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UNIVERSITY OF CALIFORNIA

College of Engineering
Electrical Engineering and Computer Sciences Department

EECS 145M: Microcomputer Interfacing Laboratory

Spring Midterm #2
Monday, April 21, 1997

- Closed book- calculators OK
- Many equations are listed at the back of the exam
- You must show your work to get full credit

PROBLEM 1 (50 points)

Design a computer controlled system for the automatic testing of 12-bit A/D converters.

You are provided with the following:

- A microcomputer equipped with a 16-bit parallel input port, and a 16-bit parallel output port.
- A 16-bit D/A converter with ±1 LSB absolute accuracy.

You may assume the following:

- The 16-bit parallel output port is in "transparent" mode. A 16-bit word *A* written to the output port using the command outport(1, *A*) immediately appears on the output lines.
- The 16-bit parallel input port requires a low-to-high edge on a "strobe" input line for external data to be latched onto the 16 bit registers. The program can read these registers using the command *B* = inport(1).
- The parallel input port has an "input data available" line that can be asserted high or low by an external device and read by the program using the command *C* = inport(2).
- The parallel input port has an external "ready for input data" line that can be set high using the program command outport(2,1), and set low using outport(2,0).
- The A/D converter requires a "start conversion" low-to-high signal and after conversion provides a "data ready" low-to-high signal that goes low when "start conversion" goes low.
- The A/D reference voltages are $V_{ref}^{-} = 0.0000$ V and $V_{ref}^{+} = 4.095$ V
- The D/A reference voltages are $V_{ref}^{-} = 0.0000$ V and $V_{ref}^{+} = 4.096$ V

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1a. [25 points] Draw a block diagram of the major components, including the A/D circuit being tested. Show and label *all* essential components, data lines, and control lines.

1b. [10 points] How would you measure the maximum absolute accuracy error of the A/D? (Explain the procedure in steps or with a flow diagram.)

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1c. [5 points] How would you measure the maximum linearity error?

1d. [5 points] How would you measure the maximum differential linearity error?

1e. [5 points] With what accuracy could this system measure the quantities in parts **b.**, **c.**, and **d.** in units of 1 LSB of the A/D?

PROBLEM 2 (50 points)

Design a microcomputer-based system for using the FFT to analyze the harmonic content of musical instruments.

The design requirements are:

- The instruments have a fundamental frequency (first harmonic) ranging from 50 Hz to 2 kHz.
- The system must sample the waveform with an amplitude accuracy of ±1% over all frequencies of interest.
- The system must compute harmonic magnitudes from the 1st to the 15th harmonic with an accuracy that is 0.2% of the largest harmonic. (You may assume that at and above the 15th harmonic, the magnitudes decrease with increasing frequency.)
- Neighboring Fourier coefficients correspond to frequencies differing by 0.5 Hz.

2a. [10 points] How does your design avoid aliasing? Give details.

2b. [10 points] What is the minimum sampling frequency required?

2c. [5 points] What is the minimum time needed to take all the required samples?

2d. [5 points] What is the minimum number of samples required?

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2e. [5 points] Would a Hanning window be useful in your design? Explain your reasoning.

2f. [5 points] To what frequency does the first FFT coefficient H_1 correspond?

2g. (10 points] For a musical instrument with a first harmonic frequency of 500 Hz, which FFT magnitudes would you expect to be non zero?

Equations, some of which you might find useful:

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

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

$$t = \frac{\Delta}{\sigma_\Delta} = \frac{\bar{a}-\bar{b}}{\sqrt{\sigma_{\bar{a}}^2 + \sigma_{\bar{b}}^2}} = \frac{\bar{a}-\bar{b}}{\sqrt{\sigma_a^2/m_a + \sigma_b^2/m_b}} \qquad \sigma_f^2 = \left(\frac{\partial f}{\partial a_1}\right)^2 \sigma_{a1}^2 + \left(\frac{\partial f}{\partial a_2}\right)^2 \sigma_{a2}^2 + \cdots + \left(\frac{\partial f}{\partial a_n}\right)^2 \sigma_{an}^2$$

$$f = k(a+b) \qquad \sigma_f^2 = k^2\left(\sigma_a^2 + \sigma_b^2\right) \qquad f = kab \qquad \sigma_f^2 / f^2 = \sigma_a^2 / a^2 + \sigma_b^2 / b^2$$

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$R_i = a + bn_i - V_i \quad V_{\text{rms}} = \sqrt{\frac{1}{m}\sum R_i^2}$

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

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

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

$$H(f) = \int_{-\infty}^{\infty} h(t) e^{-j2\pi ft}\, dt \qquad e^{j\theta} = \cos\theta + j\sin\theta$$

If $h(t) = \begin{cases} A & \text{for } |t| \le T_0/2 \\ 0 & \text{for } |t| > T_0/2 \end{cases}$, then $H(f) = AT_0 \dfrac{\sin(\pi T_0 f)}{\pi T_0 f}$

If $h(t) = 0$ for $t < 0$; $h(t) = Ae^{-t/\tau}$ for $t \ge 0$, then $H(f) = A\Big/\sqrt{1 + 4\pi^2 f^2 \tau^2}$

$$\boldsymbol{H_n = \sum_{k=0}^{M-1} h_k e^{-j2\pi nk/M}} \quad \boldsymbol{h_k = \sum_{n=0}^{M-1} \frac{H_n}{M} e^{+j2\pi nk/M}} \qquad \text{dB} = 20\log_{10}$$

$$F_n = |H_n| = \sqrt{\text{Re}(H_n)^2 + \text{Im}(H_n)^2} \qquad \tan\varphi_n = \text{Im}(H_n)\big/\text{Re}(H_n)$$

For $h_k = \sum_{i=0}^{M-1} a_i \cos(2\pi ik/M) + b_i \sin(2\pi ik/M) \qquad H_0 = Ma_0 \quad H_n = (M/2)(a_n - jb_n)$

$f_{\max} = f_s/2 \qquad \Delta t = 1/f_s \qquad S = M\Delta t \qquad \Delta f = 1/S \qquad h(t) = 0.5[1.0 - \cos(2\pi t/S)]$

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

If $a(t) = \int_{-\infty}^{+\infty} b(t')\, c(t - t')\, dt' = b(t) \otimes c(t)$, then FFT(a) = FFT(b) multiplied by FFT(c)

$$f_{\max} = \frac{1}{2^{N+1}\pi T} \qquad V(t) = V(0)\, e^{-t/RC}$$

$$\left|\frac{V_{\text{out}}}{V_{\text{in}}}\right| = \frac{1}{\sqrt{1 + (f/f_c)^{2n}}} \quad \text{(see table below)}$$

	0.999	0.99	0.9	0.707	0.01	0.001	0.0001
f/fc (n= 6)	0.596	0.723	0.886	1.000	2.154	3.162	4.642
f/fc (n= 8)	0.678	0.784	0.913	1.000	1.778	2.371	3.162
f/fc (n= 10)	0.733	0.823	0.930	1.000	1.585	1.995	2.512
f/fc (n= 12)	0.772	0.850	0.941	1.000	1.468	1.778	2.154

N =	8	9	10	11	12	13	14	15	16
2^N =	256	512	1,024	2,048	4,096	8,192	16,384	32,768	65,536