FE Electrical and Computer

Free practice problems and worked solutions

This sample contains 17 original problems, one from each knowledge area, already available free on EngineerProof. The original Form A problem numbers are retained. This is a sample, not a complete 110-question exam or a predictor of your NCEES result.

Work the questions before consulting the solutions. Each solution includes the calculation and an explanation of the other choices. The full forms, contents, and purchase conditions are at:

https://engineerproof.inshihub.com/fe-electrical-computer

Included knowledge areas

Practice questions

Mathematics

1. Two feeder branches deliver phasor currents $I_1 = 12\angle 25^\circ$ A and $I_2 = 9\angle -40^\circ$ A into a common node, both referred to the same voltage reference. The magnitude of the total current leaving the node is most nearly:

(A) 11.6 A

(B) 15.0 A

(C) 17.8 A

(D) 21.0 A

Probability and Statistics

13. A relay assembly line receives 65 percent of its relays from supplier X and 35 percent from supplier Y. Relays from supplier X are defective at a rate of 2.0 percent, and relays from supplier Y are defective at a rate of 5.0 percent. A relay drawn at random from stock fails incoming inspection. The probability that the failed relay came from supplier X is most nearly:

(A) 0.286

(B) 0.426

(C) 0.574

(D) 0.714

Ethics and Professional Practice

19. A consulting firm holds 6 concurrent-use seats of a circuit simulation package under an agreement permitting no more than the licensed number of simultaneous users. Usage logs for the past quarter show an average of 8 simultaneous users and a peak of 14. Additional seats are sold at USD 1,450 per seat per year. The additional annual license cost required to bring the firm into compliance is most nearly:

(A) USD 2,900 per year

(B) USD 8,700 per year

(C) USD 11,600 per year

(D) USD 20,300 per year

Engineering Economics

23. Two 750 kVA transformers are compared over a 15-year study period at an interest rate of 8% per year. Unit A costs USD 60,000 installed, requires USD 4,500 per year for operation and maintenance, and has a salvage value of USD 8,000 at the end of year 15. Unit B costs USD 45,000 installed, requires USD 6,800 per year, and has no salvage value. The present worth advantage of Unit A over Unit B is most nearly:

(A) USD 4,700

(B) USD 7,200

(C) USD 12,700

(D) USD 19,700

Properties of Electrical Materials

28. Silicon at 300 K is doped with donors at $3 \times 10^{16}\ \mathrm{cm}^{-3}$ and acceptors at $1 \times 10^{16}\ \mathrm{cm}^{-3}$. The intrinsic carrier concentration of silicon at this temperature is $1.5 \times 10^{10}\ \mathrm{cm}^{-3}$. The equilibrium hole concentration is most nearly:

(A) $1.1 \times 10^{4}\ \mathrm{cm}^{-3}$

(B) $2.3 \times 10^{4}\ \mathrm{cm}^{-3}$

(C) $5.6 \times 10^{3}\ \mathrm{cm}^{-3}$

(D) $7.5 \times 10^{3}\ \mathrm{cm}^{-3}$

Circuit Analysis (DC and AC Steady State)

32. A 120 V DC source is connected through a 10 Ω series resistor to a parallel section. One branch of that section is a single 60 Ω resistor; the other branch is a 12 Ω resistor in series with an 18 Ω resistor. The voltage across the 18 Ω resistor is most nearly:

(A) 21.6 V

(B) 24.0 V

(C) 32.0 V

(D) 48.0 V

Linear Systems

44. A unity-feedback position servo has closed-loop transfer function $G(s) = \dfrac{400}{s^2 + 12s + 400}$, with s in rad/s. For a step command, the percent overshoot of the output is most nearly:

(A) 9.5%

(B) 13.9%

(C) 37.2%

(D) 95.4%

Signal Processing

52. A causal discrete-time linear time-invariant system has the transfer function $H(z) = \frac{z}{(z-0.5)(z-1.25)}$. The statement that correctly describes the region of convergence and the stability of this system is:

(A) Region of convergence is $|\ z\ | > 0.5$; the system is stable.

(B) Region of convergence is $0.5 < |\ z\ | < 1.25$; the system is stable.

(C) Region of convergence is $|\ z\ | < 0.5$; the system is unstable.

(D) Region of convergence is $|\ z\ | > 1.25$; the system is unstable.

Electronics

56. An 18 V unregulated supply feeds a 220 Ω series resistor followed by a 9.1 V Zener diode in shunt with the load. The Zener requires a minimum of 5.0 mA to remain in breakdown, and its breakdown characteristic may be treated as ideal. The maximum DC load current the regulator can deliver at rated output voltage is most nearly:

(A) 35.5 mA

(B) 40.5 mA

(C) 45.5 mA

(D) 81.8 mA

Power Systems

63. A run-of-river hydroelectric plant passes $850\ \mathrm{ft^3/s}$ through its turbine at a net head of $62\ \mathrm{ft}$. The combined turbine-generator efficiency is 0.85, and the specific weight of water is $62.4\ \mathrm{lbf/ft^3}$. The electrical power delivered to the station bus is most nearly:

(A) 3,790 kW

(B) 4,460 kW

(C) 5,080 kW

(D) 5,980 kW

Electromagnetics

72. A coaxial feeder 30 m long has an inner conductor of radius 1.2 mm and an outer conductor whose inner radius is 6.0 mm. The intervening space is filled with polyethylene of relative permittivity 2.25. The capacitance of the feeder is most nearly:

(A) 77.8 pF

(B) 1040 pF

(C) 1630 pF

(D) 2330 pF

Control Systems

78. A unity-feedback antenna position loop uses a PI controller $C(s) = 4.0 + \frac{10}{s}$ driving a plant $G(s) = \frac{2.5}{s+5}$. The command is a ramp of constant rate 3.0 rad/s. The steady-state tracking error is most nearly:

(A) 0.20 rad

(B) 0.33 rad

(C) 0.60 rad

(D) 1.50 rad

Communications

84. A conventional double-sideband, full-carrier amplitude-modulated transmitter delivers a total average power of 15 kW to its antenna while modulated by a single sinusoidal tone at a modulation index of 0.80. The average power contained in one sideband is most nearly:

(A) 1.82 kW

(B) 2.40 kW

(C) 3.64 kW

(D) 11.36 kW

Computer Networks

89. A campus network is allocated the address block 10.40.96.0/19. The block is divided into equal-size subnets, each of which must accommodate at least 500 host addresses, and the number of subnets is maximized. The number of usable host addresses in each resulting subnet is:

(A) 254 addresses

(B) 500 addresses

(C) 508 addresses

(D) 510 addresses

Digital Systems

94. An 8-bit two's complement adder in a motor controller receives the operands 01011101_2 and 00110110_2. The signed decimal value left in the 8-bit result register is:

(A) -109

(B) -108

(C) -19

(D) 147

Computer Systems

102. A processor uses a two-level cache hierarchy. The L1 cache has an access time of 1.0 ns and a miss rate of 6%. An L1 miss is serviced by an L2 cache with an access time of 9 ns and a local miss rate of 25%. An L2 miss is serviced by main memory in 80 ns. The average memory access time seen by the processor is most nearly:

(A) 2.74 ns

(B) 5.80 ns

(C) 6.34 ns

(D) 21.54 ns

Software Engineering

107. A batch record-sorting routine in a utility billing system uses a comparison sort whose running time grows as $n \log_2 n$, where n is the number of records. Sorting 100{,}000 records requires 0.42 s on the target processor. On the same processor, the time required to sort 800{,}000 records is most nearly:

(A) 3.36 s

(B) 3.97 s

(C) 26.9 s

(D) 31.7 s

Worked solutions

Mathematics

Problem 1

Answer: (C)

Two feeder branches deliver phasor currents $I_1 = 12\angle 25^\circ$ A and $I_2 = 9\angle -40^\circ$ A into a common node, both referred to the same voltage reference. The magnitude of the total current leaving the node is most nearly:

Added in rectangular form, the two branch currents give a resultant of 17.8 A. The 65 degree phase separation is what holds the total below the 21 A arithmetic sum.

Phasor addition requires rectangular components, since the two branch currents differ in phase by 65 degrees.

$$I_1 = 12(\cos 25^\circ + j\sin 25^\circ) = 10.876 + j5.071\ \mathrm{A}$$

$$I_2 = 9(\cos 40^\circ - j\sin 40^\circ) = 6.894 - j5.785\ \mathrm{A}$$

Component-wise addition leaves a resultant almost aligned with the real axis, the imaginary parts nearly cancelling.

$$I_1 + I_2 = 17.770 - j0.714\ \mathrm{A}$$

Magnitude of the resultant follows from its rectangular components.

$$|\,I_1 + I_2| = \sqrt{17.770^2 + 0.714^2} = 17.8\ \mathrm{A}$$

FE REFERENCE HANDBOOK — MATHEMATICS: COMPLEX NUMBERS, POLAR AND RECTANGULAR FORMS

WHY THE OTHER CHOICES APPEAR

- **(A)** Subtracts the phasors instead of adding them, giving sqrt(225 - 91.29) = 11.56 A.
- **(B)** Treats the two currents as orthogonal, giving sqrt(12^2 + 9^2) = 15.0 A.
- **(D)** Adds the magnitudes arithmetically, 12 + 9 = 21 A, ignoring the 65 degree phase separation.

Probability and Statistics

Problem 13

Answer: (B)

A relay assembly line receives 65 percent of its relays from supplier X and 35 percent from supplier Y. Relays from supplier X are defective at a rate of 2.0 percent, and relays from supplier Y are defective at a rate of 5.0 percent. A relay drawn at random from stock fails incoming inspection. The probability that the failed relay came from supplier X is most nearly:

Weighting each supplier's defect rate by its share leaves supplier X responsible for 0.0130 of the 0.0305 total defect probability, about 43 percent of all defective relays.

Supplier share and supplier-specific defect rate combine into the unconditional defect probability that serves as the denominator of the reverse conditional.

$$P(D) = P(D \mid X)P(X) + P(D \mid Y)P(Y)$$

$$P(D) = (0.020)(0.65) + (0.050)(0.35) = 0.0305$$

Bayes' theorem rescales the single branch belonging to supplier X against that total.

$$P(X \mid D) = \frac{(0.020)(0.65)}{0.0305} = \frac{0.0130}{0.0305} = 0.426$$

FE REFERENCE HANDBOOK — ENGINEERING PROBABILITY AND STATISTICS: BAYES' THEOREM

WHY THE OTHER CHOICES APPEAR

(A) 0.286 comes from normalizing the two defect rates alone, 0.020/(0.020+0.050), discarding the 65/35 supply shares.

(C) 0.574 is 0.0175/0.0305, the posterior probability for supplier Y, obtained by inverting the wrong branch.

(D) 0.714 is 0.050/(0.020+0.050), combining both errors: unweighted defect rates and the wrong supplier.

Ethics and Professional Practice

Problem 19

Answer: (C)

A consulting firm holds 6 concurrent-use seats of a circuit simulation package under an agreement permitting no more than the licensed number of simultaneous users. Usage logs for the past quarter show an average of 8 simultaneous users and a peak of 14. Additional seats are sold at USD 1,450 per seat per year. The additional annual license cost required to bring the firm into compliance is most nearly:

A concurrent-use cap is satisfied only at the logged peak of 14 users, so the firm buys the 8-seat shortfall for an added USD 11,600 each year.

Concurrent-use terms cap simultaneous users at the number of seats held, so the entitlement must cover the logged peak; sizing to the average of 8 leaves the firm in breach on every occasion demand climbs above the seat count.

$$n_{req} = 14 \text{ simultaneous users}$$

The seats already licensed remain in force, so only the deficit between the required count and the existing entitlement is purchased.

$$n_{add} = 14 - 6 = 8 \text{ seats}$$

The per-seat charge is a recurring subscription rate, which makes the compliance cost an ongoing yearly commitment rather than a one-time purchase.

$$C_{add} = 8(1,450) = 11,600 \text{ USD per year}$$

FE REFERENCE HANDBOOK — ETHICS AND PROFESSIONAL PRACTICE: NCEES MODEL RULES, RULES OF PROFESSIONAL CONDUCT (LICENSEE'S OBLIGATION TO EMPLOYER AND CLIENT; INTELLECTUAL PROPERTY AND SOFTWARE LICENSE COMPLIANCE)

WHY THE OTHER CHOICES APPEAR

- **(A)** Sizes the purchase to the average of 8 simultaneous users, 8 - 6 = 2 seats at 1,450, giving 2,900; an average does not satisfy a cap on simultaneous users.
- **(B)** Prices the 6 seats already held, 6(1,450) = 8,700, instead of the shortfall above them.
- **(D)** Licenses all 14 peak users from zero, 14(1,450) = 20,300, ignoring the entitlement already in force.

Engineering Economics

Problem 23

Answer: (B)

Two 750 kVA transformers are compared over a 15-year study period at an interest rate of 8% per year. Unit A costs USD 60,000 installed, requires USD 4,500 per year for operation and maintenance, and has a salvage value of USD 8,000 at the end of year 15. Unit B costs USD 45,000 installed, requires USD 6,800 per year, and has no salvage value. The present worth advantage of Unit A over Unit B is most nearly:

Unit A costs USD 15,000 more to install, but its lower annual cost and its salvage credit leave it about USD 7,200 ahead in present worth.

Costs arriving on different schedules become comparable only when the first cost, the annual series, and the end-of-life salvage are all referred to time zero over the same 15-year horizon.

$$PW = P + A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] - S(1+i)^{-n}$$

$$(P/A, 8\%, 15) = 8.5595 \qquad (P/F, 8\%, 15) = 0.3152$$

Unit A carries the heavier purchase price but recovers part of it at retirement while committing to the smaller maintenance stream.

$$PW_A = 60,000 + 4,500(8.5595) - 8,000(0.3152) = 95,996$$

Unit B earns no salvage credit, so its cost stream is purchase price plus the discounted maintenance alone.

$$PW_B = 45,000 + 6,800(8.5595) = 103,204$$

Fifteen years of the USD 2,300 per year maintenance penalty on Unit B swamp its USD 15,000 lower first cost, leaving Unit A ahead by about USD 7,200.

$$PW_B - PW_A = 103,204 - 95,996 = 7,208$$

FE REFERENCE HANDBOOK — ENGINEERING ECONOMICS: UNIFORM SERIES PRESENT WORTH FACTOR AND PRESENT WORTH ANALYSIS

WHY THE OTHER CHOICES APPEAR

(A) Omits the salvage credit on Unit A: 103,204 - (60,000 + 38,518) = 4,686.

(C) Deducts the USD 8,000 salvage at face value instead of its present worth: 103,204 - (98,518 - 8,000) = 12,686.

(D) Capitalizes only the USD 2,300 per year maintenance difference and ignores both the first-cost difference and salvage: 2,300(8.5595) = 19,687.

Properties of Electrical Materials

Problem 28

Answer: (A)

Silicon at 300 K is doped with donors at 3×10^{16} cm^{-3} and acceptors at 1×10^{16} cm^{-3}. The intrinsic carrier concentration of silicon at this temperature is 1.5×10^{10} cm^{-3}. The equilibrium hole concentration is most nearly:

Compensation leaves a net donor density of 2×10^{16} cm^{-3}*, and the mass-action law puts the equilibrium hole concentration at about* 1.1×10^{4} cm^{-3}.

Compensated material carries a majority density equal to the net dopant excess, since each acceptor consumes one donor electron.

$$n = N_D - N_A = 3 \times 10^{16} - 1 \times 10^{16} = 2 \times 10^{16}\ \mathrm{cm}^{-3}$$

Mass action then fixes the minority population, which in heavily doped silicon sits many orders below the intrinsic level.

$$p = \frac{n_i^2}{n} = \frac{(1.5 \times 10^{10})^2}{2 \times 10^{16}} = \frac{2.25 \times 10^{20}}{2 \times 10^{16}}$$

$$p = 1.1 \times 10^{4}\ \mathrm{cm}^{-3}$$

FE REFERENCE HANDBOOK — PROPERTIES OF ELECTRICAL MATERIALS: INTRINSIC AND EXTRINSIC CARRIER CONCENTRATION (MASS ACTION LAW)

WHY THE OTHER CHOICES APPEAR

(B) Takes the acceptor concentration 1×10^{16} cm^{-3} as the majority density: $2.25 \times 10^{20}/(1 \times 10^{16}) = 2.25 \times 10^{4}$ cm^{-3}.

(C) Adds the acceptor density to the donor density instead of subtracting: $2.25 \times 10^{20}/(4 \times 10^{16}) = 5.6 \times 10^{3}$ cm^{-3}.

(D) Ignores compensation and divides by the donor density alone: $2.25 \times 10^{20}/(3 \times 10^{16}) = 7.5 \times 10^{3}$ cm^{-3}.

Circuit Analysis (DC and AC Steady State)

Problem 32

Answer: (D)

A 120 V DC source is connected through a 10 Ω series resistor to a parallel section. One branch of that section is a single 60 Ω resistor; the other branch is a 12 Ω resistor in series with an 18 Ω resistor. The voltage across the 18 Ω resistor is most nearly:

Only 80 V reaches the parallel section, and 48 V of that appears across the 18 Ω resistor.

Reduction starts at the far end, where the 12 Ω and 18 Ω resistors carry a common current and combine before the parallel step.

$$R_{series} = 12 + 18 = 30\ \Omega$$

$$R_p = \frac{(60)(30)}{60 + 30} = 20\ \Omega$$

With 30 Ω of total loop resistance, the source drives 4 A, and the 10 Ω resistor absorbs part of the supply voltage before the parallel section.

$$I_s = \frac{120}{10 + 20} = 4\ \text{A}$$

$$V_p = (4)(20) = 80\ \text{V}$$

Splitting that section voltage between the two series resistors of the composite branch leaves the larger share on the 18 Ω element.

$$I_{branch} = \frac{80}{30} = 2.67\ \text{A}$$

$$V_{18} = (2.67)(18) = 48.0\ \text{V}$$

FE REFERENCE HANDBOOK — ELECTRICAL AND COMPUTER ENGINEERING: RESISTORS IN SERIES AND PARALLEL, VOLTAGE AND CURRENT DIVISION

WHY THE OTHER CHOICES APPEAR

(A) Treats the two branches as being in series (60 + 30 = 90 Ω, total 100 Ω, 1.2 A), giving (1.2)(18) = 21.6 V.

(B) Inverts the current-division ratio, 4 A times 30/90 = 1.33 A, giving (1.33)(18) = 24.0 V.

(C) Solves for the drop across the 12 Ω resistor of the same branch, (2.67)(12) = 32.0 V.

Linear Systems

Problem 44

Answer: (C)

A unity-feedback position servo has closed-loop transfer function $G(s) = \dfrac{400}{s^2 + 12s + 400}$, with s in rad/s. For a step command, the percent overshoot of the output is most nearly:

A damping ratio of 0.3 governs the peak entirely, giving roughly 37 percent overshoot regardless of the 20 rad/s natural frequency.

Matching the denominator against the standard second-order form fixes both parameters at once.

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = s^2 + 12s + 400$$

$$\omega_n = 20 \text{ rad/s}, \quad \zeta = \frac{12}{2(20)} = 0.3$$

Overshoot of an underdamped step response is set by the damping ratio alone, since ω_n only rescales time.

$$M_p = 100\, e^{-\pi\zeta/\sqrt{1-\zeta^2}}$$

With $\zeta = 0.3$ the exponent falls just below unity, leaving a peak more than one-third above the final value.

$$M_p = 100\, e^{-0.9425/0.9539} = 100(0.3723) = 37.2\%$$

FE REFERENCE HANDBOOK — CONTROL SYSTEMS: SECOND-ORDER CONTROL-SYSTEM MODELS, PERCENT OVERSHOOT

WHY THE OTHER CHOICES APPEAR

(A) Setting $\zeta\omega_n = 12$ instead of $2\zeta\omega_n = 12$ gives $\zeta = 0.6$ and $100e^{-1.885/0.8} = 9.5\%$.

(B) Using the successive-peak exponent $2\pi\zeta/\sqrt{1-\zeta^2}$ squares the correct factor: $(0.3723)^2 = 13.9\%$.

(D) Taking $\omega_n = 400$ rad/s directly from the constant term gives $\zeta = 12/800 = 0.015$ and 95.4%.

Signal Processing

Problem 52

Answer: (D)

A causal discrete-time linear time-invariant system has the transfer function $H(z) = \frac{z}{(z-0.5)(z-1.25)}$. The statement that correctly describes the region of convergence and the stability of this system is:

Causality forces the region of convergence outside the outermost pole at 1.25, and that region excludes the unit circle, so the response grows without bound.

Causality admits only right-sided sequences, whose z-transforms converge in the exterior of a circle passing through the pole of largest magnitude.

$$\mid z \mid > \max(0.5,\, 1.25) = 1.25$$

Bounded-input bounded-output stability additionally demands that this exterior region contain the unit circle, which is impossible with a pole at radius 1.25.

$$|p_2| = 1.25 > 1$$

FE REFERENCE HANDBOOK — ELECTRICAL AND COMPUTER ENGINEERING: Z-TRANSFORMS, REGION OF CONVERGENCE AND STABILITY

WHY THE OTHER CHOICES APPEAR

(A) Using the innermost pole to bound the exterior region and then judging stability from that pole alone, ignoring the pole at 1.25.

(B) Selecting the annular region, which belongs to the two-sided noncausal inverse transform; it is stable but contradicts the stated causality.

(C) Reading the region as the interior of the smallest pole, the fully anticausal choice, which is inconsistent with a causal system.

Electronics

Problem 56

Answer: (A)

An 18 V unregulated supply feeds a 220 Ω series resistor followed by a 9.1 V Zener diode in shunt with the load. The Zener requires a minimum of 5.0 mA to remain in breakdown, and its breakdown characteristic may be treated as ideal. The maximum DC load current the regulator can deliver at rated output voltage is most nearly:

Subtracting the 5.0 mA holding current from the 40.45 mA that the series resistor delivers leaves about 35.5 mA available to the load.

Series-resistor current is set entirely by the 18 V source and the clamped 9.1 V output, regardless of how that current later divides between diode and load.

$$I_R = \frac{18 - 9.1}{220} = 40.45 \times 10^{-3} \text{ A}$$

Load current is whatever the Zener does not take, so the load is maximized at the instant the diode carries only its minimum breakdown current.

$$I_{L,max} = I_R - I_{Z,min} = 40.45 - 5.0 = 35.5 \text{ mA}$$

FE REFERENCE HANDBOOK — ELECTRONICS: DIODES, ZENER DIODE MODEL AND SHUNT REGULATION

WHY THE OTHER CHOICES APPEAR

(B) Omits the 5.0 mA Zener holding current and assigns the entire 40.45 mA series current to the load.

(C) Adds the 5.0 mA minimum diode current to the series current instead of subtracting it, 40.45 + 5.0 = 45.5 mA.

(D) Places the full source voltage across the series resistor, ignoring the 9.1 V clamp, 18/220 = 81.8 mA.

Power Systems

Problem 63

Answer: (A)

A run-of-river hydroelectric plant passes 850 ft^3/s through its turbine at a net head of 62 ft. The combined turbine-generator efficiency is 0.85, and the specific weight of water is 62.4 lbf/ft^3. The electrical power delivered to the station bus is most nearly:

The 3.29 million ft-lbf/s of hydraulic power, reduced by the combined turbine-generator efficiency and then converted to watts, puts about 3.8 MW on the bus.

Hydraulic power available at the runner is the weight flow rate carried through the net head.

$$P_{hyd} = \gamma Q H = (62.4)(850)(62) = 3.288 \times 10^6 \text{ ft} \cdot \text{lbf/s}$$

Converting at 550 ft · lbf/s per horsepower and charging the single combined efficiency against the shaft leaves the station output.

$$P_{hyd} = \frac{3.288 \times 10^6}{550} = 5979 \text{ hp}$$

$$P_{out} = (0.85)(5979)(0.746) = 3791 \text{ kW}$$

FE REFERENCE HANDBOOK — FLUID MECHANICS: PUMP POWER EQUATION (HYDRAULIC POWER, TURBINE FORM)

WHY THE OTHER CHOICES APPEAR

(B) Omitting the 0.85 efficiency and converting the gross 5979 hp gives $(5979)(0.746) = 4460$ kW.

(C) Reporting the net shaft value 5082 hp as if the number were already kilowatts gives 5080.

(D) Reporting the gross hydraulic value 5979 hp as if the number were already kilowatts gives 5980.

Electromagnetics

Problem 72

Answer: (D)

A coaxial feeder 30 m long has an inner conductor of radius 1.2 mm and an outer conductor whose inner radius is 6.0 mm. The intervening space is filled with polyethylene of relative permittivity 2.25. The capacitance of the feeder is most nearly:

The 30 m run comes to about 2330 pF, set by the logarithm of the conductor radius ratio and the polyethylene permittivity.

Charge on the inner conductor produces a purely radial field, and integrating that field from inner to outer radius yields the logarithmic potential difference behind the coaxial capacitance expression.

$$C = \frac{2\pi\varepsilon_0\varepsilon_r\ell}{\ln(b/a)}$$

Only the ratio of the radii enters, so the millimetre units require no conversion.

$$\frac{b}{a} = \frac{6.0}{1.2} = 5.0$$

$$\ln 5.0 = 1.609$$

Polyethylene multiplies the air-filled value by its relative permittivity, and the 30 m length scales it linearly.

$$C = \frac{2\pi(8.854 \times 10^{-12})(2.25)(30)}{1.609} = 2.33 \times 10^{-9}\ \mathrm{F}$$

FE REFERENCE HANDBOOK — ELECTRICAL AND COMPUTER ENGINEERING: CAPACITORS AND INDUCTORS, CAPACITANCE OF A COAXIAL CABLE

WHY THE OTHER CHOICES APPEAR

(A) Stopping at the per-unit-length value of 77.8 pF/m and never multiplying by the 30 m run.

(B) Omitting the relative permittivity of the polyethylene gives $2333/2.25 = 1037$ pF.

(C) Reading 1.2 mm as a diameter makes $b/a = 10$ and $\ln 10 = 2.303$, giving 1631 pF.

Control Systems

Problem 78

Answer: (C)

A unity-feedback antenna position loop uses a PI controller $C(s) = 4.0 + \frac{10}{s}$ driving a plant $G(s) = \frac{2.5}{s+5}$. The command is a ramp of constant rate 3.0 rad/s. The steady-state tracking error is most nearly:

Integral action raises the loop to type 1, so the 3.0 rad/s ramp is tracked with a constant lag of 0.60 rad rather than a growing one.

Integral action inserts a pole at the origin, making the loop type 1, for which a ramp command produces a finite error set by the velocity error constant.

$$L(s) = \left(4 + \frac{10}{s}\right)\frac{2.5}{s+5} = \frac{2.5(4s+10)}{s(s+5)}$$

Only the integral gain survives the limit, so the proportional term contributes nothing to K_v.

$$K_v = \lim_{s\to 0} sL(s) = \frac{2.5(10)}{5} = 5.0\mathrm{s}^{-1}$$

Error scales with the commanded rate, so the ramp slope must be carried through rather than assumed unity.

$$e_{ss} = \frac{R}{K_v} = \frac{3.0}{5.0} = 0.60 \text{ rad}$$

FE REFERENCE HANDBOOK — CONTROL SYSTEMS: STEADY-STATE ERROR AND STATIC ERROR CONSTANTS

WHY THE OTHER CHOICES APPEAR

(A) Using the unit-ramp result $1/K_v = 1/5 = 0.20$ rad and ignoring the 3.0 rad/s command slope.

(B) Applying the type-0 position-error form $1/(1 + K_pG(0)) = 1/(1 + 2) = 0.33$ rad, which discards the integrator.

(D) Building K_v from the proportional gain, $4(0.5) = 2.0\ \mathrm{s}^{-1}$, giving $3.0/2.0 = 1.50$ rad.

Communications

Problem 84

Answer: (A)

A conventional double-sideband, full-carrier amplitude-modulated transmitter delivers a total average power of 15 kW to its antenna while modulated by a single sinusoidal tone at a modulation index of 0.80. The average power contained in one sideband is most nearly:

The carrier absorbs 11.4 kW of the 15 kW transmitted, and each of the two sidebands takes 1.82 kW of the remainder.

Total power in a tone-modulated full-carrier signal divides between an unmodulated carrier and two sidebands, so the carrier level is recovered from the total once the index is known.

$$P_t = P_c\left(1 + \frac{m^2}{2}\right)$$

$$P_c = \frac{15}{1 + \frac{0.80^2}{2}} = \frac{15}{1.32} = 11.36 \text{ kW}$$

Each sideband carries one quarter of the carrier power scaled by the square of the index, the pair together making up the modulation-dependent remainder.

$$P_{SB} = \frac{m^2}{4}P_c = 0.16 \times 11.36 = 1.82 \text{ kW}$$

Sideband power is thus only 12 percent of the transmitted total even at 80 percent modulation, the well-known power penalty of retaining the carrier.

$$\frac{P_{SB}}{P_t} = \frac{m^2/4}{1 + m^2/2} = \frac{0.16}{1.32} = 0.121$$

FE REFERENCE HANDBOOK — COMMUNICATION THEORY AND CONCEPTS: AMPLITUDE MODULATION, POWER IN A DOUBLE-SIDEBAND FULL-CARRIER SIGNAL

WHY THE OTHER CHOICES APPEAR

(B) Using the total power in place of the carrier power in the sideband expression: 0.16 x 15 = 2.40 kW.

(C) Reporting the combined power of both sidebands: 2 x 1.82 = 3.64 kW.

(D) Reporting the carrier power, 15/1.32 = 11.36 kW, rather than a sideband.

Computer Networks

Problem 89

Answer: (D)

A campus network is allocated the address block 10.40.96.0/19. The block is divided into equal-size subnets, each of which must accommodate at least 500 host addresses, and the number of subnets is maximized. The number of usable host addresses in each resulting subnet is:

Nine host bits form the smallest field that meets the 500-host requirement, and the resulting /23 subnet leaves 510 usable addresses once the network and broadcast values are reserved.

Two addresses in every IPv4 subnet are unusable, the all-zeros network identifier and the all-ones broadcast address, so the host field must exceed the required host count by that margin.

$$2^h - 2 \geq 500$$

$$2^h \geq 502$$

Eight host bits fall short at 254 usable addresses, so nine bits is the smallest qualifying field and it fixes the subnet prefix.

$$h = 9$$

$$\text{prefix} = 32 - 9 = 23$$

The /19 block supplies 13 host bits, four of which become the subnet field, so sixteen equal /23 subnets fit and each carries the same capacity.

$$N_{sub} = 2^{23-19} = 16$$

$$H = 2^9 - 2 = 510$$

FE REFERENCE HANDBOOK — ELECTRICAL AND COMPUTER ENGINEERING: COMPUTER NETWORKS, IPV4 ADDRESSING AND SUBNET MASKS

WHY THE OTHER CHOICES APPEAR

(A) Uses eight host bits rather than nine, giving 2 ^ 8 - 2 = 254 usable addresses, which fails the 500-host requirement.

(B) Takes the stated requirement itself as the subnet capacity, omitting the rounding of the host field up to the next power of two.

(C) Subtracts four reserved addresses from the 512-address block instead of the two (network and broadcast) that are actually unusable, giving 508.

Digital Systems

Problem 94

Answer: (A)

An 8-bit two's complement adder in a motor controller receives the operands 01011101_2 and 00110110_2. The signed decimal value left in the 8-bit result register is:

Two positive operands whose true sum exceeds $+127$ *overflow the format, and the retained pattern* 10010011_2 *reads as -109.*

Both words carry a clear sign bit, so each represents a positive quantity, and their true sum climbs past the +127 ceiling that eight-bit two's complement can hold.

$$01011101_2 = 64 + 16 + 8 + 4 + 1 = 93$$

$$00110110_2 = 32 + 16 + 4 + 2 = 54$$

$$93 + 54 = 147 > 127$$

Column-by-column addition propagates a carry into the sign column but produces no carry out of it, the defining signature of two's complement overflow, so the hardware discards nothing yet stores a pattern that no longer matches the arithmetic sum.

$$01011101_2 + 00110110_2 = 10010011_2$$

$$C_{\text{in,sign}} = 1, \quad C_{\text{out,sign}} = 0 \Rightarrow \text{overflow}$$

Read back under the same convention, the leading one carries weight -128 while the remaining set bits contribute 19, so the register reports a negative quantity even though both inputs were positive.

$$-128 + 16 + 2 + 1 = -109$$

FE REFERENCE HANDBOOK — ELECTRICAL AND COMPUTER ENGINEERING: NUMBER SYSTEMS AND CODES, TWO'S COMPLEMENT REPRESENTATION ($N_{\TEXT{SIGNED}} = -B_{N-1}2^{N-1} + \SUM_{I=0}^{N-2} B_I 2^I$)

WHY THE OTHER CHOICES APPEAR

- **(B)** Treating 10010011 as one's complement inverts it to 01101100 = 108 for a reading of -108, one unit short in magnitude because the added one is omitted.
- **(C)** Treating 10010011 as sign-magnitude uses the sign bit plus the 7-bit field 0010011 = 19, giving -19.
- **(D)** Reporting the unsigned value 128 + 16 + 2 + 1 = 147 ignores the sign bit and assumes a register wide enough to avoid overflow.

Computer Systems

Problem 102

Answer: (A)

A processor uses a two-level cache hierarchy. The L1 cache has an access time of 1.0 ns and a miss rate of 6%. An L1 miss is serviced by an L2 cache with an access time of 9 ns and a local miss rate of 25%. An L2 miss is serviced by main memory in 80 ns. The average memory access time seen by the processor is most nearly:

Because the 25% L2 miss rate applies only to the 6% of references that already missed in L1, the mean latency is about 2.74 ns.

Multilevel caches compose serially: every reference pays the L1 hit time, and only the fraction that misses reaches the next level.

$$\text{AMAT} = t_{L1} + m_{L1}(t_{L2} + m_{L2}\, t_{mem})$$

Quoted for the L2 alone, the 25% miss rate is a local rate and therefore weights only the traffic that reaches L2.

$$t_{L2} + m_{L2}\, t_{mem} = 9 + 0.25(80) = 29 \text{ ns}$$

Weighting that 29 ns penalty by the 6% of references that miss in L1 gives the latency averaged over the whole reference stream.

$$\text{AMAT} = 1.0 + 0.06(29) = 2.74 \text{ ns}$$

FE REFERENCE HANDBOOK — COMPUTER SYSTEMS: MEMORY HIERARCHY, AVERAGE MEMORY ACCESS TIME

WHY THE OTHER CHOICES APPEAR

(B) Bypassing L2 entirely and charging main memory for every L1 miss: 1.0 + 0.06(80) = 5.80 ns.

(C) Adding the L2 and main-memory times as parallel penalties both weighted by the L1 miss rate: 1.0 + 0.06(9) + 0.06(80) = 6.34 ns.

(D) Treating the 25% L2 miss rate as a global rate applied to all references: 1.0 + 0.06(9) + 0.25(80) = 21.54 ns.

Software Engineering

Problem 107

Answer: (B)

A batch record-sorting routine in a utility billing system uses a comparison sort whose running time grows as $n \log_2 n$, where n is the number of records. Sorting 100{,}000 records requires 0.42 s on the target processor. On the same processor, the time required to sort 800{,}000 records is most nearly:

An eightfold increase in record count costs a factor of 9.44 in time, since the logarithmic factor grows too, and the sort runs about 3.97 s.

Runtime for a comparison sort is proportional to $n \log_2 n$, so the unknown machine constant cancels when two problem sizes are compared as a ratio.

$$\frac{T_2}{T_1} = \frac{n_2 \log_2 n_2}{n_1 \log_2 n_1}$$

The record count rises by a factor of eight while the logarithmic factor rises only from $\log_2(100,000) = 16.610$ to $\log_2(800,000) = 19.610$.

$$\frac{T_2}{T_1} = 8 \times \frac{19.610}{16.610} = 9.445$$

Scaling the measured 0.42 s by that factor gives the projected batch time.

$$T_2 = 0.42 \text{ s} \times 9.445 = 3.97 \text{ s}$$

FE REFERENCE HANDBOOK — SOFTWARE ENGINEERING: ALGORITHMS, ALGORITHM EFFICIENCY (BIG-O NOTATION)

WHY THE OTHER CHOICES APPEAR

(A) Treats the growth as purely linear in n, giving $0.42 \times 8 = 3.36$ s and discarding the logarithmic factor.

(C) Assumes quadratic growth n^2, giving $0.42 \times 8^2 = 26.9$ s.

(D) Combines quadratic and logarithmic growth as $n^2 \log_2 n$, giving $0.42 \times 64 \times 1.1806 = 31.7$ s.