Midterm — November 19, 2005

Write and sign the honor pledge:

1. (2 pts) Print your name on *each and every* sheet.
2. (8 pts)

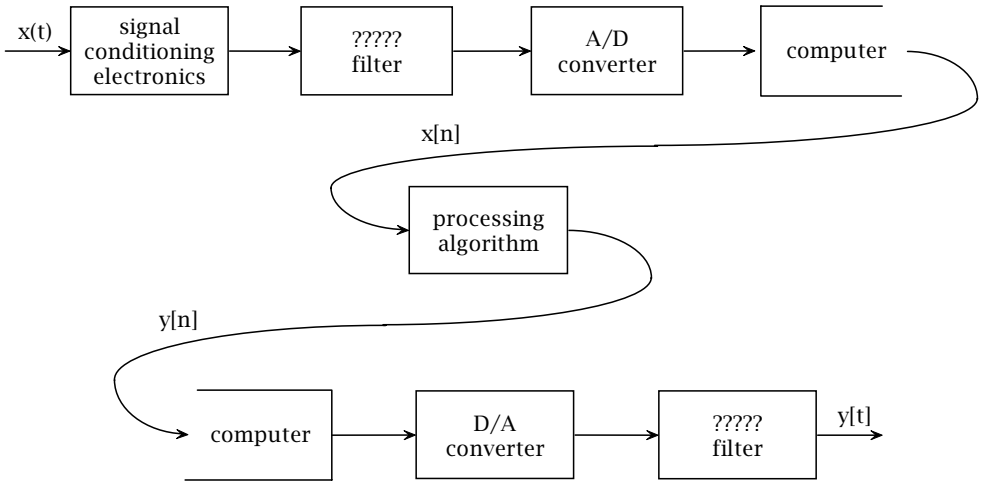


Figure 1: DSP paradigm.

Figure 1 shows the basic components that typify a DSP processing system.

(a) What is the purpose of the filter at the input of the A/D converter?

(b) What is the purpose of the filter at the output of the D/A converter?

3. What basic computer arithmetic operation is generally used to characterize whether or not a microcomputer is intended for use in doing digital signal processing?

4. Given a sine wave at 5 kHz. What is is the frequency of the original positive frequency component after sampling using sample rate

   (a) 20 kHz _____

   (b) 10 kHz _____

   (c) 5 kHz _____

   (d) 3.0 kHz _____

5. If a waveform is sampled for T seconds using a sample rate of f_s Hz and gives a data set of N samples. Then

   (a) How are f_s, T, and N related? _____

   (b) If the DFT is formed for this set of samples what are the frequencies associated with the k=0, k=1, and k=2 DFT values?

6. Given a B-bit A/D converter that can be used digitize input voltages up to a maximum $\pm V_p$ what is the voltage change that will produce one count change in the A/D converter output?

   This technique is so commonly encountered that the McBSP devices on the C5510 support on-the fly COMPANDing using it.

7. (a) The C5510 natively uses _____ point arithmetic.

   (b) We have been using an internal _____ MHz CPU clock with the C5510.

   (c) On-chip the C5510 has _____ K words of ____-bit memory.

   (d) This memory is used both for _____ and _____.

   (e) There are ___ multichannel buffered serial ports on the C5510.

(f) The C5510 generates its internal clock based on an externally supplied frequency reference. It does this using a circuit called a _____ clock generator.

(g)

(h) Not counting DMA data transfers the C5510 can simultaneously perform up to _____ memory reads and _____ memory writes.

(i) The program data address bus uses _____ bits.

(j) Data transfers in the C5510 normally use units of _____ bits.

8. The C5510 has three address spaces. These are named

   (a)

   (b)

   (c)

9. DARAM supports _____ simultaneous memory accesses per CPU cycle.

10. SARAM supports _____ simultaneous memory accesses per CPU cycle.

11. Are instructions in the C5510 fixed in length or varying in length depending on the instruction?

12. The C5510 supports how many *forms* of parallel instructions?

13. The hardware registers in the C5510 such as the accumulators have dual nature. They can be identified by name as part of an instruction and they can be accessed as if they were located in memory. The term "_____ registers" reflects this dual nature.

14. The auxiliary registers play a very similar role at the assembly language levels as do _____ in C.

15. In the C5510 there are how many

   (a) auxiliary registers? _____

   (b) accumulators? _____

   (c) status registers? _____

(d) stack pointers? _____

(e) temporary registers? _____

16. What is the purpose of the FRCT bit in status register 1?

17. The TI assembler uses special characters as a short hand notation. Which of @, #, * and $

(a) denote the use of a literal constant? _____

(b) denote the value of the current section counter? _____

(c) works as in C to de-reference a pointer? _____

(d) denotes data pointer or stack relative addressing? _____

18. What does the following instruction do?

```
mov uns(saturate(ac0)), dbl(*ar3)
```

19. Given the values, c(ar0h)=1 (i.e., the content of register ar0h has value 1) and c(ar0)=0xFFFF what are the values in registers ar0h and ar0 after executing an instruction which uses the following addressing mode, for example `mov *ar0+<<16,ac0`.

20. The name of the C5510 small memory model runtime support library is

21. In a very early lab exercise you used the CPLD register `user_reg` to gain access to the _____`s` and the _____`s`.

22. A waveform is sampled using a sample rate of 8 kHz. How many samples are required in order to have a frequency spacing of 2 Hz in the DFT of the sample set?

23. When operating under interrupts we had to use a C keyword to tell the C optimizer that a particular variable will "magically" change value and that it should not optimize it out of existence because we never explicitly change its value. That keyword was _____.

24. The C compiler divides its use of memory into named functional sections. What what are the following sections used for?

    - `.text`
    - `.bss`
    - `.cinit`

25. Which McBSP channels on the C5510 are normally dedicated on the DSK for use with the AIC23 CODEC?

26. Code composer supports two linkers. These are the visual linker and the _____ linker.

27. The C5510 possesses a significant amount of on-chip memory. There approximately _____ 16-bit words total. Of this there are 8 blocks of _____ words each of DARAM and 32 blocks of _____ words each of SARAM.

28. The Code Composer Studio C compiler uses how many bits for

    - `char`
    - `int`
    - `long`
    - `float`
    - `double`

29. In C where are automatic (local) variables placed (exist)?

30. In lecture six uses of the C stack were given. List four.

    (a)

    (b)

    (c)

    (d)

31. How does a called function know where to return when it has finished executing?

32. A major problem when using stack pointer relative addressing is the largest offset size supported in the C5510 instruction set. This places severe limitations on how much can be placed onto the stack. The offsets to the stack pointer are restricted to be in the range _____ to _____ decimal (inclusive).

33. The C5510 C system prefers to pass arguments and return values on the stack or in registers?

34. When writing in assembly language what character must be the first character in a address label or variable name in order for C to be able to see it?

35. When studying how one might write their own arctangent function a common iterative method was used to compute $1/a$ where $0.5 \leq a < 1$. This method is known as the " _____ method".

36. How many external amplifiers are used to buffer the analog input and output signals connected to the AIC23 CODEC?

37. The USB hardware on the C5510 DSK is used to provide the clock used by the AIC23. The frequency of this reference clock is _____ MHz.

38. The word size that we normally used with the AIC23 for A/D and D/A conversion was _____ bits.

39. The lowest sample rate that AIC23 can be commanded to use is _____ kHz and the highest sample rate is _____ kHz.

40. What do the following instructions do? i.e, what get moves where and what are the affected register contents afterwards?

Word Address	Memory Contents
⋮	⋮
0x000006A5	0
0x000006A6	1
0x000006B7	2
0x000006A8	3
⋮	⋮

Figure 2: Memory map

(a)
```
MOV #3, T0
```

(b)
```
MOV #0x000006A5, AR1
MOV *+AR1, T1
```

(c)
```
MOV #0x000006A5, AR1
MOV *AR1(#2), T1
```

(d)
```
MOV #0x000006A5, AR1
MOV #3, T0
MOV *(AR1+T0), T1
```

41. When setting up the AIC23 CODEC for data conversion the SPI protocol is used. Which of the C5510 or the AIC23 is the master in this operation.

42. When moving data back and forth between the C5510 and the AIC23 which is responsible for controlling the data transfer timing?

43. Does testing a program and not encountering any problems demonstrate the non-existence of bugs?

44. We say that $h(\ )$ is *linear* if

45. We say that $h(\ )$ is *time invariant* if for $y(t) = h[x(t)]$ we have

46. We say that $h(\ )$ is *causal* if

47. For a discrete time system that is said to be stable what does this imply about the locations of the poles *and* of the zeros in the z-plane.

48. Given following input/output discrete time relation

$$\begin{aligned} y[n] &= b_0x[n-0] + b_1x[n-1] + \cdots + b_Mx[n-M] \\ &\quad -a_1y[n-1] - a_2y[n-2] - \cdots - a_Ny[n-N] \end{aligned}$$

Write the expression for associated transfer function $H(z) = \dfrac{Y(z)}{X(z)}$.

49. Over what path in the z-plane do we calculate the frequency response of a discrete time filter?

50. The frequency response of a discrete time filter as a function of f and f_s is calculated using values of $H(z)$ evaluated at

$$z =$$

51. The transfer function of a moving average having unit value coefficients

$$H(z) = 1 + z^{-1} + z^{-2} + \cdots + z^{-(N-1)}.$$

forms a geometric series and can be written in closed form as

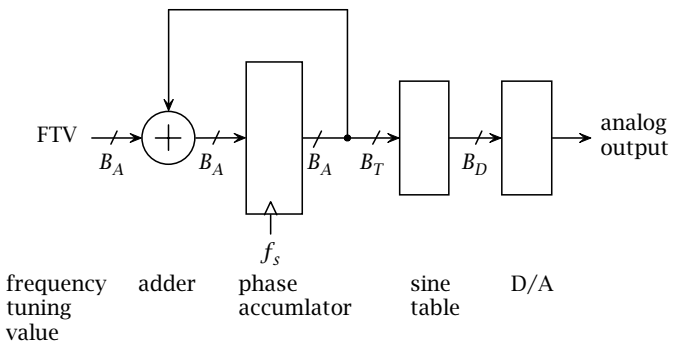
$$H(z) =$$

52. Using Horner's method rewrite

$$a_4x^4 + a_3x^3 + a_1x^1 + a_0 =$$

This rearrangement makes evaluating polynomials fairly efficient

53. We can easily implement a variable frequency waveform synthesizer using a fixed frequency source, register, adder and read-only-memory.



Consider use of a 18-bit FTV, register (phase accumulator) and adder, a 2 MHz update clock (f_s) and a ROM containing 256 samples of one period of a sine waveform. What

(a) is the smallest smallest frequency change that can be made in the analog output, in Hz.

(b) is the value of FTV that you would use to generate, as close as possible, a 5100 Hz output.

54. You are given a digital filter described using a biquadratic transfer function of the form

$$H(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

and a sample rate of f_s Hz.

(a) What is the value of $H(z)$ at 0 Hz?

Evaluating $H(z)$ at $f = 0$ is useful for determining the 0 Hz filter gain for a lowpass filter.

(b) What is the value of $H(z)$ at $f_s/2$ Hz?

Evaluating $H(z)$ at $f = f_s/2$ is useful for determining the $f_s/2$ filter gain for a highpass filter.

55. We are (or should be) very familiar writing decimal values using positional notation. The same can and is done using binary weights in place of powers of ten.

    A B-bit binary number is an ordered sequence of zero and one values:

    $$(b_{B-1}, b_{B-2}, \cdots, b_1, b_0).$$

    (a) For unsigned binary numbers what is the weight associated with bit b_{B-2}? _____

    (b) For unsigned binary numbers what is the weight associated with bit b_{B-1}? _____

    (c) For two's complement binary numbers what is the weight associated with bit b_{B-2}? _____

    (d) For two's complement binary numbers what is the weight associated with bit b_{B-1}? _____

56. Given hardware designed *specifically* for unsigned binary addition and for multiplication. Would either, neither or both produce proper results when working with two's complement values?

57. When we add two binary numbers and the result will not properly fit in the word size available the result is said to have _____.

58. Sometimes it is decided that large values exceeding the chosen word size are so rate that if they occur they will be replaced with the corresponding largest positive or negative value that will fit in that word size. This process is termed _____.

59. The two's complement of a B-bit number can ge formed by complementing all of the bits and _____.

60. What is the two's complement overflow property?

61. In order for a filter to have constant group delay over a range of frequencies its phase response must

62. (10 pts) Write the equations that define the discrete Fourier transform (DFT) and the inverse discrete Fourier transform (IDFT). Do not use the letter W in your answer.

    Forward transform:

    Inverse transform:

63. (8 pts) I have a data set of 500 sample values of a 1000 Hz sinewave. These were obtained using a sample rate of 8 kHz. Using MATLAB I take the DFT with the result being in the `X` array. I use `X=fftshift(X)` to reposition the data.

    (a) What is the frequency in Hz associated with the `X(1)` value ?

(b) What is the frequency in Hz associated with the `X(500)` value?

64. (8 pts)

Assume use of a 16-bit computer word. Given the binary bit pattern:

1111 0010 0000 0000

(a) what is the value if we interpret this an unsigned integer?

(b) what is the value if we interpret this as a two's complement integer?

(c) what is the value if we interpret this as a Q8 unsigned integer?

(d) what is the value if we interpret this as a Q15 two's complement value?

65. (12 pts) When writing hand optimized functions for use by C we need know the calling conventions used by the C compiler. The IIR functions that were used in lab used a call of the form:

```
short iircas5(DATA* x, DATA* h, DATA* r, DATA* db, ushort nh, ushort nx);
```

There are 6 parameter values that are passed. Specify the C5510 registers in which they are passed:

(a) `*x`

_____

(b) `*h`

_____

(c) `*r`

_____

(d) *db

_____

(e) nh

_____

(f) nx

_____

66. (16 pts) We have a symmetric FIR digital filter that theory indicates has a delay of 96 sample times. The sample rate is 48000 Hz. The nominal center frequency of the filter is 1500 Hz.

(a) A transfer function measurement, magnitude and phase, is made over the range of frequencies from 750 Hz to 2250 Hz. Sketch the phase as it would be measured in cycles over this frequency range. Use a vertical axis going from -1/2 cycle to +1/2 cycle. Assume that the measured phase at 1500 Hz is 0 cycles.

(b) Indicate the values of phase that would be measured at 1125 Hz, 1500 Hz, and 1875 Hz. If only the measurements made at these three frequencies were used to form an estimate of the group delay what would be the estimated group delay?

67. (10 pts)

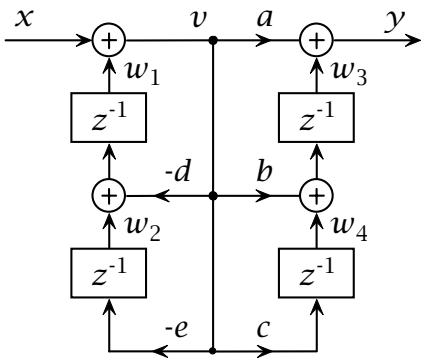


Figure 3: A filter section.

Draw the block diagram of the transposed version of the filter section shown in Figure 3.

68. (6 pts)

(a) For "simple" oversampling A/D converter how many bits of equivalent performance are obtained per each doubling of the input sample rate? By equivalent performance I mean how many additional bits (perhaps fractional) would need to be added to a "normal" A/D converter in order to provide the same quantization noise to signal signal-to-noise ratio.

(b) For the first order sigma-delta A/D converter how many bits of equivalent performance are obtained per each doubling of the input sample rate?

(c) For the second order sigma-delta A/D converter how many bits of equivalent performance are obtained per each doubling of the input sample rate?

69. (4 pts) The quantization error of the output of an amplitude quantizer was modelled as being uniformly distributed. Using this assumption an expression was derived that related the variance, σ_e^2, of the quantization error to the quantizer step size, Δ. What was this relation?

$$\sigma_e^2 =$$

70. (6 pts) Several times this semester the equation form of Parseval's theorem for the DFT was encountered, both in homework and in lecture. Write down the equation that describes Parseval's theorem and indicate whether what you wrote corresponds to the standard definition of the DFT or to the alternate form that I claim to prefer.

71. (4 pts) The transfer function of a biquad section is

$$H(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}.$$

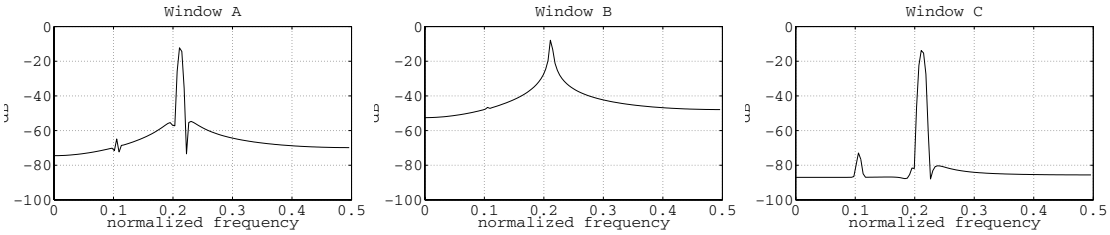
To have a stable filter section there are limits which the a_1 and a_2 values must meet (not necessarily simultaneously). These are:

$$< a_1 <$$

and

$$< a_2 <$$

72. (6 pts) In the realtime FFT lab exercise we used three window functions to demonstrate the use of windowing to reduce leakage. The above figure shows the effects that each window has on the same data set. The names of these three windows are:



(a) Window A:

(b) Window B:

(c) Window C:

73. (10 pts) What is the transfer function of the filter shown in Figure 4?

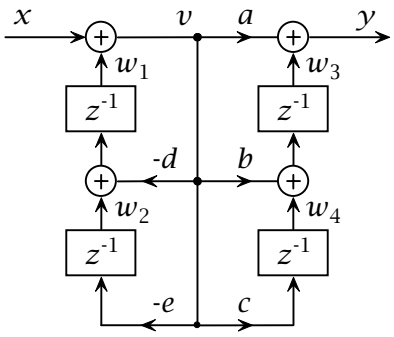


Figure 4: Filter block diagram.

74. (8 pts) If we multiply a 16-bit Q14 format number by a 16-bit Q12 number on the TI C5510 with the FRCT bit set to 1.

    (a) The result in the high-low portion of the accumulator is a 32-bit Qn number. What is the value n?

    (b) The result is moved from the high word of the accumulator. What is the Qn value for the moved 16-bit value?

75. (8 pts) In laboratory exercise 7 we use a 32-bit FFT code from the TI DSPlib. This code does not scale its results (i.e., the 1/N is associated with the inverse transform). The sample rate is 48000 Hz and the FFT size is 1024 values. The display (positive frequencies) shows a single line in fft bin (at fft index counting starting at 0) 256 with amplitude 262144. A 16-bit A/D converter was used for the data source and was calibrated so that a value of 2^{15} corresponds to 1.0 Volts.

    (a) What was the frequency in Hz of the sine wave that was sampled?

(b) What was the peak amplitude of the sinewave in volts?

76. The bit map of clock mode register, CLKMD, is shown in Figure 5. Assume that the input clock to the C5510 is 48MHz:

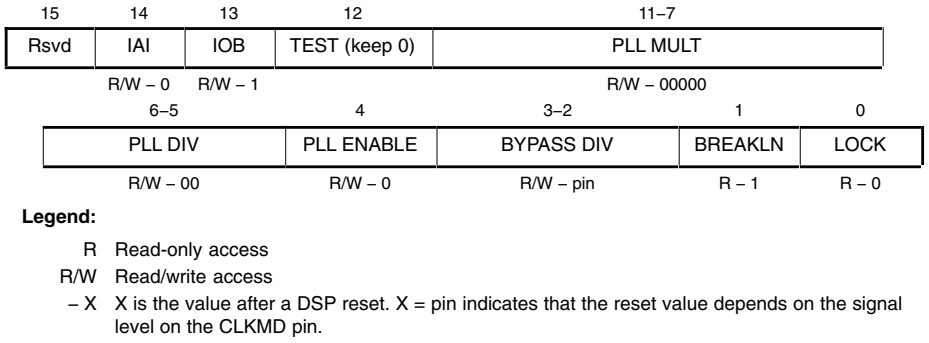


Figure 5: Clock mode register bit usage.

$$\text{Ouput frequency} = \frac{\text{PLL MULT}}{(\text{PLL DIV} + 1)} \times \text{Input frequency}$$

(a) If CLKMD=1 1 1 1 00110 01 1 00 0 1, what is CPU clock rate? _____ MHz

(b) If we want to generate a CPU clock rate of 80 MHz, change the necessary bits in CLKMD. The new CLKMD = _____

77. We use the same DSK to implement same filter with DF2 and TDF2 implementations.

Suppose we ran the TDF2 implementation first, and we found that the maximum input peak-peak voltage we can avoid overflow problem at all frequencies is 4 Volts. Now we run DF2 implementation.

What is the maximum input peak-peak voltage that can avoid overflow at all frequencies?

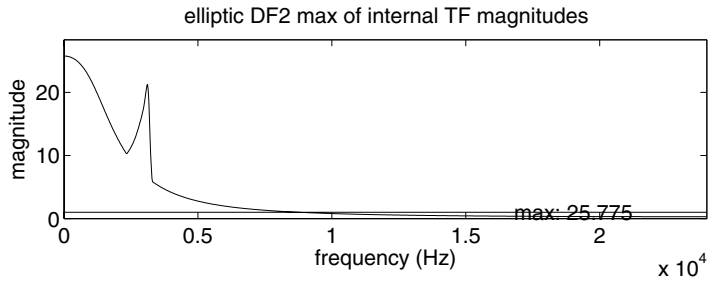


Figure 6: Across stage maxima for direct form 2 elliptic filter implementation.

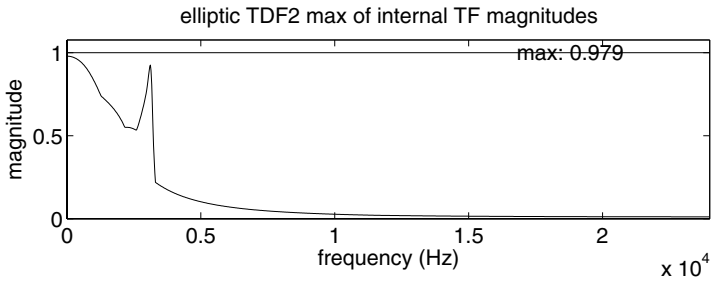


Figure 7: Across stage maxima for transposed direct form 2 elliptic filter implementation.

The maximum safe (no overflow or saturating) input is _____ Volts

78. (10 pts) Figure 8 shows the block diagram of a delta-sigma A/D converter that uses a first order loop. What are the expressions that describe the transfer functions $Y(z)/X(z)$ and $Y(z)/E(z)$?

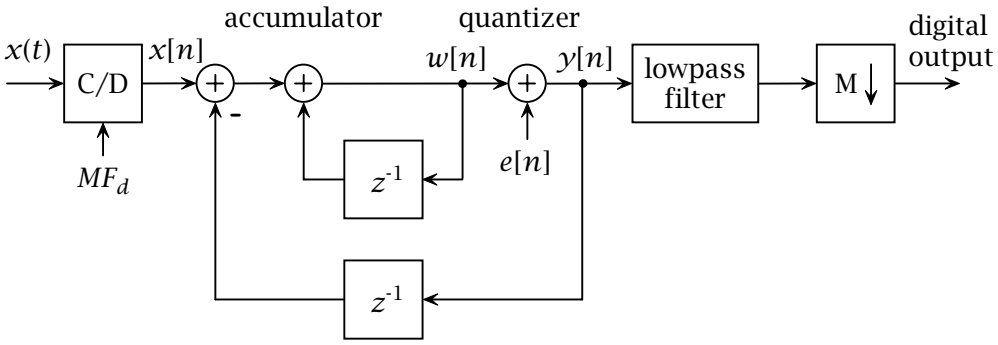


Figure 8: Delta sigma A/D converter using a first order loop.