

# PRACTICE EXAM 7: FE ELECTRICAL AND COMPUTER SIMULATION (110 QUESTIONS)

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**Time allotted: 5 hours 20 minutes**

**Materials: NCEES-approved calculator + NCEES FE Reference Handbook only**

1. For the complex number  $z = 2 \cdot e^{j\pi/4}$ , evaluate  $z^4$  in standard rectangular form.

- A.  $8 + j8$
- B.  $-16 + j0$
- C.  $16 + j0$
- D.  $0 - j16$

2. Evaluate the definite integral  $\int_0^{\pi/2} \sin^2(x) dx$ .

- A.  $\pi/4$
- B.  $\pi/2$
- C. 1
- D.  $\pi/8$

3. Find the general solution to the ODE  $y'' - 4y' + 4y = 0$ .

- A.  $y = C_1 \cdot \cos(2x) + C_2 \cdot \sin(2x)$

B.  $y = C_1 \cdot e^{-2x} + C_2 \cdot e^{2x}$

C.  $y = C_1 \cdot e^{2x} + C_2 \cdot e^{-2x}$

D.  $y = (C_1 + C_2 \cdot x) \cdot e^{2x}$

4. What is the determinant of the matrix with rows  $[2, -1, 0]$ ,  $[3, 1, 2]$ , and  $[1, 0, -4]$ ?

A. 17

B. -15

C. -22

D. 0

5. What is the result of the matrix multiplication  $[[1, 2], [3, 4]] \times [[5, 6], [7, 8]]$ ?

A.  $[[19, 22], [43, 50]]$

B.  $[[5, 12], [21, 32]]$

C.  $[[12, 14], [28, 32]]$

D.  $[[25, 36], [49, 64]]$

6. For the function  $f(x) = \ln(x^2 + 1)$ , find  $f'(2)$ .

A.  $1/5$

B.  $4/5$

C.  $2/5$

D.  $5/4$

7. Apply the Laplace transform to  $f(t) = t \cdot e^{-2t} \cdot u(t)$ .

A.  $1/(s + 2)$

B.  $2/(s + 2)^2$

C.  $1/[s(s + 2)]$

D.  $1/(s + 2)^2$

8. What is the value of  $(1 + j)^{10}$ ?

A. 0

B. 32

C.  $32j$

D.  $-32$

9. Evaluate the surface integral  $\oiint F \cdot dS$  for  $F = (x, y, z)$  over the surface of the unit sphere centered at the origin, using the divergence theorem.

A. 0

B.  $4\pi$

C.  $4\pi/3$

D.  $8\pi/3$

10. Determine the radius of convergence of the power series  $\sum_{n=1}^{\infty} (n \cdot x^n)/(2^n)$ .

A.  $1/2$

B. 1

C. 0

D. 2

11. What is the gradient of  $f(x, y, z) = x^2 \cdot y + y \cdot z^2$  at the point  $(1, 2, 1)$ ?

A.  $4 \cdot \hat{i} + 2 \cdot \hat{j} + 4 \cdot \hat{k}$

- B.  $2\hat{i} + 1\hat{j} + 4\hat{k}$
- C.  $1\hat{i} + 1\hat{j} + 2\hat{k}$
- D.  $2\hat{i} + 4\hat{j} + 1\hat{k}$

12. In how many distinct ways can the letters in "ENGINEERING" be arranged?

- A. 11!
- B. 110,000
- C. 277,200
- D. 39,916,800

13. For two unit vectors  $a$  and  $b$  satisfying  $a \cdot b = 1/2$ , what is the angle between them?

- A.  $30^\circ$
- B.  $60^\circ$
- C.  $45^\circ$
- D.  $90^\circ$

14. A binomial random variable  $X$  has  $n = 10$  trials and  $p = 0.3$ . What is the variance of  $X$ ?

- A. 3.0
- B. 0.7
- C. 4.21
- D. 2.1

15. A 95% confidence interval for the population mean is computed from a sample. If the sample size doubles (with the same sample variance), the width of the confidence interval changes by a factor of approximately:

A.  $1/\sqrt{2} \approx 0.707$

B.  $1/2$  (becomes half)

C. 2

D.  $\sqrt{2} \approx 1.414$

16. For two events A and B with  $P(A) = 0.4$ ,  $P(B) = 0.5$ , and  $P(A \cup B) = 0.7$ , what is  $P(A \cap B)$ ?

A. 0.10

B. 0.20

C. 0.30

D. 0.40

17. For a sample of  $n = 100$  measurements with sample standard deviation  $s = 10$ , the standard error of the sample mean is:

A. 0.1

B. 100

C. 1

D. 10

18. Engineer A is hired by Client X to evaluate a structural failure. The investigation reveals that Engineer B, who designed the structure, made a critical error. Engineer B is a close personal friend. Under the NSPE Code, Engineer A must:

A. Withhold the findings to protect the friendship

B. Inform Engineer B privately and let him resolve it

C. Report findings only to Engineer B's employer

D. Report findings objectively to Client X without regard to personal relationships

19. An engineer is approached to provide expert testimony in a legal case. The engineer has limited prior expert-witness experience but extensive technical knowledge in the relevant field. Under the NSPE Code, the engineer should:

- A. Provide testimony only on technical matters within his area of demonstrable competence
- B. Accept the role and prepare extensively for trial procedures across all subject matter
- C. Decline all expert-witness work since this is a first attempt
- D. Accept the role to develop legal experience

20. A licensed PE is consulted by a private homeowner about whether a deck is structurally adequate. The PE provides verbal advice without inspecting the property. If the deck later fails, the PE:

- A. Has no liability since no written contract existed
- B. Is fully protected by professional licensure
- C. May be liable since professional advice creates expectation of reasonable care
- D. Is liable only if a written report was provided

21. An engineer participating in a public hearing on a controversial infrastructure project has a financial interest in a company that would benefit from project approval. According to the NSPE Code, the engineer must:

- A. Withhold all technical opinions to avoid bias
- B. Decline to participate in the hearing entirely
- C. Provide opinions only on non-technical aspects of the project
- D. Disclose the financial interest before providing any opinions

22. A capital investment of \$40,000 generates uniform annual savings of \$10,000 for 6 years with zero salvage value. At  $MARR = 12\%$ , the net present worth is, given  $(P/A, 12\%, 6) = 4.1114$ :

- A.  $-\$1,114$

- B. \$1,114
- C. \$5,114
- D. -\$5,114

23. Two equipment alternatives are compared and have equivalent uniform annual costs (EUACs) of \$9,500 (Alternative A) and \$10,200 (Alternative B). Which is preferred and by how much per year?

- A. Alternative A by \$700/yr
- B. Alternative B by \$700/yr
- C. They are equivalent
- D. Cannot determine without service-life information

24. A capital asset costing \$50,000 has a 5-year recovery period under MACRS. The year-2 recovery percentage is 32%. The depreciation expense in year 2 is:

- A. \$10,000
- B. \$20,000
- C. \$16,000
- D. \$25,000

25. Project X has IRR of 12%, and Project Y has IRR of 15%. The MARR is 10%, and Project Y requires twice the initial investment of Project X. For mutually exclusive selection, the correct decision rule is:

- A. Choose Project Y because it has the higher IRR
- B. Choose Project X because it requires lower investment
- C. Combine both projects regardless of incremental analysis
- D. Compute incremental IRR of (Y – X) and compare against MARR

26. A series of cash flows starts at \$1,000 in year 1 and increases by \$500 each subsequent year for 5 years. The present worth, using  $i = 8\%$ , is found by:

- A. Multiplying \$1,000 by  $(P/A, 8\%, 5)$  only
- B. Computing  $(P/A, 8\%, 5) \cdot \$1,000 + (P/G, 8\%, 5) \cdot \$500$
- C. Multiplying \$3,000 by  $(P/F, 8\%, 5)$
- D. Multiplying \$500 by  $(P/G, 8\%, 5)$  only

27. In an extrinsic semiconductor at very low temperature ( $T$  approaching 0 K), the free-carrier concentration:

- A. Approaches zero (carrier freeze-out)
- B. Approaches the intrinsic value
- C. Remains fixed at the dopant concentration
- D. Becomes infinite

28. For a typical silicon p-n junction diode, the reverse saturation current  $I_S$  approximately doubles every:

- A.  $5^\circ\text{C}$
- B.  $1^\circ\text{C}$
- C.  $10^\circ\text{C}$
- D.  $100^\circ\text{C}$

29. A ferromagnetic material heated above its Curie temperature:

- A. Becomes a superconductor
- B. Behaves as a paramagnet with  $\mu_r$  slightly greater than 1
- C. Loses all magnetic properties entirely

D. Becomes diamagnetic with  $\mu_r$  less than 1

30. The skin depth in a good conductor decreases with frequency. At approximately what frequency does the skin depth in copper drop to 1 mm? ( $\sigma = 5.8 \times 10^7$  S/m,  $\mu_0 = 4\pi \times 10^{-7}$  H/m)

A. 60 Hz

B. 1 kHz

C. 100 kHz

D.  $\approx 4.4$  kHz

31. A series RLC circuit has  $R = 10 \Omega$ ,  $L = 100$  mH, and  $C = 10 \mu\text{F}$ . Calculate the quality factor  $Q$  at the resonant frequency.

A. 1

B. 31.6

C. 10

D. 100

32. In a sinusoidal steady-state circuit,  $V = 100\angle 30^\circ$  V (rms) is applied to an impedance  $Z = 5 + j5\sqrt{3} \Omega$ . The average power dissipated is:

A. 500 W

B. 1000 W

C. 707 W

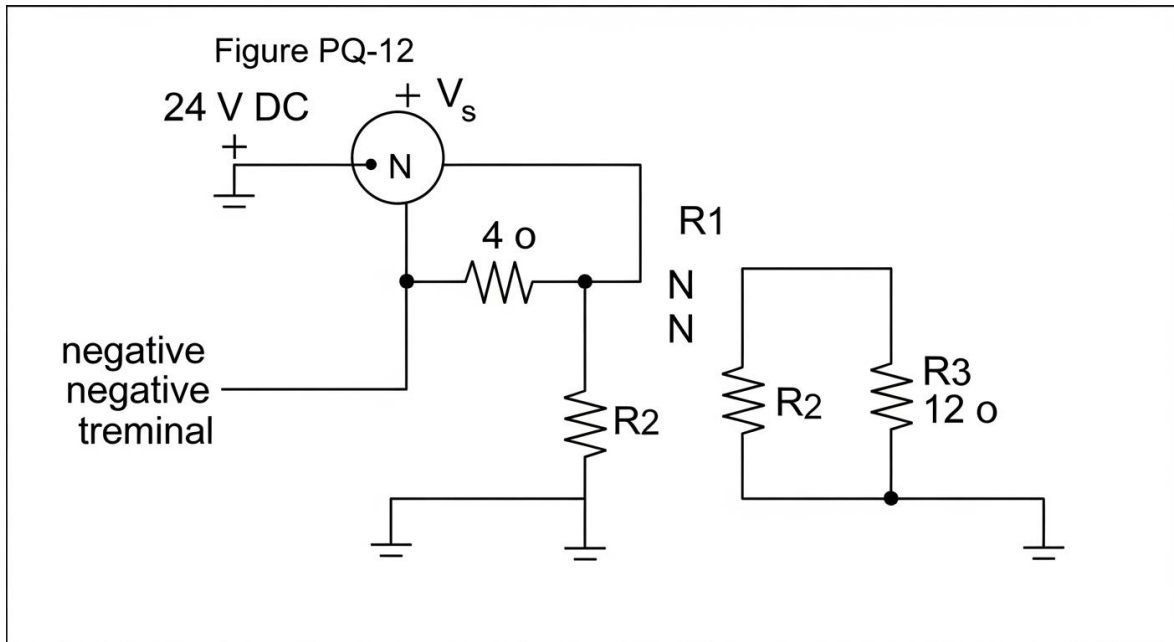
D. 250 W

33. An op-amp has a maximum output current of 25 mA. In a feedback configuration delivering  $V_{\text{out}} = 12$  V, the minimum load resistance  $R_L$  that the op-amp can drive at maximum output current is:

A.  $50 \Omega$

- B.  $200\ \Omega$
- C.  $300\ \Omega$
- D.  $480\ \Omega$

34. For the two-loop DC circuit shown in the figure, determine the current through resistor  $R_2$ .



- A. 1.5 A
- B. 2.0 A
- C. 3.0 A
- D. 4.0 A

35. When finding the Thevenin equivalent resistance  $R_{TH}$  of a circuit containing a dependent voltage source, the correct technique is to:

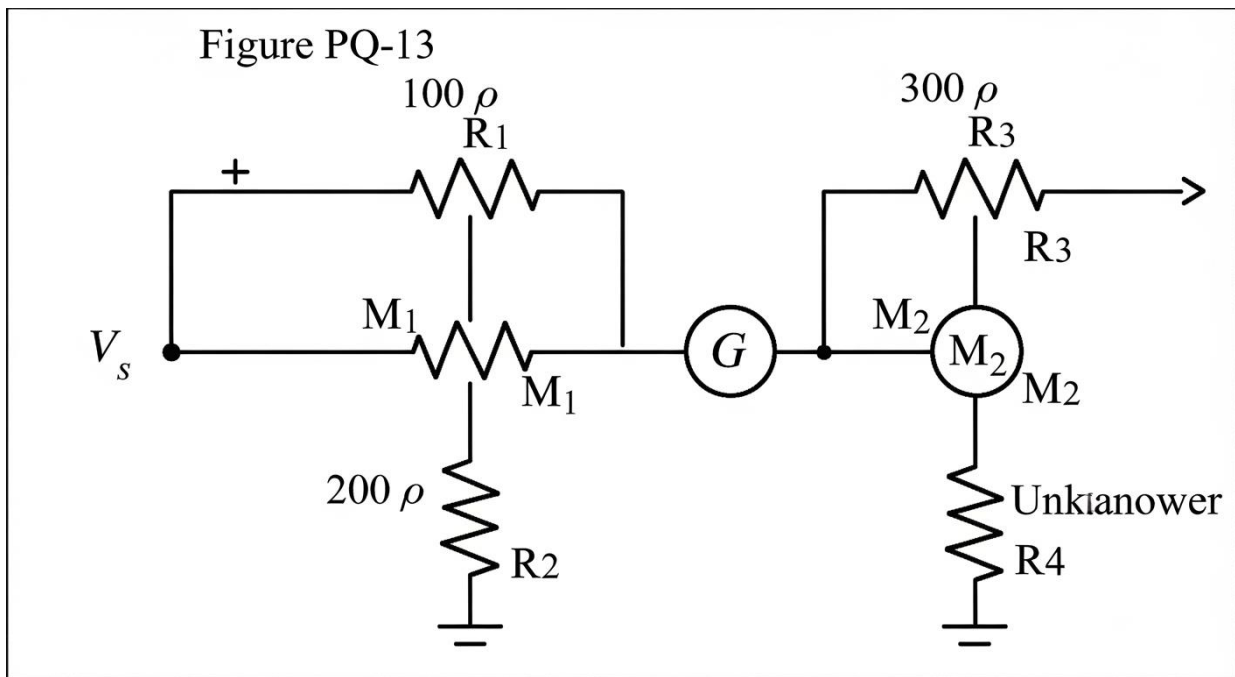
- A. Set all sources (including dependent) to zero and reduce
- B. Apply a test source (test voltage and measure current, or test current and measure voltage) at the terminals
- C. Add the dependent source's voltage to the open-circuit voltage

D. Replace dependent sources with their nominal control values

36. A series RL circuit with  $R = 50 \Omega$  and  $L = 100 \text{ mH}$  is connected to an AC source  $v(t) = 100 \cdot \cos(1000t) \text{ V}$ . The steady-state current amplitude is:

- A. 2.00 A
- B. 1.79 A
- C. 0.894 A
- D. 1.41 A

37. For the Wheatstone bridge shown in the figure, what value of  $R_4$  produces balance (galvanometer reading zero)?



- A.  $600 \Omega$
- B.  $400 \Omega$
- C.  $150 \Omega$
- D.  $67 \Omega$

38. For two coupled inductors with self-inductances  $L_1 = 4$  mH and  $L_2 = 9$  mH and mutual inductance  $M = 5$  mH, the coupling coefficient  $k$  is:

- A. 0.69
- B. 1.39
- C. 0.42
- D. 0.83

39. The two-port admittance parameters (y-parameters) for a passive, reciprocal two-port network always satisfy:

- A.  $y_{11} = y_{22}$
- B.  $y_{12} = y_{21}$
- C.  $y_{11} = y_{12}$
- D.  $y_{21} = y_{22}$

40. An inductor with  $L = 5$  mH carries a current  $i(t) = 2 \cdot \cos(1000t)$  A. The voltage  $v(t)$  across the inductor is:

- A.  $10 \cdot \cos(1000t)$  V
- B.  $0.01 \cdot \cos(1000t)$  V
- C.  $-10 \cdot \sin(1000t)$  V
- D.  $10 \cdot \sin(1000t)$  V

41. At parallel resonance of an ideal RLC parallel circuit driven by an ideal voltage source, the current drawn from the source is:

- A. Maximum
- B. Minimum but nonzero, equal to  $V/X_L$
- C. Equal to  $V/(L \cdot C)$

D. Minimum (purely the resistive component  $V/R$ )

42. Two coupled inductors  $L_1 = 10$  mH and  $L_2 = 40$  mH with mutual inductance  $M = 5$  mH are connected in series with subtractive (opposing) coupling. The total equivalent inductance is:

- A. 40 mH
- B. 50 mH
- C. 60 mH
- D. 35 mH

43. The total energy stored in a capacitor of capacitance  $C = 100$   $\mu$ F charged to 200 V is:

- A. 20 J
- B. 200 J
- C. 2 J
- D. 0.02 J

44. For a transfer function  $H(s) = K / [(s + 1)(s^2 + 2s + 5)]$ , the order of the system is:

- A. 2
- B. 3
- C. 1
- D. 4

45. A causal, stable continuous-time LTI system has an impulse response  $h(t)$  that must satisfy:

- A.  $h(t)$  is periodic
- B.  $h(t) = 0$  for  $t > 0$
- C.  $h(t)$  is infinitely long in extent

D.  $\int |h(t)| dt < \infty$  over all time

46. Compute the convolution  $h(t) * x(t)$  where  $h(t) = e^{-t} \cdot u(t)$  and  $x(t) = u(t)$ . The result is:

A.  $(1 - e^{-t}) \cdot u(t)$

B.  $e^{-t} \cdot u(t)$

C.  $t \cdot e^{-t} \cdot u(t)$

D.  $(1 + e^{-t}) \cdot u(t)$

47. For the transfer function  $H(s) = 5 / (s^3 + 3s^2 + 2s)$ , the system has poles located at:

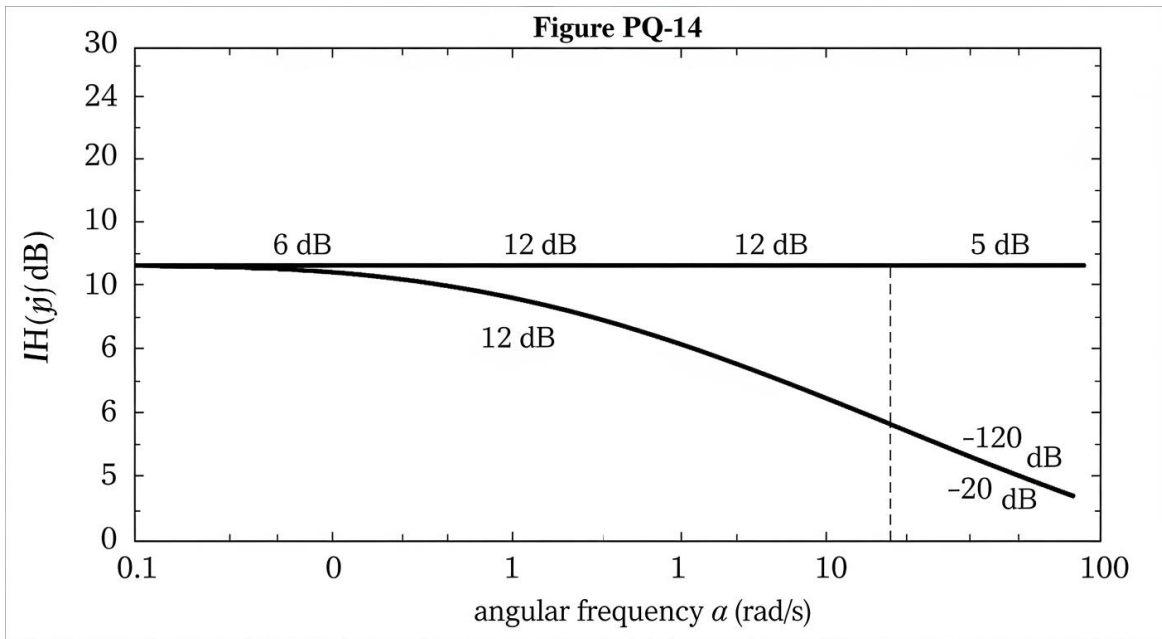
A.  $s = -1, -1, -1$

B.  $s = 0, -1, -2$

C.  $s = 0, -2, -3$

D.  $s = -1, -2, -3$

48. For a single-input single-output system whose Bode magnitude plot is shown in the figure, what is the steady-state output amplitude when the input is  $x(t) = 2 \cdot \sin(3t) \cdot u(t)$ ?



- A. 0.5
- B. 2
- C. 8
- D. 12

49. The minimum number of state variables needed to describe a linear system with transfer function  $H(s) = 10 \cdot (s + 2) / [(s + 1)^2 \cdot (s + 3)]$  is:

- A. 1
- B. 2
- C. 4
- D. 3

50. A digital filter has the difference equation  $y[n] = 0.5 \cdot y[n - 1] + x[n]$ . The transfer function  $H(z) = Y(z)/X(z)$  is:

- A.  $(z + 0.5)/z$
- B.  $1/(0.5z + 1)$

- C.  $z/(z - 0.5)$
- D.  $0.5z/(z + 1)$

51. For a finite-impulse-response (FIR) filter with  $N$  taps, the maximum length of the output sequence when the input sequence has length  $M$  is:

- A.  $M$
- B.  $N + M - 1$
- C.  $N \cdot M$
- D.  $\max(M, N)$

52. A signal is processed with sampling frequency  $f_s = 10$  kHz. The Nyquist frequency for this sampling rate is:

- A. 5 kHz
- B. 10 kHz
- C. 20 kHz
- D. 2.5 kHz

53. In digital filter design, the bilinear transform  $s = (2/T) \cdot (z - 1)/(z + 1)$  is used to:

- A. Reduce filter order
- B. Eliminate frequency warping entirely
- C. Map the analog  $s$ -plane LHP to the digital  $z$ -plane unit disk while preserving stability
- D. Increase the cutoff frequency

54. The impulse response of an ideal low-pass filter with cutoff frequency  $f_c$  is:

- A.  $\delta(t)$

- B.  $\exp(-\alpha \cdot |t|)$
- C. The unit step function
- D. A sinc function  $(\sin(2\pi f_c \cdot t)/(\pi t))$

55. A stable causal LTI discrete-time system has poles at  $z = 0.5$  and  $z = -0.3$  in the  $z$ -plane. Its impulse response:

- A. Has finite duration
- B. Grows unbounded as  $n \rightarrow \infty$
- C. Decays to zero as  $n \rightarrow \infty$
- D. Remains constant for large  $n$

56. For an NMOS transistor in saturation, doubling the  $(W/L)$  ratio while holding  $V_{GS} - V_T$  constant will:

- A. Halve the drain current
- B. Double the drain current
- C. Quadruple the drain current
- D. Leave the drain current unchanged

57. For a non-inverting op-amp circuit with open-loop gain  $A_{OL} = 10^5$  and closed-loop gain  $A_{CL} = 100$ , the approximate percent change in closed-loop gain for a 10% change in  $A_{OL}$  is:

- A. 0.01%
- B. 1%
- C. 10%
- D. 100%

58. A single-stage Class A amplifier with capacitive coupling to a resistive load has a maximum theoretical efficiency of:

- A. 100%
- B. 78.5%
- C. 50%
- D. 25%

59. In a phase-locked loop (PLL), the voltage-controlled oscillator (VCO) is locked to the input reference frequency through:

- A. Open-loop control of the phase detector
- B. Negative feedback that adjusts the VCO control voltage to drive phase error toward zero
- C. Variable resistor adjustment by the operator
- D. Detection of the second harmonic of the input signal

60. A bridge rectifier with peak input voltage  $V_m = 100 \text{ V}$  is connected to a load through a large smoothing capacitor. The average DC output voltage is approximately:

- A. Close to  $V_m$  (about 95 V with effective filtering)
- B. 0 V (AC only)
- C.  $V_m/\pi \approx 31.8 \text{ V}$
- D.  $2 \cdot V_m/\pi \approx 63.7 \text{ V}$

61. A Schmitt trigger comparator with hysteresis  $V_H = 1 \text{ V}$  is used to detect zero-crossings of a noisy sinusoidal signal. The hysteresis primarily:

- A. Increases switching speed
- B. Reduces input impedance
- C. Causes intentional oscillation at the input frequency
- D. Prevents multiple false transitions caused by noise near the threshold

62. A CMOS digital inverter operating in steady state (output stable HIGH or LOW) dissipates static (DC) power approximately equal to:

- A.  $V_{DD}^2/R$
- B. Essentially zero (only small leakage current)
- C.  $V_{DD} \cdot I_{DSS}$
- D.  $V_{DD} \cdot I_{max}$

63. In a properly biased single-stage common-emitter BJT amplifier, the small-signal output at the collector relative to the input at the base has a phase shift of:

- A.  $0^\circ$  (same phase)
- B.  $90^\circ$
- C.  $180^\circ$  (signal inversion)
- D.  $45^\circ$

64. A three-phase, 60 Hz, four-pole synchronous motor has a rated power of 100 hp. Its synchronous speed is:

- A. 1800 rpm
- B. 3600 rpm
- C. 1200 rpm
- D. 900 rpm

65. A 3-phase induction motor draws 50 A line current at 480 V (line-to-line) with power factor 0.85 lagging. The apparent power drawn is:

- A. 24 kVA
- B. 40.8 kVA
- C. 41.6 kVA

D. 35.3 kVA

66. A 60 Hz, 4-pole, 3-phase induction motor operates at 1700 rpm under load. The slip of the motor is approximately:

A. 0.1%

B. 1.5%

C. 3.0%

D. 5.6%

67. A single-phase transformer is rated 100 kVA, 11,000/440 V, 50 Hz. The full-load current on the high-voltage side is:

A. 4.55 A

B. 9.09 A

C. 22.7 A

D. 227.3 A

68. A three-phase transformer has primary voltage 13.2 kV (line-to-line) and secondary 480 V (line-to-line), and supplies a balanced load drawing 100 A on the secondary side. The approximate primary line current is:

A. 3.6 A

B. 100 A

C. 27.5 A

D. 6.3 A

69. For a balanced three-phase system supplying a balanced three-phase load, the instantaneous total power delivered to the load is:

- A. Pulsating at 60 Hz
- B. Pulsating at 120 Hz
- C. Pulsating at 180 Hz
- D. Constant in time (not pulsating)

70. In per-unit power system analysis, an equipment per-unit impedance must be converted when referred to a different voltage and power base using:

- A.  $Z_{pu,new} = Z_{pu,old} \cdot (V_{base,new}/V_{base,old})$
- B.  $Z_{pu,new} = Z_{pu,old} \cdot (V_{base,old}/V_{base,new})$
- C.  $Z_{pu,new} = Z_{pu,old} \cdot (V_{base,old}/V_{base,new})^2 \cdot (S_{base,new}/S_{base,old})$
- D.  $Z_{pu,new} = Z_{pu,old}$  (per-unit values are always invariant)

71. A balanced three-phase load draws 50 kVA at 480 V (line-to-line) and 0.8 lagging power factor. The line current is:

- A. 60.1 A
- B. 78.1 A
- C. 104.2 A
- D. 125.0 A

72. In a separately excited DC generator, the induced armature EMF  $E_a$  is proportional to which two quantities?

- A. Field current  $I_f$  and load resistance  $R_L$
- B. Rotor angular speed  $\omega$  and field flux  $\Phi$
- C. Armature voltage  $V_a$  and armature current  $I_a$
- D. Magnetic field strength  $B$  and conductor length only

73. A long air-core solenoid of length 0.2 m has 500 turns and a cross-sectional area of  $4 \times 10^{-4} \text{ m}^2$ , carrying a current of 3 A. The magnetic flux through the solenoid is approximately ( $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$ ):

- A.  $6.28 \mu\text{Wb}$
- B.  $9.42 \mu\text{Wb}$
- C.  $12.57 \mu\text{Wb}$
- D.  $3.77 \mu\text{Wb}$

74. A parallel-plate capacitor has plate area  $A$  and plate separation  $d$ . If both  $A$  and  $d$  are simultaneously doubled, the capacitance:

- A. Doubles
- B. Halves
- C. Remains unchanged
- D. Quadruples

75. For an electromagnetic wave traveling in vacuum, the electric field magnitude  $E$  and magnetic field magnitude  $B$  are related by:

- A.  $E = c \cdot B$
- B.  $E = B$
- C.  $E = B/c$
- D.  $E = B^2$

76. A non-magnetic medium has relative permittivity  $\epsilon_r = 9$ . The wavelength of an EM wave in this medium compared to the free-space wavelength  $\lambda_0$  is:

- A.  $9 \cdot \lambda_0$  (nine times longer)
- B.  $3 \cdot \lambda_0$  (three times longer)

- C.  $\lambda/3$  (one-third of free space)
- D.  $\lambda/9$  (one-ninth of free space)

77. For a unity-feedback control system with open-loop transfer function  $G(s) = K / [s \cdot (s + 10)]$ , the value of  $K$  that yields a closed-loop damping ratio  $\zeta = 0.707$  is:

- A. 25
- B. 50
- C. 100
- D. 10

78. A unity-feedback control system has open-loop transfer function  $G(s) = K / [s \cdot (s + 2)]$ . The steady-state error to a unit ramp input is:

- A. 0
- B.  $K$
- C.  $2K$
- D.  $2/K$

79. For the Bode magnitude plot of an open-loop transfer function  $K / [s \cdot (s + 10)]$ , the magnitude slope at low frequencies ( $\omega \ll 10$  rad/s) is:

- A.  $-20$  dB/decade
- B.  $-40$  dB/decade
- C.  $0$  dB/decade
- D.  $-60$  dB/decade

80. In Bode-plot stability analysis, the gain margin is defined as the:

- A. Phase shift at the gain crossover frequency
- B. Reciprocal of  $|G(j\omega)|$  (or its negative in dB) evaluated at the phase crossover frequency
- C. Distance between the gain and phase crossover frequencies
- D. Sum of all individual open-loop pole and zero gains

81. The closed-loop bandwidth of a stable feedback control system is most directly determined by:

- A. The DC gain of the open-loop transfer function only
- B. The slowest open-loop pole only
- C. The closed-loop pole(s) nearest the imaginary axis (the dominant pole)
- D. The fastest open-loop zero

82. For a closed-loop transfer function  $T(s) = K / (s^2 + 4s + K)$ , the value of  $K$  producing critical damping ( $\zeta = 1$ ) is:

- A. 1
- B. 2
- C. 8
- D. 4

83. In a Type 0 unity-feedback control system with open-loop DC gain  $K_p = 9$ , the steady-state error to a unit step input is:

- A. 0
- B. 0.10
- C. 0.5
- D.  $\infty$

84. For a double-sideband suppressed-carrier (DSB-SC) modulated signal  $s(t) = m(t) \cdot \cos(\omega_c t)$ , where  $m(t)$  is the baseband message, the spectrum  $S(\omega)$  is:

- A.  $M(\omega - \omega_c)/2 + M(\omega + \omega_c)/2$  (shifted copies of the message spectrum)
- B.  $M(\omega)$  (unchanged from the baseband)
- C.  $M(2\omega - \omega_c)$
- D. A single spectral line at frequency  $\omega_c$

85. In digital communications, Gray coding is used primarily to minimize:

- A. The required transmission bandwidth
- B. The transmitted signal power
- C. The receiver circuit complexity
- D. The number of bit errors per symbol error in M-ary modulation schemes

86. Quadrature amplitude modulation (QAM) achieves higher bandwidth efficiency than PSK by:

- A. Using multiple carrier frequencies simultaneously
- B. Using a longer symbol duration
- C. Varying both amplitude and phase to encode more bits per symbol
- D. Reducing the carrier amplitude during transmission

87. A BPSK digital communication system in AWGN has bit error rate  $BER \approx Q(\sqrt{2 \cdot E_b/N_0})$ . If  $E_b/N_0 = 9$  dB (linear value  $\approx 7.94$ ), and  $Q(4) \approx 3.2 \times 10^{-5}$ , the approximate BER is:

- A.  $10^{-9}$
- B.  $\approx 3.4 \times 10^{-5}$
- C. 0.5
- D.  $10^{-3}$

88. In OFDM (Orthogonal Frequency-Division Multiplexing), high aggregate data rate is achieved by:

- A. Transmitting many low-rate parallel subcarriers in orthogonal frequency bins
- B. Using a single very high-frequency carrier
- C. Eliminating all guard intervals between symbols
- D. Restricting modulation to AM only

89. In CIDR notation 192.168.1.0/26, how many usable host addresses are available within the subnet?

- A. 256
- B. 254
- C. 62
- D. 64

90. The Internet Control Message Protocol (ICMP) is used primarily for:

- A. Reliable end-to-end data transport
- B. Web page delivery
- C. Email forwarding
- D. Network diagnostics and error reporting (ping, traceroute)

91. In a wireless 802.11 (Wi-Fi) network, the maximum theoretical data rate of 802.11ac (Wi-Fi 5) is approximately:

- A. ~1.3 Gbps (varies with stream count and bandwidth)
- B. 54 Mbps
- C. 100 Mbps
- D. 100 Gbps

92. Which protocol in the TCP/IP suite is used to translate an IPv4 address to a MAC address on a local network?

- A. ICMP
- B. ARP (Address Resolution Protocol)
- C. DHCP
- D. DNS

93. Convert the decimal number 250 to hexadecimal.

- A. 0xC8
- B. 0xF0
- C. 0xFE
- D. 0xFA

94. Simplify the Boolean expression  $(A \cdot B') + (A \cdot B)$ .

- A.  $A \cdot B$
- B. B
- C.  $A \cdot B'$
- D. A

95. An XOR (exclusive-OR) gate outputs HIGH only when:

- A. Both inputs are HIGH
- B. Both inputs are LOW
- C. The two inputs are at different logic levels
- D. At least one input is HIGH

96. A synchronous binary counter built from  $N$  flip-flops rolls over to zero every:

- A.  $2^N$  clock cycles
- B.  $N$  clock cycles
- C.  $\log_2(N)$  clock cycles
- D.  $N!$  clock cycles

97. A binary decoder with  $k$  input lines drives how many output lines?

- A.  $k$
- B.  $2^k$
- C.  $2k$
- D.  $k^2$

98. In a ripple-carry adder for two 8-bit numbers, the worst-case carry propagation delay is approximately:

- A. Equal to the delay of one full adder
- B.  $2\times$  the delay of one full adder
- C.  $8\times$  the delay of one full adder
- D.  $64\times$  the delay of one full adder

99. A 4-bit right-shift register is loaded with the value 1011 (MSB to LSB). The serial input is 0 and the data shifts toward the LSB end. After 3 clock cycles, the register contains:

- A. 0001
- B. 1011
- C. 1000
- D. 0011

100. Which type of memory is non-volatile and retains its contents indefinitely without power?

- A. SRAM
- B. DRAM
- C. Register file
- D. ROM (and modern non-volatile flash variants)

101. A 4-input multiplexer (MUX) uses a binary control input to select one of four data inputs and route it to the output. How many select lines are required?

- A. 4
- B. 2
- C. 3
- D. 1

102. In a standard 32-bit ARM processor architecture (non-Thumb instruction set), the instruction width is:

- A. 8 bits
- B. 16 bits
- C. 32 bits
- D. 64 bits

103. A computer system has L1 cache hit rate 95% with access time 1 ns. On L1 miss, access continues to L2 with access time 10 ns (assume 100% L2 hit). Using the convention  $AMAT = hit\_rate \cdot L1 + miss\_rate \cdot L2$ , the average memory access time is:

- A. 1.45 ns
- B. 5.50 ns
- C. 1.05 ns

D. 11.00 ns

104. In an embedded system, polling is generally preferred over interrupts when:

- A. Maximum CPU efficiency is required
- B. Event timing is unpredictable
- C. Multiple events must be handled simultaneously with low latency
- D. Events occur at predictable times and design simplicity is preferred over efficiency

105. In IEEE 754 single-precision (32-bit) floating-point format, the number of explicitly stored mantissa (fraction) bits is:

- A. 23
- B. 8
- C. 32
- D. 24

106. A computer storage technology with typical access times in the millisecond range is:

- A. CPU register file
- B. Hard disk drive (HDD, rotational)
- C. L1 cache
- D. SRAM main memory

107. In the Git version control system, the command used to combine changes from one branch into another is:

- A. clone
- B. push

- C. fetch
- D. merge

108. In Big-O notation, the time complexity of finding the maximum element in an unsorted array of  $n$  elements is:

- A.  $O(1)$
- B.  $O(\log n)$
- C.  $O(n)$
- D.  $O(n^2)$

109. In agile software development, a "user story" is best described as:

- A. A short, informal description of a feature written from the end-user's perspective
- B. A detailed technical specification document
- C. A test case for unit testing
- D. A formal contract clause with the customer

110. In software design, the SOLID principle stating that a class should have only one reason to change is the:

- A. Open/Closed Principle
- B. Single Responsibility Principle (SRP)
- C. Liskov Substitution Principle
- D. Dependency Inversion Principle

## PRACTICE EXAM 7 – ANSWER KEY AND FULL ANSWER EXPLANATIONS

1. B —  $z^4 = 2^4 \cdot e^{j \cdot 4 \cdot \pi/4} = 16 \cdot e^{j\pi} = 16 \cdot (\cos \pi + j \sin \pi) = -16 + j0$ . De Moivre's theorem makes exponentiation of polar-form complex numbers straightforward and underpins phasor analysis throughout AC circuits.
2. A — Using the half-angle identity  $\sin^2 x = (1 - \cos 2x)/2$ :  $\int_0^{\pi/2} (1 - \cos 2x)/2 \, dx = [x/2 - \sin(2x)/4]_0^{\pi/2} = \pi/4 - 0 = \pi/4$ . The result is half the interval ( $\pi/2$ ), reflecting that  $\sin^2$  averages to 1/2 over a quarter cycle.
3. D — The characteristic equation  $r^2 - 4r + 4 = (r - 2)^2 = 0$  has a repeated real root  $r = 2$ . For a repeated root, the general solution carries an extra factor of  $x$ :  $y = (C_1 + C_2 \cdot x) \cdot e^{rx}$ . Recognizing repeated roots is essential because the standard two-exponential form would otherwise yield linearly dependent solutions.
4. C — Expand along row 1:  $\det = 2 \cdot [(1)(-4) - (2)(0)] - (-1) \cdot [(3)(-4) - (2)(1)] + 0 = 2 \cdot (-4) + 1 \cdot (-14) = -8 - 14 = -22$ . Cofactor expansion along any row or column produces the same determinant, with row 1 chosen here for the convenient zero entry.
5. A — Each product entry is the dot product of a row from the first matrix with a column from the second:  $(1 \cdot 5 + 2 \cdot 7, 1 \cdot 6 + 2 \cdot 8; 3 \cdot 5 + 4 \cdot 7, 3 \cdot 6 + 4 \cdot 8) = (19, 22; 43, 50)$ . This row-by-column structure is the defining rule of matrix multiplication.
6. B —  $f'(x) = (1/(x^2 + 1)) \cdot (2x) = 2x/(x^2 + 1)$  by the chain rule, since  $d/dx[\ln(g(x))] = g'(x)/g(x)$ . Evaluating at  $x = 2$ :  $f'(2) = 4/5$ . This derivative pattern appears whenever exponentials and logarithms describe charging or decay processes.
7. D — The Laplace pair  $L\{t \cdot e^{-at} \cdot u(t)\} = 1/(s + a)^2$  follows from applying the  $s$ -domain shift to  $L\{t \cdot u(t)\} = 1/s^2$ . With  $a = 2$ , the transform is  $1/(s + 2)^2$ . This pair appears whenever a system has a repeated real pole.
8. C — In polar form,  $1 + j = \sqrt{2} \cdot e^{j\pi/4}$ , so  $(1 + j)^{10} = (\sqrt{2})^{10} \cdot e^{j \cdot 10\pi/4} = 32 \cdot e^{j \cdot 5\pi/2} = 32 \cdot e^{j\pi/2} = 32j$ . Converting to polar form before raising to a power is the standard technique for handling high powers of complex numbers.
9. B — By the divergence theorem,  $\oiint F \cdot dS = \iiint \nabla \cdot F \, dV$ . For  $F = (x, y, z)$ :  $\nabla \cdot F = 1 + 1 + 1 = 3$ . Over the unit sphere (volume  $4\pi/3$ ):  $\iiint 3 \, dV = 3 \cdot (4\pi/3) = 4\pi$ . The divergence theorem converts difficult surface integrals into easier volume integrals.
10. D — Apply the ratio test:  $\lim_{n \rightarrow \infty} |a_{n+1} \cdot x^{n+1} / (a_n \cdot x^n)| = \lim_{n \rightarrow \infty} |(n+1) \cdot x / (n \cdot 2)| = |x|/2$ . Convergence requires  $|x|/2 < 1$ , giving radius  $R = 2$ . The radius bounds the open interval where the series represents an analytic function.
11. A — Compute partials:  $\partial f / \partial x = 2xy$ ,  $\partial f / \partial y = x^2 + z^2$ ,  $\partial f / \partial z = 2yz$ . At  $(1, 2, 1)$ :  $(4, 2, 4)$ , giving  $\nabla f = 4\hat{i} + 2\hat{j} + 4\hat{k}$ . The gradient points in the direction of steepest increase and is essential for analyzing potential field problems.
12. C — "ENGINEERING" has 11 letters with E $\times$ 3, N $\times$ 3, I $\times$ 2, G $\times$ 2, R $\times$ 1. Distinct arrangements =  $11! / (3! \cdot 3! \cdot 2! \cdot 2! \cdot 1!) = 39,916,800 / 144 = 277,200$ . Dividing by the factorials of repeated-letter counts removes overcounted permutations of identical letters.
13. B — For unit vectors,  $\mathbf{a} \cdot \mathbf{b} = \cos \theta$ . With  $\mathbf{a} \cdot \mathbf{b} = 1/2$ :  $\cos \theta = 1/2$ , so  $\theta = 60^\circ$ . The dot product of unit vectors directly yields the cosine of the angle between them, making it the standard tool for vector angle measurement.

14. D — Binomial variance:  $\text{Var}(X) = n \cdot p \cdot (1 - p) = 10 \cdot 0.3 \cdot 0.7 = 2.1$ . The variance is maximized at  $p = 0.5$  and decreases symmetrically toward zero at the endpoints, useful intuition for reliability analyses involving rare or near-certain events.
15. A — Confidence interval half-width is proportional to  $1/\sqrt{n}$ , so doubling  $n$  shrinks the width by  $1/\sqrt{2} \approx 0.707$ . To halve the width requires quadrupling the sample size, a key cost-precision trade-off in experimental design.
16. B — Inclusion-exclusion:  $P(A \cup B) = P(A) + P(B) - P(A \cap B)$ . Solving:  $P(A \cap B) = 0.4 + 0.5 - 0.7 = 0.2$ . This identity is the foundation for computing joint probabilities from marginal and union information.
17. C — Standard error of the mean:  $\text{SE} = s/\sqrt{n} = 10/\sqrt{100} = 1$ . The standard error shrinks as  $1/\sqrt{n}$ , so larger samples produce tighter sampling distributions of the mean and more precise interval estimates.
18. D — NSPE Code Canon 4 and Section III.4 require engineers to act as faithful agents and trustees, providing objective and truthful reports without regard to personal loyalty or friendship. Withholding adverse findings would breach the duty to the client and the public. Personal relationships never override professional obligations.
19. A — NSPE Section II.2.a limits engineers, including in expert testimony, to areas of personal competence established through education and experience. Testimony outside one's competence misleads the court and risks public harm. The principle of competence governs every professional engagement.
20. C — Professional advice creates a duty of reasonable care regardless of whether a formal written contract exists or compensation was paid. A licensed PE giving structural guidance is held to a professional standard. Engineers must recognize that informal consultations still carry legal and ethical liability.
21. D — NSPE Section II.4 requires disclosure of any circumstance that could be construed as a conflict of interest before participating in matters in which the engineer has a financial stake. Public participation without disclosure undermines the integrity of the engineering input. Transparency is the central remedy for conflicts of interest in professional practice.
22. B —  $\text{NPW} = -40,000 + 10,000 \cdot (P/A, 12\%, 6) = -40,000 + 10,000 \cdot 4.1114 = -40,000 + 41,114 = \$1,114$ . A positive NPW indicates the investment exceeds the MARR threshold and should be accepted. NPW is the most reliable single criterion when comparing alternatives with identical lives.
23. A — Lower EUAC is preferred:  $\$9,500$  (A) <  $\$10,200$  (B), so Alternative A is preferred by  $\$10,200 - \$9,500 = \$700/\text{yr}$ . EUAC enables direct comparison of alternatives with different service lives by reducing all cash flows to an equivalent annual figure.
24. C — Year-2 MACRS depreciation = initial cost  $\times$  year-2 recovery percentage =  $\$50,000 \times 0.32 = \$16,000$ . MACRS is a tabulated, front-loaded depreciation method that produces higher write-offs in early years to encourage capital investment. Recovery percentages sum to 100% over the asset's class life.
25. D — For mutually exclusive projects with different investment levels, the higher individual IRR is not automatically preferred. Incremental analysis computes IRR on the cash-flow difference (Y - X); choose Y if  $\text{IRR}(Y - X) > \text{MARR}$ . This rule prevents the common error of favoring high-IRR small projects over more profitable larger ones.
26. B — A linear gradient series with base  $\$1,000$  increasing by  $G = \$500$  has present worth  $\text{PW} = A \cdot (P/A, i, n) + G \cdot (P/G, i, n)$ . Splitting the cash flow into a uniform component A and a gradient

component  $G$  isolates the standard factors. This decomposition is the standard treatment of arithmetic gradient cash flows.

27. A — At very low temperature, thermal energy  $kT$  becomes insufficient to ionize donor or acceptor atoms — a regime known as "carrier freeze-out." Free carriers freeze onto their parent dopants, and conductivity collapses toward zero. This is why cryogenic semiconductor devices require careful dopant selection and concentration.
28. C — The reverse saturation current  $I_S$  is dominated by thermally generated minority carriers and scales as  $\exp(-E_g/kT)$ . For silicon near room temperature, this exponential dependence produces an approximate doubling every  $10^\circ\text{C}$ . This temperature sensitivity is why diode-based circuits often need thermal compensation.
29. B — Above the Curie temperature, thermal agitation disrupts the magnetic-domain alignment that produces ferromagnetism, and the material reverts to paramagnetic behavior with  $\mu_r$  slightly greater than 1. Iron, nickel, and cobalt all undergo this transition. The Curie temperature is a sharp, material-specific threshold.
30. D — Skin depth  $\delta = 1/\sqrt{\pi f \mu \sigma}$ . Solving for  $f$  when  $\delta = 1$  mm:  $f = 1/(\pi \delta^2 \mu \sigma) = 1/(\pi \cdot 10^{-6} \cdot 4\pi \times 10^{-7} \cdot 5.8 \times 10^7) \approx 4.4$  kHz. Skin effect forces high-frequency current into a thin surface layer, dramatically increasing effective AC resistance.
31. C —  $Q = (1/R) \cdot \sqrt{L/C} = (1/10) \cdot \sqrt{(0.1/10^{-5})} = (1/10) \cdot \sqrt{(10^4)} = (1/10) \cdot 100 = 10$ . The quality factor measures energy stored per cycle relative to energy dissipated, and directly sets the bandwidth-to-center-frequency ratio of a resonant circuit.
32. A — Impedance magnitude:  $|Z| = \sqrt{(5^2 + (5\sqrt{3})^2)} = \sqrt{100} = 10 \Omega$ . Current:  $|I| = 100/10 = 10$  A (rms). Average power dissipated only in resistance:  $P = |I|^2 \cdot R = 100 \cdot 5 = 500$  W. Reactive elements store and return energy without net dissipation.
33. D — Minimum load at maximum output current:  $R_{L,\min} = V_{\text{out}}/I_{\text{max}} = 12/0.025 = 480 \Omega$ . Below this value, the op-amp's current-limit circuit clips the output and waveform distortion appears. Always check current capability against the desired output swing into the actual load.
34. B —  $R_2 \parallel R_3 = (6 \cdot 12)/(6 + 12) = 4 \Omega$ . Total:  $R_1 + 4 = 8 \Omega$ . Source current:  $24/8 = 3$  A. Node N voltage:  $3 \cdot 4 = 12$  V. Current through  $R_2$ :  $12/6 = 2$  A. Systematic reduction of parallel groups then series sum yields source current, with branch currents found by KVL at the remaining nodes.
35. B — Dependent sources cannot be deactivated when computing Thevenin resistance because their values depend on circuit variables. The test-source method applies a 1 V (or 1 A) test source at the terminals after deactivating only independent sources, then  $R_{\text{TH}} = V_{\text{test}}/I_{\text{test}}$ . This technique is essential for any circuit containing controlled sources.
36. C — Inductive reactance  $X_L = \omega L = 1000 \cdot 0.1 = 100 \Omega$ . Impedance magnitude  $|Z| = \sqrt{(R^2 + X_L^2)} = \sqrt{(2500 + 10000)} \approx 111.8 \Omega$ . Current amplitude:  $|I| = 100/111.8 \approx 0.894$  A. The series RL impedance triangle is one of the most-tested AC circuit results.
37. A — Wheatstone bridge balance:  $R_1/R_2 = R_3/R_4$ , so  $R_4 = R_2 \cdot R_3/R_1 = 200 \cdot 300/100 = 600 \Omega$ . At balance, no current flows through the galvanometer because the two midpoints sit at the same potential. The bridge's null-detection principle enables extremely precise resistance measurement.
38. D — Coupling coefficient  $k = M/\sqrt{L_1 \cdot L_2} = 5/\sqrt{(4 \cdot 9)} = 5/6 \approx 0.833$ . The coefficient ranges from 0 (no coupling) to 1 (perfect coupling) and quantifies how completely the flux from one coil links the other. Real transformers achieve  $k = 0.99+$  through careful core design.
39. B — Reciprocity requires  $y_{12} = y_{21}$  for any passive linear network without dependent sources or unilateral elements. This symmetry follows from Maxwell's equations via Tellegen's theorem. Reciprocity is a powerful constraint that simplifies network analysis and synthesis.

40. C —  $v_L = L \cdot di/dt = 5 \times 10^{-3} \cdot d/dt[2 \cdot \cos(1000t)] = 5 \times 10^{-3} \cdot (-2000 \cdot \sin(1000t)) = -10 \cdot \sin(1000t)$  V. The voltage across an inductor leads the current by  $90^\circ$ , consistent with  $X_L = j\omega L$  representing a positive imaginary impedance.
41. D — At parallel resonance, the parallel L-C combination presents (ideally) infinite impedance, so the source sees only R. Source current is therefore minimum and purely resistive, equal to  $V/R$ . This contrasts with series resonance, where current is maximum at resonance.
42. A — Subtractive series coupling:  $L_{\text{total}} = L_1 + L_2 - 2M = 10 + 40 - 10 = 40$  mH. The  $-2M$  term accounts for partial flux cancellation when the coils' magnetic fields oppose. Additive coupling would instead yield  $L_1 + L_2 + 2M = 60$  mH.
43. C — Capacitor energy:  $E = \frac{1}{2} \cdot C \cdot V^2 = 0.5 \cdot (100 \times 10^{-6}) \cdot (200)^2 = 2$  J. Energy scales with the square of voltage, which is why high-voltage capacitor banks can store dangerous amounts of energy at modest capacitance values.
44. B — System order equals the degree of the denominator polynomial.  $(s + 1)(s^2 + 2s + 5)$  expands to a third-degree polynomial, so the system is order 3. Order determines the number of independent state variables and the maximum pole count.
45. D — A causal LTI system is BIBO stable if and only if its impulse response is absolutely integrable:  $\int |h(t)| dt < \infty$ . Equivalently, all poles of  $H(s)$  must lie in the open left-half plane. This integral condition guarantees that bounded inputs produce bounded outputs.
46. A — Convolution integral:  $y(t) = \int_0^t e^{-(t-\tau)} \cdot 1 d\tau = e^{-t} \cdot \int_0^t e^{\tau} d\tau = e^{-t} \cdot (e^t - 1) = 1 - e^{-t}$  for  $t \geq 0$ . This is the classic step response of a first-order system with time constant 1, asymptotically approaching unity.
47. B — Factor the denominator:  $s^3 + 3s^2 + 2s = s \cdot (s^2 + 3s + 2) = s \cdot (s + 1) \cdot (s + 2)$ . Setting each factor to zero gives poles at  $s = 0, -1, -2$ . Always factor before identifying poles to avoid treating a cubic as a single inseparable polynomial.
48. C — From the Bode magnitude plot,  $|H(j3)|$  reads 12 dB, equivalent to a linear magnitude of  $10^{(12/20)} = 4$ . Steady-state output amplitude = input amplitude  $\times |H(j\omega)| = 2 \cdot 4 = 8$ . Reading Bode magnitude in dB and converting to linear is routine in frequency-domain analysis.
49. D — System order equals the denominator polynomial degree after expansion:  $(s + 1)^2 \cdot (s + 3)$  expands to a cubic, degree 3. The minimum number of state variables in any state-space realization equals this order. No pole-zero cancellation reduces the order here.
50. C — Taking z-transforms:  $Y(z) = 0.5 \cdot z^{-1} \cdot Y(z) + X(z)$ , giving  $H(z) = 1/(1 - 0.5 \cdot z^{-1}) = z/(z - 0.5)$ . The pole at  $z = 0.5$  lies inside the unit circle, confirming the filter is stable.
51. B — Linear convolution of a length-N filter with a length-M input produces an output of length  $N + M - 1$ . This formula governs DSP buffer sizing and is the basis for fast convolution via the FFT. Circular convolution differs and requires zero-padding to match linear results.
52. A — The Nyquist frequency is half the sampling rate:  $f_s/2 = 10/2 = 5$  kHz. Signal components above this frequency alias into the baseband and corrupt the digitized signal. Anti-aliasing filters must roll off before the Nyquist frequency.
53. C — The bilinear transform  $s = (2/T) \cdot (z - 1)/(z + 1)$  maps the entire left-half s-plane onto the interior of the unit disk in the z-plane, guaranteeing that any stable analog filter maps to a stable digital filter. It introduces frequency warping, which is compensated by pre-warping the design specifications.
54. D — The ideal low-pass filter with cutoff  $f_c$  has impulse response  $h(t) = \sin(2\pi f_c \cdot t)/(\pi t)$  — the sinc function. This impulse response is non-causal and infinite in extent, so practical filters approximate it with windowed truncations. The sinc is the time-domain dual of the rectangular spectral mask.

55. C — Poles inside the unit circle ( $|z| < 1$ ) produce decaying impulse-response modes of the form  $a^n \cdot u[n]$  with  $|a| < 1$ . Both poles at  $z = 0.5$  and  $z = -0.3$  satisfy this stability condition, so  $h[n] \rightarrow 0$  as  $n \rightarrow \infty$ . Stability in discrete time is the unit-circle analog of LHP stability in continuous time.
56. B — For a MOSFET in saturation,  $I_D = (\frac{1}{2}) \cdot \mu \cdot C_{ox} \cdot (W/L) \cdot (V_{GS} - V_T)^2$ . Doubling  $(W/L)$  doubles  $I_D$  linearly, since the dependence on  $(W/L)$  is first-order. This scaling is fundamental in transistor sizing for both analog and digital design.
57. A — Sensitivity of closed-loop gain to  $A_{OL}$  changes is reduced by the factor  $(1 + A\beta) \approx A_{OL}/A_{CL} = 10^5/100 = 1000$ . A 10% change in  $A_{OL}$  therefore causes only about  $10\%/1000 = 0.01\%$  change in  $A_{CL}$ . This insensitivity to active-device variation is the central benefit of negative feedback.
58. D — Class A amplifiers conduct over the entire input cycle and have a maximum theoretical efficiency of 25% with capacitive (RC) coupling to the load. The low efficiency stems from large continuous quiescent dissipation. Transformer coupling can raise this maximum to 50%, but RC-coupled Class A is limited to 25%.
59. B — A PLL uses a phase detector to compare input and VCO phases and a loop filter to convert phase error into a control voltage that adjusts the VCO frequency. Negative feedback drives the steady-state phase error toward zero. PLLs are foundational in clock recovery, frequency synthesis, and FM demodulation.
60. A — With a large smoothing capacitor, the rectified output approaches the peak input  $V_m$  because the capacitor holds the peak between successive diode-conduction intervals. Practical filtering yields  $V_{DC} \approx 0.9\text{--}0.95 \cdot V_m$ . The capacitor transforms the pulsating rectifier output into nearly pure DC.
61. D — Hysteresis creates separate upper and lower switching thresholds, so once the comparator switches it cannot switch back until the input crosses the opposite threshold. This prevents noise jitter near a single threshold from producing rapid false transitions. Schmitt triggers are essential for cleaning up noisy logic-level signals.
62. B — A CMOS inverter in static operation has one transistor fully off in each output state, blocking any DC current path between  $V_{DD}$  and ground except small leakage. This near-zero static dissipation is why CMOS dominates digital design. Power is consumed almost entirely during switching transitions.
63. C — In a common-emitter configuration, an increase in base voltage increases collector current, which drops more voltage across  $R_C$  and reduces  $V_{out}$ . Input and output move in opposite directions — a  $180^\circ$  phase inversion. This inversion is the signature behavior of the CE topology.
64. A — Synchronous speed:  $n_s = 120 \cdot f/P = 120 \cdot 60/4 = 1,800$  rpm. Synchronous speed depends only on supply frequency and pole count; load and excitation affect slip in induction machines but not the synchronous speed itself. Pole pairs set the fundamental speed-frequency relationship.
65. C — Apparent power:  $S = \sqrt{3} \cdot V_{LL} \cdot I_L = \sqrt{3} \cdot 480 \cdot 50 \approx 41,569$  VA  $\approx 41.6$  kVA. Power factor relates apparent power to real power:  $P = S \cdot \cos \theta$ . Apparent power sets the kVA rating of transformers and switchgear, independent of the load's power factor.
66. D — Synchronous speed:  $n_s = 120 \cdot 60/4 = 1,800$  rpm. Slip:  $s = (n_s - n)/n_s = (1,800 - 1,700)/1,800 \approx 5.6\%$ . Induction motors operate at small positive slip under load, with slip directly determining torque production.
67. B — Full-load primary current:  $I_{HV} = S/V_{HV} = 100,000/11,000 = 9.09$  A. Transformer current ratings scale inversely with voltage, so the high-voltage side draws far less current than the low-voltage side at the same kVA rating. This relationship justifies using high voltage for long-distance transmission.

68. A — Voltage ratio:  $V_p/V_s = 13,200/480 = 27.5$ . Current scales inversely:  $I_p = I_s/27.5 = 100/27.5 \approx 3.6$  A. The ideal transformer conserves apparent power  $V_p \cdot I_p = V_s \cdot I_s$ , so stepping voltage down by 27.5 steps current up by the same ratio.
69. D — In a balanced three-phase system, the three single-phase instantaneous powers (each pulsating at  $2\omega$ ) sum to a constant value because the  $120^\circ$ -spaced second-harmonic components cancel. Constant power flow is one of three-phase power's principal advantages. Single-phase systems, by contrast, have inherently pulsating instantaneous power.
70. C — Per-unit conversion:  $Z_{pu,new} = Z_{pu,old} \cdot (V_{base,old}/V_{base,new})^2 \cdot (S_{base,new}/S_{base,old})$ . This formula reconciles equipment data given on different voltage and apparent-power bases. Consistent per-unit basing is essential before performing system-wide power-flow or fault studies.
71. A — Line current:  $I_L = S/(\sqrt{3} \cdot V_{LL}) = 50,000/(\sqrt{3} \cdot 480) = 50,000/831.4 \approx 60.1$  A. The  $\sqrt{3}$  factor relating line-to-line voltage to phase quantities appears in essentially every three-phase calculation. Power factor affects real and reactive components but not the apparent-power line current.
72. B — Induced EMF in a DC machine:  $E_a = K \cdot \Phi \cdot \omega$ , where  $K$  is a machine constant (poles, parallel paths, conductors),  $\Phi$  is the field flux, and  $\omega$  is the rotor angular speed. This equation underpins both generator output and motor back-EMF analysis.
73. D — Inside a long solenoid:  $B = \mu_0 \cdot N \cdot I/\ell = (4\pi \times 10^{-7} \cdot 500 \cdot 3)/0.2 \approx 9.42 \times 10^{-3}$  T. Flux through one turn:  $\Phi = B \cdot A = 9.42 \times 10^{-3} \cdot 4 \times 10^{-4} \approx 3.77$   $\mu$ Wb. The solenoid model treats the interior field as uniform, accurate when length is much greater than diameter.
74. C —  $C = \epsilon \cdot A/d$ . Doubling  $A$  multiplies  $C$  by 2; doubling  $d$  divides  $C$  by 2. Net effect:  $C_{new} = \epsilon \cdot (2A)/(2d) = \epsilon \cdot A/d = C$  — unchanged. The ratio  $A/d$  controls the final capacitance value.
75. A — In a plane EM wave in vacuum,  $E$  and  $B$  amplitudes are related by  $E = c \cdot B$ , where  $c$  is the speed of light. The two fields oscillate in phase and perpendicular both to each other and to the propagation direction. This relationship sets the impedance of free space  $\eta_0 = E/H \approx 377$   $\Omega$ .
76. C — Wavelength in a medium:  $\lambda = \lambda_0/n$  where  $n = \sqrt{\epsilon_r \cdot \mu_r}$ . For a non-magnetic medium with  $\epsilon_r = 9$ :  $n = 3$ , giving  $\lambda = \lambda_0/3$ . EM waves slow down and compress in higher-index materials, a property exploited in lenses and waveguide loading.
77. B — Closed-loop transfer function:  $T(s) = K/(s^2 + 10s + K)$ . Comparing to  $s^2 + 2\zeta\omega_n s + \omega_n^2$ :  $\omega_n^2 = K$  and  $2\zeta\omega_n = 10$ . With  $\zeta = 0.707$ :  $\omega_n = 10/(2 \cdot 0.707) \approx 7.07$ , so  $K = \omega_n^2 = 50$ . Standard second-order parameterization links physical parameters directly to time-domain performance.
78. D — Type 1 system:  $K_v = \lim_{s \rightarrow 0} s \cdot G(s) = \lim_{s \rightarrow 0} K/(s + 2) = K/2$ . Steady-state error to a ramp:  $e_{ss} = 1/K_v = 2/K$ . Increasing  $K$  reduces tracking error but risks stability. The velocity error constant  $K_v$  summarizes Type 1 ramp-tracking capability.
79. A — At low frequencies, the  $(s + 10)$  term acts approximately as the constant 10, leaving  $K/s$  as the dominant factor. A pure  $1/s$  term contributes a Bode magnitude slope of  $-20$  dB/decade. This slope identifies a Type 1 system by inspection of the low-frequency asymptote.
80. B — Gain margin =  $1/|G(j\omega_{pc})|$ , where  $\omega_{pc}$  is the phase crossover frequency at which  $\angle G = -180^\circ$ . In dB:  $GM = -20 \cdot \log_{10}|G(j\omega_{pc})|$ . Positive gain margin (in dB) indicates how much additional loop gain the system can tolerate before instability sets in.
81. C — Closed-loop bandwidth is controlled by the dominant closed-loop pole — the pole(s) nearest the imaginary axis. Faster poles affect transient detail but contribute little to bandwidth. The dominant-pole approximation simplifies higher-order analysis enormously.
82. D — Compare  $T(s)$  denominator to  $s^2 + 2\zeta\omega_n s + \omega_n^2$ :  $\omega_n^2 = K$  and  $2\zeta\omega_n = 4$ . For  $\zeta = 1$  (critical damping):  $\omega_n = 2$ , giving  $K = 4$ . Critical damping produces the fastest non-oscillatory step response and is often the design target for servo loops.

83. B — For a Type 0 unity-feedback system,  $e_{ss}$  to a unit step is  $1/(1 + K_p)$ . With  $K_p = 9$ :  $e_{ss} = 1/10 = 0.10$ . Type 0 systems always exhibit finite steady-state step error unless  $K_p$  is infinite, motivating the use of integral control to eliminate residual error.
84. A — Multiplication by  $\cos(\omega_c t)$  in time corresponds to convolution with  $[\delta(\omega - \omega_c) + \delta(\omega + \omega_c)]/2$  in frequency, producing two shifted copies of  $M(\omega)$  at  $\pm\omega_c$ , each scaled by  $1/2$ . This frequency translation is the essence of every amplitude-modulation scheme.
85. D — Gray coding assigns adjacent constellation symbols bit labels that differ in only one bit. When a symbol error causes mistaking a symbol for its nearest neighbor — the most likely error — only one bit is flipped. This minimizes the bit error rate for a given symbol error rate.
86. C — QAM independently modulates two orthogonal carriers (in-phase and quadrature), creating two-dimensional constellations that pack more bits per symbol than 1-D PSK. For example, 64-QAM transmits 6 bits/symbol versus QPSK's 2. Higher-order QAM trades SNR margin for spectral efficiency.
87. B — Compute the argument:  $\sqrt{(2 \cdot E_b/N_0)} = \sqrt{(2 \cdot 7.94)} \approx \sqrt{15.88} \approx 4$ .  $BER \approx Q(4) \approx 3.2 \times 10^{-5}$ , closest to the listed value  $3.4 \times 10^{-5}$ . The Q-function tail decreases steeply with argument, so small SNR improvements yield large BER reductions.
88. A — OFDM divides the high-rate input stream across many low-rate orthogonal subcarriers transmitted in parallel. Each subcarrier sees a nearly flat channel, simplifying equalization. The aggregate data rate equals the sum of subcarrier rates, and OFDM dominates modern broadband wireless standards.
89. C — A /26 mask leaves  $32 - 26 = 6$  host bits, giving  $2^6 = 64$  total addresses per subnet. Subtracting the network and broadcast addresses leaves  $64 - 2 = 62$  usable hosts. The subtract-two pattern applies to every IPv4 subnet calculation.
90. D — ICMP carries control and diagnostic messages such as Echo Request/Reply (used by ping) and Destination Unreachable. It is not used for end-user data transfer. Network administrators rely heavily on ICMP for connectivity testing and route tracing.
91. A — 802.11ac (Wi-Fi 5) achieves theoretical peak rates around 1.3 Gbps using wide channels (up to 160 MHz), 256-QAM, and multiple spatial streams. Actual throughput depends strongly on signal quality, channel width, and antenna configuration. Wi-Fi 6/6E and Wi-Fi 7 push these rates substantially higher.
92. B — ARP (Address Resolution Protocol) maps an IPv4 address to the corresponding MAC address on the local link by broadcasting a query and caching the reply. Without ARP, IP packets could not be encapsulated in Ethernet frames addressed to the correct destination. ARP operates entirely within the local subnet.
93. D — Convert by division:  $250 = 15 \cdot 16 + 10 = F \cdot 16 + A \rightarrow 0xFA$ . Hexadecimal grouping by 4 binary bits provides a compact notation familiar to systems programmers. 0xFA represents the bit pattern 1111 1010.
94. D — Apply distribution and complementarity:  $A \cdot B' + A \cdot B = A \cdot (B' + B) = A \cdot 1 = A$ . The OR of a variable with its complement is always 1, eliminating B entirely. This is one of the fundamental Boolean simplification identities used in K-map minimization.
95. C — An XOR gate produces a HIGH output exclusively when its two inputs are at different logic levels, implementing the binary inequality operation. XOR is the foundation of half-adder sum bits and parity-checking circuits. The truth table is  $(0,0) \rightarrow 0$ ,  $(0,1) \rightarrow 1$ ,  $(1,0) \rightarrow 1$ ,  $(1,1) \rightarrow 0$ .
96. A — An N-bit binary counter has  $2^N$  distinct states, cycling  $0 \rightarrow 2^N - 1 \rightarrow 0$  every  $2^N$  clock pulses. The rollover period is governed entirely by the bit width. Modulo-K counters use combinational reset logic to truncate this natural sequence to a shorter period.

97. B — A binary decoder with  $k$  input lines drives  $2^k$  mutually exclusive output lines, asserting exactly one output per input combination. Decoders are ubiquitous in memory-row selection and instruction decoding. The  $2^k$  relationship reflects the exponential growth of binary state space.
98. C — In a ripple-carry adder, the carry-out from each stage must propagate to the next before its sum is valid. For an 8-bit adder, the worst-case delay is 8 times the per-stage adder delay. This linear delay growth motivates faster designs like carry-lookahead and carry-select adders.
99. A — Shift 1011 right by one with zero fill at the MSB: 0101. Shift again: 0010. Shift again: 0001. After 3 right shifts with serial input 0, the register holds 0001. Right shifts effectively divide by 2 each cycle for unsigned values.
100. D — ROM and modern flash memory retain stored data without power, classifying them as non-volatile. SRAM and DRAM lose contents when power is removed. Non-volatile memory holds firmware, boot code, and persistent storage — data categories that must survive power cycles.
101. B — A 4-input MUX selects among  $4 = 2^2$  data lines, so 2 select bits are required. In general, an  $n$ -input MUX needs  $\lceil \log_2 n \rceil$  select lines. Multiplexers form the building blocks of data routing in CPUs and FPGAs.
102. C — Standard ARM (non-Thumb) instructions are exactly 32 bits wide, enabling a uniform decode pipeline and direct encoding of immediates and register operands. Thumb mode compresses to 16 bits for higher code density at some performance cost. Fixed-width instructions simplify CPU pipeline design.
103. A —  $AMAT = hit\_rate \cdot L1\_time + miss\_rate \cdot L2\_time = 0.95 \cdot 1 + 0.05 \cdot 10 = 0.95 + 0.5 = 1.45$  ns. Even modest miss rates significantly degrade average performance because L2 access is far slower than L1. Cache hit-rate optimization is a primary lever in performance tuning.
104. D — Polling continuously checks device status in software, simplifying program structure and avoiding interrupt-handler complexity. It works well when events occur predictably and CPU utilization is not critical. Interrupts are preferred when events are sporadic and low-latency response is required.
105. A — IEEE 754 single precision uses 1 sign bit + 8 exponent bits + 23 explicitly stored mantissa bits, totaling 32 bits. The mantissa carries 24 bits of effective precision due to the implicit leading 1 in normalized numbers. This format yields about 7 decimal digits of precision.
106. B — Mechanical hard disk drives have access times measured in milliseconds, dominated by rotational latency and head-seek time. SSDs measure in microseconds, DRAM in tens of nanoseconds, caches in single-digit nanoseconds. The five-orders-of-magnitude spread is exactly why the memory hierarchy exists.
107. D — `git merge` combines the commit history of one branch into another, integrating changes while preserving both branches' development records. `clone` duplicates a repository, `push` uploads commits, and `fetch` downloads commits without merging. Merging is central to collaborative Git workflows.
108. C — Finding the maximum in an unsorted array requires examining every element exactly once, giving linear time complexity  $O(n)$ . No comparison-based algorithm can do better than  $n - 1$  comparisons in the worst case. This contrasts with sorted arrays, where the maximum is the last element in  $O(1)$ .
109. A — A user story is a brief, informal description of a feature written from the end-user's perspective, typically as "As a [role], I want [feature] so that [benefit]." User stories anchor sprint planning in user value rather than technical specification. They are deliberately lightweight to encourage conversation between team and stakeholders.

110. B — The Single Responsibility Principle (SRP) states that a class should have only one reason to change — that is, one cohesive responsibility within the system. Classes mixing unrelated responsibilities become brittle and tightly coupled. SRP is the "S" in the SOLID design principles.