FEExamClick

Free FE Electrical Practice Exam

20 exam-style questions across the NCEES FE Electrical and Computer knowledge areas, with an answer key and a worked solution for every question.

20	48 min	110
questions	suggested time	questions on the real exam

How to take it

1. Set a timer for 48 minutes, about 2.4 minutes a question. The real exam gives 5 h 20 min for 110 questions, about 2.9.
2. Use only the NCEES FE Reference Handbook (free from your MyNCEES account) and an NCEES-approved calculator.
3. Answer every question: the real exam has no penalty for wrong answers.
4. Check your answers with the key after question 20, then read every worked solution, including the ones you got right.

The real exam is on a computer

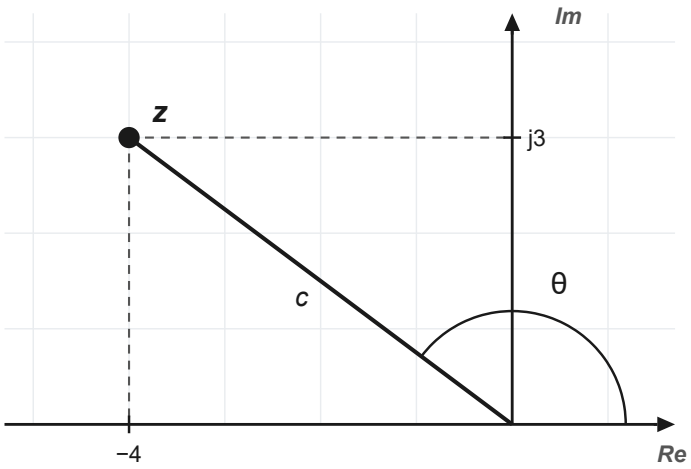
The FE is computer-based, with the Handbook on screen. To practise the same 20 questions in that interface, with a countdown and your score by topic, take the free online version at feexamclick.com/fe-electrical-practice-exam.

Original questions written to the NCEES FE Electrical and Computer exam specification; NCEES does not publish its exam questions. © 2026 FEExamClick, feexamclick.com.

Question 1 Mathematics

The complex number z is plotted on the Argand diagram shown. Written in polar form $z = c\angle\theta$, what is the angle θ?

The complex number z



A 216.87°

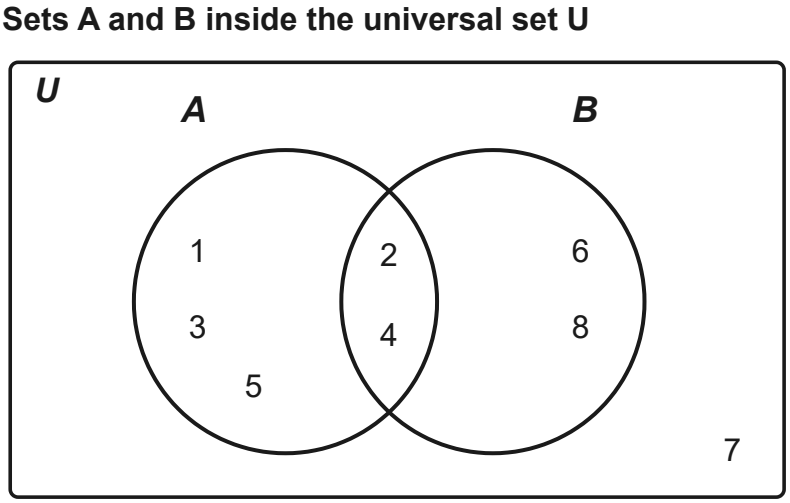
B 143.13°

C -36.87°

D 126.87°

Question 2 Mathematics

The Venn diagram shows $A = \{1, 2, 3, 4, 5\}$ and $B = \{2, 4, 6, 8\}$ inside the universal set $U = \{1, 2, 3, 4, 5, 6, 7, 8\}$. What is $A \cap B'$, the intersection of A with the complement of B?



A $\{6, 8\}$

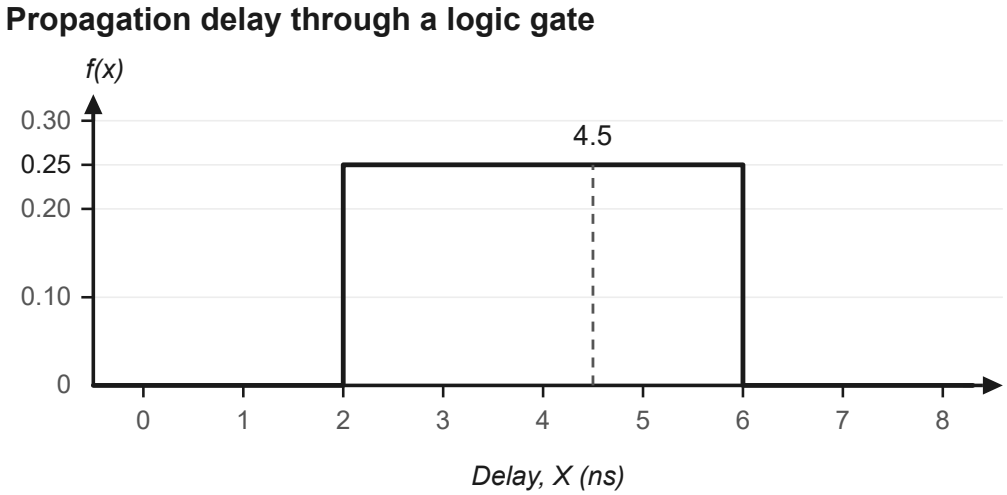
B $\{1, 3, 5, 7\}$

C $\{1, 2, 3, 4, 5\}$

D $\{1, 3, 5\}$

Question 3 Probability and Statistics

The figure shows the probability density function of the propagation delay X, in nanoseconds, through a logic gate. What is $P(X > 4.5)$?



f(x) = 0 outside 2 ns ≤ x ≤ 6 ns.

A 0.2500

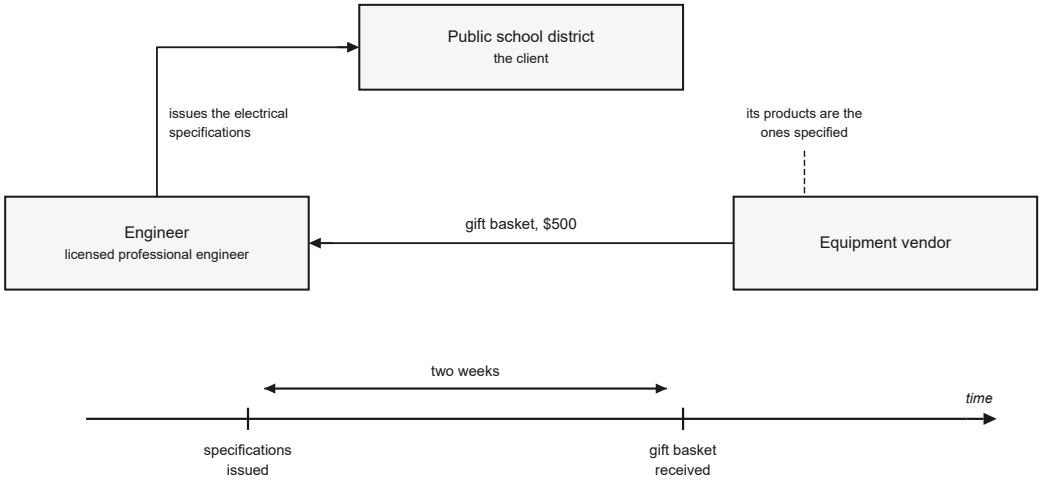
B 0.1875

C 0.6250

D 0.3750

Question 4 Ethics and Professional Practice

The figure shows the parties to a public school renovation and what passed between them. Under the NCEES Rules of Professional Conduct, what must the engineer do?



A Return or decline the gift, and tell the client what was offered.

B Keep it: the specification was finished, and decided on technical merit.

C Accept it and pass it to a charity, so that no personal benefit is taken.

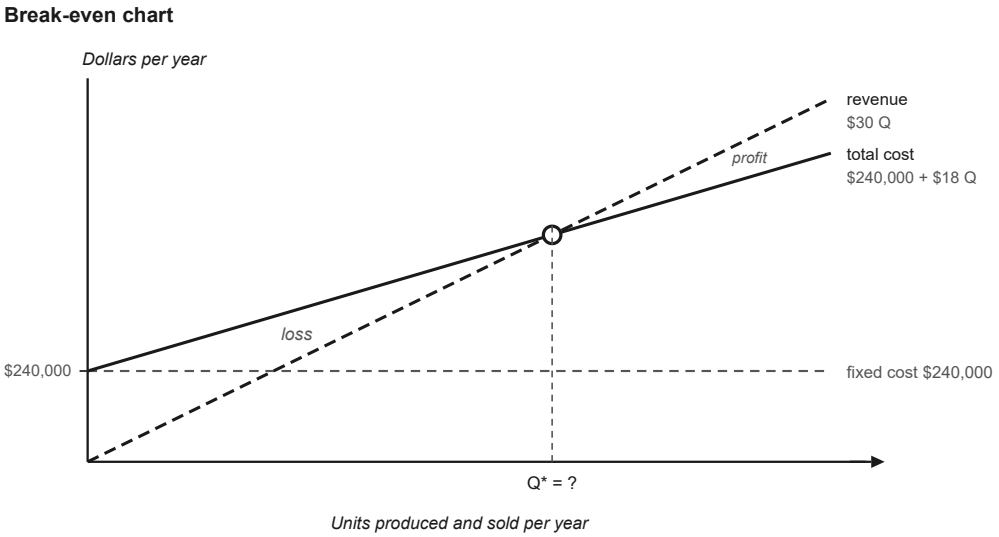
D Accept it: at $500 it falls below the value at which gifts are reported.

Question 5 Engineering Economics

A company manufactures cable harnesses with the following cost structure, shown on the break-even chart:

- Fixed costs: $\$240{,}000$ per year
- Variable cost: $\$18$ per unit
- Selling price: $\$30$ per unit

How many cable harnesses must be sold annually to break even?



Neither axis is graduated: the lines are drawn from the given slopes, so Q* must be computed rather than read off.

A 13{,}333 units

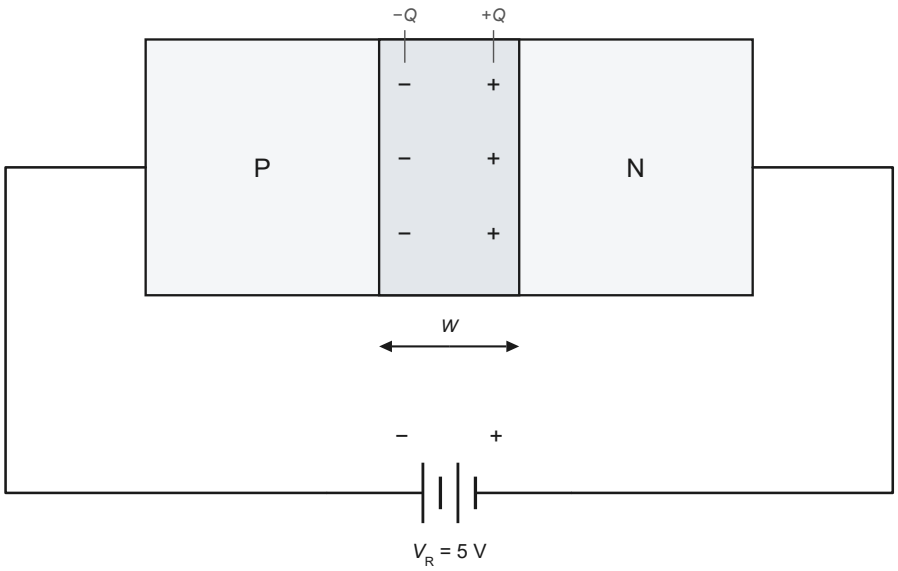
B 20{,}000 units

C 5{,}000 units

D 8{,}000 units

Question 6 Properties of Electrical Materials

A silicon abrupt P-N junction has a zero-bias junction capacitance of $C_{j0} = 20\ \text{pF}$ and a built-in potential of $V_{bi} = 0.75\ \text{V}$. It is connected as shown. What is the junction capacitance?



A $2.61\ \text{pF}$

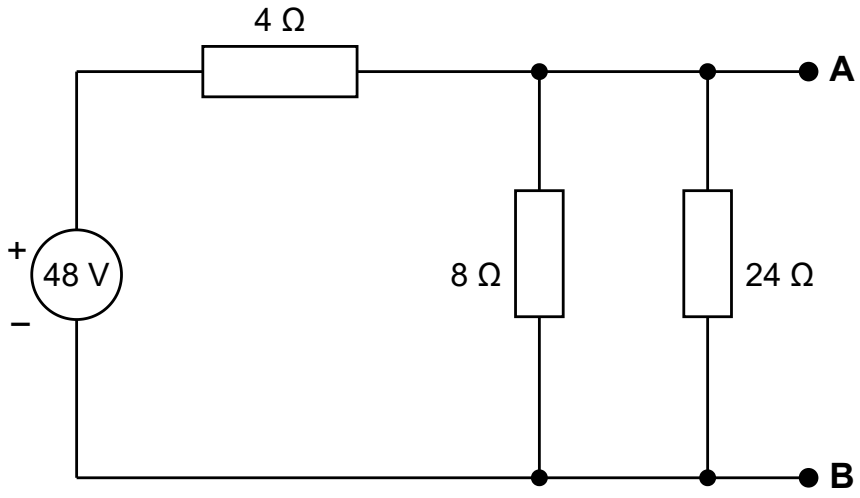
B $7.22\ \text{pF}$

C $10.14\ \text{pF}$

D $18.65\ \text{pF}$

Question 7 Circuit Analysis (DC and AC Steady State)

The 24 Ω resistor in the figure is the load. With it removed, what is the Norton equivalent current of the rest of the network at terminals A and B?



A 4 A

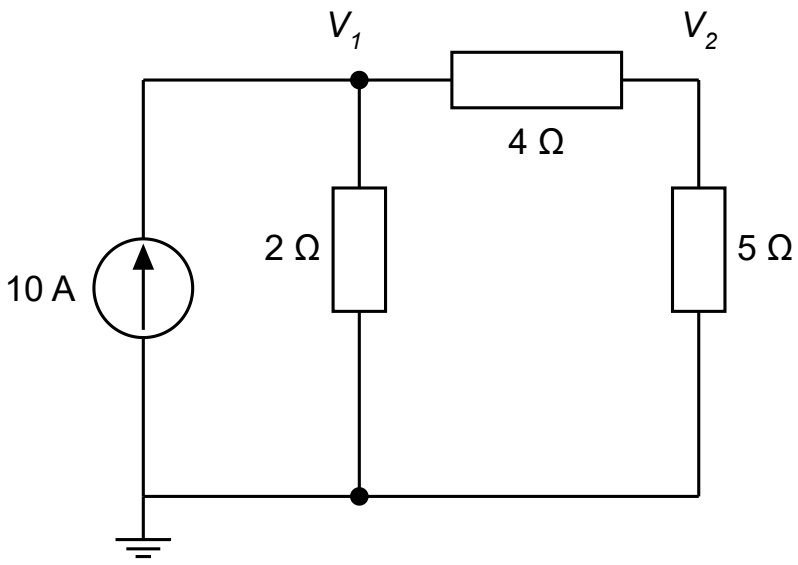
B 12 A

C 18 A

D 20 A

Question 8 Circuit Analysis (DC and AC Steady State)

What is the node voltage V_1 in the circuit shown?



A 9.09 V

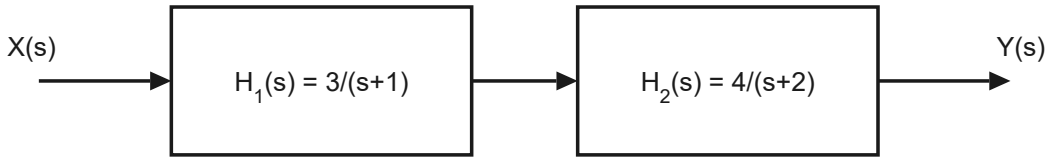
B 13.33 V

C 16.36 V

D 20 V

Question 9 Linear Systems

Two systems are cascaded as shown, with $H_1(s) = \dfrac{3}{s+1}$ and $H_2(s) = \dfrac{4}{s+2}$. What is the overall transfer function $H(s)$?



A $\frac{7}{(s+1)(s+2)}$

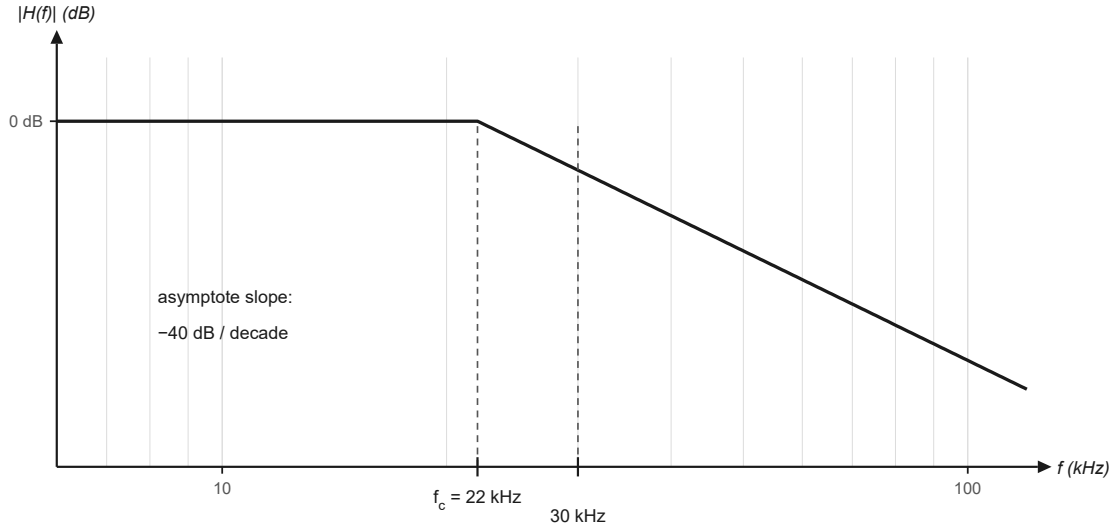
B $\frac{12}{(s+1)(s+2)+12}$

C $\frac{12}{2s+3}$

D $\frac{12}{(s+1)(s+2)}$

Question 10 Signal Processing

An anti-aliasing filter with a cutoff frequency of 22 kHz and a roll-off of -40 dB/decade is used before an ADC sampling at 48 kHz. What is the approximate attenuation of a 30 kHz interfering signal?



Asymptotic response of the anti-aliasing filter. The magnitude axis is not graduated; compute the attenuation from the slope.

A approximately -5.4 dB

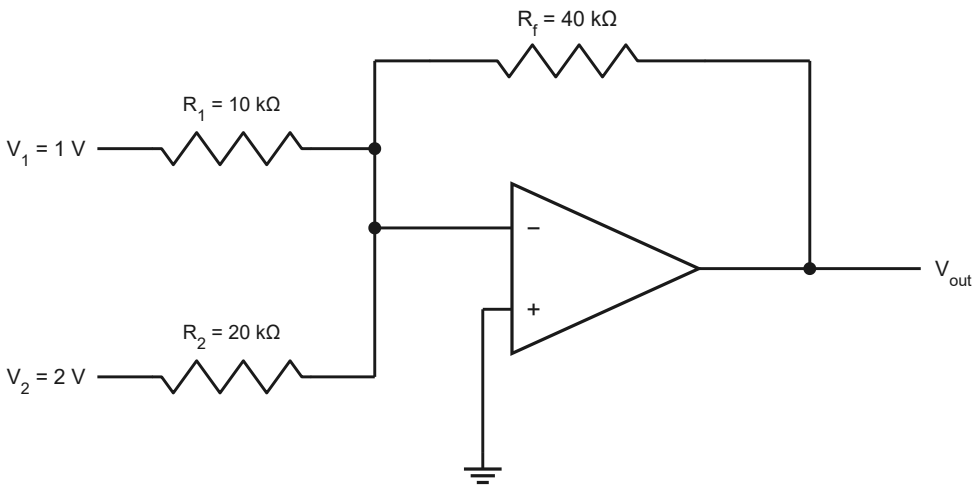
B approximately -20 dB

C approximately -40 dB

D approximately -12 dB

Question 11 Electronics

For the weighted summing amplifier shown, what is the output voltage V_{out}?



A -12 V

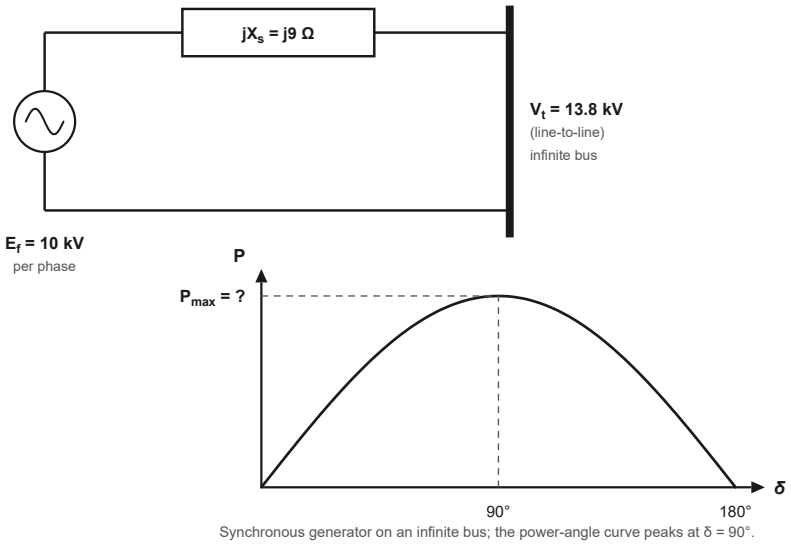
B $+8$ V

C -6 V

D -8 V

Question 12 Power Systems

The figure shows a synchronous generator tied to an infinite bus, with its power-angle curve. What is the maximum total three-phase real power the machine can deliver before losing synchronism?



Synchronous generator on an infinite bus; the power-angle curve peaks at δ = 90°.

A 8.85 MW

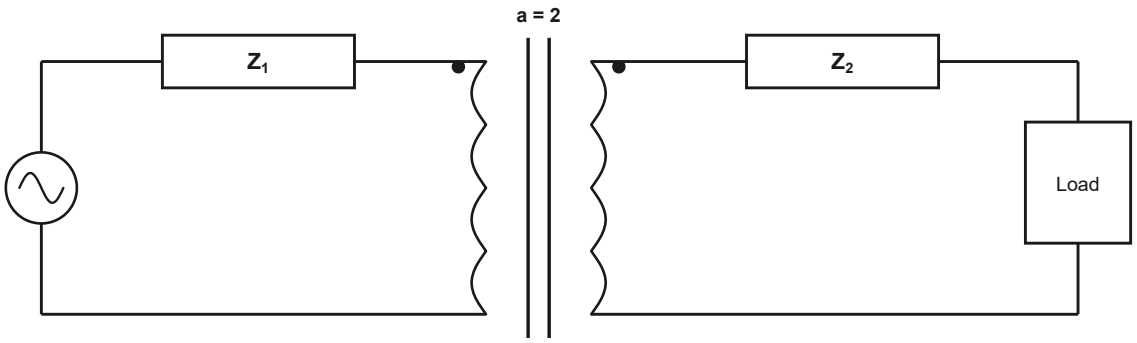
B 21.2 MW

C 26.6 MW

D 46.0 MW

Question 13 Power Systems

The figure shows a transformer with a winding impedance on each side. What is the total equivalent series impedance referred to the primary?



$Z_1 = 0.5 + j1.2\ \Omega$ (primary winding) · $Z_2 = 0.6 + j0.9\ \Omega$ (secondary winding)

A $1.1 + j2.1\ \Omega$

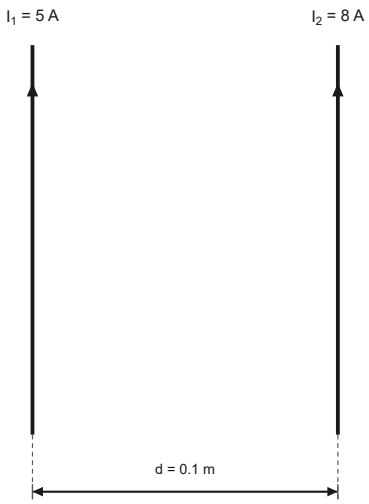
B $2.9 + j4.8\ \Omega$

C $2.4 + j3.6\ \Omega$

D $4.4 + j8.4\ \Omega$

Question 14 Electromagnetics

What is the force per unit length between the two wires in the figure, and is it attractive or repulsive?



the two wires are long, straight and parallel, and both currents run the same way

A 8.0×10^{-5} N/m, attractive

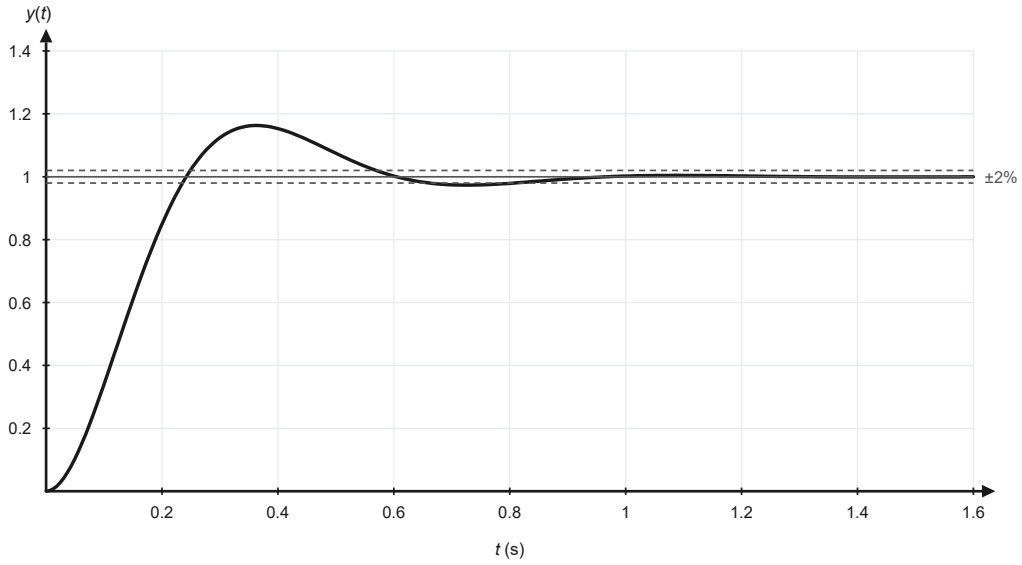
B 8.0×10^{-5} N/m, repulsive

C 1.6×10^{-4} N/m, attractive

D 1.6×10^{-4} N/m, repulsive

Question 15 Control Systems

The step response shown is that of a second-order system with $\zeta = 0.5$ and $\omega_n = 10\,\text{rad/s}$. What is its 2% settling time?



A $0.4\,\text{s}$

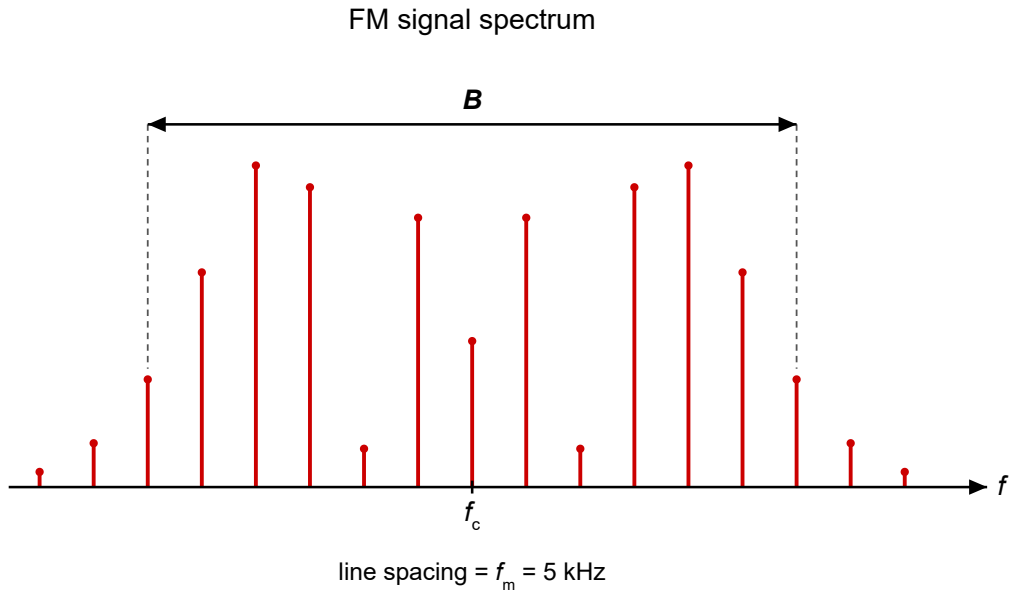
B $0.6\,\text{s}$

C $0.8\,\text{s}$

D $1.0\,\text{s}$

Question 16 Communications

The figure shows the spectrum of an FM signal. An FM broadcast station has a maximum frequency deviation of $\Delta f = 25$ kHz and the modulating audio signal has a bandwidth of $f_m = 5$ kHz. What is the modulation index β and the approximate bandwidth using Carson's rule?



A $\beta = 5$, $BW = 50$ kHz

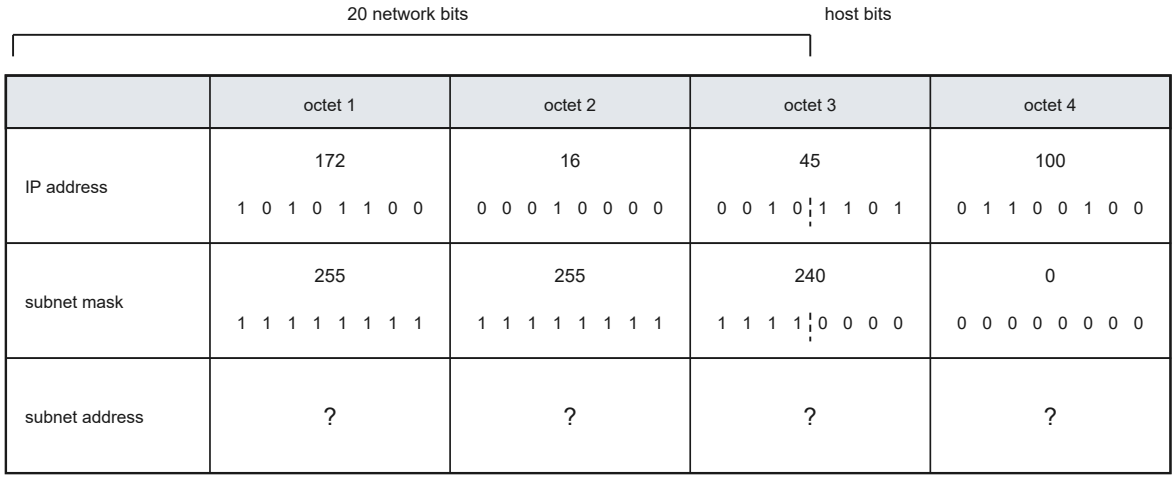
B $\beta = 0.2$, $BW = 50$ kHz

C $\beta = 5$, $BW = 60$ kHz

D $\beta = 25$, $BW = 60$ kHz

Question 17 Computer Networks

A host is assigned the IPv4 address 172.16.45.100/20. The figure gives that address and the corresponding mask in binary. What is the subnet address?



A 172.16.32.0

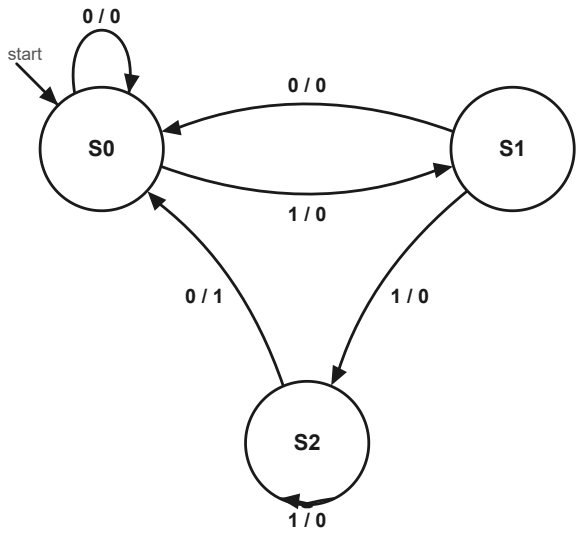
B 172.16.40.0

C 172.16.44.0

D 172.16.45.0

Question 18 Digital Systems

For the Mealy state diagram in the figure, starting in state S_0, what output sequence does the input stream $1\,1\,0\,1\,0$ produce?



Mealy machine: each edge is labelled input / output, so the output belongs to the transition.

A $0\,0\,0\,1\,0$

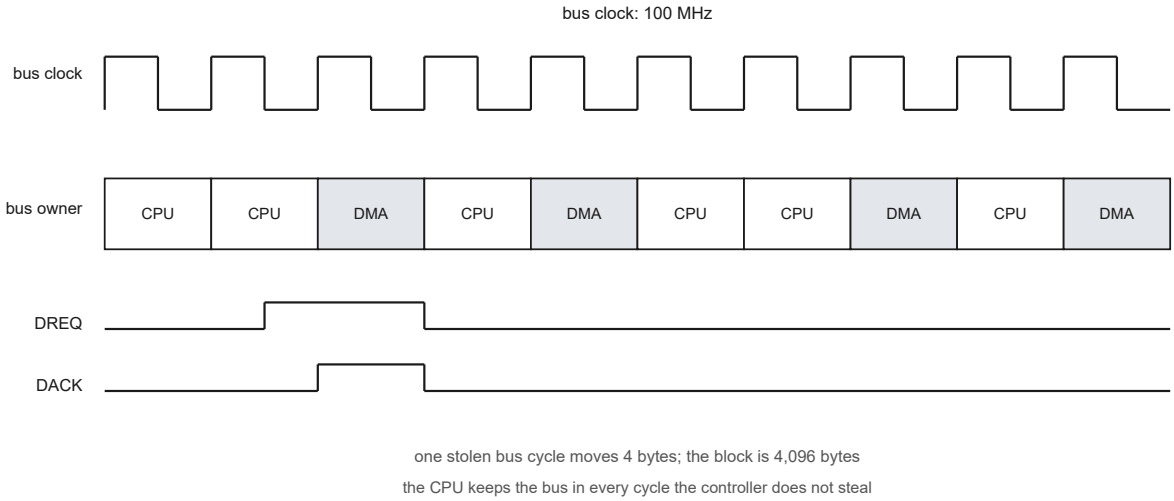
B $0\,0\,1\,0\,1$

C $0\,1\,0\,0\,1$

D $0\,0\,1\,0\,0$

Question 19 Computer Systems

The controller in the figure moves a 4,096-byte block from a peripheral into memory. How long does the block take if the controller never has to wait for the bus?



A 10.24 µs

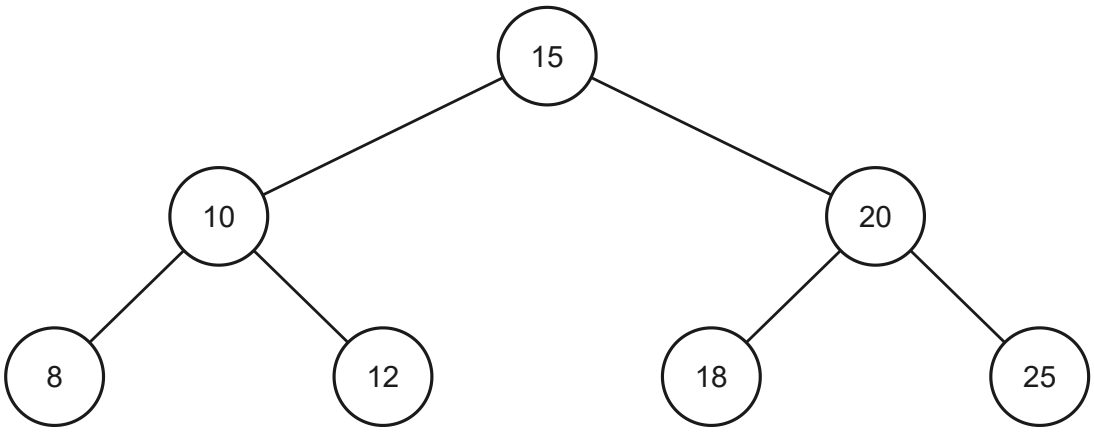
B 20.48 µs

C 40.96 µs

D 102.4 µs

Question 20 Software Engineering

The figure shows a binary search tree (BST). What is the result of an in-order traversal of this tree?



A 8, 10, 12, 15, 18, 20, 25

B 8, 12, 10, 18, 25, 20, 15

C 25, 20, 18, 15, 12, 10, 8

D 15, 10, 20, 8, 12, 18, 25

Answer key

Question	Answer	NCEES knowledge area
1	**B**	Mathematics
2	**D**	Mathematics
3	**D**	Probability and Statistics
4	**A**	Ethics and Professional Practice
5	**B**	Engineering Economics
6	**B**	Properties of Electrical Materials
7	**B**	Circuit Analysis (DC and AC Steady State)
8	**C**	Circuit Analysis (DC and AC Steady State)
9	**D**	Linear Systems
10	**A**	Signal Processing
11	**D**	Electronics
12	**C**	Power Systems
13	**B**	Power Systems
14	**A**	Electromagnetics
15	**C**	Control Systems
16	**C**	Communications
17	**A**	Computer Networks
18	**D**	Digital Systems
19	**A**	Computer Systems
20	**A**	Software Engineering

Worked solutions start on the next page.

Worked solutions

Question 1 · Answer B

Handbook: FE Reference Handbook 10.6, Mathematics → *Algebra of Complex Numbers*, p. 38 (PDF viewer: page 44). For $z = a + jb$ written in polar form $z = c\angle\theta$ — the Handbook uses c for the magnitude:

$$c = \sqrt{a^2 + b^2} \qquad \theta = \tan^{-1}\left(\frac{b}{a}\right)$$

Step 1 – Read the parts off the plot. The dashed projections give $a = -4$ on the real axis and $b = 3$ on the imaginary axis, so $z = -4 + j3$. A negative real part with a positive imaginary part puts the point in the *second* quadrant, which is where the dot is drawn.

Step 2 – The calculator's answer is not the angle. Keying in the ratio gives

$$\tan^{-1}\left(\frac{3}{-4}\right) = \tan^{-1}(-0.75) = -36.87^\circ$$

The inverse tangent only ever returns a value between -90° and $+90^\circ$, so it can never land in the second or third quadrant. It has given the direction of the *opposite* ray, pointing down and to the right.

Step 3 – Rotate it onto the drawn point. Opposite directions differ by half a turn, so add 180°:

$$\theta = -36.87^\circ + 180^\circ = \mathbf{143.13}^\circ$$

Step 4 – Answer: (B).

Check it against the picture. The argument is measured counterclockwise from the positive real axis, so the second quadrant is the range $90^\circ < \theta < 180^\circ$. Only 143.13° falls in it. As a second check, $\cos 143.13^\circ = -0.8$ is negative and $\sin 143.13^\circ = +0.6$ is positive — the signs of a and b.

Step 5 – Eliminate the distractors:

(A) 216.87° adds 180° to $+36.87^\circ$ rather than to the calculator's -36.87°. That lands in the third quadrant, where *both* parts are negative; the plotted point has a positive imaginary part.

(C) -36.87° is the raw calculator output with no quadrant correction. It is the angle of $4 - j3$, in the fourth quadrant, exactly opposite the plotted point.

(D) 126.87° takes the reference angle from the wrong ratio: $\tan^{-1}(4/3) = 53.13^\circ$ instead of $\tan^{-1}(3/4) = 36.87^\circ$, then $180^\circ - 53.13^\circ$. It divides the real part by the imaginary part, which measures the angle from the imaginary axis. The quadrant is right, so the plot alone will not catch this one — only the ratio b/a will.

Question 2 · Answer D

Handbook: FE Reference Handbook 10.6, Mathematics → *Discrete Math*, p. 36 (PDF viewer: page 42). The symbol list on that page gives $A \cup B$ for the union and $A \cap B$ for the intersection, but it does *not*

list the complement, so define it yourself: B' is everything in the universal set that is not in B.

Step 1 – Build the complement.

$$B' = U - B = \{1, 2, 3, 4, 5, 6, 7, 8\} - \{2, 4, 6, 8\} = \{1, 3, 5, 7\}$$

Step 2 – Intersect it with A. The intersection keeps only what appears in *both* lists:

$$A \cap B' = \{1, 2, 3, 4, 5\} \cap \{1, 3, 5, 7\} = \{1, 3, 5\}$$

The 7 drops out because it is not in A; the 2 and the 4 drop out because they are in B.

Step 3 – Answer: (D).

Read it straight off the diagram. $A \cap B'$ is the part of circle A that lies *outside* circle B — the left crescent. The diagram puts 1, 3 and 5 there. Written another way, $A \cap B' = A - B$, the set difference: the elements of A with the ones shared with B removed.

A check that costs nothing. The four regions of the diagram have to account for all eight elements of U exactly once: $\{1, 3, 5\}$ in A only, $\{2, 4\}$ in both, $\{6, 8\}$ in B only, $\{7\}$ in neither. That is $3 + 2 + 2 + 1 = 8$ ✓.

Step 4 – Eliminate the distractors:

(A) $\{6, 8\}$ is the mirror-image region, $B \cap A'$ — the part of B outside A. It answers the same question with the two sets swapped.

(B) $\{1, 3, 5, 7\}$ is B' on its own: the complement was taken but never intersected with A. The giveaway is the 7, which is in neither circle.

(C) $\{1, 2, 3, 4, 5\}$ is A itself, which is what $A \cap U$ would give. It keeps 2 and 4, and those are precisely the elements the complement of B is meant to remove.

Question 3 · Answer D

Handbook: FE Reference Handbook 10.6, Engineering Probability and Statistics → *Probability Density Function*, p. 66 (PDF viewer: page 72):

$$P(a \le X \le b) = \int_a^b f(x)\, dx$$

For a continuous variable a probability is an *area* under the density, never a height on it. The uniform density itself, $f(x) = 1/(b - a)$, is tabulated much later, in *Probability and Density Functions: Means and Variances* on p. 85 (PDF viewer: page 91), together with its mean $(a + b)/2$ and variance $(b - a)^2/12$.

Step 1 – Read the distribution off the plot. The density is a single rectangle: zero until $x = 2$, flat at $f = 0.25$ from $x = 2$ to $x = 6$, zero after that. So X is uniform on $[2, 6]$, and the height is exactly what the formula requires:

$$f(x) = \frac{1}{b - a} = \frac{1}{6 - 2} = 0.25 \text{ ns}^{-1}$$

Step 2 – Confirm the density is valid. The rectangle has width $6 - 2 = 4$ and height 0.25, so the area under it is $4(0.25) = 1$. Any density must enclose unit area, and this takes five seconds.

Step 3 – Take the area to the right of 4.5. The region runs from $x = 4.5$ to the end of the support at $x = 6$:

$$P(X > 4.5) = \int_{4.5}^{6} 0.25\,dx = 0.25\,(6 - 4.5) = 0.25\,(1.5) = \mathbf{0.3750}$$

Step 4 – Answer: (D).

The shortcut worth carrying. On a uniform distribution the probability of an interval is just the fraction of the support it covers: $[4.5, 6]$ is 1.5 of the 4 ns of support, and $1.5/4 = 0.3750$ with no integral at all.

The integral stops at 6, not at 8. The axis runs to 8 ns because a plot needs room past the data, but $f(x) = 0$ beyond 6, so nothing out there contributes. Integrating a zero density over empty axis adds nothing — but *dividing* by the width of that empty axis is a real way to go wrong.

Step 5 – Eliminate the distractors:

(A) 0.2500 is the *height* of the density, $f(x) = 0.25$, reported as a probability. A density is not a probability: its units here are ns^{-1}, and it becomes a probability only after multiplying by a width. The same value also comes from $1.5/6$, dividing the interval by the upper limit instead of by the width of the support.

(B) $0.1875 = 1.5/8$ divides the interval by the full width of the plotted *axis*, 0 to 8 ns, instead of by the 4 ns of support. A gate cannot switch in under 2 ns; that stretch of axis carries no probability at all.

(C) $0.6250 = 0.25(4.5 - 2)$ is $P(X < 4.5)$, the area on the *other* side of the dashed line. Read which way the inequality points before choosing a side.

Question 4 · Answer A

Rule 240.15.B.5 of the NCEES Model Rules, on p. 5 of the Handbook, is one sentence long and it settles this: *licensees shall not solicit or accept gratuities, directly or indirectly, from contractors, their agents, or other parties in connection with work for employers or clients*.

Read what is not in it. There is no figure below which a gratuity stops being one. There is no exception for a gift that arrives after the work is done, and none for an engineer whose judgment was in fact unaffected. The rule forbids accepting, and the engineer here is being asked to accept, from a vendor, in connection with work done for a client. So the basket goes back.

The timing on the figure makes the position worse rather than better. A gift that arrives two weeks after a specification names the giver's products cannot be told apart, from the outside, from a payment for having named them. That the products really were the best ones is something the engineer knows and the school district cannot see, and public money makes the appearance the school district's problem too. Telling the client what was offered is what closes that gap, and it follows from Rule 240.15.B.6 on the same page, the duty to disclose circumstances that could influence or appear to influence professional judgment.

Keeping it answers a question the rule does not ask. Whether the specification was sound, and whether it was already issued, would matter if the rule forbade being influenced; it forbids accepting. **Passing it to a charity** changes where the basket ends up and not whether it was accepted; no personal benefit is taken, and the rule was never about personal benefit. It leaves the engineer explaining a donation instead of declining a gift. **The value at which gifts are reported** is imported from somewhere else entirely: the Model Rules name no amount, and the figures above which gifts must be reported belong to public-official disclosure law, which is a different obligation with a different purpose. Rule 240.15.C.2, also on p. 5, points the same way from the other side, forbidding a licensee to offer or receive any gift or other valuable consideration in order to secure work.

Question 5 · Answer B

Handbook: FE Reference Handbook 10.6, Engineering Economics → *Breakeven Analysis*, p. 236 (PDF viewer: page 242). The page defines the breakeven point in words but gives no formula, so set the equation up yourself.

Step 1 – Write both lines.

$$\text{Revenue} = 30Q, \qquad \text{Total cost} = 240{,}000 + 18Q$$

Step 2 – Set them equal and solve.

$$30Q = 240{,}000 + 18Q \quad \Longrightarrow \quad 12Q = 240{,}000$$

$$Q^{*} = \frac{240{,}000}{30 - 18} = \mathbf{20{,}000}\ \text{units}$$

Step 3 – Answer: (B).

Think in contribution margin. Every harness sells for $\$30$ and costs $\$18$ to build, so it contributes $\$12$ toward the fixed costs. Covering $\$240{,}000$ of fixed cost therefore takes $240{,}000/12 = 20{,}000$ units. The margin — not the price, not the variable cost — is the only rate that matters.

Check it. At 20,000 units: revenue $= 30(20{,}000) = \$600{,}000$; total cost $= 240{,}000 + 18(20{,}000) = 240{,}000 + 360{,}000 = \$600{,}000$. They match.

A note on the margin. Here the contribution is 40% of the selling price ($\$12$ of $\$30$), a thinner margin than it looks: the plant must move 20,000 units a year before it earns its first dollar of profit.

Step 4 – Eliminate the distractors. Each divides the fixed cost by the wrong figure:

(A) 13,333 units $= 240{,}000/18$ divides by the *variable cost*. That number answers a different question entirely — how many units' worth of variable cost equals the fixed cost.

(C) 5,000 units $= 240{,}000/(30 + 18)$ adds the variable cost to the price instead of subtracting it. A sign error, and it makes the operation look four times more profitable than it is.

(D) 8,000 units $= 240{,}000/30$ divides by the *price*, as though all $\$30$ of each sale were available to cover fixed costs. It ignores the $\$18$ spent to build each unit.

Question 6 · Answer B

The two sheets of exposed charge in the figure are the plates of the capacitor and the depletion width W is the gap between them. Reverse bias widens W, so the capacitance falls. The Handbook gives the abrupt junction on p. 387 as

$$C_j = \frac{C_0}{\sqrt{1 - V/V_{bi}}}$$

with a sign convention that has to be read carefully: V is the potential of the anode with respect to the cathode, so the $5\ \text{V}$ reverse bias in the figure means $V = -5\ \text{V}$, not $+5$. Substituting the wrong sign puts a negative number under the square root, which is the signal that it has been done backwards.

$$1 - \frac{-5}{0.75} = 1 + 6.667 = 7.667$$

$$C_j = \frac{20}{\sqrt{7.667}} = \frac{20}{2.769} = 7.22\ \text{pF}$$

The square root is not decoration: it comes from the depletion width growing as $\sqrt{V_{bi} + V_R}$, so an abrupt junction has the exponent $1/2$. That is what the wrong answers get wrong.

$2.61\ \text{pF}$ leaves the square root out and divides by 7.667 itself, which is the exponent 1 of no real junction. $10.14\ \text{pF}$ uses the exponent $1/3$, which belongs to a *linearly graded* junction, not the abrupt one the question specifies. $18.65\ \text{pF}$ swaps the two voltages and computes $(1 + 0.75/5)^{1/2}$; the giveaway is that the answer barely moves from the $20\ \text{pF}$ zero-bias value, when $5\ \text{V}$ of reverse bias on a $0.75\ \text{V}$ junction should cut the capacitance by a factor of nearly three.

Question 7 · Answer B

The Norton current is the short-circuit current at the terminals, so lift the 24 Ω load out and put a wire across A and B instead.

That wire places zero ohms directly across the 8 Ω resistor, so all of the current takes the short and none of it goes through the 8 Ω. Only the 4 Ω is left in the path:

$$I_N = I_{sc} = \frac{48}{4} = 12\ \text{A}$$

The long way round agrees. Open-circuit: $I = 48/(4 + 8) = 4$ A and $V_{Th} = 4 \times 8 = 32$ V. Deactivating the voltage source shorts it, leaving $R_{Th} = 4 \parallel 8 = 8/3\ \Omega$. Then $I_N = V_{Th}/R_{Th} = 32/(8/3) = 12$ A. Two independent routes to the same number is the check worth doing whenever a Norton current looks surprising.

4 A is the open-circuit loop current, the value of I on the way to V_{Th}. It is the current the network delivers with the terminals open, which is the one condition under which the terminal current is not the Norton current.

18 A divides the *source* voltage by R_{Th}, $48/(8/3)$, instead of dividing the Thevenin voltage by it. Only V_{Th} belongs over R_{Th}, and V_{Th} is 32 V, not 48 V.

20 A is the same slip with the load left in place: $48/(4 \parallel 8 \parallel 24) = 48/2.4$. Once the load is part of the network there is no load left to find an equivalent for.

Question 8 · Answer C

Two unknown nodes means two KCL equations. At V_1 the source current leaves through the 2 Ω to ground and through the 4 Ω toward V_2; at V_2 nothing is injected, so what arrives through the 4 Ω leaves through the 5 Ω:

$$10 = \frac{V_1}{2} + \frac{V_1 - V_2}{4}, \qquad 0 = \frac{V_2 - V_1}{4} + \frac{V_2}{5}$$

The second gives $9V_2 = 5V_1$. Substituting into the first:

$$10 = \frac{V_1}{2} + \frac{V_1}{9} = \frac{11V_1}{18} \;\Rightarrow\; V_1 = \frac{180}{11} = 16.36 \text{ V}$$

Because no current is injected at V_2, this particular circuit can also be reduced by inspection: the 4 Ω and 5 Ω are in series, 9 Ω, in parallel with the 2 Ω, giving 18/11 Ω, and 10 A through that is 16.36 V. Node analysis earns its keep when a source sits at the second node too and no such reduction exists.

9.09 V is V_2, the other node voltage: $5(16.36)/9$. It is the last quantity many candidates write down, so check which node the question asked for.

20 V is 10×2, all of the source current pushed through the 2 Ω with the right-hand branch ignored.

13.33 V is $10 \times (2 \parallel 4)$, which treats the 4 Ω as if it ran straight to ground. It does not: its far end sits at V_2, which is well above ground, so less current flows through it than that assumption allows.

Question 9 · Answer D

Handbook: FE Reference Handbook 10.6, Instrumentation, Measurement, and Control → *Control Systems*, p. 231 (PDF viewer: page 237). Blocks in series form the open-loop product $G_1(s)G_2(s)$: cascading multiplies the transfer functions, it does not add them.

Step 1 – Multiply.

$$H(s) = H_1(s)\,H_2(s) = \frac{3}{s+1} \cdot \frac{4}{s+2} = \frac{12}{(s+1)(s+2)}$$

Step 2 – Answer: (D). Expanded, $\frac{12}{(s+1)(s+2)} = \frac{12}{s^2+3s+2}$ — the same function, written the other way.

Why multiplying is right. The output of the first block is the input of the second, so $Y = H_2(H_1X) = H_1H_2X$. Nothing is fed back, so the closed-loop formula $\frac{G}{1+GH}$ does not enter.

Check the dc gain (p. 232): $\lim_{s\to 0} H(s)$ should be the product of the two dc gains, $\frac{3}{1} \times \frac{4}{2} = 3 \times 2 = 6$. For the key, $\frac{12}{(1)(2)} = 6$ ✓. No distractor below survives it.

Step 3 – Eliminate the distractors:

(A) $\frac{7}{(s+1)(s+2)}$ adds the numerators, $3 + 4$, instead of multiplying them. Its dc gain is $7/2 = 3.5$, not 6.

(B) $\frac{12}{(s+1)(s+2)+12}$ is the closed-loop result for these two blocks in a unity-feedback loop, $\frac{G}{1+G}$. There is no feedback path in the diagram; its dc gain is $12/14 = 0.86$.

(C) $\frac{12}{2s+3}$ adds the denominators, $(s+1)+(s+2)$. Cascading two first-order blocks must give a *second*-order denominator; this one is still first order, and its dc gain is $12/3 = 4$.

Question 10 · Answer A

Handbook: FE Reference Handbook 10.6, Electrical and Computer Engineering → Decibels and Bode Plots, p. 378 (PDF viewer: page 384), which defines $\text{dB} = 20\log_{10}(V_2/V_1)$ and notes that Bode plots use a logarithmic frequency scale.

Step 1 – Locate the interfering tone relative to the corner. Attenuation on a Bode asymptote depends only on how many decades past the corner the frequency lies:

$$\log_{10}\left(\frac{f}{f_c}\right) = \log_{10}\left(\frac{30}{22}\right) = \log_{10}(1.364) = 0.1347 \text{ decade}$$

The 30 kHz tone is only about one seventh of a decade above the cutoff.

Step 2 – Multiply by the slope.

$$A = (-40 \text{ dB/decade})(0.1347 \text{ decade}) = -5.39 \approx -5.4 \text{ dB}$$

Step 3 – Answer: (A) approximately -5.4 dB.

Cross-check in octaves. -40 dB/decade is $-40\log_{10}(2) = -12.04$ dB/octave, and $30/22$ is $\log_2(1.364) = 0.4475$ octave. That gives $(-12.04)(0.4475) = -5.39$ dB — the same answer, which confirms the decade arithmetic.

Engineering point. Only 5.4 dB of rejection is very poor. Sampling at 48 kHz folds a 30 kHz tone down to $|30 - 48| = 18$ kHz, right inside the audio band, and it arrives barely attenuated. Either the corner must move well below 22 kHz or the filter order must increase; this is exactly the trade-off that forced 44.1 kHz and 48 kHz rather than the bare 40 kHz minimum.

Step 4 – Eliminate the distractors:

(B) -20 dB corresponds to a single-pole roll-off of -20 dB/decade evaluated a full decade out, or to reading the slope as -20 instead of -40. Either way it ignores the given roll-off and the actual frequency ratio.

(C) -40 dB is the slope itself, in dB per decade. It would be the attenuation only at $10f_c = 220$ kHz, a full decade past the corner.

(D) -12 dB is the same slope expressed per octave, $-40\log_{10}2$. It would be the attenuation at $2f_c = 44$ kHz. The tone is at 30 kHz, less than half an octave up.

Question 11 · Answer D

Handbook: FE Reference Handbook 10.6, Electrical and Computer Engineering → *Operational Amplifiers*, p. 386 (PDF viewer: page 392). The Handbook gives the single-input inverting result and

the two ideal rules — input currents are zero, and $v_2 - v_1 = 0$ in linear operation — but no summing formula. With unequal input resistors the general form is the one to build, and it comes straight out of KCL at the virtual ground.

Step 1 – Each branch carries its own current. The non-inverting terminal is grounded, so the inverting node sits at 0 V and every input resistor has its far end pinned there:

$$I_1 = \frac{V_1}{R_1} = \frac{1}{10\ \text{k}\Omega} = 0.1\ \text{mA} \qquad I_2 = \frac{V_2}{R_2} = \frac{2}{20\ \text{k}\Omega} = 0.1\ \text{mA}$$

Step 2 – KCL sends both through R_f.

$$V_{out} = -R_f\,(I_1 + I_2) = -\,(40\ \text{k}\Omega)\,(0.2\ \text{mA}) = -8\ \text{V}$$

Answer: (D).

The same thing written as weights. Each input arrives multiplied by its own ratio:

$$V_{out} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2\right) = -\,[4(1) + 2(2)] = -(4+4) = -8\ \text{V}$$

V_1 is weighted by 4 and V_2 by 2, because R_1 is half of R_2 and the smaller resistor lets more current in per volt. That is the whole idea of the word *weighted*: the resistor ratios, not the source voltages, decide how much each input counts.

Watch the coincidence. The two branches happen to contribute 4 V each here — a 1 V input weighted by 4, and a 2 V input weighted by 2. Equal contributions from unequal weights is a numerical accident of these values, not a property of the circuit, and it is why two of the distractors below look reasonable at a glance.

Where this circuit is used. Make the input resistors binary — R, $2R$, $4R$, $8R$ — and the weights R_f/R_n fall in the ratio 8 : 4 : 2 : 1 whatever R_f happens to be, since R_f scales all four together. Drive those inputs with logic levels and the output is the analogue value of a binary word: that is a binary-weighted digital-to-analogue converter, and it is the most common place a weighted summer is actually met.

Step 3 – Eliminate the distractors:

(A) -12 V applies $R_f/R_1 = 4$ to *both* inputs: $-4(1+2)$. That would be right only if R_2 were also 10 kΩ; the figure makes it 20 kΩ.

(C) -6 V is the mirror slip, applying $R_f/R_2 = 2$ to both: $-2(1+2)$. Between (A) and (C) lies the point of the question — each input carries its own resistor with it.

(B) $+8$ V has the right magnitude and no minus sign. Current driven *into* a node held at 0 V has to return through R_f from the output side, which puts the output below zero.

Question 12 · Answer C

Handbook: FE Reference Handbook 10.6, Electrical and Computer Engineering → *Synchronous Machines*, p. 371 (PDF viewer: page 377). For negligible armature resistance it gives the developed

power and, on the next line, the answer to this question directly:

$$P_d = 3\left(\frac{E_a V_a}{X_s}\right)\sin\delta \qquad\qquad P_{d,max} = 3\left(\frac{E_a V_a}{X_s}\right)$$

The maximum is the printed formula with $\sin\delta = 1$, which is the peak the figure draws at $\delta = 90°$. Note that the 3 is already in it: this is the **total** three-phase power, which is what the question asks for.

Step 1 – Put the bus voltage on a per-phase basis. E_f is given per phase; V_t is given line-to-line, and the formula needs both per phase:

$$V_a = \frac{13{,}800}{\sqrt{3}} = 7967 \text{ V per phase}$$

Step 2 – Substitute.

$$P_{max} = 3\left(\frac{10{,}000 \times 7967}{9}\right) = 3(8{,}852{,}000) = 26{,}560{,}000 \text{ W} = 26.6 \text{ MW}$$

Answer: (C).

What the curve is telling you. Power rises with δ only up to 90°. Past the peak, pushing more mechanical power into the shaft makes δ grow and the electrical power *fall*, so the surplus accelerates the rotor, δ grows further, and the machine slips a pole. That is the steady-state stability limit, and it is why real machines are operated at a small fraction of it — typically δ of 20° to 30°, leaving room to ride through a disturbance.

Two things the operator can change, and one he cannot. P_{max} rises with the excitation E_f and falls with the synchronous reactance X_s. V_a is fixed by the bus — that is what "infinite" means. So the way to increase the stability margin on a given machine is to raise the field current, which is exactly what an automatic voltage regulator does when the system is disturbed.

Step 3 – Eliminate the distractors:

(A) 8.85 MW is $E_f V_a / X_s$, the maximum for *one* phase. The Handbook formula carries the factor 3 for exactly this reason, and the question asks for the total.

(D) 46.0 MW uses 13,800 V as the per-phase voltage, skipping the division by $\sqrt{3}$. The figure says the 13.8 kV is line-to-line, and it is the only voltage in the problem that needed converting.

(B) 21.2 MW is $3V_a^2/X_s$, the bus voltage used for both voltages. The two are not the same: $E_f = 10$ kV is set by the field current and $V_a = 7.97$ kV by the bus, and it is the machine being over-excited relative to the bus that gives it any margin at all.

Question 13 · Answer B

Handbook: FE Reference Handbook 10.6, Electrical and Computer Engineering → *Transformers (Ideal)*, p. 369 (PDF viewer: page 375), which gives $Z_P = a^2 Z_S$ for the impedance seen at the input; and p. 366 (PDF viewer: page 372), *impedances in series combine additively*.

Step 1 – Decide which impedance has to move. Z_1 already sits on the primary side, so referring it to the primary does nothing to it. Only Z_2 has to cross the transformer:

$$Z_2' = a^2 Z_2 = 2^2(0.6 + j0.9) = 4(0.6 + j0.9) = 2.4 + j3.6\ \Omega$$

Step 2 – Now they really are in series, so add. Once both impedances are expressed on the same side of the transformer, the ideal transformer between them can be slid out of the way and the two boxes sit end to end in one loop:

$$Z_{eq1} = Z_1 + Z_2' = (0.5 + j1.2) + (2.4 + j3.6) = 2.9 + j4.8\ \Omega$$

Answer: (B).

Why they cannot simply be added as drawn. As the figure stands, Z_1 carries the primary current and Z_2 carries the secondary current, and those two differ by the factor a. Two elements carrying different currents are not in series, whatever the drawing looks like. Referring Z_2 to the primary is exactly the step that puts both on the same current, and only then does addition mean anything.

What this quantity is for. Z_{eq1} is the single impedance used in the approximate transformer equivalent circuit: one series box between the source and the ideal transformer, standing in for both windings. Every voltage-regulation and short-circuit calculation on a transformer starts from it.

The same answer from the other side. Referring everything to the *secondary* instead gives $Z_{eq2} = Z_1/a^2 + Z_2 = 0.125 + j0.3 + 0.6 + j0.9 = 0.725 + j1.2\ \Omega$, which is $Z_{eq1}/4$ — the same physical transformer, described from the other winding.

Step 3 – Eliminate the distractors:

(A) $1.1 + j2.1$ is $Z_1 + Z_2$: the two boxes added straight off the drawing, with the transformer between them ignored. It is the answer of treating a turns ratio as if it were a piece of wire.

(C) $2.4 + j3.6$ is $a^2 Z_2$ alone — the referring done correctly and then the primary winding forgotten. The question asks for the *total*, and Z_1 is already where it needs to be, which is easy to read as "nothing to do here".

(D) $4.4 + j8.4$ is $a^2(Z_1 + Z_2)$: the whole sum multiplied by four, so Z_1 gets referred as well. Referring an impedance that is already on the primary side moves it to a side it is not on.

Question 14 · Answer A

The Handbook does not give the force between two wires directly, but it gives the two pieces it is made of, and putting them together is the whole exercise.

First, the field the left wire produces where the right one sits. For a current-carrying wire, B = μI/(2πr), so at r = d

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

Second, the force that field exerts on the second wire, F = IL × B, which for a length L of wire carrying I_2 perpendicular to B gives F = I_2 L B_1. Dividing by the length:

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi \times 10^{-7})(5)(8)}{2\pi(0.1)} = 8.0 \times 10^{-5}\ \mathrm{N/m}$$

The π cancels, which is worth noticing: μ_0 carries a 4π and the field of a wire carries a 2π, so the arithmetic is $2 \times 10^{-7} \times I_1 I_2/d$ and needs no calculator.

The direction is not a separate rule to memorise; it comes out of the same cross product. Take the currents up the page and the field of the left wire at the right wire points into the page. Then $I_2\mathbf{L} \times \mathbf{B}$, with the current up and B into the page, points back toward the left wire. So currents running the same way **attract**. Reverse one current and the force reverses with it: antiparallel currents repel. It is the opposite of the rule for charges, and that is why it catches people.

1.6×10^{-4} N/m is twice the answer, and it comes from writing the field of a wire with πd instead of 2πd in the denominator. The 2 belongs there: the field of an infinite wire falls as the circumference of the circle around it, and that circumference is 2πr.

Question 15 · Answer C

Handbook: FE Reference Handbook 10.6, Instrumentation, Measurement, and Control → *Second-Order Control System Models*, p. 234 (PDF viewer: page 240): *"The time required for the output of a second-order system to settle to within 2% of its final value (2% settling time) is defined to be* $T_s = 4/(\zeta\omega_n)$*"*. Note the page: the second-order model itself, with ζ, ω_n, ω_d, t_p, M_p and %OS, is on p. 233; the settling time is on the following page, alongside the logarithmic decrement and $\omega_d \tau = 2\pi$.

Step 1 – Substitute.

$$T_s = \frac{4}{\zeta\omega_n} = \frac{4}{(0.5)(10)} = \frac{4}{5} = 0.8 \text{ s}$$

Answer: (C).

Now read it off the plot, because the plot shows something the formula hides. Follow the trace. It overshoots to 1.16, comes back down and first enters the $\pm 2\%$ band near $t = 0.58$ s — and then *leaves the band again* on the undershoot around $t = 0.7$ s, before finally re-entering at $t \approx 0.81$ s and staying. The formula's 0.8 s and the drawing agree, and the drawing makes the definition concrete: **settling time is the last time the response leaves the band, not the first time it enters.**

Where the 4 comes from. The response decays inside the envelope $1 \pm e^{-\zeta\omega_n t}/\sqrt{1-\zeta^2}$. Setting that envelope to 0.02:

$$e^{-\zeta\omega_n t} = 0.02\sqrt{1-\zeta^2} \quad \Longrightarrow \quad \zeta\omega_n t = 4.06 \quad \Longrightarrow \quad t = 0.81 \text{ s}$$

For small ζ the square root goes to 1 and the exponent is $\ln 50 = 3.91$, which is where the 4 comes from. So $T_s = 4/(\zeta\omega_n)$ is simply **four time constants of the envelope**, the time constant being $1/(\zeta\omega_n) = 0.2$ s here. That one reading organises the whole option set: three time constants is the 5% band, four is the 2% band, five is about 1%.

What actually sets the settling time. $\zeta\omega_n$ is the distance of the closed-loop poles from the imaginary axis — the poles here are at $-\zeta\omega_n \pm j\omega_d = -5 \pm j8.66$. The settling time depends on that real part alone, not on ζ and ω_n separately. Two systems with completely different overshoots settle in the same time if their poles share a real part, which is why designers draw vertical lines in the s-plane as settling-time contours and wedge-shaped regions as damping contours.

Two more numbers the same plot gives you free. The peak is at 1.163, so the overshoot is 16.3% — which is what p. 233's $\%\,\mathrm{OS} = 100e^{-\pi\zeta/\sqrt{1-\zeta^2}}$ gives at $\zeta = 0.5$. That pairing, $\zeta = 0.5$ with roughly 16% overshoot, is worth memorising outright. And the oscillation period is $\tau = 0.73$ s, which p. 234's $\omega_d\tau = 2\pi$ converts to $\omega_d = 8.66$ rad/s $= \omega_n\sqrt{1-\zeta^2}$. Either reading alone would recover ζ and ω_n if the stem had not supplied them.

Step 2 – Eliminate the distractors:

(A) 0.4 s divides by ω_n instead of $\zeta\omega_n$: $4/10$. Settling is set by the real part of the pole, $\zeta\omega_n = 5$, not by the pole's distance from the origin, $\omega_n = 10$. Dropping ζ makes the response look twice as quick as it is.

(B) 0.6 s is the **5%** settling time, $3/(\zeta\omega_n)$ — three time constants instead of four. It is also what a careless reading of the plot gives, since the trace first touches the $\pm 2\%$ band near $t = 0.58$ s. Two different routes to the same wrong answer, and the figure is drawn so that the second one can be caught: the trace comes back out.

(D) 1.0 s is five time constants, $5/(\zeta\omega_n)$, the rule of thumb for settling to about 1%. Right kind of quantity, wrong band.

Question 16 · Answer C

The FM modulation index:

$$\beta = \frac{\Delta f}{f_m} = \frac{25\ \text{kHz}}{5\ \text{kHz}} = 5$$

Using Carson's rule:

$BW \approx 2(\Delta f + f_m) = 2(25 + 5) = 2(30) = 60$ kHz

Since $\beta = 5 > 1$, this is wideband FM. The bandwidth is significantly larger than the message bandwidth.

Question 17 · Answer A

The subnet address is the bitwise AND of the address with the mask, so take it one octet at a time.

Octets 1 and 2 are masked with 255, all ones, so they pass through unchanged: 172 and 16. Octet 4 is masked with 0, all zeros, so it becomes 0. Only octet 3 does any work, and the figure shows why: the twenty-bit boundary falls in the middle of it, four bits in.

$$45 = 00101101$$

$$240 = 11110000$$

AND $= 00100000 = 32$

so the subnet address is 172.16.32.0.

There is a faster way that is worth having. A mask octet of 240 leaves 16 as the block size in that octet, so the subnets start at 172.16.0.0, 172.16.16.0, 172.16.32.0, 172.16.48.0 and so on, and 45 falls in

the block that starts at 32. Same answer, no binary, and it is how this is done under exam time pressure.

172.16.45.0 is the answer for a /24, and it is the most common error of all: stopping at the octet boundary because that is where the dots are. The whole point of CIDR is that the boundary need not fall on a dot. **172.16.40.0** comes from masking with 248, which is a /21, and **172.16.44.0** from masking with 252, which is a /22. Each is one step wrong in the prefix.

Question 18 · Answer D

Handbook: FE Reference Handbook 10.6, Mathematics → *Discrete Math* → *Finite State Machine*, p. 36 (PDF viewer: page 42) — in the Mathematics section, not the Electrical one. It defines a machine as *a finite set of states, a finite set of inputs, and a transition function*, and shows the state-table and state-diagram representations.

The Handbook's definition has **no output function**, and neither Moore nor Mealy is named anywhere in it. So the one convention this question turns on has to be known: in a Mealy machine the output belongs to the *transition*, which is why every arrow here is labelled input / output.

Step 1 – Walk the diagram, one symbol at a time. Begin in S_0 and read the output off each arrow as you take it:

step	state	input	arrow taken
1	S_0	1	$S_0 \xrightarrow{1/0} S_1$
2	S_1	1	$S_1 \xrightarrow{1/0} S_2$
3	S_2	0	$S_2 \xrightarrow{0/1} S_0$
4	S_0	1	$S_0 \xrightarrow{1/0} S_1$
5	S_1	0	$S_1 \xrightarrow{0/0} S_0$

Step 2 – Collect the outputs in order.

$$0,\ 0,\ 1,\ 0,\ 0$$

Step 3 – Answer: (D).

What the machine is doing. Only one arrow in the whole diagram carries an output of 1: $S_2 \xrightarrow{0/1} S_0$. Reaching S_2 takes two 1s, and the 1 is emitted on the 0 that follows them — so this is a detector for the pattern 110, firing on the final 0. In the given stream, $1\,1\,0\,1\,0$, that pattern occurs once, ending at the third symbol, and the single 1 in the output sits exactly there.

Why the last two symbols produce nothing. After step 3 the machine is back in S_0 with no progress banked. The 1 at step 4 only advances it to S_1, and the 0 at step 5 sends it home again. The stream ends $1\,0$, not $1\,1\,0$, so there is no second detection.

Moore or Mealy changes the answer. In a Mealy machine the output appears on the same clock as the input that caused it. Had this been a Moore machine, the 1 would have appeared one step *later*, when the machine had arrived in a state marked with output 1. That one-step shift is the commonest error on this topic, and it is worth checking which kind of diagram you are looking at before tracing anything: outputs on the arrows means Mealy, outputs inside the circles means Moore.

Step 4 – Eliminate the distractors:

(A) $0\,0\,0\,1\,0$ is the right detection reported one step too late. It is what you get by reading this diagram as though it were a Moore machine: waiting until the transition has been taken and then reporting the output of the state just entered. Every 1 in the output slides one position to the right. This is the single most common error on state-machine questions, and the guard against it is the one-second check at the top — outputs on the arrows means Mealy, so the output is emitted *during* the transition, not after it.

(B) $0\,0\,1\,0\,1$ finds the first detection correctly and then invents a second one at step 5. It counts the last $1\,0$ as a match, forgetting that the machine needs *two* 1s to reach S_2 and only one arrived.

(C) $0\,1\,0\,0\,1$ comes from picking the wrong accepting transition: it is the sequence you get if you believe the machine fires on leaving S_1 rather than on leaving S_2, so it reports a 1 on the second symbol and again on the last. Under that reading the machine fires on *any* departure from S_1, which amounts to announcing a single 1 rather than the pattern 110.

Question 19 · Answer A

Count the stolen cycles, then price one of them.

The figure says a stolen cycle carries 4 bytes, so a 4,096-byte block needs

$$\frac{4096\ \text{bytes}}{4\ \text{bytes per cycle}} = 1024\ \text{bus cycles}$$

and one bus cycle at 100 MHz lasts

$$T = \frac{1}{100 \times 10^6\ \text{Hz}} = 10\ \text{ns}$$

so the transfer occupies

$$1024 \times 10\ \text{ns} = 10{,}240\ \text{ns} = 10.24\ \mu\text{s}$$

That figure is the bus time the controller uses, not the wall-clock time the block takes on a real machine. In cycle stealing the controller takes single cycles between the processor's, as the bus-owner strip shows, so the block is spread over a longer stretch of real time while the processor keeps running in the cycles in between. The question asks for the case with no waiting, which is the 1,024 cycles of bus occupancy.

The three wrong answers are three different slips, and it is worth knowing which is which. **40.96 µs** forgets the transfer width and gives one cycle to each of the 4,096 bytes; it is four times too long, and it is the most common answer from students who never use the figure's 4 bytes per cycle. **20.48 µs** gives each transfer two bus cycles, one to put out the address and one to move the data, which is how some controllers work but not the one drawn: each shaded cell in the strip is a single cycle. **102.4 µs** comes from inverting the clock wrongly and taking the period as 100 ns instead of 10 ns; a megahertz is a microsecond, so 100 MHz is 0.01 µs, and reading it as 0.1 µs costs a factor of ten.

Question 20 · Answer A

Handbook: FE Reference Handbook 10.6, Software Engineering → Tree Traversal, p. 416 (PDF viewer: page 421), which gives In-Order Traversal as: "1. Traverse the left sub-tree. 2. Visit the root node. 3. Traverse the right sub-tree."

Step 1 – Apply the rule at the root (15): traverse the left sub-tree rooted at 10, then visit 15, then traverse the right sub-tree rooted at 20.

Step 2 – Expand the left sub-tree (10): left sub-tree is 8, then the root 10, then the right sub-tree 12 → 8, 10, 12.

Step 3 – Expand the right sub-tree (20): left sub-tree is 18, then the root 20, then the right sub-tree 25 → 18, 20, 25.

Step 4 – Assemble: 8, 10, 12 · 15 · 18, 20, 25 → **8, 10, 12, 15, 18, 20, 25**.

Step 5 – Eliminate the distractors. Each wrong option is a different traversal of the same tree, so recognizing which one you produced tells you which rule you applied:

(B) 8, 12, 10, 18, 25, 20, 15 is the postorder traversal defined on the same Handbook page: left sub-tree, right sub-tree, then the root. Note the root 15 comes last instead of in the middle.

(C) 25, 20, 18, 15, 12, 10, 8 is the in-order traversal with the sub-trees taken in the opposite order (right, root, left), which reverses the sequence.

(D) 15, 10, 20, 8, 12, 18, 25 is the level-order traversal — every node at one depth before moving down. It is not one of the three algorithms listed on p. 416.

Step 6 – Answer: The correct answer is **(A) 8, 10, 12, 15, 18, 20, 25**. Useful check: an in-order traversal of a binary *search* tree always comes out in ascending order, because every value in a left sub-tree is smaller than its root and every value in a right sub-tree is larger.