Part B (75 Points)

1. (12 Pts) ________
2. (14 Pts) ________
3. (10 Pts) ________
4. (8 Pts) ________
5. (11 Pts) ________
6. (6 Pts) ________
7. (14 Pts) ________

Total __________________

For partial credit annotate plots, even when the problem does not ask you to do this. It can help the grader understand where mistakes were made and contribute to partial credit.

Show all of your work and write/draw neatly so the grader can figure out what you did.

At least skim through the entire quiz before you begin and then start with the problems you know best.

Note that some questions involve using things you have learned in new ways and some involve some minor new information. Focusing on what you know will make the problems easier to solve.

The proctor will only answer clarification questions where wording is unclear or where there may be errors/typos. No other questions will be responded to.
Part B (75 Points)

Problem 1 (12 Points) – System Design: Devices and Functions
This problem helps to define the context for the remaining questions. Identify the functions of 6 devices by circling the cells in the bottom array and numbering them from 2 to 7. An example is shown for the HIGH-PASS Filter in column 2, row 1 as is its function ‘Block a Range of Frequencies but Pass Others’ and it is numbered 1. Be sure the number is easy to read.

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>DC VOLTAGE SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 INVERTING AMPLIFIER</td>
<td>6 CAPACITOR</td>
</tr>
<tr>
<td>5 BAND-PASS FILTER</td>
<td>7 LOW-PASS FILTER</td>
</tr>
<tr>
<td>3 PHOTOTRANSISTOR</td>
<td>4 TRANSFORMER</td>
</tr>
<tr>
<td>1 HIGH-PASS FILTER</td>
<td>5 OR GATE</td>
</tr>
<tr>
<td>6 NON-INVERTING AMPLIFIER</td>
<td>6 555 TIMER</td>
</tr>
<tr>
<td>2 RESISTOR</td>
<td>7 AND GATE</td>
</tr>
<tr>
<td>3 BAND Reject Filter</td>
<td>4 NOR GATE</td>
</tr>
<tr>
<td>4 TRANSISTOR SWITCH</td>
<td>5 LED</td>
</tr>
<tr>
<td>3 PHOTODIODE</td>
<td>6 PHOTOCELL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function</th>
<th>Make Voltage Smaller</th>
<th>Match Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convert AC Voltages to DC Voltages</td>
<td>Store Energy</td>
<td>Block DC with a Single Component</td>
</tr>
<tr>
<td>ON-OFF Switch</td>
<td>Deciding a Process is True if Any Monitored Conditions are False</td>
<td>Block a Range of Frequencies but Pass Others</td>
</tr>
<tr>
<td>Convert Light Energy into Electrical Energy</td>
<td>Change True to False or False to True</td>
<td>Block High Frequencies with a Single Component</td>
</tr>
<tr>
<td>Increase Voltage, Power and Current while keeping Polarities the Same</td>
<td>Decreasing a Process is True if Any Monitored Conditions are False</td>
<td>Deciding a Process is True if Any Monitored Conditions are True</td>
</tr>
<tr>
<td>Increase Current Without an External Power Supply</td>
<td>Measure Voltage vs Time</td>
<td>Convert Electrical Energy into Heat</td>
</tr>
<tr>
<td>Produce an Output Voltage at least Thousands of Time Larger than the Difference between Two Inputs</td>
<td>Produce a Sequence of Square Voltage Pulses</td>
<td>Make the Output Voltage Larger than the Input Voltage</td>
</tr>
<tr>
<td>Produce a Single Square Pulse</td>
<td>Convert Electrical Energy into Light</td>
<td>Convert Light Energy into Electrical Energy</td>
</tr>
</tbody>
</table>
Problem 2 (14 Points) – Logic Gates
This problem addresses building logic devices from two basic types of devices and the application of logic gates in cryptography.

a. (2 Pts) What kind of a logic gate is this and what is its truth table? Name the device and fill out the table below.

```
<table>
<thead>
<tr>
<th>Input A</th>
<th>Input B</th>
<th>Output Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
```

N OR

b. (2 Pts) What kind of a logic gate is this and what is its truth table? Name the device and fill out the table below.

```
<table>
<thead>
<tr>
<th>Input A</th>
<th>Input B</th>
<th>Output Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
```

N AND

c. (2 Pts) Assume that the two inputs for both of the gates above are tied together to create a single input device, as shown. Circle the symbol for the device or devices that will function like a NOT gate. Hint: Use the truth tables above.

Both function as NOT gate

\[ \overline{A + \overline{A}} = \overline{A} \]
\[ \overline{A \cdot \overline{A}} = \overline{A} \]

d. (2 Pts) Assume that gates from part b are combined as shown. Name the device that matches the functionality of this combination and fill out its truth table below. Note that, unlike parts a and b, you are asked to find the values at the intermediate points, not just the inputs and output.

```
<table>
<thead>
<tr>
<th>Input A</th>
<th>Input B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Output Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
```

\[ C = A \cdot B \]
\[ D = A \cdot \overline{C} \]
\[ E = C \cdot \overline{B} \]
\[ Q = D \cdot E \]
e. (2 Pts) One more configuration using gates from part a. Name the device this combination produces and fill out its truth table. Again, you must find the values at intermediate points, not just the inputs and output.

<table>
<thead>
<tr>
<th>Input A</th>
<th>Input B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Output Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
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<td>0</td>
<td>1</td>
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<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ C = A + B \quad D = A + C \quad E = B + C \quad F = D + E \quad Q = \overline{F} \]

f. (4 Pts) XOR Gate Cryptography – Two sets of XOR gates are used to encrypt an ASCII letter. The 8 bit code is \([C_1 \ C_2 \ C_3 \ C_4 \ C_5 \ C_6 \ C_7 \ C_8] = [00011000] \) and the 8 bit key is \([K_1 \ K_2 \ K_3 \ K_4 \ K_5 \ K_6 \ K_7 \ K_8] = [01010111] \). Given that a coded word is known except for two missing letters \(B \ 0 \ 0 \ LE\) and that the missing letters are the same, find the letter. That is, input the 8 bits of the coded letter and the key one-by-one in the eight XOR gates to decode the letter into \([L_1 \ L_2 \ L_3 \ L_4 \ L_5 \ L_6 \ L_7 \ L_8]\). Then use the ASCII table found on page 7 to identify the letter.
Problem 3 (10 Points) – Operational Amplifiers

The amplifier circuit below is configured with an ideal generic op-amp and resistors $R_{in} = 11\, k\Omega$ and $R_f = 22\, k\Omega$.

a. (2 Pts) Identify which type of amplifier it is and the magnitude and sign of its gain $G = \frac{V_{out}}{V_{in}}$.

\[ G = \frac{-R_f}{R_{in}} = \frac{-22 \, k\Omega}{11 \, k\Omega} = -2 \]

Inverting amplifier.

b. (3 Pts) If the op-amp is powered with $\pm 15$V power supplies, which of the following input voltages listed below will the amplifier be able to amplify without distortion? Circle all correct answers. Hint: Since the op-amp is ideal, assume its output voltage can swing to $\pm 15$V.

- a. 2.2V
- b. 3.9V
- c. 4.4V
- d. 5.8V
- e. 7.3V
- f. 8.7V
- g. 9.2V

Vin $\times (-2) < \pm 15$

Vout

\[ V_{in} \times (-2) < \pm 15 \]

\[ V_{in} \times (-2) < \pm 13.5 \]

c. (3 Pts) Now assume the circuit has been built with the OP27G op-amp found in our parts kit. From the information provided on pages 4-6, find the maximum possible output voltage, when the op-amp is powered with $\pm 15$V power supplies, and then circle the voltages below that can be amplified without distortion.

- a. 2.2V
- b. 3.9V
- c. 4.4V
- d. 5.8V
- e. 7.3V
- f. 8.7V
- g. 9.2V

\[ V_{in} \times (-2) < \pm 13.5 \]

\[ V_{in} \times (-2) < \pm 13.5 \]

d. (2 Pts) In the graph below draw Vout for the op-amp circuit shown above. The input Vin is a triangular wave with an amplitude of 1V and time period of 4 seconds. Sketch and label Vout on the same graph clearly.

[Graph of triangular wave with amplitude 2V and frequency $f = \frac{1}{T} = 0.25$]
Problem 4 (8 Points) – Complex Impedance

A series RC circuit is shown above with $R = 159\Omega$ and $C = 10\mu F \ (10^{-5} F)$.

a. (2 Pts) Symbolically (no numbers), the impedance of the resistor and the impedance of the capacitor are

$$Z_R = R$$

$$Z_C = \frac{1}{j\omega C}$$

b. (1 Pts) At what frequency is the impedance of the resistor twice that of the capacitor, $|Z_R|=2|Z_C|$?

$$12.1 = 79.5 = \frac{1}{2\pi f \ 10^{-5}}$$

$$f = \frac{200}{\text{Hz}} \quad \text{(or } \omega = 400\pi)$$

c. (2 Pts) For your part b answer, what is the magnitude of the total impedance $|Z|=|Z_R+Z_C|$?

$$|Z_{\text{total}}| = 159 - j79.5$$

$$|Z_{\text{total}}| = \sqrt{(159^2 + 79.5^2)} = 177.7$$

d. (2 Pts) For your part b answer, what is the angle of the total impedance, $\theta_z$?

$$\angle Z_{\text{total}} = \tan^{-1} \left( \frac{-79.5}{159} \right) = -0.464 \text{ rad}$$

or $-26.5^\circ$

e. (1 Pt) Write the total impedance in phasor (polar) form.

$$Z_{\text{total}} = 177.7 e^{-j0.464} \quad \text{or} \quad 177.7 e^{-j26.5^\circ}$$
Problem 5 (11 Points) – Transformers

Shown at the right is a transformer circuit, similar to the one you built by winding magnet wires on a toroidal ferrite core. Unlike the one you made, this transformer does not have the same number of turns on the primary and the secondary. Rather it has 45 turns on the primary and 5 turns on the secondary.

a. (2 Pts) What is the ratio of $\frac{V_{out}}{V_{in}}$?

\[ \frac{V_{out}}{V_{in}} = \frac{1}{9} = \frac{N_2}{N_1} \]

b. (2 Pts) What is the ratio of $\frac{I_{out}}{I_{in}}$?

\[ \frac{I_{out}}{I_{in}} = \frac{9}{1} = 9 = \frac{N_1}{N_2} \]

c. (3 Pts) What is the input impedance of the loaded transformer $Z_{in}$? That is, what is $\frac{V_{in}}{I_{in}}$?

\[ Z_{in} = \frac{RL}{N_2^2} = \frac{25}{(9)^2} = 2.025 \Omega \]

d. (1 Pt) If the current source, Isource has an amplitude of 1mA (0.001A), what is the amplitude of Vin?

\[ V_{in} = I_{source} Z_{in} \]

\[ V_{in} = (0.001)(2.025) = 2.025 \text{ V} \]

e. (3 Pts) If RL actually represents the input impedance of a second transformer, as shown below, determine the number of windings, N, on the secondary side of the second transformer. The first transformer is the same as above and the second transformer has 10 windings on the primary side.

\[ Z_{in} = \frac{2.5}{(\frac{N_4}{N_3})^2} \Rightarrow \frac{N_4}{N_3} = 2 \]

\[ N_4 = 20 \]
**Problem 6 (6 Points) – Photocell Voltage Divider**

A photocell, like the one we have used in class, is part of a simple voltage divider, as shown in the figure. The divider is connected to a 5V DC power supply. The lower resistor, $R_1 = 5k\Omega$, while the photocell (the upper resistor) varies as shown in the following table (LUX are units of illumination)

<table>
<thead>
<tr>
<th>LUX</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100k</td>
</tr>
<tr>
<td>10</td>
<td>20k</td>
</tr>
<tr>
<td>100</td>
<td>7k</td>
</tr>
<tr>
<td>1000</td>
<td>0.9k</td>
</tr>
</tbody>
</table>

a. (2 Pts) Determine $V_{out}$ when the illumination is 10 LUX.

\[ V_{out} = \frac{R_1}{R_1 + R_{photo}} \cdot 5V = \frac{5k}{5k + 20k} \cdot 5V = 1V \]

b. (2 Pts) If the output voltage is 2.5V, based on the table, what is the range of LUX values?

\[ V_{out} = \frac{R_1}{R_1 + R_{photo}} \cdot 5V \Rightarrow 2.5 = \frac{5k}{5k + R_{photo}} \cdot 5 \]

\[ \Rightarrow R_{photo} = 5k \Rightarrow 100 \leq \text{LUX} \leq 1000 \]

c. (2 Pts) If two photocells were used in parallel and had the same illumination value as part a, would the output voltage increase or decrease. Justify your answer descriptively or using equations.

Resistors in parallel have a smaller effective resistance. If $R_{photo}$ decreases, $V_{out}$ increases, from the voltage divider equation
Problem 7 (14 Points) – Multi-stage circuits

The circuit shown above is a multi-stage circuit. Each stage is a circuit we have studied over the semester. Also, for the given design, each stage may be analyzed individually. In other words, the circuit properties of one stage will not affect the circuit properties of the other stages.

Stage 1 is the familiar voltage divider circuit.

a. (2 Pts) Determine the ratio of $V_{out1}/V_{in}$ for Stage 1 of the circuit.

$$V_{out1} = \frac{R_2}{R_1+R_2} \cdot V_{in} \Rightarrow \frac{V_{out1}}{V_{in}} = \frac{4k}{1k+4k} = 0.8$$

Stage 2 is an amplifier circuit, from one of our more recent laboratories.

b. (2 Pts) What type of amplifier configuration is shown in Stage 2?

Non-inverting amplifier

c. (2 Pts) For your above answer, determine the gain of the amplifier, including the sign.

$$\text{Gain} = (1 + \frac{R_4}{R_3}) = (1 + \frac{3k}{1k}) = 1$$

Stage 3 is an RC filter with the output measured across the resistor.

d. (2 Pts) Is the filter a lowpass filter or a highpass filter?

Highpass filter
e. (2 Pts) The input voltage, \( V_{in} \), is shown above. Determine the equation of the input voltage, using the expression \( V_n(t) = V_o \sin(\omega t + \theta) \).

Amplitude = 0.5 V or 500 mV

4 periods \( \Rightarrow 10 \text{ ms} \Rightarrow T = 2.5 \text{ ms} \) \( \Rightarrow f = \frac{1}{T} = 400 \text{ Hz} \)

\[ V_n(t) = 0.5 \sin(800\pi t) \]

f. (1 Pt) For this input voltage and using your part a result, what is the amplitude of the voltage, \( V_{out1} \)?

\[ V_{out1} = 0.8(V_n) = (0.8)(0.5) = 0.4 \text{ V or 400 mV} \]

g. (1 Pt) For this input voltage and using your part f and part e results, what is the amplitude of the voltage, \( V_{out2} \)?

\[ V_{out2} = (4)(V_{out1}) = 1.6 \text{ V} \]

h. (2 pts) The capacitor is chosen such that a frequency of 120Hz (be careful) is the corner frequency of the filter. What is the value of that capacitor?

\[ f_c = \frac{1}{2\pi} \cdot \frac{1}{RC} \Rightarrow C = \frac{1}{R \cdot 2\pi f_c} \]

\[ = \frac{1}{(32)(2\pi)(120)} \]

\[ = 41.4 \mu F \]