The level of knowledge and detail expected for the exam is that of the lectures. Items marked with * are beyond the scope of this exam but included for general interest. The exact scope of the exam will be defined the week of the exam in order to reflect what was actually covered this term.

1. **Data Domains**

1.1. Be able to discuss the concepts of measurement and control as defined in class. What are the major components of an experiment? What is the flow of information?

1.2. Be able to discuss in general: input transducers, output transducers, data domain converters, and interfaces.

1.3. Be able to discuss data domain maps. You will not be required to create the general map, but be prepared to draw such a map for a given experimental setup if you are given the general map and the descriptions of all transducers and data domain converters involved.

2. **Oscilloscopes**

2.1. Be able to discuss the CRT including the main components. What is meant by x-axis, y-axis, z-axis?

2.2. Be able to discuss the use of a CRT to produce an x-y plot of two time varying signals, both periodic and fixed length in time. What are Lissajous figures?

2.3. Be able to discuss the concept of horizontal sweep, i.e. the use of a standard time base for one axis of the CRT.

2.4. What is meant by z-axis blanking? Synchronized time base? Flyback?

2.5. Be able to discuss triggering: trigger event; trigger mechanism; time course for x- and z-axes; internal, external, line sources; slope; threshold.

2.6. Be able to discuss multiple traces and alternate and chopped modes.

2.7. Be able to discuss DC and AC coupling.
3. **DC Circuit Analysis**

3.1. Ohm’s Law – Be able to state and utilize.

3.2. Kirchoff’s Current and Voltage Laws - Be able to state and utilize.

3.3. Simple Devices (symbol, transfer function, and applications; real and ideal): Voltage Sources, Resistors, Conductors, Capacitors, Voltage Sensing device,

3.4. Be able to solve for the behavior of combinations of two, three or more resistors.

3.5. Thevenin’s Theorem - Be able to state and discuss. You will **NOT** be asked to do a derivation of the Thevenin Equivalent circuit for a given circuit such as done in class, but you might be asked to discuss that derivation.

3.6. Loading (Current and Voltage) - Be able to discuss the concept and apply to situations such as covered in class.

4. **AC Circuit Analysis**

4.1. Be able to state and discuss the concepts: periodic and aperiodic signals; the functional and graphic description of a sine wave; the amplitude, frequency, and phase of a sine wave.

4.2. Be able to discuss the response of the RC circuit to a step function, including the graphical and functional description of the charging and discharging cases.

4.3. Be able to discuss the **steady state** response of the RC circuit to a sine wave, including the functional and graphical forms of the outputs across the resistor and the capacitor.

4.4. Be able to discuss high pass, low pass, band pass, and notch filters. Be able to produce a Bode plot for a high pass or low pass first order RC filter.

4.5. For what purposes are filters used?

5. **Power Supplies**

5.1. Transformer - Be able to identify, reproduce and/or utilize the name and schematic for simple, multiple secondary windings, and center tapped transformers. Be able to manipulate the voltage/turn ratio relationships and sketch the input and output waveforms.

5.2. Rectifier - Be able to identify, reproduce and/or utilize the name, schematic, and operating characteristics for the half wave, full wave/center tapped and full wave/bridge rectifiers based on the use of "ideal" diodes.

5.3. Filter - Be able to identify, reproduce and/or utilize the name, schematic, transfer function, and operating characteristics of a simple first order (RC) low pass filter.
5.4. **Regulator** - Be able to identify, reproduce and/or utilize the name, schematic, and operating characteristics of a series linear regulator and the shunt regulator.

5.5. **Diodes** - Know the generalized characteristic curve (i vs v) for a diode. Be able to identify and discuss the significance of the three operating regions of a diode: avalanche, reverse bias, forward bias. Be able to discuss the common uses of diodes: switching, power, light sensitive, temperature sensitive, zener.

6. **Operational Amplifiers**

6.1. You will **NOT** be asked to do any of the derivations done in class.

6.2. Be able to identify and/or reproduce the name, schematic, and transfer function (both algebraic and graphical forms) for each of the operational amplifier configurations: comparator, follower, follower with gain, inverter, summing amp, integrator, differentiator, difference, and potentiostat. These configurations are illustrated in Figure 1. For each of these configurations, you should also be able to apply the transfer function to problems such as the next problems.
Table 1 - Voltage Input OA Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Schematic</th>
<th>Transfer Function</th>
</tr>
</thead>
</table>
| comparator             | Figure 1-a    | Is \( v_1 > v_2 \)?  
                       |               | Yes: \( v_{out} = V_{oh} \)  
                       |               | No: \( v_{out} = V_{ol} \)  |
| follower               | Figure 1-b    | \( v_{out} = v_{in} \)                                  |
| follower with gain     | Figure 1-c    | \( v_{out} = v_{in} \left( \frac{R_1 + R_2}{R_1} \right) \) |
| inverter               | Figure 1-d    | \( v_{out} = -v_{i} \left( \frac{R_f}{R_i} \right) \)  |
| summing amp            | Figure 1-e    | \( v_{out} = -\sum_{i=1}^{n} v_{i} \left( \frac{R_f}{R_i} \right) \)  |
| Integrator             | Figure 1-f    | \( v_{out} = -\frac{1}{R_i C_f} \int v_{i} dt \)        |
| Integrator with Offset | Figure 1-g    | \( v_{out} = -\frac{1}{R_i C_f} \int v_{i} dt - v_2 \left( \frac{R_f}{R_2} \right) \)  |
| differentiator         | Figure 1-h    | \( v_{out} = -R_f C_i \frac{dv_{i}}{dt} \)              |
| difference             | Figure 2-h    | \( v_{out} = -\frac{R_f}{R_i} (v_2 - v_1) \)            |
| potentiostat           | Figure 2-i    | \( v_{a} = -v_{ref} \)                                 |
|                        |               | \( v_{out} = -\frac{R_1 + R_2}{R_2} v_{ref} \)          |
| potentiostat           | Figure 2-k    | \( v_{a} = -\left\{ v_{i} \left( \frac{R_f}{R_1} \right) + v_{2} \left( \frac{R_f}{R_2} \right) \right\} \) |
| potentiostat           | Figure 2-l    | \( v_{a} = -\left\{ v_{i} \left( \frac{R_f}{R_1} \right) + v_{2} \left( \frac{R_f}{R_2} \right) \right\} \) |

6.3. Figure 1 illustrates 12 different OA circuits. Figures 2-a, 2-b, and 2-c illustrate 9 voltage signals as a function of time. Table 2 contains values for the various parameters of these circuits to be used in this problem.
This exercise consists of connecting a given time varying voltage signal from the set illustrated in Figure 2 to the \( v_1 \) input of a given circuit from Figure 1 and sketching the resultant signal, \( v_{\text{out}} \), that would appear at the output of that circuit. A blank plot is provided for your convenience right below each input signal. You might want to make copies of the three pages of Figure 2, since you may want to apply the same signal to more than one configuration.

For the configurations with multiple inputs, try using one of the time varying signals for one input and a constant voltage for the other.

Assume that the OA's follow the first order model, i.e. \( i_+ = i_- = 0 \) and \( e_o = A(e_+ - e_-) \), and \( e_o \) is bounded by \( V_{\text{OL}} \) and \( V_{\text{OH}} \). Assume that \( V_{\text{OL}} = -12\text{v} \) and \( V_{\text{OH}} = +12\text{v} \). Assume that all capacitors are discharged at \( t = 0 \).

[Note: The intention is not for you to necessarily to do all 12*9 permutations. Rather, you should do several combinations of one OA configuration and various input signals. Then repeat the process for several different configurations. Once you know the procedure and if you know the transfer functions of the circuits, you should be able to easily derive the behavior of any of the circuits to time varying signals.]

Table 2 Circuit Parameters for OA Configurations in Figure 2

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>( v_2 = +2.0 \text{ volts} )</td>
</tr>
<tr>
<td>b</td>
<td>( R_1 = 10K\Omega, R_2 = 10K\Omega )</td>
</tr>
<tr>
<td>c</td>
<td>( R_1 = 10K\Omega, R_2 = 10K\Omega )</td>
</tr>
<tr>
<td>d</td>
<td>( R_1 = 10K\Omega, R_f = 20K\Omega )</td>
</tr>
<tr>
<td>e</td>
<td>( R_1 = 10K\Omega, R_3 = 10K\Omega, R_f = 10K\Omega, v_2 = -2.0\text{v} )</td>
</tr>
<tr>
<td>f</td>
<td>( R_{\text{in}} = 1M\Omega, C_f = 0.1\mu\text{F} )</td>
</tr>
<tr>
<td>g</td>
<td>( R_1 = 1M\Omega, R_2 = 1M\Omega, C_f = 0.1\mu\text{F} )</td>
</tr>
<tr>
<td>h</td>
<td>( R_f = 1M\Omega, C_1 = 0.1\mu\text{F} )</td>
</tr>
<tr>
<td>i</td>
<td>( R_1 = 10K\Omega, R_f = 20K\Omega )</td>
</tr>
<tr>
<td>j</td>
<td>( R_1 = 10K\Omega, R_2 = 10K\Omega )</td>
</tr>
<tr>
<td>k</td>
<td>( R_1 = 10K\Omega, R_3 = 10K\Omega, R_2 = 20K\Omega, R_4 = 15K\Omega )</td>
</tr>
<tr>
<td>l</td>
<td>( R_1 = 10K\Omega, R_2 = 10K\Omega, R_3 = 20K\Omega, R_4 = 15K\Omega )</td>
</tr>
</tbody>
</table>

6.4. *The input, \( v_1 \), of a follower (Figure 1b) is connected directly to common. The output, \( v_{\text{out}} \), is measured to be 37.5 millivolts. The input, \( v_1 \), is then connected to ground through a 2 M\Omega resistor. The output is then measured to be 45.0 millivolts. What is the offset for the OA? What is \( i_+ \)?*
Figure 1 - Operational Amplifier Configurations
6.5. A follower is to be used to buffer a real voltage source from a real voltage meter. $R_s$ is 3 KΩ. $V_s$ is 2.5 volts. $i_+$ for the follower is $10^{-9}$ amps. $R_{m}$ for the meter is 10 KΩ. $i_{0l}$ for the follower OA is 20 milliamp. What would the voltage be at the output of the OA if the meter was not connected? Can the OA drive the meter? Explain.

6.6. What are the primary characteristics of the basic operational amplifier?

6.7. What is the circuit symbol for the operational amplifier?
6.8. Why is one of the inputs called the inverting input?

6.9. What determines the output voltage limits of the OA?

6.10. What condition exists at the OA inputs when the output is not at limit?

6.11. What is the circuit and what are the characteristics of the voltage follower?

6.12. Draw the circuit of a voltage follower with a gain of 100?

6.13. Assuming an output limit of ± 12V for the above amplifier, what are the input signal limits for linear operation?

6.14. *If the raw gain of the OA in the above amplifier is $10^6$, by what factor does the gain deviate from the expected value of 100?

6.15. *If the resistors in the above amplifier have an accuracy of 0.1%, how will this affect the gain accuracy? The gain precision?

6.16. Defend the statement that the voltage follower presents a nearly ideal load to a voltage source.

6.17. Design a current follower that will produce a 1V output for an input current of $10^{-7}$ A.

6.18. Defend the statement that the current follower presents a nearly ideal load to a current source.

6.19. How does an inverting amplifier with a gain of 1 differ from a voltage follower?

6.20. Design an inverting amplifier with a gain of 100.

6.21. What is input resistance of the above amplifier?

6.22. Design a summing amplifier with an output that is $-(10v_1 + 5v_2 + 2v_3)$.

6.23. *What are the main considerations in choosing the resistor values for the above amplifier?

6.24. Draw the circuits for and describe the function of the integrator and the differentiator.

6.25. Design an integrator circuit that will produce a sweep signal with an output sweep rate of 10 V per second.

7. Digital Logic Circuits.

7.1. Make truth tables for the AND, OR, and NOT functions.

7.2. Draw the symbols for the AND and OR gates and the NOT circuit and make their tables of states.
7.3. Defend the statement that all logic functions can be accomplished with a combination of AND, OR, and NOT functions.

7.4. Define HI and LO for logic level signals.

7.5. What is the truth table, symbol, and sign for the exclusive-or function?

7.6. Why are AND and OR circuits called gates?

7.7. Describe the one function of a data latch.

7.8. Be able to apply the generic flip flop described in class including symbol, input and output signals, operation, table of states, and timing diagrams.

7.9. Be able to couple an arbitrary number of the generic flip flops and generate the table of states and timing diagrams for the combinations.

**Analog Signal Processing.**

7.10. What are the characteristics of an ideal switch?

7.11. What are the characteristics of a real mechanical switch? What is bounce? "Bounce" is a concern in which contexts? Why?

7.12. What are the characteristics of a real solid-state switch? What is the time behavior of a real solid-state switch?

7.13. Describe the switching circuits involved in making a sweep generator from a constant voltage source and an OA integrator.

7.14. Design a circuit that will generate a true symmetrical triangular wave based on an OA integrator.

7.15. *Be able to assess the error caused by open and closed switch resistance in signal switching applications.

7.16. Understand the operation of the Monostable Multi-vibrator. You will not have to reproduce the schematic diagram or the timing diagrams used in the derivation. Be able to reproduce and identify the symbol used for the 1 Shot or monostable. Be able to describe the timing relationship of the input and output signals of the device. Be able to qualitatively describe the relationship of the timing of these signals with the values of the resistance and capacitance used. Be able to derive the behavior of combinations of monostables to achieve a set of signals with varying timing relationships, i.e. delays, and pulse widths.

7.17. Be able to identify and/or reproduce the name, schematic, and transfer function for the analog multiplexer. What are the operational constraints that differentiate the analog multiplexer from the summing amp? How is this circuit used?
7.18. Be able to discuss the phenomena called “cross talk.”

8. **Time and Frequency Measurement**

8.1. Asynchronous binary counters

8.2. Asynchronous counters of arbitrary modulus

8.3. Crystal stabilized clock, variable output and programmable clock

8.4. Time and Frequency measurement – Understand, be able to reproduce, and apply the operation of the simple circuit used for time, period, frequency, period ratio, and frequency ratio measurement.