Problem 1. A circuit diagram for a modified light dimmer is shown below. The dimmer employs an ideal 30V diac, and an ideal triac. Determine the firing angle (in degrees).

Voltage divider

\[
V_{CN}(\theta) = (V\sin \theta) \left( \frac{R_2}{R_1 + R_2} \right)
\]

Firing occurs when

\[
V_{CN}(\theta) = V_{B K D W N}, \quad \alpha = \theta
\]

\[
(V\sin \alpha) \left( \frac{R_2}{R_1 + R_2} \right) = V_{B K D W N}
\]

\[
\sin \alpha = \left( \frac{R_1 + R_2}{R_2} \right) \frac{V_{B K D W N}}{V} = \frac{(3,3+410)(30)}{4,7(100)}
\]

\[
\sin \alpha = 0.511, \quad \alpha = 30.7^\circ
\]

a. 30.7°  b. 46.7°  c. 58.1°  d. 36.6°  e. Other

Problem 2. Use the integral definition of rms to determine the rms value of the periodic voltage waveform shown.

\[
V_{Rms}^2 = \frac{1}{T} \int_0^T V^2(t) \, dt
\]

\[
V_{Rms}^2 = \frac{1}{T} \left[ \int_0^{T/3} V^2(t) \, dt + \int_{T/3}^T V^2(t) \, dt \right]
\]

\[
V_{Rms}^2 = \frac{1}{T} \left[ 36 \left( \frac{T}{3} - 0 \right) + 4 \left( T - \frac{T}{3} \right) \right]
\]

\[
V_{Rms}^2 = \frac{1}{T} \left[ 36 \left( \frac{T}{3} \right) + 4 \left( \frac{2T}{3} \right) \right] = 12 + \frac{8}{3} = \frac{44}{3}
\]

\[
V_{Rms} = \sqrt{\frac{44}{3}} = 3.83 \text{ V}
\]

a. 3.32V  b. 3.83V  c. 3.33V  d. 2.93V  e. Other
Problem 3. Use the integral definition of average to determine the average value of the periodic full-wave rectified sinusoidal voltage waveform shown.

\[ V_{\text{AVE}} = \frac{1}{\pi} \int_{\theta=0}^{\pi} V \sin \theta \, d\theta = -\frac{V \cos \theta}{\pi} \bigg|_{\theta=0}^{\pi} = -\frac{V}{\pi} \left[ -1 - 1 \right] = \frac{2V}{\pi} = \frac{2(120)}{\pi} = 76.4 \, \text{V} \]

A. 70.0V  B. 89.1V  C. 60.0V  D. 76.4V  E. Other

Problem 4. A 100V (peak), 60Hz, AC voltage source energizes a resistor in series with an ideal diode (i.e., the diode never breaks down when reverse biased, and it has zero forward voltage drop when conducting). Which of the following shapes best approximates the instantaneous power \( p(t) \) consumed by the ideal diode? (Note – the horizontal line through the center of each graph corresponds to zero)

- When the diode conducts, \( i(t) > 0 \), but \( v(t) = 0 \), so \( p(t) = 0 \)
- When the diode is reverse biased, \( v(t) < 0 \), \( i(t) = 0 \), so \( p(t) = 0 \)
- \( p(t) = 0 \) all the time

A.  
B.  
C.  
D.  
E. Other
Problem 5. The circuit shown is operating in periodic steady-state. The bi-directional switch repetitively closes for 1μsec, and opens for 2μsec. Use KVL in the average sense to determine the average voltage across the resistor.

\[
\begin{align*}
\text{KVL in Average Sense} & \quad -10 + V_{\text{Ravg}} + V_{\text{Lavg}} = 0 \\
\text{But } V_{\text{Lavg}} = 0 \text{ due to S.S. Inductor Principle,} \\
\text{So } -10 + V_{\text{Ravg}} + 0 &= 0 \\
V_{\text{Ravg}} &= 10 \text{V}
\end{align*}
\]

<table>
<thead>
<tr>
<th>a. 15V</th>
<th>b. 10V</th>
<th>c. 2V</th>
<th>d. 3V</th>
<th>e. Other</th>
</tr>
</thead>
</table>

Problem 6. An 18,000μF DBR capacitor is charged to 40V. The AC input is switched off, and the capacitor then slowly discharges through a 2kΩ bleeder resistor. How long does it take for the capacitor voltage to decay to 10V? (Hint – use the decaying exponential \(e^{-t/RC}\))

\[
\begin{align*}
V(t) &= V_0 e^{-t/RC} \\
\frac{V(t)}{V_0} &= e^{-t/RC} \\
\ln\left[\frac{V(t)}{V_0}\right] &= -\frac{t}{RC} \\
t &= -RC\ln\left[\frac{V(t)}{V_0}\right] = -(2000)(18\times10^{-3}) \ln\left[\frac{10}{40}\right] = 49.9 \text{ sec}
\end{align*}
\]

<table>
<thead>
<tr>
<th>a. 36.0 sec</th>
<th>b. 49.9 sec</th>
<th>c. 25.0 sec</th>
<th>d. 9.0 sec</th>
<th>e. Other</th>
</tr>
</thead>
</table>
Problem 7. The following two average voltage readings were taken at the output of a DBR:

Reading 1, no load attached, \( V_{\text{out,avg}} = 40\text{V} \).
Reading 2, 5Ω load resistor attached, \( V_{\text{out,avg}} = 35\text{V} \).

The DBR output has a Thevenin equivalent circuit in the average sense. Determine the value of \( R_{\text{th,avg}} \).

\[
\begin{align*}
40\text{V} & \quad \frac{R_{\text{th,avg}}}{5\Omega} & \quad 35\text{V} \\
\end{align*}
\]

\[
R_{\text{th,avg}} = \frac{5\Omega}{40\text{V} - 35\text{V}} = \frac{5\Omega}{5\text{V}} = 1\text{Ω}
\]

Problem 8. The FFT of a voltage waveform is shown in the screen snapshot. The reference value for 0db is 1Vrms. What is the rms voltage of the component identified by the dotted circle?

\[
20\log_{10} \frac{V_{\text{rms}}}{1} = -13.2\text{db}, \quad \log_{10} \frac{V_{\text{rms}}}{1} = -13.2/20 \Rightarrow V_{\text{rms}} = 0.219\text{V} = V_{\text{rms}}
\]

a. 0.202V  b. 0.407V  c. 0.0479V  d. 0.219V  e. Other
Problem 9. At its present operating temperature, a 5kΩ (at 25°C) thermistor has resistance 1.5kΩ. Using linear interpolation with the table below, determine the temperature of the thermistor.

\[
\frac{1.5 \text{kΩ}}{5.0 \text{kΩ}} = 0.300 = \frac{R_T}{R(25\degree\text{C})}
\]

<table>
<thead>
<tr>
<th>Temp T °C</th>
<th>RT/R(T=25 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.0</td>
</tr>
<tr>
<td>10</td>
<td>2.0</td>
</tr>
<tr>
<td>20</td>
<td>1.2</td>
</tr>
<tr>
<td>30</td>
<td>0.80</td>
</tr>
<tr>
<td>40</td>
<td>0.50</td>
</tr>
<tr>
<td>50</td>
<td>0.35</td>
</tr>
<tr>
<td>60</td>
<td>0.25</td>
</tr>
<tr>
<td>70</td>
<td>0.17</td>
</tr>
</tbody>
</table>

- In between, slope = \(\frac{0.25 - 0.35}{60 - 50} = -0.10\) units/°C
- So down 0.10 units corresponds to up 5°C

\[\text{(a) 55.0°C} \quad \text{(b) 53.0°C} \quad \text{(c) 15.00°C} \quad \text{(d) 16.25°C} \quad \text{(e) Other)}\]

Problem 10. When lighted, an LED cluster has a voltage drop of 12V. A series dropping resistor will be used to limit the LED cluster current to no more than 20mA in a DBR application where the voltage ranges from 30-40V dc. Which of the following resistors is best suited for this job? (Note – the first two colors represent the two leading digits of R, and the third color represents the power of 10)

\[
\text{Use } \text{max } V \text{ to limit max } I
\]

\[
I = \frac{40-12}{R}, \quad R = \frac{40-12}{0.020A} = 1400 \text{Ω}
\]

- a. white, black, brown
- b. brown, yellow, red
- c. red, gray, red
- d. brown, gray, red
- e. Other
EE36L, Test 1, February 22, 2005. Name:  

Ten multiple choice questions. One page of notes permitted. No credit for guessing. You must show the steps on the test sheet that sufficiently justify your answers. Circle the correct answer. If the correct answer is not among the choices, choose “other” and give your answer. Do not un staple. Synchronized starting. If you finish before 10:30, go ahead and quietly turn.in your test. Otherwise, wait until 10:45 to avoid unnecessary commotion.

Problem 1. A circuit diagram for a modified light dimmer is shown below. The dimmer employs an ideal 35V diac, and an ideal triac. Determine the firing angle (in degrees).

\[ (V\sin \alpha) \left( \frac{R_z}{R_1+R_z} \right) = V_{B\!K\!D\!W\!N} \]

\[ \sin \alpha = \frac{(R_1+R_z) V_{B\!K\!D\!W\!N}}{VR_z} \]

\[ = \frac{(3.3+4.7)(35)}{(100)(4.7)} = 0.596 \]

\[ \alpha = 36.6^\circ \]

a. 46.7°  
    b. 36.6°  
    c. 30.7°  
    d. 58.1°  
    e. Other

Problem 2. Use the integral definition of rms to determine the rms value of the periodic voltage waveform shown.

\[ V_{rms} = \frac{1}{T} \left[ \int_0^{T/3} (5)^2 \, dt + \int_{T/3}^{T} (-2)^2 \, dt \right] \]

\[ = \frac{1}{T} \left[ 25 \left( \frac{T}{3} - 0 \right) + 4 \left( T - \frac{T}{3} \right) \right] = \frac{1}{T} \left[ 25 \left( \frac{T}{3} \right) + 4 \left( \frac{2T}{3} \right) \right] \]

\[ = \frac{25}{3} + \frac{8}{3} = \frac{33}{3} = 11 \]

\[ V_{rms} = \sqrt{11} = 3.32 \text{ V} \]

a. 3.32V  
    b. 2.93V  
    c. 3.33V  
    d. 3.83V  
    e. Other

Page 1 of 5
Problem 3. Use the integral definition of average to determine the average value of the periodic full-wave rectified sinusoidal voltage waveform shown.

\[
V_{AVG} = \frac{1}{\pi} \int_{0}^{\pi} V \sin \theta \, d\theta = \frac{-V}{\pi} \cos \theta \bigg|_{\theta=0}^{\theta=\pi} \\
= -\frac{V}{\pi} \left[ \cos(\pi) - \cos(0) \right] = \frac{-V}{\pi} \left[ -1 - 1 \right] \\
V_{AVG} = \frac{2V}{\pi} = \frac{2(140)}{\pi} = 89.1 \text{ V},
\]

---

Problem 4. A 100V (peak), 60Hz, AC voltage source energizes a resistor in series with an ideal diode (i.e., the diode never breaks down when reverse biased, and it has zero forward voltage drop when conducting). Which of the following shapes best approximates the instantaneous power \( p(t) \) consumed by the ideal diode? (Note – the horizontal line through the center of each graph corresponds to zero)

\[
p(t) = v(t) \cdot i(t)
\]

- **Diode conducts**, \( v(t) \) shown > 0, \( i(t) > 0 \), \( p(t) > 0 \)
- **Diode blocks**, \( v(t) \) shown > 0, \( i(t) = 0 \), \( p(t) = 0 \)
- So, \( p(t) = 0 \) Always

---

- a. 
- b. 
- c. 
- d. 
- e. Other
Problem 5. The circuit shown is operating in periodic steady-state. The bi-directional switch repetitively closes for 1μsec, and opens for 2μsec. Use KVL in the average sense to determine the average voltage across the resistor.

\[ KVL \text{ in average sense } = 0 \text{ because of Inductor Principle} \]

\[ -15 + V_{R_{AVG}} + V_{L_{AVG}} = 0 \]

So, \[ V_{R_{AVG}} = 15V \]

a. 10V  b. 15V  c. 2V  d. 3V  e. Other

Problem 6. An 18,000μF DBR capacitor is charged to 40V. The AC input is switched off, and the capacitor then slowly discharges through a 2kΩ bleeder resistor. How long does it take for the capacitor voltage to decay to 20V? (Hint – use the decaying exponential \( e^{-t/RC} \))

\[ V(t) = V_0 e^{-t/RC} \]

\[ \frac{V(t)}{V_0} = e^{-t/RC} \]

\[ \ln \left( \frac{V(t)}{V_0} \right) = -\frac{t}{RC} \]

\[ t = -RC \ln \left( \frac{V(t)}{V_0} \right) = -(2000)(18 \times 10^{-3}) \ln \left( \frac{20}{40} \right) = 25.0 \text{ sec} \]

a. 36.0 sec  b. 49.9 sec  c. 25.0 sec  d. 9.0 sec  e. Other
Problem 7. The following two average voltage readings were taken at the output of a DBR:

Reading 1, no load attached, $V_{\text{out,avg}} = 40\, \text{V}$.

Reading 2, 10Ω load resistor attached, $V_{\text{out,avg}} = 38\, \text{V}$.

The DBR output has a Thevenin equivalent circuit in the average sense. Determine the value of $R_{\text{th,avg}}$.

$$ R_{\text{TH, AVG}} = \frac{40 - 38}{3.8\, \text{A}} = 0.526\, \text{Ω} $$

| a. 2.50Ω | b. 0.526Ω | c. 0.714Ω | d. 5.00Ω | e. Other |

Problem 8. The FFT of a voltage waveform is shown in the screen snapshot. The reference value for 0db is 1Vrms. What is the rms voltage of the component identified by the dotted circle?

$$ 20 \log_{10} \frac{V_{\text{rms}}}{1} = -13.9\, \text{db}, \quad \log_{10} \frac{V_{\text{rms}}}{1} = -\frac{13.9}{20}, \quad \frac{V_{\text{rms}}}{1} = 10^{(-13.9/20)} = 0.202 \, \text{V} $$

| a. 0.219V | b. 0.0479V | c. 0.202V | d. 0.407V | e. Other |
Problem 9. At its present operating temperature, a 5kΩ (at 25°C) thermistor has resistance 1.6kΩ. Using linear interpolation with the table below, determine the temperature of the thermistor.

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<td>0.25</td>
</tr>
<tr>
<td>70</td>
<td>0.17</td>
</tr>
</tbody>
</table>

\[
\frac{1.6 \text{ kΩ}}{5.0 \text{ kΩ}} = 0.32 = \frac{R_T}{R(25 \degree \text{C})}
\]

\[\text{Slope} = \frac{0.25 - 0.35}{60 - 50} = -0.10 \text{ units/°C} \]

\[\frac{R_T}{R} = 0.35 \quad 0.32 \quad 0.25 \]

- In here Down 0.01 units/°C, 50 degrees
- 0.03 units corresponds to up 3°C

a. 15.00°C  b. 55.0°C  c. 53.0°C  d. 16.25°C  e. Other

Problem 10. When lighted, an LED cluster has a voltage drop of 12V. A series dropping resistor will be used to limit the LED cluster current to no more than 10mA in a DBR application where the voltage ranges from 30-40Vdc. Which of the following resistors is best suited for this job? (Note – the first two colors represent the two leading digits of R, and the third color represents the power of 10)

a. brown, gray, red
b. white, black, brown
c. red, gray, red
d. brown, yellow, red
e. Other

\[\frac{40 - 12}{R} = 10 \text{ mA} \]

\[R = \frac{40 - 12}{0.010} = 2800 \text{ Ω} \]

\[10^2 = \text{red} \]
Ten multiple choice questions. One page of notes permitted. No laptop computers. **Multiple answers are given only for your convenience—there is no credit given for guessing or for simply working problems backward using the given answers.** You must show your steps that sufficiently justify your answers. Circle the correct answers. If a correct answer is not among the choices, then choose “other” if it is provided and write in your answer. Do not unstaple. Synchronized starting. Seating assignments. If you finish before 10:30, go ahead and quietly turn in your test. Otherwise, wait until 10:45 to avoid unnecessary commotion while others are still working.

---

**Buck Converter Notes**

\[
V_{\text{out}} = DV_{\text{in}}
\]

---

**Boost Converter Notes**

\[
V_{\text{out}} = \frac{V_{\text{in}}}{1 - D}
\]
Buck/Boost Converter Notes

\[
V_{out} = \frac{DV_{in}}{1 - D}
\]

Switch Closed for DT Seconds

Switch Open for (1-D)T Seconds
Problem 1. A 20Ω resistor is attached to the output terminals of our new BP3150U panel. With the operating conditions represented by the I-V curve shown, how much power (in Watts) will be delivered to the 20Ω resistor? (Hint – use a graphical solution, finding the point where the I-V curve of the solar panel intersects the I-V curve of the 20Ω resistor)

New Panel, BP3150U, April 2, 2005, 12:30pm, Bright Sun

- 2Ω Resistor
  - Intersection
  - 9V, 4.8A
  - $P = 43.2\, \text{W}$

- 20Ω Resistor
  - Intersection
  - 35V, 1.7A
  - $P = 35(1.7) = 59.5\, \text{W}$

<table>
<thead>
<tr>
<th>a. 38 to 48</th>
<th>b. 53 to 63</th>
<th>c. 97 to 107</th>
<th>d. 173 to 183</th>
<th>e. Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Ω Case</td>
<td>20Ω Case</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Problem 2. March 12\textsuperscript{th} was a sunny day in Austin. The dotted curve below shows the incident power on our solar panels, in Watts per square meter, for that day. Approximate the area under the incident power curve. Then, assuming a panel efficiency of 14\%, and use the area to estimate the \textbf{kilowatt hours of energy per square meter} that could have been produced by our panels on that day.

\begin{equation}
\text{Area} = \frac{1}{2}(800\text{W})(4\text{hrs}) = 1600 \text{ Wh/m}^2
\end{equation}

\begin{equation}
\text{Area} = \frac{1}{2}(825\text{W})(3.5\text{hrs}) = 1444 \text{ Wh/m}^2
\end{equation}

\begin{equation}
\text{Area} = (880\text{W})(4\text{hrs}) = 3520 \text{ Wh/m}^2
\end{equation}

Total Area = 1600 + 3520 + 1444 = 6564 \text{ wh/m}^2

Captured = (0.14)(6564 \text{ kwh/m}^2) = \boxed{924 \text{ kwh/m}^2}
Problem 3. Help me determine when in the spring semester to lower the solar panel tilt angles from their winter values ($44^\circ$) to their best year-round values ($30^\circ$). Make this determination using the graphs of cosine of the incidence angles for tilt angles of $44^\circ$ and $30^\circ$, respectively. The spacing between vertical lines is one hour. Use the criteria of maximizing the number of hours having cosine(incidence angle) > 0.90 to determine which of the given days is the best choice. You must justify your answer, marking on the graphs to show your logic process.

<table>
<thead>
<tr>
<th>Date</th>
<th>Tilt Angle 44°</th>
<th>Tilt Angle 30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 15</td>
<td>Better</td>
<td></td>
</tr>
<tr>
<td>Feb 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Switch here

Better
Problem 4. You are provided with a solar panel that, with its present orientation and solar incident power, can deliver maximum power at the operating point $V_{\text{panel}} = 32V$, $I_{\text{panel}} = 4A$. To deliver this maximum power to a $100\Omega$ resistor, you connect a boost converter between the solar panel and the resistor. What boost converter duty cycle $D$ will achieve this objective?

<table>
<thead>
<tr>
<th></th>
<th>a. 0.717</th>
<th>b. 0.500</th>
<th>c. 0.635</th>
<th>d. 0.680</th>
<th>e. Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>For 100Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P = 32(4) = 128W$</td>
<td>$P = 128W$ (Conservation of power)</td>
<td>$\frac{V_{\text{out}}^2}{100} = P$, $V_{\text{out}}^2 = 100P$, $V_{\text{out}} = 113.1V$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{\text{out}} = \frac{1}{1-D}$, $1-D = \frac{V_{\text{IN}}}{V_{\text{out}}}$, $D = 1 - \frac{V_{\text{IN}}}{V_{\text{out}}} = 1 - \frac{32}{113.1}$</td>
<td>$D = 0.7117$ for 100Ω case</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For 60Ω |

$\frac{V_{\text{out}}^2}{60} = P$, $V_{\text{out}}^2 = 60P$, $V_{\text{out}} = 87.6$ |

$D = 1 - \frac{V_{\text{IN}}}{V_{\text{out}}} = 1 - \frac{32}{87.6} = 1 - 0.365$ |

$D = 0.635$ for 60Ω case
Problem 5. An ideal buck converter is operating in continuous conduction at 100kHz. Diode current $I_D$ is shown below. The input voltage is 50V. What is the output voltage of the converter? (Hint – find D from the graph)

OR (100V)

\[ V_{out} = D \times V_{in} = (0.3)(50) = 15 \text{ V for } 50 \text{V case} \]

\[ V_{out} = (0.3)(100) = 30 \text{ V for } 100 \text{V case} \]
Problem 6. An ideal buck/boost converter is operating in continuous conduction at 100kHz. MOSFET current $I_D$ is shown below. The output voltage is 90V. What is the input voltage of the converter?

![Buck/Boost IDS - amps](image)

$D = 0.6$

- **90V Case**
- **60V Case**

<table>
<thead>
<tr>
<th>a. 90V</th>
<th>b. 60V</th>
<th>c. 135V</th>
<th>d. 40V</th>
<th>e. Other</th>
</tr>
</thead>
</table>

Buck/Boost

\[
V_{\text{out}} = V_{\text{in}} \left( \frac{D}{1-D} \right) 
\]

\[
V_{\text{in}} = V_{\text{out}} \left( \frac{1-D}{D} \right) = 90 \left( \frac{1-0.6}{0.6} \right) 
\]

\[
V_{\text{in}} = 90 \left( \frac{0.4}{0.6} \right) = 60 \text{ V.}
\]

\[
V_{\text{out}} = 60 \text{ V} 
\]

\[
V_{\text{in}} = 60 \left( \frac{1-0.6}{0.6} \right) = 60 \left( \frac{0.4}{0.6} \right) = 40 \text{ V}
\]
Problem 7. MOSFET voltage $V_{DS}$ for an ideal boost converter operating in continuous conduction is shown. What is the input voltage of the converter?

![Graph showing Boost VDS - volts with $V_{out} = 250$]  

**Options:**
- a. 250V
- b. 50V
- c. 62.5V
- d. 200V
- e. Other

**Solution:**

For a boost converter, the input voltage $V_{IN}$ is given by:

$$V_{IN} = V_{out}(1-D)$$

Given $V_{out} = 250$ V and $D = 0.8$, then:

$$V_{IN} = 250(1-0.8) = 250(0.2) = 50V.$$
Problem 8. MOSFET voltage $V_{DS}$ for an ideal buck/boost converter operating in continuous conduction is shown. What is the output voltage of the converter?

\[ V_{IN} + V_{Out} = 70 \]

- **D** = 0.7

| a. 21V | b. 49V | c. 70V | d. 30V | e. Other |

**Buck/Boost**

\[ V_{Out} = V_{IN} \left( \frac{D}{1-D} \right) \]

\[ V_{Out} (1-D) = V_{IN} D \]

Sub in $V_{IN} + V_{Out} = 70$ → $V_{IN} = 70 - V_{Out}$

\[ V_{Out} (1-D) = (70 - V_{Out}) D \]

\[ V_{Out} (1-D +D) = 70 D \]

\[ V_{Out} = 70 D = 49V \]

**Check.**

\[ V_{IN} = V_{Out} \left( \frac{1-D}{D} \right) = 49 \left( \frac{1-0.7}{0.7} \right) = 21V. \]

\[ V_{Out} + V_{IN} = 70V \text{ (OK)} \]
Problem 9. An ideal **buck converter** is operating in continuous conduction at 50kHz. The converter inductor current has the waveform shown below. The average value of this current is 10A, and the max and min currents are 11A and 9A. Assuming that no other changes are made, what will be the **new max inductor current** if the frequency is increased from 50kHz to 100kHz?

![Buck converter waveform](image)

<table>
<thead>
<tr>
<th>25kHz Case</th>
<th>100kHz Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 12A</td>
<td>c. 10.5A</td>
</tr>
<tr>
<td>b. 9.5A</td>
<td>d. 8A</td>
</tr>
<tr>
<td>e. Other</td>
<td></td>
</tr>
</tbody>
</table>

50 kHz → 100 kHz Case
We have half the rise & fall times,
So $I_{\text{max}} = 10.5A$, $I_{\text{min}} = 9.5A$

50 kHz → 25 kHz Case
We have twice the rise and fall times
So $I_{\text{max}} = 12A$, $I_{\text{min}} = 8A$
Problem 10. An ideal boost converter is operating in continuous conduction at 50kHz. MOSFET voltage $V_{DS}$ and inductor current $I_L$ waveforms are shown below. The average value of $I_L$ is 3A. What is the output power of the converter?

\[
P_{out} = P_{in} = V_{out} I_{out} = V_{in} I_{in}
\]

Get $V_{in}$ using $V_{out} = V_{in} \left( \frac{1}{1-D} \right)$, $V_{in} = V_{out} (1-D)$

\[
V_{in} = 40V, \quad P_{out} = P_{in} = (40)(3) = 120W
\]
Fifteen multiple choice questions. Three pages of notes permitted. No laptop computers. You must show sufficient work to justify your answers. Circle the correct answers. I intended for the correct answer to be one of the choices. If a correct answer is not among the choices, then choose “other” (if provided) and write in your answer. Do not staple. Synchronized starting. Seating assignments. No partial credit. If you finish more than 15 minutes early, go ahead and quietly turn in your test. Otherwise, wait until the end to avoid unnecessary commotion while others are still working.

**Buck Converter Notes**

\[ V_{out} = DV_{in} \]

Switch Closed for DT Seconds

Switch Open for (1-D)T Seconds

**Boost Converter Notes**

\[ V_{out} = \frac{V_{in}}{1-D} \]

Switch Closed for DT Seconds

Switch Open for (1-D)T Seconds
Buck/Boost Converter Notes

\[ V_{out} = \frac{DV_{in}}{1 - D} \]

Switch Closed for DT Seconds

Switch Open for (1-D)T Seconds
**Problem 1.** The average current through an ideal 100μH inductor operating in periodic steady-state is 10 amps. The voltage across the inductor is shown below. What is the maximum current in the inductor?

\[ \dot{I} \text{ rises at } \frac{10V}{100\mu H} = 0.1 A/s, \Delta I = +2A \]

\[ \frac{\dot{V}}{L} = \frac{\Delta I}{\Delta t}, \frac{\dot{I}}{\Delta t} = \frac{\Delta V}{L} \]

\[ \dot{I} \text{ falls at } \frac{-20V}{100\mu H} = -0.2 A/s, \Delta I = -2A \]

\[ I_{\text{MAX}} = 10 + 1 = 11A \]

\[ I_{\text{AVG}} = 10A \]

\[ I_{\text{MIN}} = 10 - 1 = 9A \]

- a. 8A
- b. 12A
- c. 9A
- d. 11A
- e. Other

**Problem 2.** The average voltage across an ideal 10μF capacitor operating in periodic steady-state is 30 volts. The current through the capacitor is shown below. What is the minimum voltage across the capacitor?

\[ \dot{V} \text{ rises at } \frac{6A}{10\mu F} = 0.6 V/\mu s, \Delta V = 9V \]

\[ \dot{I} = C \frac{\dot{V}}{t}, \frac{\dot{V}}{\Delta t} = \frac{\dot{I}}{C} \]

\[ \dot{V} \text{ falls at } \frac{-3A}{10\mu F} = -0.3 A/\mu s, \Delta V = -9V \]

\[ V_{\text{MAX}} = 30 + \frac{9}{2} = 34.5V \]

\[ V_{\text{AVG}} = 30V - \frac{9}{2} = 25.5V \]

- a. 34.5V
- b. 21.0V
- c. 25.5V
- d. 39.0V
- e. Other
**Problem 3.** An FFT of the ideal unfiltered voltage output of a unipolar PWM H-bridge inverter is shown below. The vertical axis is in dB, and the horizontal axis is in kHz. The fundamental component is 60Hz. What is the switching frequency?

For unipolar PWM converters, like the one we built, the first cluster of FFT activity corresponds to twice the switching frequency (i.e., twice the triangle wave freq). So, 20kHz implies a switching frequency of 10kHz.

- a. 60Hz
- b. 20kHz
- c. 40kHz
- d. 10kHz
- e. Other

**Problem 4.** Consider the solar condition represented by the I-V curve of one BP3150U panel. What minimum number of these panels must be connected in series to yield at least 900W?

New Panel, BP3150U, April 2, 2005, 12:30pm, Bright Sun

\[
\frac{900}{118} = 7.6
\]

Need 8 panels.

- a. 7
- b. 9
- c. 8
- d. 11
- e. Other
Problem 5. A light bulb is connected to 60Hz wall outlet through a light dimmer circuit. The light bulb voltage waveform is shown below. The FFT is taken and the magnitudes of the first few significant frequency components are plotted on a linear scale. One of the FFTs shown correctly represents the load voltage. Which one is correct?

Load Voltage

[Graph showing load voltage waveform with no DC and no even harmonics because of wave symmetry]

a. [Graph showing FFT with no DC and no 2nd harmonic]
b. [Graph showing FFT with 3rd, 5th, and 7th harmonics]
c. [Graph showing FFT with no 2nd harmonic]
d. [Graph showing FFT with no 2nd harmonic]

State reasons here. **Process of elimination. The waveform has no DC. The waveform has no even harmonics.**

Problem 6. You design a circuit in which the MOSFET is expected to have losses as high as 10W. The MOSFET temperature is to be kept below 60°C, and it will operate in a room with ambient temperature ranging from 30°C to 40°C. Which of the following heat sinks, with thermal coefficients given in degrees rise per watt, will meet the temperature requirement for the least weight? Note - assume that low thermal coefficients correspond to heavy heat sinks.

**Limiting condition, 60°C with ambient at 40°C, ΔT = 20°C.**

\[
\frac{\text{°C rise}}{\text{W}} = \frac{20\text{°C}}{10} = 2\text{°C/W} \text{ will guarantee } T \leq 60°C
\]

Thus, we should keep \(\Delta T \leq 20°C\).

- a. 0.5°C/W | b. 1.5°C/W | c. 2.5°C/W | d. 3.5°C/W | e. 6.5°C/W

Heaviest not as heavy These perform worse than 2°C/Watt

These two choices perform better than 2°C/Watt
Problem 7. The tilt angles for our panels are 22° in summer, and 44° in winter. Today, the solar panels are in their summer positions. Using the criterion of maximizing the number of hours per day that have $\cos(\beta) > 0.9$, where $\beta$ is the angle of incidence, use the mid-month $\cos(\beta)$ graphs shown below to determine which one of the days Jly. 1, Aug. 1, Sep. 1, Oct. 1, or Nov. 1 is the best choice for moving the panels to their winter tilt angles. The time between vertical bars is one hour.

Circle one

- a. Jly. 1
- b. Aug. 1
- c. Sep. 1
- d. Oct. 1
- e. Nov. 1

State your reasons here.

Switch in between Sep 15 & Oct 15
Description for problems 8, 9, and 10. Assume that a lossless buck/boost converter will operate in continuous conduction with $f = 100\text{kHz}$, $30 \leq V_{IN} \leq 50\text{V}$, $20 \leq V_{OUT} \leq 100\text{V}$, $P \leq 200\text{W}$.

**Problem 8.** Taking into account the doubling of MOSFET voltage due to overshoot, what minimum MOSFET voltage rating is suitable?
From the buck/boost converter "switch open" circuit, the MOSFET voltage is $(V_{IN} + V_{OUT})$. Our "worst case" sum of $(V_{IN} + V_{OUT})$ is $(50 + 100) = 150\text{V}$. Doubling produces a $300\text{V}$ rating. Higher ratings are OK, too.

- **a. 300V**
- **b. 200V**
- **c. 150V**
- **d. 250V**
- **e. Other**

**Problem 9.** What is the maximum average value of MOSFET current that can be expected?

Consider the junction of $L_1$, $C_1$, and the MOSFET. KCL in the average sense makes the MOSFET average current equal to $I_{IN}$. 

$$I_{IN} = \frac{P_{MAX}}{V_{IN,MIN}} = \frac{200\text{W}}{30\text{V}} = 6.67\text{A}$$

- **a. 2.50A**
- **b. 4.00A**
- **c. 6.67A**
- **d. 10.0A**
- **e. Other**

**Problem 10.** What is the maximum average value of diode current that can be expected?

Consider the junction of the diode and $C_2$.

$$I_{\text{davg}} = I_{OUT} \quad \text{because} \quad I_{C2\text{avg}} = 0.$$ 

$$I_{\text{davg, max}} = I_{OUT, max} = \frac{P_{MAX}}{V_{OUT,MIN}} = \frac{200\text{W}}{20\text{V}} = 10\text{A}$$

- **a. 6.67A**
- **b. 2.0A**
- **c. 4.0A**
- **d. 10.0A**
- **e. Other**
Filter circuit for problems 11 and 12. The filter is connected to the output of a unipolar PWM H-bridge inverter. The switching frequency is 15kHz.

\[ V_{PWM}(\omega) \quad 100\mu\text{H} \quad + \quad 10\mu\text{F} \quad V_{load}(\omega) \quad \text{To load} \]

**Problem 11.** When no load is connected, what dB reduction in the 30kHz component of \( \frac{V_{load}(\omega)}{V_{PWM}(\omega)} \) will the filter provide? (Hint – use phasor voltage divider and impedances)

\[ j\omega L = j(30000)(2\pi)(100\times10^{-6}) = j 18.85 \Omega \]

\[ j\omega C = j(30000)(2\pi)(10\times10^{-6}) = j 0.531 \Omega \]

Voltage divider, \( \frac{V_{load}}{V_{PWM}} = \frac{Z_C}{Z_L + Z_C} = \frac{-j0.531}{j 18.85 - j 0.531} = \frac{-j0.531}{j 18.32} = -0.0290 \)

Reduction in magnitude is 0.0290.

\[ 20 \log_{10}(0.0290) = -30.8 \text{ dB} \]

a. -31.2dB  b. -30.8dB  c. -23.4dB  d. -20.0dB  e. Other

**Problem 12.** In the no-load condition, how many rms amperes of 30kHz current will flow through the filter inductor if the 30kHz voltage component of \( V_{PWM}(\omega) \) is 20Vrms?

\[ \tilde{I} = \frac{\tilde{V}_{PWM}}{Z_L + Z_C}, \quad |I| = \frac{|\tilde{V}_{PWM}|}{|Z_L + Z_C|} = \frac{20 \text{ Vrms}}{18.32 \Omega} = 1.09 \text{ A (rms)} \]

a. 3.33A  b. 1.06A  c. 6.67A  d. 1.09A  e. Other
Problem 13. The current pulse for any one of the four diodes in a 60Hz, full-wave rectifier module can be roughly approximated by the triangle wave shown below. If the forward voltage on each diode is a constant 0.8V during conduction, what is the average power consumed by the entire rectifier module (i.e., all four diodes)?

\[
P_{avg} = \frac{1}{T} \int_0^T p(t) dt = \frac{1}{0.01667} \left[ \int_0^{0.002} 0.8i(t) dt + \int_0^{0.002} 0.0 \cdot dt \right]
\]

\[
= \frac{2}{16.67} (0.8) I_{avg} \quad \text{during conduction}
\]

\[
= \left( \frac{2}{16.67} \right) (0.8) (15A) = 1.440W,
\]

4 diodes yield 4(1.440) = 5.76W

a. 5.76W  b. 1.44W  c. 11.5W  d. 2.88W  e. Other

Problem 14. A lossless buck converter is operating in continuous conduction with \( f = 50kHz \), \( V_{IN} = 40V \), \( V_{OUT} = 20V \), \( P = 100W \). What is the average value of the diode current?

KCL in average sense, \( \frac{I_{IN}}{AVG} + \frac{I_{DAVG}}{AVG} = \frac{I_{LAVG}}{AVG} \)

Also, \( \frac{I_{LAVG}}{AVG} = \frac{I_{OUT}}{AVG} \)

So \( \frac{I_{DAVG}}{AVG} = \frac{I_{LAVG}}{AVG} - \frac{I_{IN}}{AVG} = \frac{I_{OUT}}{AVG} - \frac{I_{IN}}{AVG} = \frac{P}{V_{OUT}} - \frac{P}{V_{IN}} \)

\[
\frac{I_{DAVG}}{AVG} = \frac{100}{20} - \frac{100}{40} = 5A - 2.5A = 2.5A
\]

a. 5.0A  b. 2.0A  c. 3.0A  d. 4.0A  e. Other 2.5A
Problem 15. When a 12V MOSFET gate driver turns on, MOSFET voltage $V_{GS}$ increases toward its 12V asymptote according to time constant $RC_{GS}$, where $R = 1k\Omega$ is the gate driver resistance, and $C_{GS}$ is the MOSFET gate-to-source capacitance. Determine $C_{GS}$ using the turn-on portion of the $V_{GS}$ curve shown below. Hint – identify the time constant $\tau = RC_{GS}$ using the graph, and then use rising exponential form $V_{GS}(t) = 12(1 - e^{-t/\tau})$ to find $C_{GS}$.

$$(1 - e^{-1}) = 0.632. \text{ When } t = \tau, \text{ the voltage has climbed to } (12)(0.632) = 7.58V$$

$$\tau = RC_{GS}, \quad C_{GS} = \frac{\tau}{R} = \frac{11\mu\text{sec}}{1000\Omega} = 11nF$$

a. 5nF  
 b. 22nF  
 c. 20nF  
 d. 11nF  
 e. Other