A recent request from the Dean of Students Office asked that faculty consider giving multiple versions of examinations so as to assess the level of cheating. I am happy to report that after giving four different versions of the second exam I find no indications of cheating in this class. I’m proud of you! Keep it up.

When you look at the solutions below, be sure to compare you exam with the correct version.

Thanks,

Henry Zmuda
Problem 1 (20 points)

The circuit shown is to function as a constant current source. Assume that the op-amp is ideal.

a) (10 points) Determine the value of $I_L$.

b) (10 points) Determine the largest value of $R_L$ that may be used.

Answer: $I_L = 63.8 \mu A$, $R_L = 94 K \Omega$

\[
\frac{V_i}{47 K} + \frac{V_i - V_o}{R_L} = 0
\]

\[
V_o = R_L V_i \left( \frac{1}{47 K} + \frac{1}{R_L} \right)
\]

\[
= V_i \frac{R_L + 47 K}{47 K}
\]

\[
I_L = \frac{V_o}{R_L + 47 K} = \frac{V_i}{47 K}
\]

\[
V_1 = V_2 = 3 V
\]

\[
I_L = 63.8 \mu A
\]

\[
V_{o_{\text{max}}} = 9 \Rightarrow 9 = 3 \frac{R_L + 47 K}{47 K}
\]

\[
R_{L_{\text{max}}} = (3) 47 K - 47 K = 94 K \Omega
\]
PROBLEM 1 (20 points)

The circuit shown is to function as a constant current source. Assume that the op-amp is ideal.

a) (10 points) Determine the value of $I_L$.

b) (10 points) Determine the largest value of $R_L$ that may be used.

Answer: $I_L =$ \text{Version A}, $R_L =$ ______

\[
V_b = R_L V_1 \left( \frac{1}{47k} + \frac{1}{R_L} \right) = V_1 \frac{R_L + 47k}{47k}
\]

$V_{o \max} = 6$

$6 = 3 \frac{R_L + 47k}{47k} \Rightarrow R_{L\max} = 47k$
PROBLEM 1 (20 points)

The circuit shown is to function as a constant current source. Assume that the op-amp is ideal.

a) (10 points) Determine the value of $I_L$.

b) (10 points) Determine the largest value of $R_L$ that may be used.

Answer: $I_L = \text{versus A}$, $R_L =$

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See versus A

$$V_{omax} = 15 \Rightarrow R_{Lmax} = 188\,k\Omega$$
PROBLEM 1 (20 points)

The circuit shown is to function as a constant current source. Assume that the op-amp is ideal.

a) (10 points) Determine the value of $I_L$.

b) (10 points) Determine the largest value of $R_L$ that may be used.

Answer: $I_L = \frac{3V}{47k\Omega}$, $R_L = 141k\Omega$

See version A

$V_{omax} = 12V$
PROBLEM 2 (20 points)

The op-amp shown in the circuit is ideal. If the signal voltages are \( v_a = 0.2 \text{ V} \) and \( v_b = 0.5 \text{ V} \), calculate:

a) The output voltage \( v_o \) (10 points)
b) The currents \( i_a, i_b, \) and \( i_b \) (10 points)

Answers: \( v_o = 6 \text{ V} \), \( i_a = -25 \mu\text{A} \), \( i_b = 25 \mu\text{A} \), \( i_b = 0 \text{ A} \)

\[ V_1 = V_2 \]

\( I_c = 0 \) (ideal op-amp)

\[ I_a = -I_b = \frac{v_a - v_b}{12k} = \frac{0.2 - 0.5}{12k} = -25 \mu\text{A} \]

\[ V_2 = I_a \cdot 4k + v_b = -25 \mu\text{A} \cdot 4k + 0.5 = 0.4 \text{ V} \]

\[ \frac{v_a + v_1 - v_0}{k} = 0 \Rightarrow v_0 = 14k \cdot \frac{v_1}{14k} \]

\[ = 15v_1 = 15v_2 = 6 \text{ V} \]
PROBLEM 2 (20 points)

The op-amp shown in the circuit is ideal. If the signal voltages are $v_a = 0.2 \text{ V}$ and $v_b = 0.1 \text{ V}$, calculate:

a) The output voltage $v_o$ (10 points)

b) The currents $i_a$, $i_b$, and $i_b$ (10 points)

Answers: $v_o = 1.6 \sqrt{2}, \quad i_a = \frac{16.7\mu A}{2}, \quad i_b = \frac{-16.7\mu A}{2}, \quad i_b = 0$

\[ V_1 = V_2 \]

\[ \frac{V_1}{11k} + \frac{V_1 - V_b}{11k} = 0 \Rightarrow V_o = \sqrt{2} \cdot 11k \cdot \frac{12k}{1k \cdot 11k} \]

\[ V_{v_a - V_b} = k = -k \]

\[ V_o = 12V_2 = 1.6 V \]

\[ V_2 = 16.7\mu A \cdot 2k + 0.1 \]

\[ = 0.133 \]
PROBLEM 2 (20 points)

The op-amp shown in the circuit is ideal. If the signal voltages are $v_a = 0.5 \, \text{V}$ and $v_b = 0.25 \, \text{V}$, calculate:

a) The output voltage $v_o$ (10 points)

b) The currents $i_a$, $i_b$, and $i_c$ (10 points)

Answers: $v_o = \frac{2 \, \text{V}}{2 \, \text{V}}$, $i_a = \frac{4.17 \, \mu \text{A}}{4.17 \, \mu \text{A}}$, $i_b = -\frac{4.17 \, \mu \text{A}}{4.17 \, \mu \text{A}}$, $i_c = 0$

\[
\begin{align*}
\frac{V_1}{1k} + \frac{V_1 - V_o}{5k} &= 0 \Rightarrow V_o &= 5k \times V_1 \left(\frac{1}{1k} + \frac{1}{5k}\right) \\
&= 6V_1
\end{align*}
\]

\[
\begin{align*}
I_a &= \frac{V_a - V_b}{60k} = \frac{0.5 - 0.25}{60k} \\
&= 4.167 \, \mu \text{A}
\end{align*}
\]

\[
\begin{align*}
V_1 &= 4.167 \, \mu \text{A} \times 2k + 0.25 \\
&= 0.333 \, \text{V}
\end{align*}
\]
PROBLEM 2 (20 points)

The op-amp shown in the circuit is ideal. If the signal voltages are $v_a = 1.0 \text{ V}$ and $v_b = 0.5 \text{ V}$, calculate:

a) The output voltage $v_o$ (10 points)

b) The currents $i_a$, $i_b$, and $i_c$ (10 points)

Answers: $v_o = 6 \text{ V}$, $i_a = 20.8 \mu\text{A}$, $i_c = 0$, $i_b = -20.8 \mu\text{A}$
PROBLEM 3 (20 points)

The rectangular shaped current pulse is applied to a 0.4 Farad capacitor. The initial voltage on the capacitor is 7 V in the reference direction of the current.

a) (10 points) Determine the voltage across the capacitor at time \( t = 40 \) seconds.

b) (10 points) Determine the energy stored by the capacitor at time \( t = 40 \) seconds.

Remember to include units.

Answers: \( V_c(40) = 1257 \), \( \delta V_c(40) = 316010 \) J

\[
V_c(t) = \frac{1}{C} \int_0^t i(t) dt + V_c(0) = \frac{1}{0.4} \int_0^{10} (-10) dt + \frac{1}{0.4} \int_{10}^{40} 20 dt + 7
\]

\[
= 2.5 \left[ -10t \right]_{10}^{40} + 2.5 \left[ 20t \right]_{10}^{40} + 7
\]

\[
= -250 + 4000 - 500 + 7 = 1257 V
\]

\[
\delta V_c(40) = \frac{1}{2} C \delta V_c^2(40) = \frac{1}{2} (0.4)(1257)^2 = 316010
\]
PROBLEM 3 (20 points)

The rectangular shaped current pulse is applied to a 0.2 Farad capacitor. The initial voltage on the capacitor is 5 V in the reference direction of the current.

a) (10 points) Determine the voltage across the capacitor at time $t = 20$ seconds.
b) (10 points) Determine the energy stored by the capacitor at time $t = 20$ seconds.

Remember to include units.

Answers: $v_c(20) = 505 V$, $w_c(20) = 25502 J$

\[
N(20) = \frac{1}{0.2} \int_0^{10} (-10) \, dt + \frac{1}{0.2} \int_{10}^{20} 10 \, dt + 5
\]

\[
= 5(-10t) \bigg|_0^{10} + 5(20t) \bigg|_{10}^{20} + 5
\]

\[
= 5(-100) + 2000 - 100 + 5
\]

\[
= 505
\]

\[
\frac{1}{2} CV^2 = \frac{1}{2} (0.2)(505)^2
\]
PROBLEM 3 (20 points)

The rectangular shaped current pulse is applied to a 0.3 Farad capacitor. The initial voltage on the capacitor is 6 V in the reference direction of the current.

a) (10 points) Determine the voltage across the capacitor at time $t = 30$ seconds.

b) (10 points) Determine the energy stored by the capacitor at time $t = 30$ seconds.

Remember to include units.

Answers: $v_c(30) = \underline{1066 \checkmark}$, $w_c(30) = \underline{151805}$

\[ i \text{ (amps)} \]

$\begin{array}{c}
\text{20} \\
\text{-10}
\end{array}$

\[ \begin{array}{c}
10 \\
20 \\
30 \\
50
\end{array} \text{ (seconds)} \]

\[ N_c = \frac{1}{0.3} \int_{0}^{10} (-10) \, dt + \frac{1}{0.3} \int_{10}^{30} 20 \, dt + 6 \]

\[ = 1006 \text{ V} \]

\[ E = \frac{1}{2} CV^2 = \frac{1}{2} (0.3)(1006)^2 \]
PROBLEM 3 (20 points)

The rectangular shaped current pulse is applied to a 0.5 Farad capacitor. The initial voltage on the capacitor is 8 V in the reference direction of the current.

a) (10 points) Determine the voltage across the capacitor at time $t = 50$ seconds.

b) (10 points) Determine the energy stored by the capacitor at time $t = 50$ seconds.

Remember to include units.

Answers: $v_C(50) = \frac{1408}{\text{V}}$, $w_C(50) = \frac{495616}{\text{J}}$

\[ N_c(t) = \frac{1}{0.5} (-10) \cdot 10 \cdot \frac{1}{0.5} (20 \cdot 50 - 20 \cdot 10) + 8 \]

\[ = -200 + 1600 + 8 = 1408 \text{ V} \]

\[ E = \frac{1}{2} C V^2 = \frac{1}{2} (0.5) (1408)^2 \]
PROBLEM 4 (20 points)

At the time the switch is closed in the circuit shown the capacitors are charged as shown.

a) (5 points) Find $v_0(t)$ for $t \geq 0$
b) (10 points) Find $v_1(t)$ for $t \geq 0$
c) (5 points) Find the energy stored by the 15 Farad capacitor as $t \to \infty$.

Remember to include units.

Answers: $v_0(t) = \frac{25}{t/60}$, $v_1(t) = \frac{-15}{t/60}$, $w_{15F(\infty)} = 1687.5 \text{ J}$

\[ R C = 10.6 = 60 \]

\[ N_0(t) = 2.5 e^{-t/60} \]

\[ N_1(t) = 2.5 e^{-t/60} \]

\[ N_1 = -\frac{1}{C} \int_0^t N_1(t) \, dt + N_1(0) \]

\[ = -\frac{1}{15} 2.5(-60)e^{-t/60}\bigg|^t_0 \]

\[ = -15 + 10 e^{-t/60} \]
PROBLEM 4 (20 points)

At the time the switch is closed in the circuit shown the capacitors are charged as shown.

a) (5 points) Find \( v_0(t) \) for \( t \geq 0 \)

b) (10 points) Find \( v_1(t) \) for \( t \geq 0 \)

c) (5 points) Find the energy stored by the 15 Farad capacitor as \( t \to \infty \).

Remember to include units.

Answers: \( v_0(t) = 30e^{-t/60} \), \( v_1(t) = \frac{4}{60} - 32 + 12e^{-2t} \), \( W_{15F}(\infty) = 7680 J \)
PROBLEM 4 (20 points)

At the time the switch is closed in the circuit shown the capacitors are charged as shown.

a) (5 points) Find $v_0(t)$ for $t \geq 0$

b) (10 points) Find $v_1(t)$ for $t \geq 0$

c) (5 points) Find the energy stored by the 15 Farad capacitor as $t \to \infty$.

Remember to include units.

Answers: $v_0(t) = 10e^{-\frac{t}{60}}$, $v_1(t) = -34 + 4e^{-\frac{t}{60}}$, $w_{15F(\infty)} = 86.70 \text{ J}$
PROBLEM 4 (20 points)

At the time the switch is closed in the circuit shown the capacitors are charged as shown.

a) (5 points) Find \( v_0(t) \) for \( t \geq 0 \)

b) (10 points) Find \( v_1(t) \) for \( t \geq 0 \)

c) (5 points) Find the energy stored by the 15 Farad capacitor as \( t \rightarrow \infty \).

Remember to include units.

Answers: \( v_0(t) = 50e^{-t/60} \), \( v_1(t) = -30 + 20e^{-t/60} \), \( W_{15F}(\infty) = 6750 \)
PROBLEM 5 (20 points)

For the circuit shown, both switches close simultaneously at \( t = 0 \). The inductor has an initial current \( i_L(0^-) = I_o \) directed as shown. The inductor current will have the form:

\[
i_L(t) = I_f - (I_f - I_i) e^{-\frac{t}{\tau}} \]

Determine the time constant \( \tau \). (Remember to include units.)

\[\text{See Prob. 5, Test 1 for } R_{TH} = 2.5 \Omega \]

\[\tau = \frac{L}{R} = \frac{5}{2.5} = 2 \text{ see.}\]
PROBLEM 5 (20 points)

For the circuit shown, both switches close simultaneously at $t = 0$. The inductor has an initial current $i_L(0^-) = I_o$ directed as shown. The inductor current will have the form:

$$i_L(t) = I_f - (I_f - I_i)e^{-\frac{t}{\tau}}$$

Determine the time constant $\tau$. (Remember to include units.)

See Prob. 5, Test 1

for $R_{in} = 2.5 \Omega$

$$\tau = \frac{L}{R} = \frac{10}{2.5} = 4 \text{ s}.$$
PROBLEM 5 (20 points)

For the circuit shown, both switches close simultaneously at $t = 0$. The inductor has an initial current $i_L(0^-) = I_o$ directed as shown. The inductor current will have the form:

$$i_L(t) = I_f - (I_f - I_i)e^{-\frac{t}{\tau}}$$

Determine the time constant $\tau$. (Remember to include units.)

\[
\text{See Prob. 5 Test 1 for } \tau_{\text{in}} = 2.5 \text{s} \\
\tau = \frac{L}{\tau_{\text{in}}} = \frac{15}{2.5} = 6 \text{ s}
\]
PROBLEM 5 (20 points)

For the circuit shown, both switches close simultaneously at \( t = 0 \). The inductor has an initial current \( i_L(0^-) = I_0 \) directed as shown. The inductor current will have the form:

\[
    i_L(t) = I_f - (I_f - I_i) e^{-\frac{t}{\tau}}
\]

Determine the time constant \( \tau \). (Remember to include units.)

I have abided by the University Honor Code:

Signature

END OF EXAM