NAME (please print) ______________________________________________

STUDENT (SID) NUMBER _________________________

# UNIVERSITY OF CALIFORNIA

College of Engineering
Electrical Engineering and Computer Sciences
Berkeley

## EECS 145M: Microcomputer Interfacing Lab

LAB REPORTS:

| | | |
|---|---|---|
| 1 __________ (100 max) | 8 __________ (100 max) | 21 __________ (100 max) |
| 2 __________ (100 max) | 9 __________ (100 max) | 22 __________ (100 max) |
| 3 __________ (100 max) | 10 __________ (100 max) | 23 __________ (100 max) |
| * two lowest grades dropped | | 25 __________ (100 max) |

| | | | |
|---|---|---|---|
| HIGHEST 8 LAB GRADES ×7/8 | __________ | (700 max) | COURSE LETTER GRADE |
| MID-TERM | __________ | (100 max) | |
| FINAL EXAM | __________ | (200 max) | |
| TOTAL COURSE GRADE | __________ | (1000 max) | |

## Spring 1991 FINAL EXAM

**May 20, 1991**

Answer the questions on the following pages completely, but as concisely as possible. The exam is to be taken ***closed book***. Although the exam was designed to be completed in two hours, you can use the full three hour assigned period. Use the reverse side of the exam sheets if you need more space. Calculators are OK but not needed. **In answering the problems, you are not limited by the particular equipment you used in the laboratory exercises.** Many formulae from the course have been provided for you on the last page.

***Partial credit can only be given if you show your work.***

**FINAL EXAM GRADE :**

| | | |
|---|---|---|
| 1 ________ (42 max) | 3 ________ (30 max) | 5 ________ (30 max) |
| 2 ________ (48 max) | 4 ________ (50 max) | TOTAL ________ (200 max) |

Initials ________________________

**Problem 1** (total 42 points):

Define the following terms (30 words or less)

**a.** (6 points) **Glitch** (of a D/A converter)

**b.** (6 points) **Handshaking** (between any sender and receiver- either could be the computer)

**c.** (6 points) **Frequency Aliasing**

**Problem 1** (continued):

**d.** (6 points) **Sample and Hold Amplifier**

**e.** (6 points) **Settling Time** (of a D/A converter)

**f.** (6 points) **Two's Complement**

**g.** (6 points) **Formants of Vowels**

Initials ________________________

**Problem 2** (48 points)

Design a microcomputer-based data acquisition system that contains a microcomputer and a number of external circuits. Your design must satisfy the requirements given below:

**The microcomputer:**

- Has a disk drive, keyboard, screen, and a binary I/O port with 16 input and 16 output lines.
- Has an internal timer board with a 9513 counter/timer chip (like the one you used in labs 2 and 3). Assume a clock speed of 1 MHz.
- You can call a function `setup_go (T,N)` that does the following:

  (i) Sets up the timer board to use two 16-bit cascaded counters (numbers 0 and 1) for controlling the time interval T between output pulses. Assume that it counts down to zero, produces an output pulse on an external line, reloads, and then resumes counting down.

  (ii) Sets up the timer board to use two 16-bit counters (numbers 2 and 3) to control the number of pulses N. Assume that it counts down for every output pulse and stops at zero.

  (iii) Starts the counters.
- You have another function `counter(M)` that returns the contents of counters M and M+1 as a packed 32-bit integer.
- Your program should ask the user for the number of samples, the time interval between samples, and the name of the output data file.
- Your program should wait until the requested number of samples has been taken, read the sample values, and write them to the output data file.

**A/D converter:**

- Has a successive approximation 16-bit A/D converter with 10 µs conversion time and 0–20 volt input range. Your design must insure that the A/D input is constant during the 10 µs conversion time. Conversion is initiated by the low-to-high edge of a “start conversion” pulse. The A/D produces a low-high-low output pulse when conversion is complete and the 16 data bits are stable.

**Adder:**

- Has two input lines and 20 output lines. A low-to-high edge on one input line causes the adder to be set to zero and a low-to-high edge on the other input line causes the number to be incremented (increased) by one. The number is always present on the 20 output lines.

**Memory:**

- Has $2^{20}$ 16-bit storage locations. There are 20 address lines (input) and 16 data lines (input and output). An additional input line ($R/\overline{W}$) is used to determine whether the address on the memory chip is being written to or read from. The low-to-high edge of another input line (CS) clocks data between memory and the external data lines. If $R/\overline{W}$ is high, a low-to-high edge of CS reads data from memory to the data lines. If $R/\overline{W}$ is low, a low-to-high edge of CS writes data from the data lines into memory. The memory location is always that specified by the address lines.

**Anti-aliasing filter:**

- You have instructed the user of your data acquisition system to use an anti-aliasing filter, whose design depends on the desired sampling frequency and the frequency content of the signal.

Initials ________________________

**Problem 2** (continued):

**Note:**

- Unlike Laboratory Exercise 9 (A/D Conversion and Periodic Sampling), the computer is not used to take the individual samples - only to provide the user interface, to set up and start the sampling, and to retrieve the sampled values after they have been taken.
- Other circuits may be needed in your design to satisfy the requirements.

Do the following:

**a.** (14 points) Draw the block diagram for the microcomputer, external circuits, and the lines that connect them. Label every essential item, control line, and data line.

**b.** (14 points) Describe in step-by-step sequence how your program and external circuit works. (There is no need to write detailed C code- just a flow chart in list form)

Initials ________________________

**Problem 2** (continued):

**c.** (5 points) What are the minimum and maximum sampling rates that the system can perform?

**d.** (5 points) What is the maximum number of samples that can be stored in memory and how long would it take to acquire them at the maximum sampling rate?

**e.** (5 points) The A/D data sheet claims a differential linearity of ±4 LSB. Describe what this means (in terms of input voltage) to someone who is not familiar with this A/D characteristic.

**f.** (5 points) For a signal containing noise from 0 to 10 kHz and a sampling frequency of 1 kHz, what anti-aliasing filter would you advise?

Initials ________________________

**Problem 3** (total 30 points):

Briefly describe the following processes. Be sure to include all necessary steps (pretend that you are writing a detailed procedure for an inexperienced young colleague).

**a.** (10 points) **Digital Filtering of a Sampled Waveform with Analog Output**

**b.** (10 points) **Sampling, Digital Storage, and Playback of the Human Voice**

c. (10 points) **Measuring the Time Required for the FFT Function to Compute a 4096 element FFT**

Initials ________________________

**Problem 4** (total 50 points):

You are asked to design a system for using the FFT to analyze the harmonic content of certain musical instruments. The requirements are:

- The instruments have a fundamental frequency (first harmonic) ranging from 20 Hz to 2 kHz.
- The system must measure harmonic amplitudes from the 1st to the 25th harmonic with an accuracy of 0.025% of the A/D full scale. Note: higher harmonics may be present.
- Neighboring Fourier coefficients correspond to frequencies differing by 0.1 Hz.

Answer the following questions about these design requirements:

**a.** (5 points) What is the minimum sampling frequency required?

**b.** (5 points) What is the minimum time needed to take all the samples required?

**c.** (5 points) What is the minimum number of samples required?

**d.** (5 points) How many bits of A/D accuracy are required?

**e.** (5 points) How does your design avoid aliasing? Give details.

**Problem 4** (continued):

**f.** (5 points) How would you avoid the error in Fourier coefficients resulting from the discontinuity that occurs when the last samples do not join onto the next cycle of the first samples?

**g.** (5 points) You use the system to sample a pure 100 Hz sine wave and take the FFT. What does the modulus of the FFT output look like? (Either sketch or list the nonzero elements $F_n$, showing relative size.)

**h.** (5 points) You use the system to sample a pure 100.05 Hz sine wave and take the FFT. What does the modulus of the FFT output look like? (Either sketch or list the nonzero elements $F_n$, showing relative size.)

**i.** (5 points) How would the answer to part **h.** change if you do not take the measures mentioned in part **f**?

**j.** (5 points) You use the system to sample a distorted sine wave where the first harmonic is at 100 Hz and the amplitude of the higher harmonics falls as 1/f. Assume that the waveform is not symmetric. What does the modulus of the FFT output look like? (Either sketch or list the nonzero elements $F_n$, showing relative size.)

**Problem 5** (total 30 points):

In Laboratory Exercises 21 and 22, you took 512 samples, stored them in memory, called the FFT function to generate 512 complex Fourier coefficients, and computed 512 modulus values. Design a system using digital filtering to do these same tasks continuously, rather than in "batch" mode. Assume that you have available a large number of low-cost processors suitable for digital filtering.

**a.** (13 points) Give the formula for your digital filter. Is it FIR or IIR?

**b.** (13 points) Draw a representative section of the block diagram, showing components and interconnections.

**c.** (4 points) How many processors are needed in all?

Initials ________________________

**Equations, some of which you might find useful:**

$$V(n) = V_{ref}^{-} + n\left(\frac{V_{ref}^{+} - V_{ref}^{-}}{2^N}\right) = V_{min} + n\left(\frac{V_{max} - V_{min}}{2^N - 1}\right)$$

$$n = \left[\frac{V - V_{ref}^{-}}{\Delta V} + \frac{1}{2}\right]_{INTEGER} \qquad V(n-1,n) = V_{ref}^{-} + (n-0.5)\Delta V \qquad \Delta V = \frac{V_{ref}^{+} - V_{ref}^{-}}{2^N - 1}$$

$$a = \frac{st - rq}{ms - r^2} \quad \text{and} \quad b = \frac{mq - rt}{ms - r^2} \qquad \text{where } r = \sum n_i \quad s = \sum n_i^2 \quad q = \sum n_i V_i \quad t = \sum V_i$$

$$rms = \sqrt{\tfrac{1}{m}\sum R_i^2} \qquad R_i = a + bn_i - V_i$$

$$G(a) = \frac{\exp\left[-\frac{1}{2}\left(\frac{a-\mu}{\sigma}\right)^2\right]}{\sqrt{2\pi\sigma^2}} \qquad \mu \approx \bar{a} = \tfrac{1}{m}\sum_{i=1}^{m} a_i$$

$$\sigma^2 = Var(a) = \left(\frac{1}{m-1}\right)\sum_{i=1}^{m} R_i^2 = \left(\frac{1}{m-1}\right)\sum_{i=1}^{m}(a_i - \bar{a})^2 \qquad Var(\bar{a}) = Var(a)\,/\,m$$

$$F_n = \sum_{k=0}^{N-1} f_k e^{-i2\pi nk/N} \qquad f_k = \sum_{n=0}^{N-1}\frac{F_n}{N} e^{+i2\pi nk/N} \qquad |F_n| = \sqrt{Re(F_n)^2 + Im(F_n)^2}$$

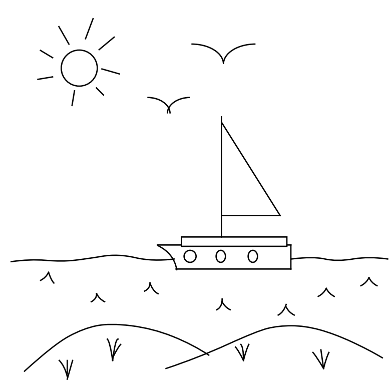
$$\text{For } f_k = \sum_{j=0}^{N-1} a_j \cos(2\pi jk/N) + b_j \sin(2\pi jk/N) \qquad F_0 = Na_0 \quad F_n = (N/2)(a_n - ib_n)$$

$f_{max} = f_s/2$ $\quad T = 1/f_s$ $\quad S = NT$ $\quad \Delta f = 1/S$

$$y_i = A_1 x_{i-1} + A_2 x_{i-2} + \ldots + A_M x_{i-M} + B_1 y_{i-1} + \ldots + B_N y_{i-N}$$

$$t = \frac{\Delta}{\sqrt{Var(\Delta)}} = \frac{\bar{a} - \bar{b}}{\sqrt{Var(\bar{a}) + Var(\bar{b})}} = \frac{\bar{a} - \bar{b}}{\sqrt{Var(a)/m_a + Var(b)/m_b}}$$

$$t = \frac{\bar{d}}{\sqrt{Var(\bar{d})}} = \frac{\bar{d}}{\sqrt{\left(\frac{1}{m}\right)\left(\frac{1}{m-1}\right)\left(\sum d_i^2 - m\bar{d}^2\right)}}$$



$$f_{max} = \frac{1}{2^{N+1}\pi T} \qquad e^{i\theta} = \cos\theta + i\sin\theta$$

$2^8 = 256$ $\quad 2^{10} = 1{,}024$ $\quad 2^{12} = 4{,}096$

$2^{14} = 16{,}384$ $\quad 2^{15} = 32{,}768$ $\quad 2^{16} = 65{,}536$

# Have a pleasant summer!