open diode results in no output voltage.
4. An open diode produces a half-wave output voltage.
5. The shorted diode may burn open. Transformer will be damaged. Fuse will blow.
6. The amplitude of the ripple voltage increases with a leaky filter capacitor.
7. There will be no output voltage when the primary opens.
8. The problem may be a partially shorted secondary winding.

RELATED PROBLEMS FOR EXAMPLES

2–1 $V_D = 5$ V; $V_{LIMIT} = 0$ V
2–2 3.82 V
2–3 **(a)** 2.3 V **(b)** 49.3 V
2–4 **(a)** 623.3 V **(b)** 624 V **(c)** negative half-cycles rather than positive half cycles
2–5 98.7 V
2–6 79.3 V including diode drop
2–7 41.0 V; 41.7 V
2–8 26.9 mV
2–9 3.7%
2–10 A positive peak of 9.9 V and clipped at −0.7 V
2–11 Limited at +10.7 V and −10.7 V
2–12 Change R_3 to 100 Ω or R_2 to 220 Ω.
2–13 Same voltage waveform as Figure 2–66
2–14 Verify C is shorted and replace it.

TRUE/FALSE QUIZ

1. F **2.** F **3.** T **4.** F **5.** T **6.** T **7.** F **8.** T **9.** F
10. F **11.** T **12.** T **13.** T **14.** F **15.** T **16.** F **17.** F **18.** T
19. F **20.** T

CIRCUIT-ACTION QUIZ

1. (a) **2.** (c) **3.** (c) **4.** (a) **5.** (a) **6.** (c) **7.** (b) **8.** (a)
9. (a) **10.** (b) **11.** (c) **12.** (c) **13.** (b) **14.** (a) **15.** (a) **16.** (c)
17. (b) **18.** (c) **19.** (b) **20.** (a)

SELF-TEST

1. (c) **2.** (d) **3.** (d) **4.** (b) **5.** (b) **6.** (b) **7.** (d) **8.** (b)
9. (a) **10.** (c) **11.** (a) **12.** (d) **13.** (a) **14.** (c) **15.** (d) **16.** (a)
17. (b) **18.** (a) **19.** (d) **20.** (b) **21.** (c) **22.** (a) **23.** (b) **24.** (c)
25. (a) **26.** (d) **27.** (b) **28.** (d) **29.** (c) **30.** (b) **31.** (a) **32.** (b)
33. (c) **34.** (b) **35.** (a) **36.** (c) **37.** (b)

ANSWERS

Chapter 3

SECTION CHECKUPS

Section 3–1 The Zener Diode

1. Zener diodes are operated in the reverse-breakdown region.
2. The test current, I_Z
3. The zener impedance causes the voltage to vary slightly with current.
4. The zener voltage increases (or decreases) 0.05% for each degree centigrade increase (or decrease).
5. Power derating is the reduction in the power rating of a device as a result of an increase in temperature.

Section 3–2 Zener Diode Applications

1. An infinite resistance (open)
2. With no load, there is no current to a load. With full load, there is maximum current to the load.
3. Approximately 0.7 V, just like a rectifier diode

Section 3–3 The Varactor Diode

1. A varactor exhibits variable capacitance.
2. A varactor is operated in reverse bias.
3. The depletion region
4. Capacitance decreases with more reverse bias.
5. The capacitance ratio is the ratio of a varactor's capacitance at a specified minimum voltage to the capacitance at a specified maximum voltage.

Section 3–4 Optical Diodes

1. Infrared and visible light
2. Infrared has the greater wavelength.
3. An LED operates in forward bias.
4. Light emission increases with forward current.
5. False, V_F of an LED is usually greater than 1.2 V.
6. A tiny grouping of red, green, and blue LEDs.
7. A photodiode operates in reverse bias.
8. The internal resistance decreases.
9. Dark current is the reverse photodiode current when there is no light.

Section 3–5 Other Types of Diodes

1. *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation
2. Coherent light has only a single wavelength, but incoherent light has a wide band of wavelengths. A laser diode produces coherent light.
3. High-frequency and fast-switching circuits
4. *Hot carrier* is another name for Schottky diodes.
5. Tunnel diodes have negative resistance.
6. Oscillators
7. *p* region, *n* region, and intrinsic (*i*) region
8. A current regulator operates between V_L (limiting voltage) and POV (peak operating voltage).

Section 3–6 Troubleshooting

1. The output voltage is too high and equal to the rectifier output.
2. More

3. Series limiting resistor open, fuse blown. A shorted zener could have caused this.
4. The output voltage changes as the load resistance changes.

RELATED PROBLEMS FOR EXAMPLES

3–1 5 Ω

3–2 The voltage will decrease by 0.45 V.

3–3 7.5 W

3–4 $V_Z = -11.9$ V at 10 mA; $V_Z = 12.08$ V at 30 mA

3–5 $V_{IN(min)} = 6.77$ V; $V_{IN(max)} = 21.9$ V

3–6 $I_{L(min)} = 0$ A; $I_{L(max)} = 43$ mA; $R_{L(min)} = 76.7\ \Omega$

3–7 **(a)** 11.8 V at I_{ZK}; 12.9 V at I_{ZM}
(b) 133 Ω
(c) 151 Ω

3–8 **(a)** A waveform identical to Figure 3-20(a)
(b) A sine wave with a peak value of 5 V

3–9 Increase V_2.

3–10 approximately 0.7

3–11 Sixteen parallel branches with four LEDs in each branch.
$R_{LIMIT} = (12\text{ V} - 9.2\text{ V})/30\text{ mA} = 93\ \Omega$.

3–12 approximately 6.6 μA

TRUE/FALSE QUIZ

1. T **2.** T **3.** F **4.** F **5.** T **6.** F
7. T **8.** T **9.** F **10.** T **11.** T **12.** T

CIRCUIT-ACTION QUIZ

1. (c) **2.** (b) **3.** (a) **4.** (a) **5.** (b) **6.** (c) **7.** (c) **8.** (b)
9. (a) **10.** (a) **11.** (b)

SELF-TEST

1. (a) **2.** (b) **3.** (c) **4.** (b) **5.** (d) **6.** (a) **7.** (c) **8.** (d)
9. (d) **10.** (d) **11.** (b) **12.** (b) **13.** (d) **14.** (b) **15.** (d)

ANSWERS

Chapter 4

SECTION CHECKUPS

Section 4–1 Bipolar Junction Transistor (BJT) Structure

1. The two types of BJTs are *npn* and *pnp*.
2. The terminals of a BJT are base, collector, and emitter.
3. The three regions of a BJT are separated by two *pn* junctions.

Section 4–2 Basic BJT Operation

1. To operate as an amplifier, the base-emitter is forward-biased and the base-collector is reverse-biased.
2. The emitter current is the largest.
3. The base current is much smaller than the emitter current.
4. The base region is very narrow compared to the other two regions.
5. $I_E = 1\text{ mA} + 10\ \mu\text{A} = 1.01\text{ mA}$

Section 4–3 BJT Characteristics and Parameters

1. $\beta_{DC} = I_C/I_B$; $\alpha_{DC} = I_C/I_E$; h_{FE} is β_{DC}.
2. $\beta_{DC} = 100$; $\alpha_{DC} = 100/(100 + 1) = 0.99$
3. I_C is plotted versus V_{CE}.
4. Forward-reverse bias is required for amplifier operation.
5. β_{DC} increases with temperature.
6. No. β_{DC} generally varies some from one device to the next for a given type.

Section 4–4 The BJT as an Amplifier

1. Amplification is the process where a smaller signal is used to produce a larger identical signal.
2. Voltage gain is the ratio of output voltage to input voltage.
3. R_C and r'_e determine the voltage gain.
4. $A_v = 5\text{ V}/250\text{ mV} = 20$
5. $A_v = 1200\ \Omega/20\ \Omega = 60$

Section 4–5 The BJT as a Switch

1. A transistor switch operates in cutoff and saturation.
2. The collector current is maximum in saturation.
3. The collector current is approximately zero in cutoff.
4. $V_{CE} = V_{CC}$ in cutoff.
5. V_{CE} is minimum in saturation.

Section 4–6 The Phototransistor

1. The base current of a phototransistor is light induced.
2. Base
3. The collector current depends on β_{DC} and I_λ.
4. Current transfer ratio

Section 4–7 Transistor Categories and Packaging

1. Three categories of BJTs are small signal/general purpose, power, and RF.
2. Emitter is the lead closest to the tab.
3. The metal mounting tab or case in power transistors is the collector.

Section 4–8 Troubleshooting

1. First, test it in-circuit.
2. If R_B opens, the transistor is in cutoff.
3. The base voltage is +3 V and the collector voltage is +9 V.

RELATED PROBLEMS FOR EXAMPLES

4–1 10 mA

4–2 $I_B = 241\ \mu\text{A}$; $I_C = 21.7\text{ mA}$; $I_E = 21.94\text{ mA}$; $V_{CE} = 4.23\text{ V}$; $V_{CB} = 3.53\text{ V}$

4–3 Along the horizontal axis

4–4 Not saturated

4–5 10 V

4–6 $V_{CC(max)} = 44.5\text{ V}$; $V_{CE(max)}$ is exceeded first.

4–7 4.55 W

4–8 $P_{D(max)} = 500\text{ mW @ }50°\text{C}$

4–9 2.5 kΩ

4–10 78.4 μA

4–11 Reduce R_C to 140 Ω and R_B to 2.2 kΩ.

4–12 R_B open

TRUE/FALSE QUIZ

1. T **2.** F **3.** T **4.** T **5.** F **6.** F
7. F **8.** T **9.** F **10.** T **11.** F **12.** T

CIRCUIT-ACTION QUIZ

1. (a) **2.** (a) **3.** (c) **4.** (b) **5.** (c) **6.** (b)
7. (c) **8.** (a) **9.** (b) **10.** (a) **11.** (a) **12.** (a)

SELF-TEST

1. (d) **2.** (c) **3.** (a) **4.** (d) **5.** (a) **6.** (c) **7.** (b)
8. (a) **9.** (c) **10.** (c) **11.** (b) **12.** (b) **13.** (f) **14.** (c)
15. (b) **16.** (b) **17.** (b) **18.** (a) **19.** (d) **20.** (a) **21.** (c)

ANSWERS

Chapter 5

SECTION CHECKUPS

Section 5–1 The DC Operating Point

1. The upper load line limit is $I_{C(sat)}$ and $V_{CE(sat)}$. The lower limit is $I_C = 0$ and $V_{CE(cutoff)}$.
2. The Q-point is the dc point at which a transistor is biased and is specified by V_{CE} and I_C.
3. Ideally, saturation occurs at the intersection of the load line and the *y*-axis ($V_{CE} = 0$ V). Cutoff occurs at the intersection of the load line and the $I_B = 0$ curve.
4. The Q-point must be centered on the load line for maximum V_{ce}.

Section 5–2 Voltage-Divider Bias

1. $R_{IN(BASE)} = V_{IN}/I_{IN} = 5\text{ V}/5\ \mu\text{A} = 1\text{ M}\Omega$
2. $R_{IN(BASE)} = (\beta_{DC}V_B)/I_E = [(190)(2\text{ V})]/2\text{ mA} = 190\text{ k}\Omega$
3. $V_B = 5$ V
4. Voltage-divider bias is stable and requires only one supply voltage.

Section 5–3 Other Bias Methods

1. Emitter bias is much less dependent on the value of beta than is base bias.
2. Emitter bias requires two separate supply voltages.
3. I_C increases with β_{DC}, causing a reduction in V_C and, therefore, less voltage across R_B, thus less I_B.
4. Base bias is beta-dependent.
5. The Q-point changes due to changes in β_{DC} and V_{CE} over temperature.
6. Emitter-feedback improves stability.

Section 5–4 Troubleshooting

1. A transistor is saturated when $V_{CE} = 0$ V. A transistor is in cutoff when $V_{CE} = V_{CC}$.
2. R_E is open because the BE junction of the transistor is still forward-biased.
3. If R_C is open, V_C is about 0.7 V less than V_B.

RELATED PROBLEMS FOR EXAMPLES

5–1 $I_{CQ} = 19.8$ mA; $V_{CEQ} = 4.2$ V; $I_{b(peak)} = 42\ \mu$A

5–2 The voltage divider would be loaded, so V_B would decrease.

5–3 92.3 kΩ

5–4 $R_{IN(BASE)} = 453$ kΩ

5–5 $\beta_{DC} = 288$

5–6 7.83 V

5–7 $I_C = 1.41$ mA; $V_{CE} = 9.27$ V

5–8 10.3 mA

5–9 5.38 mA

5–10 $I_C = 853\ \mu$A; $V_{CE} = 1.47$ V
$\%\Delta I_C = 8.2\%$; $\%\Delta V_{CE} = -30.7\%$

TRUE/FALSE QUIZ

1. T	**2.** F	**3.** T	**4.** F	**5.** T	**6.** F
7. T	**8.** T	**9.** F	**10.** T	**11.** T	**12.** T

CIRCUIT-ACTION QUIZ

1. (a)	**2.** (b)	**3.** (b)	**4.** (b)	**5.** (a)
6. (c)	**7.** (c)	**8.** (a)	**9.** (b)	**10.** (a)

SELF-TEST

1. (b)	**2.** (c)	**3.** (d)	**4.** (d)	**5.** (c)	**6.** (a)	**7.** (b)	**8.** (d)
9. (a)	**10.** (c)	**11.** (c)	**12.** (a)	**13.** (c)	**14.** (f)	**15.** (b)	**16.** (d)

ANSWERS

Chapter 6

SECTION CHECKUPS

Section 6–1 Amplifier Operation

1. Positive, negative
2. V_{CE} is a dc quantity and V_{ce} is an ac quantity.
3. R_e is the external emitter ac resistance, r'_e is the internal emitter ac resistance.

Section 6–2 Transistor AC Models

1. α_{ac}—ac alpha, I_c/I_e; β_{ac}—ac beta, I_c/I_b; r'_e—ac emitter resistance; r'_b—ac base resistance; r'_e—ac collector resistor.
2. h_{fe} is equivalent to β_{ac}.
3. $r'_e = 25\text{ mV}/15\text{ mA} = 1.67\ \Omega$

Section 6–3 The Common-Emitter Amplifier

1. The capacitors are treated as opens.
2. The gain increases with a bypass capacitor.
3. Swamping eliminates the effects of r'_e by partially bypassing R_E.
4. Total input resistance includes the bias resistors, r'_e, and any unbypassed R_E.
5. The gain is determined by R_c, r'_e, and any unbypassed R_E.
6. The voltage gain decreases with a load.
7. The input and output voltages are 180° out of phase.

Section 6–4 The Common-Collector Amplifier

1. A common-collector amplifier is an emitter-follower.
2. The maximum voltage gain of a common-collector amplifier is 1.
3. A common-collector amplifier has a high input resistance.

Section 6–5 The Common-Base Amplifier

1. Yes
2. The common-base amplifier has a low input resistance.
3. The maximum current gain is 1 in a CB amplifier.

Section 6–6 Multistage Amplifiers

1. A stage is one amplifier in a cascaded arrangement.
2. The overall voltage gain is the product of the individual gains.
3. $20 \log (500) = 54.0$ dB
4. At lower frequencies, X_C becomes large enough to affect the gain.

Section 6–7 The Differential Amplifier

1. Double-ended differential input is between two input terminals. Single-ended differential input is from one input terminal to ground (with other input grounded).
2. Common-mode rejection is the ability of an op-amp to produce very little output when the same signal is applied to both inputs.
3. A higher CMRR results in a lower common-mode gain.

Section 6–8 Troubleshooting

1. If C_4 opens, the gain drops. The dc level would not be affected.
2. Q_2 would be biased in cutoff.
3. The collector voltage of Q_1 and the base, emitter, and collector voltages of Q_2 would change.

RELATED PROBLEMS FOR EXAMPLES

6–1 $I_C = 5$ mA; $V_{CE} = 1.5$ V

6–2 3.13 mA

6–3 9.3 mV

6–4 $C_2 = 28.4\ \mu$F

6–5 97.3

6–6 83

6–7 5; 165

6–8 9.56

6–9 Increases

6–10 71. A single transistor loads the CE amplifier much more than the Darlington pair.

6–11 64.1

6–12 $A'_v = 1500$; $A_{v1(\text{dB})} = 27.96$ dB; $A_{v2(\text{dB})} = 13.98$ dB; $A_{v3(\text{dB})} = 21.58$ dB; $A'_{v(\text{db})} = 63.52$ dB

6–13 34,000; 90.6 dB

6–14 C_3 open

TRUE/FALSE QUIZ

1. T	**2.** T	**3.** F	**4.** T	**5.** F	**6.** F	**7.** T	**8.** T
9. T	**10.** F	**11.** T	**12.** F	**13.** T	**14.** T	**15.** F	

CIRCUIT-ACTION QUIZ

1. (a) **2.** (b) **3.** (a) **4.** (b) **5.** (a) **6.** (c) **7.** (c) **8.** (c) **9.** (c) **10.** (c)

SELF-TEST

1. (a) **2.** (b) **3.** (c) **4.** (b) **5.** (a) **6.** (b) **7.** (b) **8.** (d) **9.** (d) **10.** (d) **11.** (d) **12.** (c) **13.** (a) **14.** (c) **15.** (a) **16.** (d) **17.** (b) **18.** (a) **19.** (c)

ANSWERS

Chapter 7

SECTION CHECKUPS

Section 7–1 The Class A Power Amplifier

1. To dissipate excessive heat

2. The collector

3. Cutoff and saturation clipping

4. 25%

5. The ratio of input resistance to output resistance

Section 7–2 The Class B and Class AB Push-Pull Amplifiers

1. The class B Q-point is at cutoff.

2. The barrier potential of the base-emitter junction causes crossover distortion.

3. Maximum efficiency of a class B amplifier is 79%.

4. Push-pull reproduces both positive and negative alternations of the input signal with greater efficiency.

5. Both transistors in class AB are biased slightly above cutoff. In class B they are biased at cutoff.

Section 7–3 The Class C Amplifier

1. Class C is biased well into cutoff.

2. The purpose of the tuned circuit is to produce a sinusoidal voltage output.

3. $\eta = [1\text{ W}/(1\text{ W} + 0.1\text{ W})]100 = 90.9\%$

Section 7–4 Troubleshooting

1. Excess input signal voltage

2. Open bypass capacitor, C_2

RELATED PROBLEMS FOR EXAMPLES

7–1 Power gain increases.

7–2 The efficiency goes up because no power is wasted in R_{E3}. The problem is that the speaker has direct current in the coil and may burn open.

7–3 15 V, 0.1 A

7–4 7.5 V; 0.25 A

7–5 $P_{out} = 1.76$ W; $P_{DC} = 2.24$ W

7–6 R_{in} would increase.

7–7 3 mW

7–8 The efficiency decreases.

7–9 Halve the input frequency.

TRUE/FALSE QUIZ

1. T **2.** T **3.** F **4.** T **5.** F **6.** T
7. T **8.** F **9.** T **10.** T **11.** F **12.** T

CIRCUIT-ACTION QUIZ

1. (c) **2.** (c) **3.** (c) **4.** (a) **5.** (a)
6. (b) **7.** (c) **8.** (c) **9.** (c) **10.** (a)

SELF-TEST

1. (a) **2.** (b) **3.** (b) **4.** (a) **5.** (b) **6.** (c) **7.** (a) **8.** (e) **9.** (c)
10. (c) **11.** (a) **12.** (c) **13.** (b) **14.** (d) **15.** (a) **16.** (d) **17.** (c)

ANSWERS

Chapter 8

SECTION CHECKUPS

Section 8–1 The JFET

1. Drain, source, and gate
2. An *n*-channel JFET requires a negative V_{GS}.
3. I_D is controlled by V_{GS}.

Section 8–2 JFET Characteristics and Parameters

1. When $V_{DS} = 7$ V at pinch-off and $V_{GS} = 0$ V, $V_P = -7$ V.
2. As V_{GS} increases negatively, I_D decreases.
3. For $V_P = -3$ V, $V_{GS(off)} = +3$ V.

Section 8–3 JFET Biasing

1. A *p*-channel JFET requires a positive V_{GS}.
2. $V_{GS} = V_G - V_S = 0\text{ V} - (8\text{ mA})(1.0\text{ k}\Omega) = -8\text{ V}$
3. $V_{GS} = V_G - V_S = 3\text{ V} - 5\text{ V} = -2\text{ V}$

Section 8–4 The Ohmic Region

1. $2\text{ k}\Omega$
2. Channel resistance increases.
3. $1176\ \Omega$

Section 8–5 The MOSFET

1. Enhancement MOSFET (E-MOSFET) and depletion MOSFET (D-MOSFET)
2. I_D increases.
3. I_D decreases.

Section 8–6 MOSFET Characteristics and Parameters

1. The D-MOSFET has a structural channel; the E-MOSFET does not.
2. $V_{GS(th)}$ and K are not specified for D-MOSFETs.
3. ESD is ElectroStatic Discharge.

Section 8–7 MOSFET Biasing

1. When $V_{GS} = 0$ V, the drain current is equal to I_{DSS}.
2. V_{GS} must exceed $V_{GS(th)} = 2$ V for conduction to occur.

Section 8–8 **The IGBT**

1. IGBT stands for insulated-gate bipolar transistor.
2. High-voltage switching applications
3. The IGBT has a lower output saturation voltage than the MOSFET.
4. The IGBT has a very high input resistance compared to a BJT.
5. Latch-up is a condition in which the IGBT is in the *on* state and cannot be turned off by the gate voltage.

Section 8–9 **Troubleshooting**

1. R_S open, no ground connection
2. Because V_{GS} remains at approximately zero
3. The device is off and $V_D = V_{DD}$.

RELATED PROBLEMS FOR EXAMPLES

8–1 I_D remains at approximately 12 mA.
8–2 $V_P = -4$ V
8–3 $I_D = 3.52$ mA
8–4 $g_m = 1800\ \mu$S; $I_D = 4.32$ mA
8–5 $R_{IN} = 25{,}000$ MΩ
8–6 $V_{DS} = 2$ V; $V_{GS} = -3.12$ V
8–7 $R_S = 245\ \Omega$
8–8 $R_S = 889\ \Omega$
8–9 $R_S = 294\ \Omega$; $R_D = 3$ kΩ
8–10 $V_{GS} \cong -1.8$ V, $I_D \cong 1.8$ mA
8–11 $I_D = 1.81$ mA, $V_{GS} = -2.44$ V
8–12 $I_D \cong 1.25$ mA, $V_{GS} \cong -2.25$ V
8–13 I_D does not change because of the constant-current source.
8–14 R_{DS} values would not change because slopes are constant.
8–15 1.07 kΩ
8–16 $I_D = 25$ mA
8–17 **(a)** *p* channel **(b)** 6.48 mA **(c)** 35.3 mA
8–18 $V_{GS} = 3.13$ V; $V_{DS} = 21.4$ V
8–19 $I_D = 2.13$ mA
8–20 $V_{DS} = 5.6$ V

TRUE/FALSE QUIZ

1. T **2.** F **3.** T **4.** F **5.** F **6.** T **7.** T
8. F **9.** T **10.** T **11.** F **12.** T **13.** F **14.** T

CIRCUIT-ACTION QUIZ

1. (b) **2.** (c) **3.** (b) **4.** (b) **5.** (a) **6.** (a) **7.** (c) **8.** (b)

SELF-TEST

1. (e) **2.** (b) **3.** (a) **4.** (c) **5.** (d) **6.** (c) **7.** (a) **8.** (c)
9. (b) **10.** (d) **11.** (a) **12.** (c) **13.** (d) **14.** (b) **15.** (d) **16.** (c)
17. (d) **18.** (c) **19.** (d) **20.** (b) **21.** (a) **22.** (a) **23.** (d) **24.** (c)
25. (c)

ANSWERS — Chapter 9

SECTION CHECKUPS

Section 9–1 The Common-Source Amplifier

1. The FET with $g_m = 3.5$ mS can produce the higher gain.
2. $A_v = g_m R_d = (2500\ \mu S)(10\ k\Omega) = 25$
3. I_d is at its positive peak and V_{ds} is at its negative peak when V_{gs} is at its positive peak.
4. V_{gs} is an ac quantity, V_{GS} is a dc quantity.
5. Voltage gain of a CS amplifier is determined by g_m and R_d.
6. The gain is halved because $R_d = R_D/2$.

Section 9–2 The Common-Drain Amplifier

1. The ideal maximum voltage gain of a CD amplifier is 1.
2. The voltage gain of a CD amplifier is determined by g_m and R_s.

Section 9–3 The Common-Gate Amplifier

1. The CG amplifier has a low input resistance ($1/g_m$).
2. g_m affects both voltage gain and input resistance.
3. High input resistance, high gain, and excellent high-frequency response

Section 9–4 The Class D Amplifier

1. Modulator, push-pull switching amplifier, and low-pass filter
2. The pulse width is proportional to the amplitude of the input signal.
3. It is passed through a low-pass filter.

Section 9–5 MOSFET Analog Switching

1. When it is turned *off*
2. When it is turned *on*
3. A pulse or dc voltage
4. *R* depends inversely on frequency and capacitance.

Section 9–6 MOSFET Digital Switching

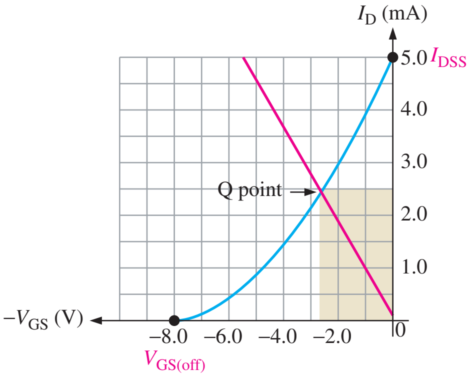
1. A CMOS inverter consists of a *p*-channel and an *n*-channel MOSFET connected in a cascade arrangement.
2. NAND gate
3. NOR gate

Section 9–7 Troubleshooting

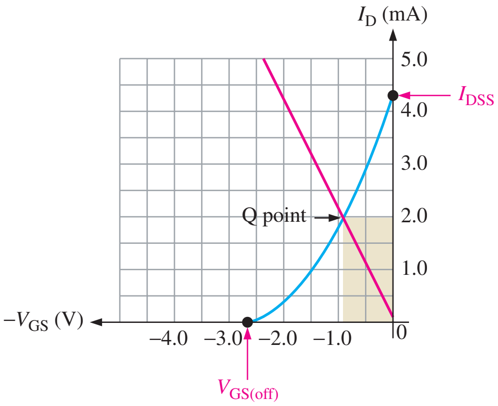
1. To be a good troubleshooter, you must understand the circuit.
2. There would be a lower than normal first-stage gain if C_2 opens.
3. No, but there would be a loss of signal to the second stage.

RELATED PROBLEMS FOR EXAMPLES

9–1 13.2
9–2 See Figure ANS9–1.
9–3 2.319 mA
9–4 See Figure ANS9–2.
9–5 350 mV
9–6 $R_{in} = 9.99\ M\Omega$



▲ ANS9–1



▲ ANS9–2

9–7 ΔI_D decreases; distortion and clipping at cutoff

9–8 $V_{GS} = 2.23$ V; $I_D = 1.09$ mA; $V_{DS} = 11.4$ V; $V_{out} = 750$ mV

9–9 0.976

9–10 $R_{in} = 476\ \Omega$

9–11 The gain increases.

9–12 0.951

9–13 The MOSFET switch would turn *off*.

9–14 > 24 kHz

9–15 Same as the input (no inversion)

TRUE/FALSE QUIZ

1. T **2.** T **3.** F **4.** F **5.** T **6.** F **7.** F **8.** T
9. T **10.** F **11.** T **12.** T **13.** T **14.** F **15.** F

CIRCUIT-ACTION QUIZ

1. (a) **2.** (b) **3.** (a) **4.** (c) **5.** (a) **6.** (b)
7. (b) **8.** (c) **9.** (b)

SELF-TEST

1. (f) **2.** (b) **3.** (c) **4.** (d) **5.** (a) **6.** (c) **7.** (a) **8.** (c)
9. (b) **10.** (a) **11.** (d) **12.** (a) **13.** (b) **14.** (d) **15.** (c) **16.** (a)
17. (c) **18.** (b) **19.** (d) **20.** (a) **21.** (b)

ANSWERS

Chapter 10

SECTION CHECKUPS

Section 10–1

Basic Concepts

(a) The coupling and bypass capacitors affect the low-frequency gain.

(b) The high-frequency gain is limited by internal capacitances.

(c) Coupling and bypass capacitors can be neglected at frequencies for which their reactances are negligible.

(d) $C_{in(Miller)} = (5\text{ pF})(51) = 255$ pF

(e) $C_{out(Miller)} = (3\text{ pF})(1.04) = 3.12$ pF

Section 10–2 **The Decibel**

(a) +12 dB corresponds to a voltage gain of approximately 4.

(b) $A_p = 10 \log(25) = 13.98$ dB

(c) 0 dBm corresponds to 1 mW.

Section 10–3 **Low-Frequency Amplifier Response**

(a) $f_{cl2} = 167$ Hz is dominant.

(b) $A_{v(\text{dB})} = 50 \text{ dB} - 3 \text{ dB} = 47 \text{ dB}$

(c) -20 dB attenuation at one decade below f_{cl}.

(d) $\theta = \tan^{-1}(0.5) = 26.6°$

(e) $f_{cl} = 1/(2\pi(6500\ \Omega)(0.0022\ \mu\text{F})) = 11.1$ kHz

Section 10–4 **High-Frequency Amplifier Response**

(a) The internal transistor capacitances determine the high-frequency response.

(b) $C_{in(tot)} = C_{in(Miller)} + C_{ce} = (4 \text{ pF})(81) + 8 \text{ pF} = 342 \text{ pF}$

(c) The input *RC* circuit dominates.

(d) C_{iss} and C_{rss} are usually specified on a FET datasheet.

(e) $C_{in(tot)} = (3 \text{ pF})(26) + 4 \text{ pF} = 82 \text{ pF}$

Section 10–5 **Total Amplifier Frequency Response**

(a) The gain is 1 at f_T.

(b) $BW = 25 \text{ kHz} - 100 \text{ Hz} = 24.9 \text{ kHz}$

(c) $A_v = 130 \text{ MHz}/50 \text{ MHz} = 2.6$

Section 10–6 **Frequency Response of Multistage Amplifiers**

(a) $f'_{cl(dom)} = 1$ kHz

(b) $f'_{cu(dom)} = 49$ kHz

(c) *BW* decreases.

Section 10–7 **Frequency Response Measurements**

(a) $f_{cl} = 125$ Hz; $f_{cu} = 500$ kHz

(b) Rise time is between the 10% and 90% points and fall time is between the 90% and 10% points.

(c) $t_r = 150$ ns

(d) $t_f = 2.8$ ms

(e) Since $f_{cu} \gg f_{cl}$, $BW \cong f_{cu} = 2.5$ MHz.

RELATED PROBLEMS FOR EXAMPLES

10–1 **(a)** 61.6 dB **(b)** 17 dB **(c)** 102 dB

10–2 **(a)** 50 V **(b)** 6.25 V **(c)** 1.56 V

10–3 0.22 μF

10–4 212 @ 400 Hz; 30 @ 40 Hz; 3 @ 4 Hz

10–5 It will increase the gain and reduce the lower critical frequency.

10–6 C_2 "sees" a smaller resistance.

10–7 f_{cl} changes from 16.2 Hz to 16.1 Hz.

10–8 Ideally, the low-frequency response is not affected because an infinite load makes f_c of the output stage even lower, so the input stage determines the lower cutoff frequency of the amplifier.

10–9 The resistance of the input will be higher, so the critical frequency is lower.

10–10 Change C_1 to 0.68 μF.

10–11 320 Ω in series with 215 pF, $f_c = 2.31$ MHz

10–12 28.7 MHz

10–13 1 pF

10–14 f_c decreases to 83.8 MHz.

10–15 48.2 MHz

10–16 *BW* decreases; *BW* increases

10–17 20 MHz

10–18 980 Hz

10–19 39.8 kHz

10–20 26 dB

TRUE/FALSE QUIZ

1. T **2.** F **3.** F **4.** T **5.** T **6.** F
7. T **8.** T **9.** T **10.** F **11.** T **12.** T

CIRCUIT-ACTION QUIZ

1. (a) **2.** (a) **3.** (a) **4.** (b) **5.** (a) **6.** (b) **7.** (c) **8.** (a) **9.** (b) **10.** (b)

SELF-TEST

1. (d) **2.** (c) **3.** (b) **4.** (d) **5.** (c) **6.** (b) **7.** (a) **8.** (a)
9. (d) **10.** (b) **11.** (c) **12.** (c) **13.** (d) **14.** (b) **15.** (c) **16.** (c)
17. (a) **18.** (c) **19.** (b) **20.** (d) **21.** (b) **22.** (a) **23.** (a)

ANSWERS

Chapter 11

SECTION CHECKUPS

Section 11–1 The Four-Layer Diode

1. The 4-layer diode is a thyristor because it has four semiconductor layers in a *pnpn* configuration.
2. A region of 4-layer diode operation in which the device is nonconducting
3. The device turns on and conducts when V_{AK} exceeds the forward-breakover voltage.
4. When the anode current is reduced below the holding current value, the device turns off.

Section 11–2 The Silicon-Controlled Rectifier (SCR)

1. An SCR (silicon-controlled rectifier) is a three-terminal thyristor.
2. The SCR terminals are anode, cathode, and gate.
3. A positive gate pulse turns the SCR on.
4. Reduce the anode current below I_H (holding current) to turn a conducting SCR off.
5. Open the series switch

Section 11–3 SCR Applications

1. The SCR will conduct for more than 90° but less than 180°.
2. To block discharge of the battery through that path

Section 11–4 The Diac and Triac

1. The diac is like two parallel 4-layer diodes connected in opposite directions.
2. A triac is like two parallel SCRs having a common gate and connected in opposite directions.
3. A triac has a gate terminal, but a diac does not.

Section 11–5 The Silicon-Controlled Switch (SCS)

1. An SCS can be turned off with the application of a gate pulse, but an SCR cannot.

2. A positive pulse on the cathode gate or a negative pulse on the anode gate turns the SCS on.

3. An SCS can be turned off by any of the following:

(a) positive pulse on anode gate

(b) negative pulse on cathode gate

(c) reduce anode current below holding value by complete interruption of the anode current

Section 11–6 The Unijunction Transistor (UJT)

1. The UJT terminals are base 1, base 2, and emitter.

2. $\eta = r'_{B1}/r'_{BB}$

3. R, C, and η determine the period.

Section 11–7 The Programmable Unijunction Transistor (PUT)

1. *Programmable* means that the turn-on voltage can be adjusted to a desired value.

2. The PUT is a thyristor, similar in structure to an SCR, but it is turned on by the anode-to-gate voltage. It has a negative resistance characteristic like the UJT.

RELATED PROBLEMS FOR EXAMPLES

11–1 10 MΩ

11–2 47.1 Ω

11–3 Yes. The current is greater than I_H.

11–4 $V_{AK} = V_s$

11–5 By increasing V_{BB}

11–6 $343\text{ k}\Omega > R_1 > 1.95\text{ k}\Omega$

TRUE/FALSE QUIZ

1. T **2.** F **3.** T **4.** T **5.** F **6.** T
7. T **8.** F **9.** T **10.** T **11.** T **12.** F

CIRCUIT-ACTION QUIZ

1. (b) **2.** (b) **3.** (c) **4.** (b)

SELF-TEST

1. (b) **2.** (d) **3.** (c) **4.** (c) **5.** (a) **6.** (e) **7.** (b) **8.** (b)
9. (d) **10.** (a) **11.** (d) **12.** (d) **13.** (c) **14.** (d) **15.** (c)

ANSWERS Chapter 12

SECTION CHECKUPS

Section 12–1 Introduction to Operational Amplifiers

1. Inverting input, noninverting input, output, positive and negative supply voltages

2. A practical op-amp has very high input impedance, very low output impedance, and very high voltage gain.

3. Differential amplifier, voltage amplifier, and push-pull amplifier

4. The difference between its two input voltages

Section 12–2 Op-Amp Input Modes and Parameters

1. Double-ended input is between two input terminals. Single-ended input is from one input terminal to ground (with other input grounded).
2. Common-mode rejection is the ability of an op-amp to produce very little output when the same signal is applied to both inputs.
3. A higher common-mode gain results in a lower CMRR.
4. Input bias current, input offset voltage, drift, input offset current, input impedance, output impedance, maximum output voltage swing, CMRR, open-loop voltage gain, slew rate, frequency response.
5. A fast pulse is used as the input and the rate of change of the output is measured.

Section 12–3 Negative Feedback

1. Negative feedback provides a stable controlled voltage gain, control of impedances, and wider bandwidth.
2. The open-loop gain is so high that a very small signal on the input will drive the op-amp into saturation.

Section 12–4 Op-Amps with Negative Feedback

1. The main purpose of negative feedback is to stabilize the gain.
2. False
3. $A_{cl} = 1/0.02 = 50$

Section 12–5 Effects of Negative Feedback on Op-Amp Impedances

1. The noninverting configuration has a higher Z_{in} than the op-amp alone.
2. Z_{in} increases in a voltage-follower.
3. $Z_{in(\mathrm{I})} \cong R_i = 2\ \mathrm{k}\Omega, Z_{out(\mathrm{I})} = Z_{out}/(1 + A_{ol}B) = 25\ \mathrm{m}\Omega$

Section 12–6 Bias Current and Offset Voltage

1. Input bias current and input offset voltage are sources of output error.
2. Add a resistor in the feedback path equal to the input source resistance.

Section 12–7 Open-Loop Frequency and Phase Responses

1. Open-loop voltage gain is without feedback, and closed-loop voltage gain is with negative feedback. Open-loop voltage gain is larger.
2. $BW = 100$ Hz
3. A_{ol} decreases.
4. $A_{v(tot)} = 20\ \mathrm{dB} + 30\ \mathrm{dB} = 50\ \mathrm{dB}$
5. $\theta_{tot} = -49° + (-5.2°) = -54.2°$

Section 12–8 Closed-Loop Frequency Response

1. Yes, A_{cl} is always less than A_{ol}.
2. $BW = 3{,}000\ \mathrm{kHz}/60 = 50\ \mathrm{kHz}$
3. $f_T = 3{,}000\ \mathrm{kHz}/1 = 3\ \mathrm{MHz}$

Section 12–9 Troubleshooting

1. Check the output null adjustment.
2. After a verification that there is power supply voltage to the op-amp, then the absence of an output signal probably indicates a bad op-amp.

RELATED PROBLEMS FOR EXAMPLES

12–1 340,000; 111 dB

12–2 20 V/μs

12–3 32.9

12–4 67.5 kΩ

12–5 **(a)** 20.6 GΩ, 14 mΩ **(b)** 23

12–6 Z_{in} increases, Z_{out} decreases.

12–7 $Z_{in(I)} = 560\ \Omega$; $Z_{out(I)} = 110\ \text{m}\Omega$; $A_{cl} = -146$

12–8 **(a)** 79,996 **(b)** 79,900 **(c)** 6380

12–9 173 Hz

12–10 75 dB; $-71.6°$

12–11 2 MHz

12–12 **(a)** 29.6 kHz **(b)** 42.6 kHz

TRUE/FALSE QUIZ

1. T	**2.** F	**3.** T	**4.** T	**5.** F	**6.** T	**7.** T
8. F	**9.** T	**10.** F	**11.** T	**12.** T	**13.** T	**14.** F

CIRCUIT-ACTION QUIZ

1. (b)	**2.** (a)	**3.** (b)	**4.** (a)
5. (a)	**6.** (b)	**7.** (c)	**8.** (b)

SELF-TEST

1. (c)	**2.** (b)	**3.** (d)	**4.** (b)	**5.** (a)	**6.** (c)
7. (b)	**8.** (d)	**9.** (c)	**10.** (d)	**11.** (a)	**12.** (b)
13. (c)	**14.** (d)	**15.** (c)	**16.** (c)	**17.** (a)	**18.** (c)
19. (d)	**20.** (b)	**21.** (b)	**22.** (b)	**23.** (d)	**24.** (a)
25. (d)	**26.** (b)	**27.** (b)	**28.** (a)	**29.** (c)	**30.** (d)

ANSWERS

Chapter 13

SECTION CHECKUPS

Section 13–1 Comparators

1. **(a)** $V = (10\ \text{k}\Omega/110\ \text{k}\Omega)15\ \text{V} = 1.36\ \text{V}$

(b) $V = (22\ \text{k}\Omega/69\ \text{k}\Omega)(-12\ \text{V}) = -3.83\ \text{V}$

2. Hysteresis makes the comparator less susceptable to noise.

3. Bounding limits the output amplitude to a specified level.

Section 13–2 Summing Amplifiers

1. The summing point is the point where the input resistors are commonly connected.

2. $R_f/R = 1/5 = 0.2$

3. 5 kΩ

Section 13–3 Integrators and Differentiators

1. The feedback element in an ideal integrator is a capacitor.

2. The capacitor voltage is linear because the capacitor current is constant.

3. The feedback element in a differentiator is a resistor.

4. The output of a differentiator is proportional to the rate of change of the input.

Section 13–4 **Troubleshooting**

1. An op-amp can fail with a shorted output.
2. Replace suspected components one by one.

RELATED PROBLEMS FOR EXAMPLES

13–1 1.96 V

13–2 +3.83 V; −3.83 V

13–3 +1.81 V; −1.81 V

13–4 More accurately

13–5 −11.5 V

13–6 −5.73 V

13–7 Changes require an additional 100 kΩ input resistor and a change of R_f to 20 kΩ.

13–8 0.45, 0.12, 0.18; $V_{OUT} = -3.03$ V

13–9 Yes. All should be doubled.

13–10 Change C to 5000 pF.

13–11 Same waveform but with an amplitude of 6.6 V

13–12 A pulse from −0.88 V to +7.79 V

13–13 −3.76 V

13–14 Change R_6 to 25 kΩ.

TRUE/FALSE QUIZ

1. T **2.** F **3.** T **4.** T **5.** T **6.** F **7.** F **8.** T
9. T **10.** T **11.** F **12.** T

CIRCUIT-ACTION QUIZ

1. (b) **2.** (a) **3.** (a) **4.** (b) **5.** (b) **6.** (c) **7.** (b)
8. (a) **9.** (c) **10.** (a)

SELF-TEST

1. (c) **2.** (a) **3.** (c) **4.** (e) **5.** (b) **6.** (d)
7. (c) **8.** (c) **9.** (a) **10.** (b) **11.** (c) **12.** (b)
13. (d) **14.** (d) **15.** (a) **16.** (d) **17.** (c)

ANSWERS Chapter 14

SECTION CHECKUPS

Section 14–1 **Instrumentation Amplifiers**

1. The main purpose of an instrumentation amplifier is to amplify small signals that occur on large common-mode voltages. The key characteristics are high input impedance, high CMRR, low output impedance, and low output offset.
2. Three op-amps and seven resistors including the gain resistor are required to construct a basic instrumentation amplifier (see Figure 14–2).
3. The gain is set by the external resistor R_G.
4. The gain is approximately 6.
5. To reduce effects of noise on the common-mode operation of an IA

Section 14–2 Isolation Amplifiers

1. Isolation amplifiers are used in medical equipment, power plant instrumentation, industrial processing, and automated testing.
2. The two stages of an isolation amplifier are input and output and their purpose is isolation.
3. The stages are connected by capacitive, optical, or transformer coupling.
4. The oscillator is used to provide the signal to be modulated.

Section 14–3 Operational Transconductance Amplifiers (OTAs)

1. OTA stands for Operational Transconductance Amplifier.
2. Transconductance increases with bias current.
3. Assuming that the bias input is connected to the supply voltage, the voltage gain increases when the supply voltage is increased because this increases the bias current.
4. The voltage gain decreases as the bias voltage decreases.

Section 14–4 Log and Antilog Amplifiers

1. A diode or transistor in the feedback loop provides the exponential (nonlinear) characteristic.
2. The output of a log amplifier is limited to the barrier potential of the *pn* junction (about 0.7 V).
3. The output voltage is determined by the input voltage, the input resistor, and the emitter-to-base leakage current.
4. The transistor in an antilog amplifier is in series with the input rather than in the feedback loop.

Section 14–5 Converters and Other Op-Amp Circuits

1. $I_L = 6.8\text{ V}/10\text{ k}\Omega = 0.68\text{ mA}$; same value to $5\text{ k}\Omega$ load.
2. The feedback resistor is the constant of proportionality.

RELATED PROBLEMS FOR EXAMPLES

14–1 241 Ω

14–2 Make $R_G = 1.1\text{ k}\Omega$.

14–3 The ripple could be removed by an output low-pass filter.

14–4 Many combinations are possible. Here is one: $R_{f1} = 10\text{ k}\Omega$, $R_{i1} = 1.0\text{ k}\Omega$, $R_{f2} = 10\text{ k}\Omega$, and $R_{i2} = 1.0\text{ k}\Omega$

14–5 $I_{BIAS} \cong 62.5\ \mu A$

14–6 Yes. The gain will change to approximately 110.

14–7 The output is a square-wave modulated signal with a maximum amplitude of approximately 3.6 V and a minimum amplitude of approximately 1.76 V.

14–8 −0.167 V

14–9 −0.193 V

14–10 −4.39 V

TRUE/FALSE QUIZ

1. T	**2.** F	**3.** T	**4.** F	**5.** T
6. F	**7.** F	**8.** T	**9.** T	**10.** T

CIRCUIT-ACTION QUIZ

1. (b)	**2.** (c)	**3.** (b)	**4.** (a)
5. (c)	**6.** (b)	**7.** (a)	**8.** (a)

SELF-TEST

1. (d)	**2.** (b)	**3.** (a)	**4.** (e)	**5.** (c)	**6.** (b)	**7.** (a)	**8.** (c)
9. (d)	**10.** (c)	**11.** (a)	**12.** (b)	**13.** (f)	**14.** (b)	**15.** (c)	**16.** (b)

ANSWERS

Chapter 15

SECTION CHECKUPS

Section 15–1 Basic Filter Responses

1. The critical frequency determines the passband.
2. The inherent frequency limitation of the op-amp limits the bandwidth.
3. Q and BW are inversely related. The higher the Q, the better the selectivity, and vice versa.

Section 15–2 Filter Response Characteristics

1. Butterworth is very flat in the passband and has a −20 dB/decade/pole roll-off. Chebyshev has ripples in the passband and has greater than −20 dB/decade/pole roll-off. Bessel has a linear phase characteristic and less than −20 dB/decade/pole roll-off.
2. The damping factor
3. Frequency-selective circuit, gain element, and negative feedback circuit are the parts of an active filter.

Section 15–3 Active Low-Pass Filters

1. A second-order filter has two poles. Two resistors and two capacitors make up the frequency-selective circuit.
2. The damping factor sets the response characteristic.
3. Cascading increases the roll-off rate.

Section 15–4 Active High-Pass Filters

1. The positions of the Rs and Cs in the frequency-selective circuit are opposite for low-pass and high-pass configurations.
2. Decrease the R values to increase f_c.
3. −140 dB/decade

Section 15–5 Active Band-Pass Filters

1. Q determines selectivity.
2. $Q = 25$. Higher Q gives narrower BW.
3. A summing amplifier and two integrators make up a state-variable filter.
4. An inverting amplifier and two integrators make up a biquad filter.

Section 15–6 Active Band-Stop Filters

1. A band-stop rejects frequencies within the stopband. A band-pass passes frequencies within the passband.
2. The low-pass and high-pass outputs are summed.

Section 15–7 Filter Response Measurements

1. To check the frequency response of a filter
2. Discrete point measurement: tedious and less complete; simpler equipment. Swept frequency measurement: uses more expensive equipment; more efficient, can be more accurate and complete.

RELATED PROBLEMS FOR EXAMPLES

15–1 500 Hz

15–2 1.44

15–3 7.23 kHz; 1.29 kΩ

15–4 $C_{A1} = C_{A2} = C_{B1} = C_{B2} = 0.234\ \mu F$; $R_2 = R_4 = 680\ \Omega$; $R_1 = 103\ \Omega$; $R_3 = 840\ \Omega$

15–5 $R_A = R_B = R_2 = 10\ k\Omega$; $C_A = C_B = 0.053\ \mu F$; $R_1 = 5.86\ k\Omega$

15–6 Gain increases to 2.43, frequency decreases to 544 Hz, and bandwidth decreases to 96.5 Hz.

15–7 $f_0 = 21.9\ \text{kHz}$; $Q = 101$; $BW = 217\ \text{Hz}$

15–8 Decrease the input resistors or the feedback capacitors of the two integrator stages by half.

TRUE/FALSE QUIZ

1. T	**2.** F	**3.** T	**4.** F	**5.** T	**6.** F	**7.** T
8. T	**9.** F	**10.** T	**11.** T	**12.** F	**13.** T	**14.** T
15. T	**16.** T	**17.** F	**18.** F	**19.** T	**20.** T	

CIRCUIT-ACTION QUIZ

1. (a) **2.** (b) **3.** (b) **4.** (b) **5.** (c) **6.** (a) **7.** (b) **8.** (b)

SELF-TEST

1. (c)	**2.** (d)	**3.** (a)	**4.** (b)	**5.** (c)	**6.** (c)	**7.** (b)	**8.** (a)
9. (d)	**10.** (b)	**11.** (a)	**12.** (a)	**13.** (d)	**14.** (c)	**15.** (b)	**16.** (d)

ANSWERS

Chapter 16

SECTION CHECKUPS

Section 16–1 **The Oscillator**

1. An oscillator is a circuit that produces a repetitive output waveform with only the dc supply voltage as an input.
2. Positive feedback
3. The feedback circuit provides attenuation and phase shift.
4. Feedback and relaxation

Section 16–2 **Feedback Oscillators**

1. Zero phase shift and unity voltage gain around the closed feedback
2. Positive feedback is when a portion of the output signal is fed back to the input of the amplifier such that it reinforces itself.
3. Loop gain greater than 1

Section 16–3 **Oscillators with *RC* Feedback Circuits**

1. The negative feedback loop sets the closed-loop gain; the positive feedback loop sets the frequency of oscillation.
2. 1.67 V
3. The three *RC* circuits contribute a total of 180° and the inverting amplifier contributes 180° for a total of 360° around the loop.

Section 16–4 **Oscillators with *LC* Feedback Circuits**

1. Colpitts uses a capacitive voltage divider in the feedback circuit; Hartley uses an inductive voltage divider.
2. The higher FET input impedance has less loading effect on the resonant feedback circuit.
3. A Clapp has an additional capacitor in series with the inductor in the feedback circuit.

Section 16–5 **Relaxation Oscillators**

1. A voltage-controlled oscillator exhibits a frequency that can be varied with a dc control voltage.
2. The basis of a relaxation oscillator is the charging and discharging of a capacitor.

Section 16–6 **The 555 Timer as an Oscillator**

1. Two comparators, a flip-flop, a discharge transistor, and a resistive voltage divider
2. The duty cycle is set by the external resistors.

RELATED PROBLEMS FOR EXAMPLES

16–1 R_f too high causes clipping. R_f too low causes oscillations to die out.

16–2 **(a)** 238 kΩ **(b)** 7.92 kHz

16–3 7.24 kHz

16–4 6.06 V peak-to-peak

16–5 1122 Hz

16–6 31.9%

TRUE/FALSE QUIZ

1. T	**2.** F	**3.** F	**4.** T	**5.** F	**6.** T	**7.** T	**8.** T
9. F	**10.** T	**11.** F	**12.** T	**13.** F	**14.** F	**15.** T	

CIRCUIT-ACTION QUIZ

1. (b)	**2.** (a)	**3.** (a)	**4.** (b)	**5.** (a)	**6.** (b)	**7.** (c)	**8.** (a)

SELF-TEST

1. (b)	**2.** (c)	**3.** (b)	**4.** (d)	**5.** (c)	**6.** (a)	**7.** (b)
8. (d)	**9.** (a)	**10.** (c)	**11.** (c)	**12.** (b)	**13.** (a)	**14.** (c)

ANSWERS

Chapter 17

SECTION CHECKUPS

Section 17–1 **Voltage Regulation**

1. The percentage change in the output voltage for a given change in input voltage.
2. The percentage change in output voltage for a given change in load current.
3. 1.2%; 0.06%/V
4. 1.6%; 0.0016%/mA

Section 17–2 **Basic Linear Series Regulators**

1. Control element, error detector, sampling element, reference voltage
2. 2 V

Section 17–3 **Basic Linear Shunt Regulators**

1. In a shunt regulator, the control element is in parallel with the load rather than in series.
2. A shunt regulator has inherent current limiting. A disadvantage is that a shunt regulator is less efficient than a series regulator.

Section 17–4 **Basic Switching Regulators**

1. Step-down, step-up, inverting
2. Switching regulators operate at a higher efficiency.
3. The duty cycle varies to regulate the output.

Section 17–5 Integrated Circuit Voltage Regulators

1. Input, output, and ground
2. A 7809 has a +9 V output; A 7915 has a −15 V output.
3. Input, output, adjustment
4. A two-resistor voltage divider

Section 17–6 Integrated Circuit Voltage Regulator Configurations

1. A pass transistor increases the current that can be handled.
2. Current limiting prevents excessive current and prevents damage to the regulator.
3. Thermal overload occurs when the internal power dissipation becomes excessive.

RELATED PROBLEMS FOR EXAMPLES

17–1 0.6%/V

17–2 1.12%, 0.0224%/mA

17–3 7.33 V

17–4 0.7 A

17–5 17.5 W

17–6 12.7 V

17–7 467 mA

17–8 12 W

17–9 16 Ω

TRUE/FALSE QUIZ

1. T **2.** F **3.** T **4.** F **5.** T
6. F **7.** T **8.** T **9.** T **10.** F

CIRCUIT-ACTION QUIZ

1. (c) **2.** (a) **3.** (b) **4.** (a) **5.** (c) **6.** (a) **7.** (b) **8.** (b)

SELF-TEST

1. (c) **2.** (d) **3.** (c) **4.** (b) **5.** (d) **6.** (a) **7.** (c) **8.** (d) **9.** (a)
10. (g) **11.** (c)

ANSWERS Chapter 18

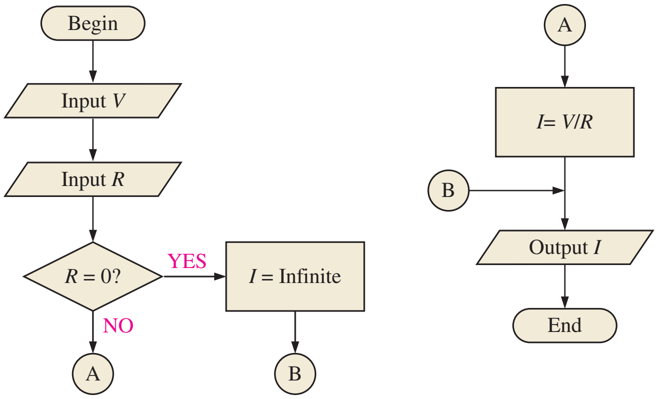
SECTION CHECKUPS

Section 18–1 Programming Basics

1. The five basic instruction types are basic instructions, conditional instructions, looping instructions, branching instructions, and exception instructions.
2. Two methods for defining the tasks and sequence of tasks that a computer must perform are flowcharts and pseudocode.
3. See Figure ANS18–1.

▶ ANS18–1

Modified flowchart.



4. Advantages of using pseudocode, compared to using a flowchart, are that pseudocode provides greater structure to the finished code, can be incorporated into the program headers to document the source code, and is generally quicker and easier to create and modify than flowcharts.

Section 18–2 Automated Testing Basics

1. The four components that make up a basic automated test system are the test controller, the test equipment and instrumentation, the test fixture, and the unit under test.
2. The test controller in an automated test system executes the test code that defines the test tasks, configures the test equipment, instrumentation, and fixture, and coordinates the activities of the test system.
3. The test fixture connects the test equipment and instrumentation to the unit under test.
4. Introducing delays in an automated test system compensates for the finite response time of practical test equipment, instrumentation, and circuits.

Section 18–3 The Simple Sequential Program

1. Some applications that use simple sequential programs are those used by programmable consumer products, such as microwave ovens, video recorders, and automated sprinkler systems.
2. The simple sequential program can contain any instructions that do not alter the sequence of program execution.
3. A subroutine is a section of code, often used by complex programs to perform simple but frequently-used tasks.

Section 18–4 Conditional Execution

1. The flowchart block associated with conditional execution is the decision block.
2. The two instructions used in conditional execution are the IF-THEN-ELSE and CASE instructions.
3. The basic difference between the IF-THEN and IF-THEN-ELSE instruction is that the IF-THEN instruction takes no action if the tested condition is not TRUE.
4. The major difference between the IF-THEN-ELSE and CASE instruction is that the CASE instruction determines whether a program variable is equal to or not equal to specific values. The IF-THEN-ELSE instruction determines whether some condition is TRUE, and can test whether a program variable is less than or greater than as well as equal to or not equal to specific values.

Section 18–5 Program Loops

1. A basic program loop is a sequence of program execution in which the program returns to a previous point of execution.
2. Program execution forms a circular path, or "loop" in the program.
3. The three major types of program loops are the FOR-TO-STEP loop, the WHILE-DO loop, and the REPEAT-UNTIL loop.

4. A WHILE-DO loop differs from a REPEAT-UNTIL loop in that the WHILE-DO loop checks the loop condition before executing the loop instructions rather than after, and it remains in the loop while the loop condition is TRUE rather than FALSE.
5. A nested loop is a sequence of instructions in which part of a loop is itself a loop, creating a loop within a loop.

Section 18–6 Branching and Subroutines

1. A branching instruction is an instruction that transfers control to some specific section of code.
2. The two objectives that branching accomplishes is to avoid executing code that immediately follows the branching instruction, and to access code that does not immediately follow the branching instruction.
3. Coupling reflects the extent to which one part of a program interacts with or potentially affects another part of the program. Cohesion refers to how well a program or procedure keeps together all the code that is associated with a specific task.
4. Three basic guidelines for using general branches in programs are (a) programs, especially high-level programs, should avoid unconditional branching, (b) programs should avoid nested branches, especially unconditional branches, and (c) branches should always be a conscious design decision to simplify the program.
5. A subroutine call differs from a general branching instruction in that once a subroutine completes, the program execution automatically resumes at the instruction that immediately follows the instruction that called the subroutine.

RELATED PROBLEMS FOR EXAMPLES

18–1 Terminal *B* of Port 1 connects to the terminal for TP4 through the contacts of relay K_8. Relay K_8 is energized.

18–2 The diode can be reverse-biased by connecting the positive and negative terminals of the dc supply to test point terminals 3 and 1, respectively. To do so, the test controller can energize the coils of relays K_3 and K_5, connecting terminals *A* and *B* of Port 1 to test point terminals 3 and 1, respectively.

18–3 Two advantages of measuring the resistor value are (1) the test will compensate for variations in resistor value due to the initial resistor tolerance, resistor aging, and ambient temperature, and (2) the test will not require modification if the resistor value in the circuit changes.

18–4 One possible pseudocode description is

```
program NewCalculatePower
    begin
        input current value
        input resistance value
        power value is current value squared times
            resistance value
        output power value
    end NewCalculatePower
```

18–5 One possible pseudocode description is

```
program CalculateMaximumValue
    begin
        input resistance value
        input tolerance value
        deviation value is resistance value times
            tolerance value
        maximum value is resistance value plus deviation value
        output maximum value
    end CalculateMaximumValue
```

18–6 One possible pseudocode description is

```
program DiodeCheck
    begin
        apply 5 V to circuit
        measure diode voltage
```

```
      if (diode voltage equals 0.7 V) then
         begin if
            print "Diode forward biased"
         end if
      else
         begin else
            print "Diode reverse biased"
         end else
   end DiodeCheck
```

18–7 One possible pseudocode description for the program is

```
program NewAndImprovedDiodeCheck
   begin
      apply 5 V to circuit
      measure diode voltage
      if (diode voltage is less than 1 V) then
         begin if
            if (diode voltage is 0 V) then
               begin if
                  print "Diode shorted"
               end if
            else
               begin else
                  print "Diode forward biased"
               end else
         end if
      else
         begin else
            if (diode voltage is greater than 4.5 V) then
               begin if
                  if (diode voltage equals 5 V) then
                     begin if
                        print "Diode open"
                     end if
                  else
                     begin else
                        print "Diode reverse biased"
                     end else
               end if
            else
               begin else
                  print "Diode bad"
               end else
         end else
   end NewAndImprovedDiodeCheck
```

18–8 One possible pseudocode description for the program is

```
program NewAndImprovedCaseDiodeCheck
   begin
      apply 5 V to circuit
      measure diode voltage
      case (diode voltage)
         begin case
            0.0:     print "Diode shorted"
                     break
            0.7:     print "Diode forward biased"
                     break
            4.5:     print "Diode reverse biased"
                     break
```

```
            5.0:     print "Diode open"
                     break
            default: print "Diode bad"
                     break
        end case
    end NewAndImprovedCaseDiodeCheck
```

If the measured diode voltage is 2.5 V, the program prints “Diode bad”.

18–9 One possible pseudocode description for the program is

```
program MixedDiodeCheck
    begin
        apply 5 V to circuit
        measure diode voltage
        if (diode voltage is less than 1.0 V)
            begin if
                if (diode voltage is 0 V)
                    begin if
                        set diode condition to 1
                    end if
                else
                    begin else
                        set diode condition to 2
                    end else
            end if
        else
            begin else
               if (diode voltage is greater than 4.5 V) then
                   begin if
                       if (diode voltage is 5.0 V) then
                           begin if
                                set diode condition to 3
                           end if
                        else
                           begin else
                               set diode condition to 4
                           else else
                   end if
                else
                    begin else
                        set diode condition to 5
                    end else
            end else
        case (diode condition)
            begin case
                1: print "Diode shorted"
                   break
                2: print "Diode forward biased"
                   break
                3: print "Diode open"
                   break
                4: print "Diode reverse biased"
                   break
                5: print "Diode bad"
                   break
        end case
    end MixedDiodeCheck
```

18–10 The procedure and results using the pseudocode are:

The multiplicand value is set to 4 and the multiplier value is set to 5.

The product value is set to 0.

The loop index is set to 1.

The loop index does not exceed 5, so the loop executes.

The product value = product value + multiplicand value, so the product value = 0 + 4 = 4.

The loop index is adjusted by 1 so the loop index = 1 + 1 = 2.

The loop index does not exceed 5, so the loop executes.

The product value = product value + multiplicand value, so the product value = 4 + 4 = 8.

The loop index is adjusted by 1 so the loop index = 2 + 1 = 3.

The loop index does not exceed 5, so the loop executes.

The product value = product value + multiplicand value, so the product value = 8 + 4 = 12.

The loop index is adjusted by 1 so the loop index = 3 + 1 = 4.

The loop index does not exceed 5, so the loop executes.

The product value = product value + multiplicand value, so the product value = 12 + 4 = 16.

The loop index is adjusted by 1 so the loop index = 4 + 1 = 5.

The index does not exceed 5, so the loop executes.

The product value = product value + multiplicand value, so the product value = 16 + 4 = 20.

The loop index is adjusted by 1 so the loop index = 5 + 1 = 6.

The loop index exceeds 5, so the program exits the loop.

The procedure outputs the product value of 20.

18–11 One possible pseudocode description to decrease the voltage across TP1 and TP3 from 0 V to −1 V in 0.1 V increments and to plot the zener current vs. zener voltage for each voltage setting is

```
program Plot1N4732ForwardBias
    begin
        set DMM1 function to dc voltmeter mode
        connect Port 2A to TP1 and Port 2B to TP2
        set DMM2 function to dc voltmeter mode
        connect Port 3A to TP2 and Port 3B to TP3
        set dc supply to 0 V
        connect Port 1A to TP3 and Port 1B to TP1
        for (index = 0) to (index equals -1) step (-0.1)
            begin for-to-step
                set dc supply value to index value
                read resistor voltage value on DMM1
                zener current value is resistor voltage
                    value divided by 1.0 kilohms
                read zener voltage value on DMM2
                plot zener current value vs. zener voltage
                    value
            end for-to-step
    end Plot1N4732ForwardBias
```

18–12 A possible problem with the WHILE-DO loop in the pseudocode description in Example 18–12 is that system noise or meter resolution will prevent DMM1 from ever reading exactly 0 V. As a result, the program could enter an infinite loop and possibly damage the JFET as V_{GS} continued to increase beyond $V_{GS(off)}$. Although the best solution would be to ensure that the test system is well-grounded and shielded from noise, another way to correct this is to modify the WHILE-DO condition to a more practical termination value that closely approximates the actual cutoff condition:

```
while (DMM1 voltage value is greater than 5 mV)
    begin while-do
        increase dc supply 2 by 0.1 V
        read voltage value on DMM1
    end while-do
```

This will terminate the WHILE-DO loop when the I_D value calculated from the measured voltage value first drops below 50 μA.

8–13 One possible pseudocode description that uses a REPEAT-UNTIL loop to determine and print the value of breakover voltage that will fire the SCR into conduction for $I_G = 0$ is

```
program FindSCRBreakoverValue
    begin
        set DMM1 function to dc voltmeter mode
        set DMM2 function to dc voltmeter mode
        set dc supply 1 to 0 V
        set dc supply 2 to 0 V
        connect Port 1A to TP2 and Port 1B to TP3
        connect Port 2A to TP1 and Port 2B to TP3
            read voltage value on DMM2
        IAK is DMM2 voltage value divided by 100
        repeat until (IAK is greater than 45 mA)
            begin repeat-until
                increase dc supply 2 by 0.1 V
                read voltage value on DMM2
                IAK is DMM2 voltage value divided by 100
            end repeat-until
        VBR(F) value is DMM2 value
        print VBR(F) value
    end FindSCRBreakoverValue
```

18–14 The pseudocode description in Example 18–14 would require that the polarities of the base and collector biasing voltages be reversed. The simplest way to do so would be to reverse the connections to the UUT through the test fixture.

```
program Plot2N3906Curves
    begin
        set DMM1 function to dc voltmeter mode
        set DMM2 function to dc voltmeter mode
        set dc supply 1 to 0 V
        set dc supply 2 to 0 V
        connect Port 1A to TP3 and Port 1B to TP2
        connect Port 2A to TP3 and Port 2B to TP1
        for (index1 = 0.7) to (index1 equals 1.0) step (0.05)
            begin for-to-step
                set dc supply 1 to index1 value
                IB value is dc supply voltage value divided
                   by 5 kilohms
                plot label "IB = " and IB value
                for (index2 = 0) to (index2 equals 10) step (1)
                    begin for-to-step
                        set dc supply 2 to index2 value
                        read voltage on DMM2
                        IC value is DMM2 voltage value
                           divided by 100 ohms
                        VCE value is index 2 value minus
                           DMM2 voltage value
                        plot IC value vs. VCE value
                    end for-to-step
            end for-to-step
    end Plot2N3906Curves
```

18–15 Rewriting the pseudocode consists only of replacing the unconditional branches with the code to which the program branches. The pseudocode without the unconditional branch instructions is

```
program TestInvertingAmplifier
    begin
        initialize test fixture
        print "Test fixture initialized"
```

```
NewTestInit:
       set signal generator offset to 500 mVdc
       set signal generator ac output to 0 Vpp
       print "System intialized for dc test"
DCTest:
       measure and record dc output signal
       print "500 mV dc test completed"
       dc gain value is output signal divided by 500 mV
       print "Gain calculated for dc input"
ACTest:
       set signal generator offset to 0 Vdc
       set signal generator ac output to 100 mVpp
       apply input test signal
       measure and record peak-to-peak output signal
       print "100 mV ac test completed"
CalculateNominalGain:
       nominal gain value is output signal divided by 100 mV
       print "Gain calculated for nominal input"
TestMinimumSignal:
       set signal generator ac output to 10 mVpp
       measure and record peak-to-peak output signal
       print "10 mV ac test completed"
       minimum gain value is output test divided by 10 mV
       print "Gain calculated for minimum input"
TestMaximumSignal:
       set signal generator ac output to 1 Vpp
       measure and record peak-to-peak output signal
       print "1 V ac test completed"
       maximum gain value is output signal
       print "Gain calculated for maximum input"
AllTestsRun:
       print "AC test completed"
       print "Inverting amplifier testing complete"
   end TestInvertingAmplifier
```

18–16 Although the multiple instances of "measure summing amplifier output" could be replaced with calls to a subroutine MeasureSummingAmplfiierOutput, modifying the program to do so would not provide any benefit. The overhead to call, execute, and return from the procedure would take more time and require more instructions than the original program requires.

18–17 One possible pseudocode description to replace the subroutines MeasureNominalGain, MeasureMinimumGain, and MeasureMaximumGain with a single subroutine MeasureGain is

```
program CalculateAmplifierGains
   begin
       call ConfigureTestFixture (5.0)
       print "Test fixture initialized"
       NewTestInit:
       set signal generator offset to 500 mVdc
       set signal generator ac output to 0 Vpp
       print "System intialized for dc test"
NominalACTest:
       call MeasureGain(0.05)
MinimumACTest:
       call MeasureGain(0.5)
MaximumACTest:
       call MeasureGain(5.0)
AllGainsMeasured:
       print "AC test completed"
       print "Inverting amplifier testing complete"
```

```
        call ConfigureTestFixture (0.0)
    end CalculateAmplifierGains

procedure ConfigureTestFixture(DCSupply1Value)
    begin
        open all relays
        set dc supply 1 to DCSupply1Value
        set dc supply 2 to 0.0
        set dc supply 3 to 0.0
    end ConfigureTestFixture

procedure MeasureGain(InputValue)
    begin
        set signal generator offset to 0 Vdc
        set signal generator ac output to InputValue
        apply input test signal
        measure and record peak-to-peak output signal
        nominal gain value is output signal divided by
            InputValue
        print InputValue and "ac test completed"
    end MeasureGain
```

TRUE/FALSE QUIZ

1. T **2.** T **3.** T **4.** F **5.** F **6.** F **7.** T
8. F **9.** T **10.** F **11.** T **12.** T **13.** F

SELF-TEST

1. (d) **2.** (b) **3.** (c) **4.** (c) **5.** (a) **6.** (d) **7.** (d) **8.** (c) **9.** (a)
10. (b) **11.** (c) **12.** (a) **13.** (b) **14.** (c) **15.** (a) **16.** (d) **17.** (b) **18.** (a)

ANSWERS

GreenTech Application

GA1

1. Solar module (panel) or array, Charge controller, batteries, inverter.
2. Cells must be in series to increase output voltage.
3. The charge controller maintains proper charging of the batteries.
4. The inverter converts the dc voltage from the solar panel or the batteries to ac voltage.
5. Result will vary depending on source. Typical range: voltage 12 V-48 V, power up to 200 W.

GA2

1. Deep-cycle batteries can be repeatedly discharged by as much as 89%.
2. Higher charge voltage ensures proper charging.
3. The MPPT charge controller is most efficient.
4. Result will vary depending on source. Up to 8400 W is typical.
5. Output voltage is 24 V. Ah rating is 500 Ah.

GA3

1. A stand-alone inverter is used in small systems where all the power is used on-site. The grid-tie inverter connects to the electrical grid and supplies power to users on the grid or to users on the grid and on-site.
2. Sine-wave and modified sine-wave inverters are common. A third type, square wave, is seldom used.

3. Results will vary with the individual.
4. Results will vary with the location.
5. Result will vary depending on source. Typical range: 1 kW to 100 kW.

GA4

1. The types of solar trackers are azimuth and elevation.
2. Azimuth trackers follow the sun's path daily. Elevation trackers follow the sun's position seasonally.
3. Winter solstice is on December 21 or December 22.
4. Summer solstice is on June 20 or June 21.
5. Results will vary. Dual-axis collects more energy year round but single axis is less expensive.

GA5

1. HAWT is horizontal axis wind turbine.
2. The amplitude varies depending on speed of rotation.
3. Wind velocity, air density, length of blades.
4. Betz limit is 59% of the wind energy that can be extracted.
5. Results will vary. It depends on regional laws, the size of the turbines, and the terrain.

GA6

1. VAWT is vertical axis wind turbine.
2. Darrieus, giromill, savonius, and helical
3. Advantages of a VAWT are that the generator and control electronics can be placed on the ground and VAWTs can be placed closer together.
4. Results will vary.