Write the first letter in your last name, your 6-digit identification number, and your student identification number below.

Do not open the exam until instructed to do so.

Do not use separate scratch paper. If you need more space, use the backs of the exam pages and write a note directing my attention to these pages.

You will have 100 minutes to complete the exam.

If you have extra time, check your answers.

Remember to include units with each of your answers.

Problem 1:______/ 14
Problem 2:______/ 11
Problem 3:______/ 15
Problem 4:______/ 10

Total:______/ 50

First Letter in Last Name:______________

6-Digit Identification Number:____________

Student Identification Number:____________
1. Steady-state Sinusoidal Analysis and Thevenin/Norton Equivalents (14 pts)

Use the circuit below to answer the following questions.

(a) (4 pts) Label the values assigned to all of the circuit elements in the phasor domain equivalent of the circuit shown below. Use polar coordinates for the independent sources and rectangular coordinates for the passive circuit elements.

(b) (2 pts) Find the Thevenin/Norton equivalent impedance of the circuit.

\[
\begin{align*}
Z_{eq} &= \frac{V}{I} = V = -374 + j687 \ \Omega \\
Z_{eq} &= -374 + j687 \ \Omega
\end{align*}
\]

(b) (2 pts) Find the open-circuit voltage phasor at the terminals \( a \) and \( b \).

Strategy: Solve for \( I_{sc} \) then use \( V_{oc} = I_{sc} Z_{eq} \).

\[
-2 \angle 42^\circ + \frac{V_a}{7k} + \frac{V_a - 9 \angle -12^\circ}{-j10k} = 0
\]

\[
V_a = 15.9 \angle 18.0^\circ
\]

\[
I_{sc} = \frac{V_a - 9 \angle -12^\circ}{-j10k} + 0.002V_a = 31.8 \angle 19.2^\circ \ \text{mA}
\]

\[
V_{oc} = I_{sc} Z_{eq} = 24.8 \angle 138^\circ \ \text{V}
\]
1. Steady-state Sinusoidal Analysis and Thevenin/Norton Equivalents Continued (14 pts)

c. (2 pts) Find the short-circuit current phasor at the terminals $a$ and $b$.

See previous problem for solution.

$I_{sc} = 31.8 \angle 19.2^\circ \text{ mA}$

d. (4 pts) Draw both the Thevenin and Norton equivalents of the circuit as seen from the terminals $a$ and $b$. Clearly label these terminals in the equivalent circuits.
2. Operational Amplifiers (11 pts)

Use the circuit below to answer the following questions. The op amps in the circuit are ideal. For partial credit, include algebraic expressions for each answer next to the corresponding question. Each expression may include variables listed in earlier questions.

b. (3 pts) Circle the circuit elements that have no effect on voltages labeled in the circuit diagram above. Hint: there are more than 3.

c. (1 pt) Find the voltage phasor \( V_1 \). Express your answer in polar coordinates.

\[
V_1 = -(-j\frac{6k}{3k})(5\angle0^\circ) = 10\angle90^\circ \text{ V}
\]

d. (1 pt) Find the voltage phasor \( V_2 \). Express your answer in polar coordinates.

\[
V_2 = 3k(2\angle43^\circ \text{ m}) = 6\angle43^\circ \text{ V}
\]

e. (1 pt) Find the voltage phasor \( V_3 \). Express your answer in polar coordinates.

\[
V_3 = V_2\left(\frac{8k + 3k}{3k}\right) = 22\angle43^\circ \text{ V}
\]

f. (1 pt) Find the voltage phasor \( V_4 \). Express your answer in polar coordinates.

\[
V_4 = V_3\left(\frac{-j\frac{4k}{4k - j4k}}{4k - j4k}\right) = 15.6\angle-2.00^\circ \text{ V}
\]

g. (1 pt) Find the current phasor \( I_1 \). Express your answer in polar coordinates.

\[
I_1 = \frac{V_1}{-j\frac{4k}{4k}} + \frac{V_1}{-j\frac{6k}{6k}} = 4.17\angle180^\circ \text{ mA}
\]

h. (1 pt) Find the current phasor \( I_2 \). Express your answer in polar coordinates.

\[
I_2 = 2\angle43^\circ \text{ mA}
\]

i. (1 pt) Find the current phasor \( I_3 \). Express your answer in polar coordinates.

\[
I_3 = \frac{V_3}{j3k} = 7.33\angle-47^\circ \text{ mA}
\]

j. (1 pt) Find the current phasor \( I_4 \). Express your answer in polar coordinates.

\[
I_4 = \frac{V_3}{3k + 8k} + \frac{V_3}{j3k} + \frac{V_3}{4k - j4k} = 6.60\angle-0.977^\circ \text{ mA}
\]
3. First-Order Circuits (15 pts)
Use the circuit below to answer the following questions. The switches have been in their initial position for a long time. At t=0, both switches flip simultaneously and effectively replace the short-circuit bypass with the current source. Use the following page for additional workspace.

\[\begin{array}{c}
\text{Voltage Sources: } 48 \text{ V} \\
\text{Resistance: } 5 \text{ kΩ} \\
\text{Inductor: } 2 \text{ mH} \\
\text{Capacitor: } 1.5 \mu \text{F} \\
\text{Current Source: } 2 \text{ mA} \\
\end{array}\]

\[\begin{array}{c}
\text{a. (10 pts) Fill in the table below. Remember to include units with your answers.} \\
\text{Immediately before } t = 0. & \text{Immediately after } t = 0. & \text{Long after } t = 0. \\
\text{ } & t = 0^- & t = 0^+ & t \rightarrow \infty \\
\hline
i_L = 2.4 \text{ mA} & i_L = 2.4 \text{ mA} & i_L = -1 \text{ mA} \\
v_L = 0 \text{ V} & v_L = -27.2 \text{ V} & v_L = 0 \text{ V} \\
i_C = 0 \text{ A} & i_C = 4.18 \text{ mA} & i_C = 0 \text{ A} \\
v_C = -38.4 \text{ V} & v_C = -38.4 \text{ V} & v_C = 16 \text{ V} \\
\end{array}\]

\[\begin{array}{c}
\text{b. (1 pt) What is the time constant for the portion of the circuit that contains the inductor?} \\
\tau_L = \frac{L}{R} = \frac{2 \text{ mH}}{8 \text{ kΩ}} = 250 \text{ ns} \\
\end{array}\]

\[\begin{array}{c}
\text{c. (1 pt) What is the time constant for the portion of the circuit that contains the capacitor?} \\
\tau_C = R\!C = 13 \text{ kΩ} \cdot 1.5 \mu \text{F} = 19.5 \text{ ms} \\
\end{array}\]

\[\begin{array}{c}
\text{d. (1 pt) Write the expression for the current through the capacitor for } t > 0. \\
i_C(t) = 4.18e^{-t/19.5 \mu \text{s}} \text{ mA} \\
\end{array}\]

\[\begin{array}{c}
\text{e. (1 pt) Write the expression for the voltage across the inductor for } t > 0. \\
v_L(t) = -27.2e^{-t/250 \text{ ns}} \text{ V} \\
\end{array}\]

\[\begin{array}{c}
\text{f. (1 pt) Write the expression for the energy stored in the capacitor for } t \geq 0. \\
w_C(t) = \frac{1}{2}Cv_C(t)^2 = 0.75\mu \left(16 - 54.4e^{-t/19.5 \mu \text{s}}\right)^2 \text{ J} \\
\end{array}\]
3. First-Order Circuits Workspace (15 pts)
Use this page as workspace. The circuit is repeated below for convenience.
4. Linear Transformers (10 pts)

a. (1 pt) Solve for the transformer’s coefficient of coupling.

\[ k = \frac{M}{\sqrt{L_1 L_2}} = \frac{j \omega M}{\sqrt{(j \omega L_1)(j \omega L_2)}} = \frac{3k}{\sqrt{7.2k \cdot 2.3k}} = 0.737 \]

b. (1 pt) How much impedance is reflected from the secondary side (right) to the primary side (left) of the transformer?

\[ Z_{R1} = \frac{(3k)^2}{6k - j5k + j2.3k + j2.3k} = 1490 + j99.6 \ \Omega \]

c. (1 pt) How much impedance is reflected from the primary side (left) to the secondary side (right) of the transformer?

\[ Z_{R2} = \frac{(3k)^2}{6k + 6k + j7.2k} = 551 - j331 \ \Omega \]

d. (1 pt) What is the equivalent impedance at the primary terminals of the transformer?

\[ Z_{ab} = 6k + j7.2k + Z_{R1} = 7.49 + j7.30 \ \text{k} \Omega \]

e. (1 pt) What is the equivalent impedance at the secondary terminals of the transformer?

\[ Z_{cd} = 6k + j2.3k + Z_{R2} = 6.55 + j1.97 \ \text{k} \Omega \]

f. (1 pt) Solve for the current phasor \( I_1 \).

\[ I_1 = \frac{5 \angle 23^\circ}{6k + Z_{ab}} = 0.326 \angle -5.42^\circ \ \text{mA} \]

g. (2 pts) Solve for the current phasor \( I_2 \).

\[ I_2 = \frac{j3k}{Z_{22}} I_1 = -0.163 \angle 88.4^\circ \ \text{mA} \]

h. (1 pt) Solve for the voltage across the transformer on the primary side.

\[ V_{ab} = I_1 Z_{ab} = 3.41 \angle 38.8^\circ \ \text{V} \]

i. (1 pt) Solve for the voltage across the transformer on the secondary side.

\[ V_{cd} = I_2(-j5k + j2.3k) = -0.440 \angle -1.60^\circ \ \text{V} \]