Answer all questions and show your work. Clearly indicate your answers. You may use your calculator, but all work must be shown for full credit. You may use an 8.5 x 11" sheet of formulas. No books, or notes; turn your cell phone and PDA off during the exam. Include units in your answers where appropriate.

1. Circle T (true) or F (false) for each of these statements. (2 pts. each)

   (a). T F A mesh is a loop with no other loops inside it.
   (b). T F A voltage source with parallel R transforms to a current source with R in series.
   (c). T F The Thévenin equivalent voltage $V_{TH}$ is the short-circuit voltage.
   (d). T F A buffer amplifier, or voltage follower, has unity gain ($V_o/V_i = 1$).
   (e). T F Saturated op amp output voltage $|V_o| > V_{CC}$, power supply voltage.

2. (35 pts) Given the resistive circuit below:

2(a). Find the open-circuit voltage $V_{TH}$ across terminals a and b of the Thévenin equivalent circuit. You may use whatever method you prefer. Show all your work. 2(a) continues on the next page.
2(a). (cont.) Ohm's Law: \( V_{TH} = 10k\Omega \cdot i_2 \), \( i_2 = \frac{V_{TH}}{10k\Omega} \)

KVL: \(-10 + 5k\Omega \cdot i_1 + 15k\Omega \cdot i_2 = 0\)

Plug into KCL: \( -\frac{10}{5k} + \frac{15kV_{TH}}{50\times10^6} - 1mA + V_{TH}/10k = 0 \)

\( V_{TH} = \frac{3\times10^{-3}}{4\times10^{-4}} = 7.5V \)

Mesh analysis:

KVL: \(-10 + 5k\Omega \cdot i_a + 15k\Omega \cdot i_b = 0\)

\( i_a = \frac{i + 1mA + i_b}{20k\Omega} \)

\( 20k\Omega \cdot i_a = 10 - 15k\Omega \cdot (1mA) = 10 - 15 = -5V \)

\( i_a = -0.25mA, i_b = (-0.25 + 1)mA = 0.75mA \)

\( V_{TH} = 10k\Omega \cdot i_b = 10,000(7.5 \times 10^{-3}) + 7.5V \)

2(b). Find the Thévenin resistance \( R_{TH} \) of the Thévenin equivalent circuit. You may use either the short-circuit current \( (i_{sc}) \) method or the equivalent resistance method.

Equivalent Resistance: Deactivate sources: voltage \( \rightarrow \) short current \( \rightarrow \) open

Short-Circuit Current \( i_{sc} \):

\( V_{ab} = 0 \) because of short circuit from a to b

\( V_{ab} = 0 \) so \( i_2 = \frac{V_{ab}}{10k\Omega} = 0 \)

KCL: \(-i_1 - 1mA + i_0 = 0\)

KVL: \(-10 + 5k\Omega \cdot i_a + 5k\Omega \cdot i_0 + V_{ab} = 0\)

Plug in \( i_1 + i_0 \) eqns

\( i_{sc} = \frac{15V}{10k\Omega} = 1.5mA \)

\( R_{TH} = \frac{V_{TH}}{i_{sc}} = \frac{7.5V}{1.5mA} = 5k\Omega \)
2(c). Draw your Thévenin equivalent circuit below. Label all circuit elements and terminals.

![Thévenin Equivalent Circuit](image1)

\[ V_{TH} = 7.5 \text{ V} \]

2(d). Draw the Norton equivalent circuit of your Thévenin equivalent circuit. Label all circuit elements and terminals.

\[ I_N = \text{source transform} \quad \Delta \quad V_{TH} = \frac{V_{TH}}{R_{TH}} = \frac{7.5 \text{ V}}{5 \text{ k} \Omega} \]

\[ I_N = 1.5 \text{ mA} \]

\[ R_N = R_{TH} = 5 \text{ k} \Omega \]

2(e). Using your Thévenin equivalent circuit found above, assume a load resistance \( R_L \) is connected across the terminals a and b. What value of \( R_L \) provides the maximum power transferred to the load \( R_L \)? You don’t have to prove what value will provide maximum power, just use the appropriate value of \( R_L \) that does transfer maximum power.

\[ R_L = R_{TH} = 5 \text{ k} \Omega \]

2(f). Using the value of \( R_L \) obtained above, find the power \( P_L \) transferred to (or absorbed by) the load \( R_L \).

\[ P_L = \frac{V_{TH}^2}{4R_{TH}} = \frac{(7.5)^2}{4 \times 5 \text{ k} \Omega} = \frac{56.25}{20 \text{ k} \Omega} = .01125 \text{ W} = 11.25 \text{ mW} \]
3. (25 pts total) Using source transformation, find the voltage $V_1$ across the 20 kΩ resistor in the circuit given below. Draw a small sketch of each source transformation that you make. Show all your work.

\[ V_1 = 5 \left( \frac{20k\Omega}{25k\Omega} \right) = 5 \left( \frac{4}{5} \right) = 4V \]
4. (30 pts total)  Consider the operational amplifier circuit given below.

4(a). What are the two rules or equations that are true for an ideal op amp?

Rule 1: \( i_n = i_p = 0 \)

Rule 2: \( V_n = V_p \)

4(b). Find an equation for the output voltage \( V_o \) in terms of the input voltage \( V_s \). Show all equations used (i.e. use Ohm’s Law, KVL and KCL).

\[ \begin{align*}
\text{KCL: } & -i_s + i_n + i_f = 0; \quad i_n = 0 \text{ so } -i_s + i_f = 0 \\
\text{Note that } & V_s = V_p + V_p = V_n, \text{ so } V_n = V_s \\
\text{KVL: } & 2k \cdot i_s + V_n = 0; \quad i_s = -\frac{V_n}{2000} = -\frac{V_s}{2000} \\
\text{KVL: } & -V_n + 8k \cdot i_f + V_o = 0; \quad i_f = \frac{V_n - V_o}{8000} = \frac{V_s - V_o}{8000} \\
\text{Plug in values for } & i_s + i_f \text{ into KCL:} \\
-(\frac{-V_s}{2000}) + \frac{V_s - V_o}{8000} = 0; \quad \frac{V_s}{2000} + \frac{V_s}{8000} = \frac{V_o}{8000} \\
V_s(\frac{1}{2000} + \frac{1}{8000}) = V_o/8000; \quad V_o = V_s(4 + 1) = 5V_s
\end{align*} \]

\[ V_o = 5V_s \]

4(c). What type of op amp circuit is this?

Op Amp Circuit = Non-inverting op amp

4(d). What is the output \( V_o \) if the input \( V_s = 1 \text{ V} \)?

\[ V_o = 5 \text{ V} \]

4(e). What is the output \( V_o \) if the input \( V_s = 4 \text{ V} \)?

\[ V_o = 10 \text{ V} \]

4(f). What is the output \( V_o \) if the input \( V_s = 1 \text{ V} \)?

\[ V_o = 5 \text{ V} \]

\[ 5 \times 4 = 20 \text{ but } 20 > 10 \text{ V power supply; } \]

\[ |V_o| \leq V_{cc}, \text{ so } V_o = 10 \text{ V} \]