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UNIVERSITY OF CALIFORNIA

College of Engineering
Electrical Engineering and Computer Sciences Department

EECS 145M: Microcomputer Interfacing Laboratory

Spring Midterm #2 (Closed book- calculators OK)
Monday, April 15, 1996

PROBLEM 1 (70 points)

Design a system for analyzing the harmonic content of musical instruments using the FFT. You know that the sounds will have a fundamental frequency and higher harmonics of that frequency.

The requirements are:

- Maximum frequency of interest 20 kHz (but higher frequencies may occur)
- Frequency resolution 0.1 Hz (closest frequencies that can be clearly resolved in the FFT)
- Waveform voltage resolution ±0.015% of full range
- Minimal spread of spectral leakage

You have available the following:

- A microphone and instrumentation amplifier capable of converting music to an analog waveform with an amplitude of ±5 volts.
- A microcomputer with a counter/timer, an digital input port, and FFT program code.
- The digital input port has a “data available” status bit (input). The input port requires 1 µs to read a byte of data or the status bit. You may assume that other computer operations take a negligible amount of time.
- An external successive approximation A/D converter chip with a “start conversion” input and a “conversion complete” output. The input must be held constant during conversioon.
- The counter/timer can be set up by the computer to generate external pulses with any width and any time interval.
- A 12-pole Butterworth low-pass filter with a gain = 0.99 at 20 kHz and 0.00002 at 50 kHz.

a. (4 points) What is the maximum allowable time period between samples?

b. (4 points) What is the minimum number of required A/D bits?

c. (4 points) What is the maximum allowable conversion time of the A/D?

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d. (4 points) How long do you need to sample the waveform?

e. (4 points) What is the minimum number of samples required?

f. (20 points) Sketch your system design, showing and labeling all essential components and signal lines.

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g. (20 points) List the steps (hardware and software) involved in sampling the waveform and taking the FFT.

h. (5 points) For a musical instrument with a fundamental frequency of 100 Hz, at what Fourier amplitude H_n would expect the fundamental to occur? (give Fourier frequency index n).

i. (5 points) At what Fourier amplitude H_n would expect the mth harmonic to occur?

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PROBLEM 2 (30 points)

a. (10 points) Sketch the internal components of the successive approximation A/D converter

b. (10 points) List the necessary steps for the conversion of a analog input voltage by the successive approximation A/D converter

c. (5 points) You need to convert voltages in the 0 to 5 volt range with an accuracy of ±0.25%. What type of A/D converter provides the highest possible speed for this situation?

d. (5 points) You need to convert voltages in the 0 to 5 volt range with an accuracy of ±0.001%. What type of A/D converter provides the highest possible speed for this situation?

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Equations, some of which you might find useful:

$$V(n) = V_{\text{ref}}^{-} + n\left(\frac{V_{\text{ref}}^{+} - V_{\text{ref}}^{-}}{2^N}\right) = V_{\min} + n\left(\frac{V_{\max} - V_{\min}}{2^N - 1}\right) \qquad \left|\frac{V_{\text{out}}}{V_{\text{in}}}\right| = \frac{1}{\sqrt{1 + (f/f_c)^{2n}}}$$

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

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

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

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

$$H(f) = \int_{-\infty}^{\infty} h(t)e^{-j2\pi ft}\,dt \qquad \text{If } h(t) = \begin{cases} A & \text{for } |t| \le T_0/2 \\ 0 & \text{for } |t| > T_0/2 \end{cases}, \text{ then } H(f) = AT_0\frac{\sin(\pi T_0 f)}{\pi T_0 f}$$

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

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

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

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

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

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

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)

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

$$n = \frac{\ln\left[\left(G_1^{-2} - 1\right)\big/\left(G_2^{-2} - 1\right)\right]}{2\ln[f_1/f_2]} \qquad f_c = f_1\left(G_1^{-2} - 1\right)^{-1/2n} = f_2\left(G_2^{-2} - 1\right)^{-1/2n}$$

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