Final Exam Page 1

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May 12, 2015

Final Examination

1) Write your official:
   Last Name (use capital letters): SOLUTIONS
   First Name (use capital letters):
   NetID:
   UIN:

2) Fill in the Orange bubble sheet with all the information requested:
   a. LAST NAME, FIRST INITIAL example: SCHMITZ C
   b. STUDENT NUMBER (UIN) example: 678912345
   c. SECTION   (AL1 9am enter 111, AL2 10am enter 222,
      AL3 2pm enter 333, AL4 3pm enter 444)
   d. NETWORK ID (NetID) example: cdenschmit
   e. Also, fill out the hand-written center of the sheet with course,
      instructor, section and your signature.

DO NOT TURN THIS PAGE UNTIL YOU ARE TOLD

A. NO CALCULATORS ARE PERMITTED ON THE EXAM!
   Using a calculator will be treated as cheating.
B. One two-sided sheet of notes is permitted on the exam.
C. Write or print clearly in this exam booklet for your own benefit. Circle the correct answer
   within the exam booklet and then mark it on the orange bubble sheet. You may not argue
   for points because you marked one answer in the exam and another on the bubble sheet,
   so be careful when marking your answers.
D. All problems are equally weighted.
E. Your grade will be determined based on the answers submitted on your bubble sheet.

Submit both the bubble sheet AND the complete exam booklet.

Students caught cheating on this exam will earn a grade of F for the entire course. Other
penalties may include suspension and /or dismissal from the university.

I have read and acknowledge the above statements. Furthermore, I promise not to give or
receive help on this or any other exam.

______________________________
Signature

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1. What is the voltage at which a 2 μF (2 × 10⁻⁶ F) capacitor stores 1 J of energy?
   a. 250 V  
   b. 500 V  
   c. 1000 V  
   d. 2000 V  
   e. 4000 V

   \[ E = \frac{1}{2} CV^2 \]
   \[ 1 = \frac{1}{2} \times 2 \times 10^{-6} \times V^2 \]
   \[ V^2 = 10^6 \Rightarrow V = 1000 \text{ V} \]

2. A motor pulls 200 mA of current from a 9-V battery. If it converts electrical energy to mechanical energy with an efficiency of 25%, how much mechanical power does the motor deliver?
   a. 0.45 W  
   b. 0.90 W  
   c. 1.8 W  
   d. 3.6 W  
   e. 7.2 W

   \[ P = (\text{efficiency}) \times I \times V \]
   \[ = 0.25 \times (0.2 \text{ A}) \times 9 \text{ V} \]
   \[ = 0.25 \times 1.8 \]
   \[ = 0.45 \text{ W} \]

3. Apply KVL to find the values of V1 and V2 in the diagram below.
   a. V1 = 6 V, V2 = 3 V  
   b. V1 = 6 V, V2 = 7 V  
   c. V1 = 2 V, V2 = 7 V  
   d. V1 = 2 V, V2 = 11 V  
   e. V1 = 2 V, V2 = 15 V

   ![Diagram]

4. What is the value of Vout, the voltage across the 200 Ω resistor, in the circuit below?
   a. 50 V  
   b. 30 V  
   c. 20 V  
   d. 12 V  
   e. 6 V

   \[ I_2 = \frac{300}{300 + 200} \times 0.1 = \frac{3}{5} \times 0.1 = 0.06 \text{ A} \]

   \[ V_{out} = 200 \times I_2 = 200 \times 0.06 \]
   \[ = 12 \text{ V} \]
5. What is the value of the resistance, \( R \), if the voltage across it is 4 V?
   a. 4 kΩ
   b. 6 kΩ
   c. 8 kΩ
   d. 16 kΩ
   \[ \frac{2R}{4} = \frac{R}{2} \]
   e. 24 kΩ
   \[ 2R + 14 = 3R \]
   \[ R = 24 \text{ kΩ} \]

6. All lightbulbs below are identical and can be modeled as resistors. Of the labeled lightbulbs, which one is dissipating the most power?
   a. 1
   b. 2
   c. 3
   d. 4
   e. 5
   \[ P = \frac{V^2}{R} \]
   4 has the most voltage across it

7. What is \( R_{AB} \)?
   a. 0.67 kΩ
   b. 0.90 kΩ
   c. 2.4 kΩ
   d. 3.0 kΩ
   e. 3.6 kΩ
   \[ R_{AB} = \frac{12}{\frac{12}{13} + \frac{1}{6} \Omega} = 6 \frac{12kΩ}{6\Omega} = 2.4 \text{ kΩ} \]

8. All four resistors below have the same resistance \( R \). What is \( R \) if the equivalent resistance is \( R_{eq} = 150 \Omega \)?
   a. 300 Ω
   b. 250 Ω
   c. 200 Ω
   d. 150 Ω
   e. 100 Ω
   \[ 150 = \frac{(R||R) + R}{2} = \frac{(0.5kΩ + R) + R}{2} = \frac{1.5kΩ}{2} = \frac{1.5}{2} kΩ \]
   \[ R = 150 \times \frac{2.5}{1.5} = 250 \Omega \]
9. What is the power supplied by the current source?
   a. 1.2 W  
   b. 2.0 W  
   c. 2.4 W  
   d. 3.2 W  
   e. 4.4 W  
   \[ P = -IV \text{ for current source} \]  
   \[ P = -(0.4 \text{ A})(11 \text{ V}) \]  
   \[ P = -4.4 \text{ W} \]

10. What is the labeled node voltage, \( V_1 \)?
   a. 5 V  
   b. 6 V  
   c. 7 V  
   d. 8 V  
   e. 9 V  
   \[ KCL @ V_1 \]  
   \[ \frac{10 - V_1}{2} + \frac{8 - V_1}{2} = \frac{V_1}{2} \]  
   \[ 18 = 2V_1 \]  
   \[ V_1 = 9 \text{ V} \]

11. What is the power supplied (delivered) by the voltage source?
   a. 1.2 W  
   b. 1.5 W  
   c. 1.8 W  
   d. 2.1 W  
   e. 2.4 W  
   \[ KCL @ V \]  
   \[ \frac{9 - V}{30} = \frac{V}{60} \]  
   \[ 18 - 2V = V + 0.2 \times 60 \]  
   \[ 2V = 3V \]  
   \[ V = 2 \text{ V} \]  
   \[ I = \frac{9 - V}{30} = \frac{7}{30} \text{ A} \]  
   \[ P = -9 \times \frac{7}{30} = -2.1 \text{ W} \]

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12. What is the current, $I_2$, flowing through the 2 V source?
   a. 0 mA
   b. 2.5 mA
   c. 5 mA
   d. 10 mA
   e. 15 mA

\[ \frac{5 - V}{500} + \frac{5 - (V + 2)}{125} = \frac{V^2}{500} + \frac{V}{125} \]
\[ 5 - V + 20 - 4V - 8 = V + 2 + 4V \]
\[ 15 = 10V \]
\[ V = 1.5V \]

13. What is the correct I-V expression, for the circuit below?
   a. $I = -\frac{V}{20} + 1$
   b. $I = -\frac{V}{20} + 2$
   c. $I = -\frac{V}{30} + 1$
   d. $I = -\frac{V}{30} + 2$
   e. $I = -\frac{V}{40} + 1$

\[ I = I_{sc} - \frac{I_{sc}}{V_{oc}} \]
\[ = \frac{2}{30} - \frac{2}{60} \]
\[ = \frac{1}{30} \]
14. Consider a circuit, $C$, with two terminals shown connected to three loads below. If its open-circuit voltage is 12 V, short circuit current is 2 A, what is the power dissipated (absorbed) by a 2 Ω load connected to the circuit?

![Circuit Diagram]

- a. 72 W
- b. 36 W
- c. 24 W
- d. 8 W
- e. 4.5 W

$$I = \frac{V}{2} = 2 - \frac{2}{12} V$$

$$3I = 6 \Rightarrow I = \frac{3}{2} A$$

$$P = I^2 R = \left(\frac{3}{2}\right)^2 \frac{9}{2} = 4.5 \text{ W}$$

15. What is the Norton equivalent of the circuit below?

![Norton Equivalent Circuit Diagram]

- a. $I_N = 1.5 A$, $R_N = 9 \Omega$
- b. $I_N = 1.5 A$, $R_N = 6 \Omega$
- c. $I_N = 1.5 A$, $R_N = 2 \Omega$
- d. $I_N = 0.5 A$, $R_N = 6 \Omega$
- e. $I_N = 0.5 A$, $R_N = 2 \Omega$

$$I_{sc} = \frac{4.5 V}{3 \Omega} = 1.5 A$$

$$R_{eff} = \frac{3 \Omega}{6 \Omega} = \frac{3 \times 6}{3 + 6} = 2 \Omega$$
16. Two identical linear circuits, each with a Thevenin equivalent given by \( V_T = 9 \, \text{V}, \, R_T = 3 \, \Omega \), are combined in parallel to form a new circuit. The new circuit’s Thevenin equivalent is given by:

a. \( V_T = 18 \, \text{V}, \, R_T = 3 \, \Omega \)
b. \( V_T = 18 \, \text{V}, \, R_T = 1.5 \, \Omega \)
c. \( V_T = 9 \, \text{V}, \, R_T = 3 \, \Omega \)
d. \( V_T = 9 \, \text{V}, \, R_T = 1.5 \, \Omega \)
e. \( V_T = 4.5 \, \text{V}, \, R_T = 3 \, \Omega \)

Parallel combination \( \Rightarrow V_T = V_{oc} \) stays same and \( R_T = R_{eff} = \frac{3}{3} = 1.5 \, \Omega \)

17. What is a good estimate of the lightbulb resistance, if the lightbulb absorbs 50W of average power when the AC voltage across it is given by the following equation? (If you need, \( 1.4^2=2 \))

\[ v(t) = 140 \cos(120\pi t) \]

\[ V_{rms} = \frac{140}{\sqrt{2}} \approx 100 \, \text{V} \]

\[ P = \frac{V_{rms}^2}{R} \]

\[ R = \frac{V_{rms}^2}{P} = \frac{100 \times 100}{50} = 200 \, \Omega \]

18. Assuming an offset ideal model, what is the resistance, \( R \), needed to set the current to 50 mA through the blue LED which has the turn on voltage \( V_{on} = 3 \, \text{V} \)?

\[ R = \frac{1.5 \, \text{V}}{50 \, \text{mA}} = \frac{1.5 \, \text{V}}{0.05 \, \text{A}} = \frac{150}{5} = 30 \, \Omega \]
19. What is the current, \( I \), supplied by the voltage source, if \( V_{\text{on}} = 0.7 \text{ V} \), assuming offset ideal diode model?
   a. 0 mA
   b. 1.5 mA
   c. 3.0 mA
   d. 4.0 mA
   e. 5.0 mA

\[
I = \frac{(1-0.7)V}{200 \Omega} = \frac{0.3V}{0.2 \Omega} = 1.5 \text{ mA}
\]

20. How many of the blue light-emitting diodes are ON in the diagram below, assuming an offset ideal model with \( V_{\text{on}} = 3 \text{ V} \)?

   a. 0
   b. 1
   c. 3
   d. 5
   e. 7

At least 9 V is needed to turn on the first bunch of diodes

21. What are the minimum and maximum values of \( V_{\text{out}} \) assuming the offset ideal model for the diodes with \( V_{\text{on}} = 0.7 \text{ V} \) and the input signal given by \( V_{\text{in}} = 1.1 \cos(120\pi t) \text{ V} \)?

   a. minimum -1.1 V, maximum 1.1 V
   b. minimum -1.1 V, maximum 0.7 V
   c. minimum -1.1 V, maximum 1.4 V
   d. minimum -0.7 V, maximum 1.1 V
   e. minimum -1.4 V, maximum 1.1 V

Both diodes stay OFF for the entire range \(-1.1 \leq V_{\text{in}} \leq 1.1\).

So, \( V_{\text{out}}(t) = V_{\text{in}}(t) \)
22. What is $I_C$ if $V_B = 2.2$ V, $R_B = 500$ Ω, and $R_C = 15$ Ω?
   a. 0 mA
   b. 100 mA
c. 200 mA
d. 300 mA
e. 580 mA

   $I_B = \frac{2.2 - 0.7}{0.5 \text{kΩ}} = \frac{1.5V}{0.5 \text{kΩ}} = 3 \text{ mA}$

   $I_{C,\text{sat}} = \frac{6}{0.015} = 400 \text{ mA}$

   $I_C = (100) I_B = 300 \text{ mA}$

23. What is $V_B$ if $V_O = 4.7$ V, $R_B = 500$ Ω, and $R_C = 15$ Ω?
   a. 0.5 V
   b. 1.2 V
c. 1.7 V
d. 2.2 V
e. 2.7 V

   $I_C = \frac{6.2 - 4.7}{1.5} = \frac{1.5}{1.5} = 100 \text{ mA}$

   $I_B = 1 \text{ mA}$

   $V_B = 0.7 + (1 \text{ mA})(0.5 \text{kΩ}) = 1.2$ V

24. For which of the following $V_B$ values is the transistor absorbing (dissipating) the most power if $R_B = 500$ Ω, and $R_C = 15$ Ω?

   $I_B = \frac{V_B - 0.7}{0.5}$

   $I_{C,\text{sat}} = 400 \text{ mA}$

   $V_{CE} = 6.2 - I_C(0.015)$

   $P = V_{BE}I_B + V_{CE}I_C$

   

<table>
<thead>
<tr>
<th>$V_B$ (mV)</th>
<th>$I_B$ (mA)</th>
<th>$V_{CE}$ (V)</th>
<th>$P$ (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0</td>
<td>6.2</td>
<td>0</td>
</tr>
<tr>
<td>1.2</td>
<td>1.00</td>
<td>4.7</td>
<td>0.7 + 470</td>
</tr>
<tr>
<td>1.7</td>
<td>2.00</td>
<td>3.2</td>
<td>1.4 + 640</td>
</tr>
<tr>
<td>2.2</td>
<td>3.00</td>
<td>1.7</td>
<td>2.1 + 510</td>
</tr>
<tr>
<td>2.7</td>
<td>4.00</td>
<td>0.2</td>
<td>2.8 + 80</td>
</tr>
</tbody>
</table>

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25. Given the BJT below biased with \( V_{CC} = 12 \, V \), \( R_C = 200 \, \Omega \), \( R_B = 1 \, k\Omega \), what is/are the regime(s) of operation of the BJT if the input voltage is given by \( V_I(t) = 1.3 + 0.5 \cos(2000\pi t) \)?

a. Active only
b. Cut-off (Off) and Active
c. Cut-off (Off) and Saturation
d. Active and Saturation
e. Cut-off (Off), Active, and Saturation

26. If the BJT circuit below is biased with \( V_{CC} = 12 \, V \), \( R_C = 300 \, \Omega \), \( R_B = 2 \, k\Omega \), what is the active-region slope of the transfer characteristics given by \( G = \frac{V_{o2}-V_{o1}}{V_{i2}-V_{i1}} \)?

\[ G = -\frac{\beta R_C}{R_B} = -\frac{100 \times 300}{2000} = -15 \]
27. Consider the graph and the nMOS circuit below.

If \( I_1 = 10 \text{ mA}, \ V_{TH} = 2 \text{ V} \) and \( V_{GS} = V_{DD} = 4 \text{ V} \), what is the value of \( R_D \) which would result in \( V_{DS} = 3 \text{ V} \)?

\[ V_{GS} - V_{TH} = 4 - 2 = 2 \text{ V} \]

\[ I_D = \frac{4 \ I_1}{\frac{40}{mA}} = 25 \Omega \]

\[ a. \ 100 \Omega \]
\[ b. \ 75 \Omega \]
\[ c. \ 50 \Omega \]
\[ d. \ 25 \Omega \]
\[ e. \ 15 \Omega \]

28. Which of the following output columns correctly represents the output of the logic gate circuit below for inputs A and B?

\[ A = 0 \]
\[ B = 0 \]

\[ a. \ Z_1 \]
\[ b. \ Z_2 \]
\[ c. \ Z_3 \]
\[ d. \ Z_4 \]
\[ e. \ Z_5 \]
29. Which of the following output columns correctly represents the output of the logic circuit below for inputs A, B and C?

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Output Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>1</td>
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<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

a. Z_1  
b. Z_2  
c. Z_3  
d. Z_4  
e. Z_5

O if C = 0 OR (A = 0 AND B = 0)

30. Why is the cMOS logic circuit below improperly constructed?

a. The pMOS transistors should be in the lower part of the circuit
b. The output Z is independent of inputs A and B

c. The output Z is undefined when A=0 and B=0

d. The output Z is undefined when A=0 and B=1

e. The power source can be mistakenly shorted to ground
31. A certain CMOS chip running with a 20% activity rate at 2 GHz is dissipating 60 W. What would be the power dissipation if the chip was slowed down to 1.5 GHz and the activity rate was increased to 40%?
   a. 30 W
   b. 45 W
   c. 60 W
   d. 90 W
   e. 120 W

\[ P = nafCV^2 \]

\[ P_{\text{new}} = P_{\text{old}} \times \frac{a_{\text{new}}}{a_{\text{old}}} \times \frac{f_{\text{new}}}{f_{\text{old}}} \]

\[ = 60 \times \frac{0.4}{0.2} \times \frac{1.5}{2} = 90 \text{ W} \]

32. If thermal noise with RMS voltage of 0.05 V is added to a sinusoidal signal with the RMS voltage of 1 V, the ratio of signal power to noise power is

\[ \text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} = \frac{V_{\text{RMS, signal}}}{V_{\text{RMS, noise}}} = \frac{1}{(0.05)^2} = 20^2 = 400 \]

33. What is the minimum sampling rate for a digital voice mail system if all the frequencies below 4 kHz should be preserved (and correctly reproduced)?

   a. 2 kHz
   b. 4 kHz
   c. 8 kHz
   d. 20 kHz
   e. 40 kHz

\[ f_{\text{Nyquist}} = 2f_{\text{max}} < 2 \times 4 \text{ kHz} = 8 \text{ kHz} \]
34. The sinusoidal signal below is sampled with the sampling interval of 0.05 s. What is the frequency of the sinusoidal signal reconstructed from the obtained samples (after D/A)?

![Graph showing a sinusoidal signal](image)

- a. 22 Hz
- b. 20 Hz
- c. 10 Hz
- d. 4 Hz
- e. 2 Hz

One period = 0.5 s

\[ f = \frac{1}{0.5 \text{ s}} = 2 \text{ Hz} \]

35. What is the minimum number of bits per sample needed to digitize a signal in 0 to 2.4 V range if the quantization error (half of level spacing) should be less than 0.1 V?

![Quantization levels diagram](image)

- a. 4
- b. 5
- c. 6
- d. 7
- e. 8

If max error = 0.1 V, spacing = 0.2 V

To ensure max error < 0.1 V, #levels = 13

\[ \Rightarrow \# \text{ bits} = 4 \text{ since } 2^4 = 16 \text{ covers 13 levels} \]
36. How many 16-megapixel (16×10^6 pixels/image) images can be stored on a 4 GB (~4×10^9 bytes) SD card, if 48 bits (3×16, 16 per color) are recorded for every pixel and the images are **compressed** with a 24-fold compression ratio (DCR = 24)?

**Hint:** 1 Byte = 8 bits

- a. 16,000
- b. 4,000
- c. 1,000
- d. 500
- e. 125

37. The following birds are observed at the bird feeder with the frequencies given below. If a Huffman code is created to encode the visitors, which of the following is a correct code for **robbins**?

Pigeons 47%  Sparrows 25%  Crows 12%  Robins 9%  Finches 4%  Jays 3%

- a. 10
- b. 110
- c. 1111
- d. 11100
- e. 11101

38. The four sandwich choices on the menu are ordered with the estimated probabilities given in the table below. What is the best estimate of entropy \( H = \sum p_i \log_2 \frac{1}{p_i} \) of a sandwich order?

(Hint: \( \log_2 3 \approx 1.6 \))

<table>
<thead>
<tr>
<th>Sandwich</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>3/4</td>
<td>1/8</td>
<td>1/16</td>
<td>1/16</td>
</tr>
</tbody>
</table>

- a. 0.9 bits
- b. 1.2 bits
- c. 1.5 bits
- d. 1.8 bits
- e. 2.0 bits
39. Which assertion below is always correct if there are 7 possible symbols, which occur with entropy, H, and are Huffman coded with an average code length, L?

- a. \( H \leq L \) always
- b. \( L \leq H \)
- c. \( L \leq 3 \) because there are 7 symbols and you can always code 8 symbols with 3 bits
- d. \( 3 \leq H \leq L \)
- e. \( 3 \leq L \leq H \)

40. What is the percent saving if a 1200 kByte file is compressed to 240 kByte?

- a. 5%
- b. 20%
- c. 80%
- d. 95%
- e. 100%

\[
\text{DCR} = \frac{1200}{240} = 5
\]

\[
S = \left(1 - \frac{1}{5}\right) 100\% = 80\%
\]

41. If a single-channel audio signal is sampled at the rate of 40 kHz and quantized to 256 levels, what is the data compression rate (DCR) needed to compress the data rate to 64 kbps (kilobits per second)?

- a. 160
- b. 40
- c. 16
- d. 10
- e. 5

\[
\text{Orig rate} = \frac{40000 \text{ samples}}{5} \times 8 \text{ bits} = 320 \text{ kbps}
\]

\[
\text{DCR} = \frac{320 \text{ kbps}}{64 \text{ kbps}} = 5
\]

42. What is the ratio of the photon rate coming out of a 1 mW 540 nm source to the photon rate coming out of a 2 mW 1080 nm source?

- a. \( \frac{1}{2} \)
- b. \( \frac{1}{3} \)
- c. 1
- d. 2
- e. 4

\[
\text{Ratio of photon rate} = \frac{1 \text{ mW}}{1240 \text{ nm}} \div \frac{2 \text{ mW}}{1080 \text{ nm}} = \frac{1 \times 540}{2 \times 1080} = \frac{1}{4}
\]
43. A table of lasers and their wavelengths is attached below. Which of them are absorbed by Ge if its bandgap energy is 0.66 eV? Hint: \( E(eV) = \frac{1240}{\text{wavelength(nm)}} \)

<table>
<thead>
<tr>
<th>Laser</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Er:Glass</td>
<td>1540 nm</td>
</tr>
<tr>
<td>InGaAs</td>
<td>980 nm</td>
</tr>
<tr>
<td>HeNe</td>
<td>633 nm</td>
</tr>
</tbody>
</table>

\[ \lambda_{max} = \frac{1240}{0.66} \approx 1900 \text{ nm} \]

d. Er:Glass and InGaAs

e. All of them

44. If two identical photodiodes, with \( V_{oc} \) and \( I_{sc} \) given for a certain illumination, are connected in parallel, what is the change in \( V_{oc} \) and \( I_{sc} \) for the resulting combination (under the same illumination), in comparison to a single photodiode?

a. \( V_{oc} \) and \( I_{sc} \) both remain the same
b. \( V_{oc} \) and \( I_{sc} \) both increase by about 40%
c. \( V_{oc} \) and \( I_{sc} \) both double in value
d. \( V_{oc} \) doubles and \( I_{sc} \) remains the same
e. \( V_{oc} \) remains the same and \( I_{sc} \) doubles

45. A solar cell array has \( V_{oc} = 12 \) V and \( I_{sc} = 20 \) A for a certain illumination. What is the maximum power provided under this illumination if the fill factor is 0.75?

\[ P = 0.75 \times \frac{12 \times 20}{15} = 180 \text{ W} \]

a. 90 W
b. 120 W
c. 180 W
d. 240 W
e. 320 W