Problem 1 – Short Answers (8 points)

If you make any assumption that you think might be unclear to the grader, mark that question with an asterisk (*) in the right-hand margin and explain your assumption on the back of the page. Note that some of the non-true/false questions may have more than one correct answer.

[1 pt.] (a) T √ F  The peak value of the AC voltage at the wall outlets in your lab in Cory Hall is 170 volts.

[1 pt.] (b) T __ F √ An ideal discharged capacitor is a nonlinear component.

[1 pt.] (c) T __ F X A phasor voltage \( V \) is a function of time.

[1 pt.] (d) Name a component or device that turns a steady current into a steady voltage.

Answer: **Resistor**

[1 pt.] (e) Name a two-terminal component that can never pass a steady current with a steady voltage applied.

Answer: **Capacitor**

[2 pts.] (f) Name two components or devices that can increase the amplitude of an AC voltage.

Answer: **Transformers, amplifiers, MOSFET**

[1 pt.] (g) Name a component or device that can use a steady voltage to control a steady current.

Answer: **MOSFET: voltage-controlled current source**
Problem 2 – Phasors (13 points)

[6 pts.] (a) Determine the Thévenin equivalent of the following circuit using phasors:

\[
\begin{align*}
V_0 \cos \omega t &\quad \text{(a)} \\
A: 1 \times 10^{-8} \text{F} &\quad \text{B: } 3 \times 10^{-8} \text{F} \\
100 &\quad \text{R} \quad \text{v}_1(t)
\end{align*}
\]

where \( \omega = 10^6 \text{ rad/sec} \)

\[
\begin{align*}
A: &\quad C = 1 \times 10^{-8} \text{F} \quad WRC = 1 \\
B: &\quad C = 3 \times 10^{-8} \text{F} \quad WRC = 3
\end{align*}
\]

\[
\begin{align*}
\text{A: } &\quad V_{TH} = \frac{1 + j}{2} V_0 \\
\text{Z}_{TH} &\quad = \frac{100 - 100j}{2j}
\end{align*}
\]

(Express answers in simplest rectangular form \( A + Bj \).)

\[
\begin{align*}
\text{B: } &\quad V_{TH} = \frac{9 + 3j}{10} V_0 \\
\text{Z}_{TH} &\quad = \frac{100 - 300j}{10} = 10 - 30j
\end{align*}
\]

[3 pts.] (b) What is the time average power in the 100 ohm resistor?

\[
\begin{align*}
\text{A: } &\quad P_{ave} = \frac{1}{2} \text{Re} \left[ V_1 V_1^* \right] = \frac{1}{2} \text{Re} \left[ \frac{V_{TH}^*}{R} \right] \\
&\quad = \frac{4}{2R} \left( \frac{1}{2} V_{TH} \right)^2 = \frac{V_0^2}{400}
\end{align*}
\]

\[
\begin{align*}
\text{B: } &\quad \left( \frac{3 \sqrt{10}}{10} \right)^2 = \frac{9 V_0^2}{2000}
\end{align*}
\]

[4 pts.] (c) The output voltage is of the form \( v_1(t) = V_1 \cos (\omega t + \phi) \). Determine \( V_1 \) and \( \phi \).

\[
\begin{align*}
\text{A: } &\quad |V_{TH}| = \frac{\sqrt{2}}{2} V_0 \\
\phi &\quad = \arctan \frac{1}{\sqrt{2} WRC}
\end{align*}
\]

(Express answers in simplest rectangular form \( A + Bj \).)

\[
\begin{align*}
\text{B: } &\quad |V_{TH}| = \frac{3 \sqrt{10}}{10} V_0 \\
\phi &\quad = \arctan \frac{1}{\sqrt{3} WRC}
\end{align*}
\]
Problem 3 – Phasors (18 points)

\[ V_{\text{in}}(t) = \cos(\omega t) \] and \( L = 2 \times 10^{-4} \, \text{H}, R = 200\Omega \)

[2 pts.] (a) What is \( |V_{\text{out}}(t)| \) for \( \omega = 0 \)?

Since the circuit is open circuit, the output voltage is zero.

[2 pts.] (b) What is \( |V_{\text{out}}(t)| \) for \( \omega \to \infty \)?

\( |V_{\text{out}}(t)| = \sqrt{2} \)

[8 pts.] (c) What is \( |V_{\text{out}}(t)| \) for \( \omega = 10^6 \)?

\[
\frac{200 \cdot 200 j}{200 + 200 j} = \frac{200 j}{1 + j} = \frac{200 j (1 - j)}{2} = 100 + 100 j = \sqrt{2} \cdot \sqrt{2} \]

[6 pts.] (d) Let \( G(\omega) = \frac{V_{\text{out}}}{V_{\text{in}}} \). Sketch the general behavior of \( |G(\omega)| \) vs. \( \omega \) on axes provided. (Note linear scales.)

\( |G(\omega)| \)

\( \omega \) (rad/sec)

10^6  2 \times 10^6  3 \times 10^6  4 \times 10^6  5 \times 10^6

Check: \( G(\omega = 5 \times 10^6) \approx 1 \)
Problem 4 – Short Answers (15 points)

A circuit made with three ideal op amps is shown below:

version A

version B

[6 pts.] (a) Of what three basic op-amp circuits is this circuit composed? (Circle them individually.)

Sub-circuit with output $v_a$ is an inverting amplifier

Sub-circuit with output $v_b$ is non-inverting amplifier

Sub-circuit with output $v_o$ is inverting summing amplifier

[9 pts.] (b) Find the voltages $v_a$, $v_b$, and $v_o$ in terms of $v_1$ and $v_2$. Make your methods clear to the grader.

\[
\begin{align*}
v_a &= \frac{-3v_1}{2k} \quad \frac{V_1}{2k} = \frac{-v_a}{6k} \quad v_a = -3v_1 \\
v_b &= \frac{3v_2}{12} \quad \frac{V_b}{12} = -v_2 \quad v_b = 3v_1 \\
v_o &= \frac{6v_1 - 2v_2}{10k} \quad \frac{V_o}{10k} = \frac{v_a}{5k} + \frac{v_b}{15k} \\
&= -2v_a - \frac{2}{3}v_b \\
&= 6v_1 - 2v_2
\end{align*}
\]
Problem 5 (20 points)

An ideal op amp is shown with its input sources and its power supplies.

version A

version B

Given \( v_2 = \begin{cases} -2v & \text{for } v_1 \leq -3v \\ v_2 & \text{for } v_1 > -3v \end{cases} \) plot \( V_0 \) vs. \( V_1 \) for \(-3 \leq v_1 \leq 3\) volts.
Problem 6 (10 points)

A DC circuit that was connected up one week ago is shown attached to a Very Strange Component whose I-V characteristic is shown. Find I and V for this circuit. Make your method clear for the grader and state any assumptions you make.

**version A**

\[ I_o = 0.5 \text{ mA} \]
\[ R = 10k\Omega \]
\[ C = 300\mu\text{F} \]

Using KCL:
\[ I_o - \frac{V}{R} - I = 0 \]
\[ I = \frac{I_o - V}{R} \]

**version B**

\[ I_o = 1 \text{ mA} \]
\[ R = 3k\Omega \]
\[ C = 100\mu\text{F} \]

Using KCL:
\[ I_o - \frac{V}{R} - I = 0 \]
\[ I = \frac{I_o - V}{R} \]
Problem 7 (16 points)

\[ i_D = \frac{10V - V_{DS}}{3k\Omega} \]

\[ V_{GS} = 2V - i_D (2k\Omega) \]

\[ V_{DS} \approx 9.46 \text{ Volts} \]

[3 pts.] (a) What is \( i_D \) as a function of \( V_{DS} \)?

\[ i_D = \frac{10V - V_{DS}}{3k\Omega} \]

[3 pts.] (b) What is \( V_{GS} \) as a function of \( i_D \)?

\[ V_{GS} = 2V - i_D (2k\Omega) \]

[10 pts.] (c) What is \( V_{DS} \) at quiescent point?

(Hint: \( i_D = K(V_{GS} - V_{t0})^2 \). If needed, you may use \( \sqrt{2} = 1.4, \sqrt{3} = 1.7 \).)

\[ i_D = K(V_{GS} - V_{t0})^2 \]

Constitute \( i_D = \frac{2V-V_{DS}}{2k\Omega} \) from (b).

\[ \frac{2V-V_{DS}}{2k\Omega} = K(V_{GS}-1)^2 \]

\[ 2V-V_{DS} = V_{GS}^2 - 2V_{GS} + 1 \]

\[ V_{GS}^2 - V_{GS} - 1 = 0 \]

\[ V_{GS} = \frac{1 \pm \sqrt{1+4}}{2} = \frac{1 \pm \sqrt{5}}{2} \]

\[ V_{t0} = 1V \text{ (threshold voltage)} \]

\[ K = \frac{500\mu A}{V^2} \]