Midterm — November 7, 2007

Write out and sign the honor pledge:

Unless otherwise indicated, multiple part questions have the shown points split uniformly between the parts.

1. (2 pts) Print your name on *each and every* sheet.
2. (8 pts) Write down the equations for the forward and inverse Discrete Fourier Transform. Indicate which is which. Use the "standard" definitions.

3. (8 pts)

   Relate the frequency spacing Δf between FFT values to: the sample rate f_s, the number of samples N in a data set, and the sample set duration T?

   _____

4. (2 pts each)

   The following questions deal with the TI hardware and software tools.

   (a) What McBSP channel is used to communicate with the Spartan-3? _____

   (b) What McBSP channel is used to move samples between the C5510 and the AIC23? _____

(c) How many A/D channels does the AIC23 support? _____

(d) The analog line input to the AIC23 has a nominal gain of? _____

(e) How many bits are there in a C5510 C char? _____

(f) How many bits are there in a C5510 unsigned int? _____

(g) How many bits are there in a C5510 long? _____

(h) How many bits are there in a C5510 float? _____

(i) How many bits are there in a C5510 double? _____

(j) What is the name of the linker section used by the C compiler to place the executable code? _____

(k) What is the name of the linker section used by the C compiler to place uninitialized data values? _____

(l) What is the maximum possible number of values in an array of integers? _____

(m) What is the entry needed to specify the processor version to the C compiler? _____

(n) The file extension of the file used to specify the memory organization to the linker is? _____

(o) The C5510 has how many 16-bit words contained on-chip? _____

(p) The C5510 stack grows toward the higher or the lower memory addresses? _____

(q) The C5510 possesses how many temporary registers? _____

(r) The C5510 possesses how many accumulators? _____

(s) The C5510 possesses how many auxiliary registers? _____

(t) The C5510 possesses how many status registers? _____

(u) The name of the manufacturer of the C5510 is? _____

5. (4 pts each)

When allocating storage in assembly language for a long it is important to insure that the allocation is made on a proper address boundary. For the `.bss` section the syntax to be used is:

```
label, n, m, o
```

What are roles of:

(a) `label`

(b) `m`

(c) `n`

(d) `o`

6. (4 pts each)

Part of a text linker file for the C5510 program is given as the following:

```
...
MEMORY
{
  PAGE 0:      /* ---- Unified Program/Data Address Space ---- */
    MMR_RSVD      : origin = 0x000000, length = 0x0000BF /* 192 bytes MMR reserved */
    VECT   (RWIX) : origin = 0x000100, length = 0x000100 /* 256 byte interrupt vector */
    DARAM  (RWIX) : origin = 0x000200, length = 0x00FD00 /* almost 64KB of DARAM */
    SARAM0 (RWIX) : origin = 0x010000, length = 0x010000 /*   64KB of SARAM */
    SARAM1 (RWIX) : origin = 0x020000, length = 0x020000 /*  128KB of SARAM */
    SARAM2 (RWIX) : origin = 0x040000, length = 0x010000 /*   64KB of SARAM */
    /* SDRAM has 0xB0000 37776 KB of SDRAM .. notall  allocated here */
    SDRAM0 (RWIX) : origin = 0x050000, length = 0x010000 /*   64KB of SDRAM */
    SDRAM1 (RWIX) : origin = 0x060000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM2 (RWIX) : origin = 0x080000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM3 (RWIX) : origin = 0x0A0000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM4 (RWIX) : origin = 0x0C0000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM5 (RWIX) : origin = 0x0E0000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM6 (RWIX) : origin = 0x100000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM7 (RWIX) : origin = 0x120000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM8 (RWIX) : origin = 0x140000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM9 (RWIX) : origin = 0x160000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM10(RWIX) : origin = 0x180000, length = 0x020000 /*  128KB of SDRAM */
    SDRAM11(RWIX) : origin = 0x1A0000, length = 0x020000 /*  128KB of SDRAM */
    FLASH         : origin = 0x400000, length = 0x80000
    VECS (RIX)    : origin = 0xffff00, length = 0x000100 /* 256-byte int vector*/
}
...
     SDRAMA     > SDRAM0  PAGE 0   /* 32K word page */
     SDRAMB     > SDRAM1  PAGE 0   /* 64K word page */
     SDRAMC     > SDRAM2  PAGE 0   /* 64K word page */
     SDRAMD     > SDRAM3  PAGE 0   /* 64K word page */
     SDRAME     > SDRAM4  PAGE 0   /* 64K word page */
     SDRAMF     > SDRAM5  PAGE 0   /* 64K word page */
     SDRAMG     > SDRAM6  PAGE 0   /* 64K word page */
     SDRAMH     > SDRAM7  PAGE 0   /* 64K word page */
     SDRAMI     > SDRAM8  PAGE 0   /* 64K word page */
     SDRAMJ     > SDRAM9  PAGE 0   /* 64K word page */
     SDRAMK     > SDRAM10 PAGE 0   /* 64K word page */
     SDRAML     > SDRAM11 PAGE 0   /* 64K word page */
...
```

(a) How to assign an array named "my_array" to the memory location SDRAM7 in a C program? Write down the line(s) of code for this task.

(b) What is the addressing mode (# of bits) used in the text linker file?

7. (2 pts each)

Function fn was written in assembly and called by C. The prototype of fn is:

```
void fn(int i1, int i2, int *p3, int *p4, int i5, int *p6, long l7, long l8);
```

Specify the C5510 registers that store the following values:

(a) (1pt) `i1` _____

(b) (1pt) `i5` _____

(c) (1pt) `p6` _____

(d) (1pt) `l8` _____

8. (2 pts each)

What do the following abbreviations stand for?

(a) DFT _____

(b) FFT _____

(c) DDS _____

(d) FPGA _____

(e) DSP _____

(f) CODEC _____

(g) McBSP _____

9. (2 pts each)

The following questions deal with the Xilinx hardware and software tools.

(a) Then nominal equivalent number gates on the Spartan-3 used in lab is? _____

(b) The number of bits in a Block Ram is? _____

(c) What is the file extension used by the file that maps signals into physical pins? _____

(d) The name of the manufacturer of the Spartan-3 Starter Board is? _____

10. (2 pts each)

When working in VHDL we divide up a design into logical units called *entities*. In a sense these are the logic design equivalents of software functions.

(a) The purpose of the _____ portion of an entity is to define and make externally visible signals/connections.

(b) The purpose of the _____ portion of an entity is to define internal signals and to describe how these are used to accomplish the purpose(s) of the entity.

(c) Within an entity sequential statements need to be placed into a section coded called _____.

11. (4 pts)

In laboratory Exercise 4, a level-shifting circuit was built as an interface between the signal generator and the A/D PMod module used on the Spartan-3 Starter Board. Why was this necessary?

12. (2 pts each)

(a) The technical name for the norm that we used to check for overflow in our IIR filter design is _____

(b) The numerical method that we used with the arctangent to approximate the reciprocal is _____

(c) The window used in lab that gave the best performance allowing us to view low level signals was _____

(d) There are how many types of FIR filters that yield linear phase? _____

13. (8 pts)

The key property of linear system that we almost constantly exploit is:

14. (4 pts)

    Point by point multiplication of two equal size DFTs corresponds to what in the time domain?

15. (8 pts)

    A DDS is used to generate samples of cosine and sine waveforms for use in an I/Q modulator. The radio system this is to be used in is to at least tune the frequency range from 100 kHz through 80 MHz in less than or equal to 0.1 Hz steps. The clock rate used to generate sample values is 200 MHz. Assuming a binary phase accumulator what is the smallest number bits, N, used in the accumulator that will accomplish this?

    Recall that $\log_a(x) = \log_b(x)/\log_b(a)$.

16. (4 pts each)

    An amplitude 1000 sine wave data set is generated using MATLAB. The frequency is 125 Hz. The sample rate is 16000 Hz. The MATLAB function `fft` is used to take the DFT of a 4096 sample data set.

    For the resulting output what is

    (a) The frequency spacing between adjacent array values in Hz?

    (b) The MATLAB index associated with +125 Hz.

(c) The MATLAB index associated with -125 Hz.

_____

(d) The magnitude (`abs( )`) of the largest value.

_____

17. (4 pts)

If the waveform used in the above problem has phase angle θ what is the magnitude of the difference in angle between the -125 Hz and +125 Hz lines in the FFT output?

_____

18. (4 pts)

The main cause of spectral leakage in a DFT output is?

19. (8 pts)

Use MATLAB's `linspace` to generate 1024 samples of three periods of a sinusoid. (Can be more than one line of MATLAB script.)

20. (2 pts each)

Assume the use of a B-bit word size.

(a) What is the value of the largest unsigned integer value that can be represented?

(b) What is the value of the largest positive two's complement integer value that can be represented?

(c) What is the value of the most negative two's complement integer value that can be represented?

(d) What is the value of the largest unsigned Q(B-1) value that can be represented?

(e) What is the value of the largest positive Q(B-1) value that can be represented?

(f) What is the value of the most negative two's complement Q(B-1) value that can be represented?

21. (4 pts each)

What are the two major reasons to implement filters using biquad cascades?

22. (4 pts each)

Regarding the Direct Form 2 (DF2) and the Transposed Direct Form 2 (TDF2) filter implementations:

(a) What is the major advantage that, for our implementation, the TDF2 had over the DF2?

(b) Which implemented (code efficiency) the easiest?

23. (10 pts)

Complete the inner loop for implementing a simple DDS. The frequency to be generated should be 2000 Hz. The sample rate is 48000 Hz. The values are moved by an interrupt handler (not shown) from the `sinval` and `cosval` registers to the AIC23. The interrupt handler sets the value of `adflag` to 1 whenever a new value is needed. You can hard code the FTV value. Use the back of the preceding page if you would like to have more working space.

```
extern int volatile adflag, volatile sinval, volatile cosval;
unsigned long paccum, ftv;
long *sinetable=(0xFFFA00>>1); // ROM sine table address

void main(void)
{
    int forever =1;
    unsigned long ftv, ultemp;

    paccum = 0;
    ftv = 178956971;   // round((2^32)(f=2000) /(fs=48000)+0.5);
    while(forever != 0) {
        . if (adflag != 0) {
        .
        .
        .
        .
        .
        .
        }
    }
}
```

24. (10 pts)

To implement the equation $c = (a + b)/2$ in FPGA using VHDL, will the following piece of code work? If not, why? and how do you fix the problem? Assume two's complement arithmetic is used.

```
...
    signal a : std_logic_vector(15 downto 0);
    signal b : std_logic_vector(15 downto 0);
    signal c : std_logic_vector(15 downto 0);
    signal temp_a : std_logic_vector(15 downto 0);
```

```
    signal temp_b : std_logic_vector(15 downto 0);
...
    temp_a(14 downto 0) <= a(15 downto 1);
    temp_b(14 downto 0) <= b(15 downto 1);
    c <= temp_a + temp_b;
...
```

25. (4 pts each)

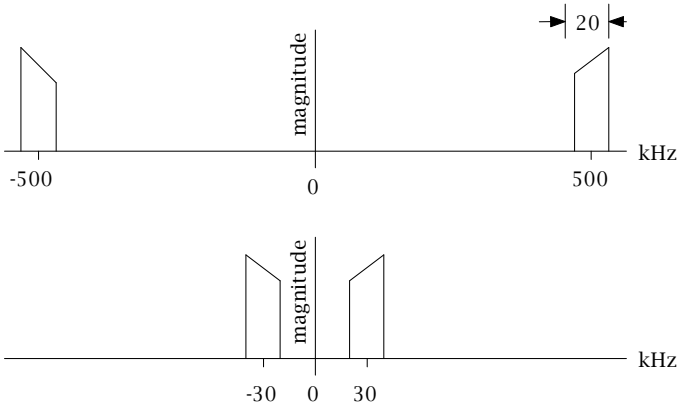

Figure 1: Before and after sampling spectra. Top: unsampled. Bottom: after sampling. Not to scale.

Aliasing can be used to frequency shift the spectrum of a bandpass waveform from higher to lower frequencies. For the spectra before sampling (top) and after (bottom) shown in Figure 1 what is:

(a) the highest sampling rate (if any) that will yield the bottom spectrum?

(b) the lowest usable sampling rate (if any) that will yield the bottom spectrum?

26. (8 pts)

The Fourier series representation of a triangle wave is given by

$$x(t) = \frac{8}{\pi^2} \sum_{k=1}^{\infty} \sin\left(\frac{k\pi}{2}\right) \frac{\sin(2\pi k f_o)}{k^2}$$

where $f_o = 330$ Hz is the frequency of the signal. The signal is sampled at $f_s = 10$ KHz and then passed through an ideal lowpass filter with unit gain in the passband and cutoff frequency 1000 Hz. Take the DFT with size $N = 1000$ and $\frac{1}{N}$ in the forward transform of the filter output samples. Sketch the DFT output (spectrum) with proper labeling of the frequency and amplitude.

27. (8 pts)

One of the problems with the sampling scheme in the previous problem is that, after aliasing, if one wants the positive frequency component to end up being centered at 0 Hz (a common need in communication system design) the negative frequency component is also centered at 0 Hz.

An alternative sampling method, termed quadrature sampling, effectively multiplies samples of the received waveform by samples of $e^{-j2\pi f_c/f_s}$ where f_c is the frequency that is to be shifted to 0 Hz and $f_s = 4f_c$. The values of the complex exponential that are used are: $1, -j, -1, j, 1, -j, \ldots$. The sample rate can be reduced by an integer factor R until the positive and frequency components again overlap. What is the largest R value and the associated sampling rate that can shift the positive component in Figure 1 to be centered at 0 Hz without spectral overlap with the negative frequency component?

28. (4 pts)

When implementing the CORDIC algorithm iterations the first four angle step sizes in degrees are (round to tenths of a degree):

29. (4 pts each)

Why are *anti-alias* and *anti-image* filters used?

30. (8 pts)

Write the definition of group delay indicating the units involved:

31. (4 pts each)

There were three methods shown in lecture describing how one can use a DFT to take the inverse DFT. Given a set of samples $x[n], n = 0, 1, 2, \ldots, N-1$ write the corresponding DFT as $X[k], k = 0, 1, 2, \ldots, N-1$.

Write the equations for the two methods that I indicated in lecture that are particularly easy to implement for using the DFT to determine the $x[n]$ values given the $X[k]$ values. Use the notation DFT( ) rather than writing out the summations.

32. (4 pts)

The *overlap-and-save* method is a means of computing the outputs of a P-stage FIR filter using a N value FFT. How many filter output values are generated per FFT iteration (assume that $N > P$)?

33. (8 pts)

What is the transfer function of the filter shown in Figure 2?

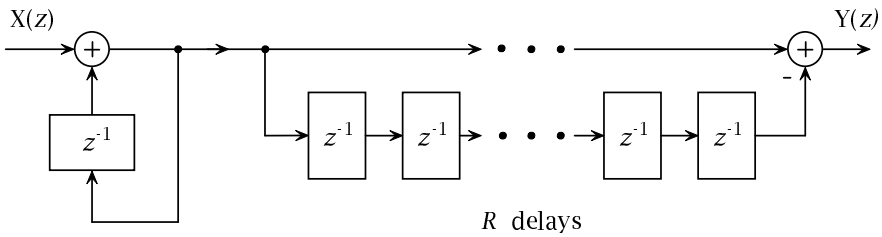

Figure 2: Filter block diagram.

34. (2 pts each)

For the IIR lab exercise we considered the use of four filter types offered us by MATLAB.

(a) Which filter type (name) did we not use because it required an excessive number of poles?

_____

(b) Which filter type (name) has equiripple only in the passband?

_____

(c) Which filter type (name) has equiripple only in the stop band?

_____

(d) Which filter type (name) has equiripple in both the passband and the stopband?

_____

(e) Which filter type (name) has the smallest transition band for a given order?

_____

(f) Which filter type (name) has the maximally flat passband?

_____

35. (8 pts)

Figure 3 shows the pole and zero locations for a Elliptic filter design similar to the one we used for the IIR lab exercise. The letters `a` through `d` identify the upper half pole pair positions and the letters `r` through `u` identify the upper half plane zero pair positions.

To implement our cascade of biquad sections we followed some commonly accepted guidelines regarding matching poles and zeros and ordering the resulting sections.

(a) Which zero pairs should be paired with which pole pairs to form biquad sections?

(b) When cascading biquad sections how should the sections be ordered going from the filter input to output? Identify the sections using the letters identifying the poles.

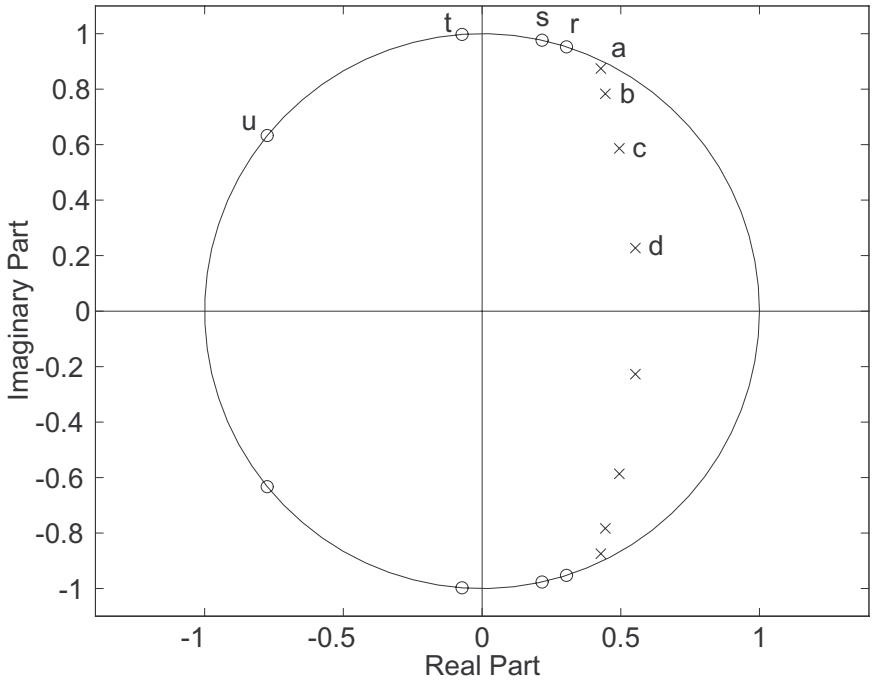

Figure 3: Elliptic filter pole-zero locations in the z-plane.

36. (2 pts each)
Laboratory Exercise 6 focused on IIR filter implementation.

(a) What Q format did we use in our program to denote the biquad coefficients?

(b) Why did we divide the coefficients a_1 and b_1 of biquad sections by 2?

(c) What is the major problem of TI's iircas5.asm compared to our MyDF2IIR.asm?