1) (8 Points)
$V_{in}$ for each of the circuits below is a 1.0 kilohertz sine wave with a peak-to-peak amplitude of 5.00 V. For each circuit, make a sketch showing the input and output signals on the same graph as a function of time for at least two full periods of the input signal. Indicate clearly the amplitude of the output signal. You may assume that any op-amps are ideal and that they saturate at $\pm 15$ V and the forward voltage drop on the diodes, $V_{DiodeOn}$ is 0.5 V. Assume that the output impedance of the source driving these circuits is 0 $\Omega$.

![Figure 1a](image1a.png)

![Figure 1b](image1b.png)

![Figure 1c](image1c.png)

![Figure 1d](image1d.png)
2) (7 Points)
For the circuit in Figure 2, assume that the 74LS193 (used in the frequency counter lab) 4-bit binary counter’s TTL output voltages are exactly: LO = 0 V, HI = 5 V and that it is configured to count continuously. Your assignment will be to draw $V_{out}$ vs. $t$ for two periods of the output signal, specifically:

a) What is the period of the output signal? (How long does it take until $V_{out}$ repeats itself?)
b) What is $V_{out}$ when all the counter outputs $Q_0$, $Q_1$, $Q_2$ and $Q_3$ are LO?
c) What is $V_{out}$ when all the counter outputs $Q_0$, $Q_1$, $Q_2$ and $Q_3$ are HI?
d) What is $|\Delta V|$, absolute value of the change in $V_{out}$ for a “typical” one-bit change? Ignore the case when the counter outputs switches from all HI to all LO.
e) From the information above, draw $V_{out}$ vs. $t$ for two periods of the output signal. Clearly label all voltages and times involved. (If you were not able to calculate all parts, at least try to draw a qualitative picture.)

3) (7 Points) This time your instructors wire up the multiplexer circuit shown in Figure 3 as a joke. They use the same 8-bit multiplexer that you used for the 31-day machine. Note that $A_0$ is the least significant address bit.

a) Write down the truth table.
b) Write down a simple logic circuit using only one or two-input gates (AND, NAND, OR, NOR, XOR, NOT) that performs the same function as your lab instructor’s circuit. For your answer use the minimum number of gates.

4) (10 Points)
a) Write a stand-alone ANSI-C function that returns the average value for an array of type double with $n$ elements.
b) Write another stand-alone ANSI-C function that compacts a large array with $m$ elements by a factor of 100 by averaging “chunks” of 100 array elements together in the following manner:
   - Take the first 100 elements of the array, calculate the corresponding average and then store this result in the very first element of the original array.
   - Take the second set of 100 elements, i.e., array elements 100 to 199, average them and store them at the second position of the original array.
   - Continue this way until the first $m - 100$ elements have been averaged. (Note: $m$-100 is used to avoid exceeding the limits of the array.)
   - Finally, the function must return how many sets of 100 elements were averaged.

The array is of type double and all averaging calculations must be carried out by calling the function you wrote for part a!

For both parts a) and b) the array and its size must be passed to the function as arguments and no global variables may be used! You will be graded on program logic and syntax mistakes.
5) (10 Points)
You are studying a waveform that is represented by:

\[ y(t) = \sin(2\pi f_0 t) + \frac{\sin(6\pi f_0 t)}{3} + \frac{\sin(10\pi f_0 t)}{5} + \frac{\sin(14\pi f_0 t)}{7}, \]

where \( f_0 = 300 \text{ Hz} \). The signal is measured in Volts.

a) What familiar waveform does this approximate? Sketch two periods of the waveform as quantitatively as possible. (Do not worry about small wiggles.) What is the approximate peak-to-peak amplitude (to within 20%)?

b) Sketch the amplitude spectrum that you observe if your sampling rate is 5 kHz. Indicate all peak frequencies and amplitudes clearly. Do not worry about the widths of the peaks.

c) Sketch the amplitude spectrum that you observe if your sampling rate is 2.5 kHz. Indicate all peak frequencies and amplitudes clearly. Do not worry about the widths of the peaks.

d) You now run your signal through a simple RC low-pass filter with a –3dB point of 300 Hz. The output of the filter is connected to the input of your A to D card. Sketch the spectrum you observe if your sampling rate is 5 kHz. What would you see if you look at the output of the filter on an oscilloscope? Explain in a few sentences.

6) (8 Points)
a) You measure the outer diameter of a spherical shell to be 10.0 ± 0.1 cm. Assuming that the thickness of the shell is negligible, what is the volume of the sphere?

b) You see a balance in the corner of the room and mass the sphere, finding a mass of 339 ± 5 grams. You know the sphere is made of pure aluminum, for which the density is 2.699 g/cm³. What is the thickness of the shell, i.e., the difference between the inner radius and the outer radius?

c) You are the proud owner of a toy cannon, which mounts on an angular bracket making an angle \( \theta \) with respect to the horizontal. The manufacturer tells you that the muzzle velocity of the cannon is \( v_0 = 10.0 \pm 0.1 \) m/sec and that you can read the angular bracket to measure \( \theta \) with a precision of 1 degree. Calculate the angle \( \theta \) at which the fractional error in the range \( R \) is minimized. At this angle, what is the range of the cannon (with uncertainty)? You may use the fact that \( R = \frac{v_0^2 \sin 2\theta}{g} \). For the purposes of this problem, you may assume that \( g \) is exactly 10.00 m/sec².