Midterm — March 26, 2003

Write and sign the honor pledge.

1. (2 pts) Print your name on *every* sheet.
2. (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:

3. (10 pts) I have a set of N consecutive samples of a waveform. The sample rate is f_s. I form the DFT and use `fftshift` to reorder the samples so that they go from the most negative analysis frequency to the most positive. Write the line of code that you would use in MATLAB to generate an array of frequencies associated with the reordered DFT values. Use the variable `fs` to represent the sample rate and the variable `N` to represent the number of values in the data set.

4. (10 pts) I have a data set of 700 sample values of a 1000 Hz sinewave. These were obtained using a sample rate of 7 kHz. I copy the values into a new array placing 3 zero values after each of the original values. The new array contains 2800 values. I use the FFT to take the DFT of the 2800 value data set. I next use MATLAB's `fftshift` to place the zero Hz analysis frequency near the center of the array. Sketch the spectrum identifying, by value, the frequencies (Hz) where there are non-zero spectrum values.

5. (5 pts) I have a data set of 700 sample values of a 1000 Hz sinewave. These were obtained using a sample rate of 7 kHz. I append 2100 zero values to this array. The new array contains 2800 values. I use the FFT to take the DFT of the 2800 value data set. I next use MATLAB's `fftshift` to place the the zero Hz analysis frequency near the center of the array. What is the frequency step size in Hz between adjacent values in the array?

6. (10 pts) Briefly state what each of the following MATLAB functions and tools do or are used for.

   (a) `freqz`

   (b) `tf2sos`

(c) `zplane`

(d) `grpdelay`

(e) `FDAtool`

7. (8 pts)

   (a) Write a line of MATLAB script that uses `kron` to take the vector [1 2 3 4] and create the vector [1 0 0 2 0 0 3 0 0 4 0 0].

   (b) Write a line of MATLAB script that uses `kron` to take the vector [1 2 3 4] and create the vector [1 1 1 2 2 2 3 3 3 4 4 4].

   (c) Write a line of MATLAB script that uses `kron` to take the vector [1 2 3 4] and create the vector [1 2 3 4 1 2 3 4 1 2 3 4].

   (d) Write a line of MATLAB script that uses `kron` to take the vector [1 2 3 4] and create the vector [1 2 3 4 0 0 0 0 1 2 3 4].

8. (8 pts) Frequently binary values obtained using a B-bit A/D converter are placed in the most significant bits of a word. Often A/D values are represented as two's complement integers (and if they aren't we generally do whatever is necessary in order to make them so).

Assume use of a 16-bit computer word and a 12-bit A/D converter.

If we place a 12-bit sample value having bit pattern F00 (a hexadecimal number) into the low bits of the computer word

(a) what would be the decimal value we would be representing if we interpret the result as being in $Q15.0$ format?

(b) as being in $Q0.15$ format?

If we have a sample value having bit pattern F00 (a hexadecimal number) and place these 12 bits into the top most significant bits of our computer word (essentially changing it into the pattern F000)

(a) what would be the decimal value we would be representing if we interpret the result as being in $Q15.0$ format?

(b) as being in $Q0.15$ format?

9. (5 pts) On the Motorola DSP56303

   (a) if we multiply a $Q5.18$ value by a $Q0.23$ and discard the lowest 24 bits. What are the values of m and n in the $Qm.n$ description of what remains?

10. (14 pts) The Motorola DSP56303 has a number of addressing modes. Given the contents of R1 = 106, N1 = 15 and M1 = \$FFFF

    - what are the effective source value memory addresses for each of the following instructions?
    - what is the value contained in R1 following the execution of each instruction?

Note that each instruction is being considered stand alone. We are not considering consecutive execution.

```
move  x:(R1),x0

move  x:(R1)+N1

move  x:(R1+2),x0

move  x:-(R1),x0

move  x:(R1)+,x0

move  x:(R1-N1),x0

move  (R1)+
```

11. (4 pts) The C5402 Smem instruction class uses a bit (i) to distinguish between direct stack relative addressing and indirect addressing using the auxiliary registers. Figure 1 shows the basic instruction organization.

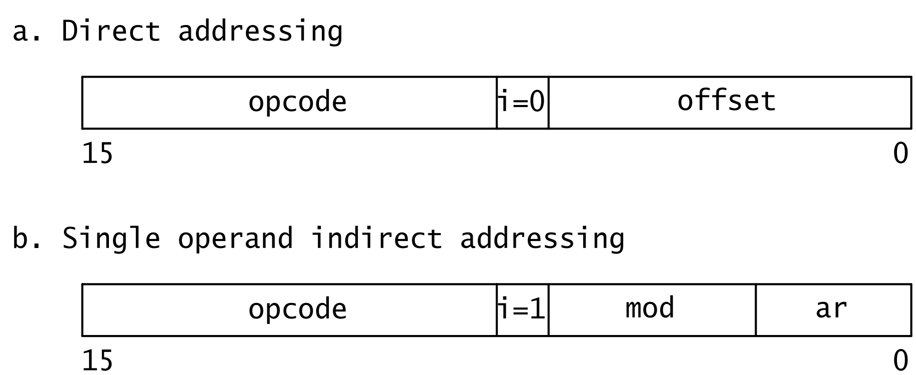

Figure 1: C5402 Smem bit usage.

(a) How many bits are available to specify the instruction?

(b) How many indirect addressing modes are available?

12. (9pts) During the semester we designed IIR filters based on analog prototypes. To do this we used MATLAB's FDAtool. FDAtool offers a choice of four filter prototypes. These are: Butterworth, Chebyshev type 1, Chebyshev type 2, and elliptic. These prototypes have differing transfer function characteristics in terms of monotonicity and ripple.

    For lowpass use what are the distinguishing characteristics of each prototype's transfer function?

    Butterworth
    - passband characteristic?
    - stopband characteristic?

    Chebyshev type 1
    - passband characteristic?
    - stopband characteristic?

    Chebyshev type 2
    - passband characteristic?
    - stopband characteristic?

    Elliptic
    - passband characteristic?
    - stopband characteristic?
    - transition band characteristic?

13. (10pts) We have a symmetric FIR digital filter that we suspect has a delay of 256 sample times. The sample rate is 16000 Hz. The nominal center frequency of the filter is 1500 Hz.

    (a) (8pts) What is the band of frequencies centered on the nominal center frequency, in Hz, over which the filter phase will change by 360 degrees?

    (b) (2pts) Will the phase be increasing or decreasing as the frequency increases?

14. (10 pts) 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.

15. (4 pts) Two data structure types that we made of use this semester are the first-in-first-out (FIFO) and the last-in-first-out (LIFO).

    (a) a stack is a ______

    (b) a circular buffer is a ______

16. (20pts) The block diagram shown in Figure 2 is a biquad filter section based on the normalized ladder configuration. The normalized ladder has the reputation of possessing superior performance based on the amount quantization noise cause by internal quantization (the throwing away of the least significant bits when writing values into the delay stages).

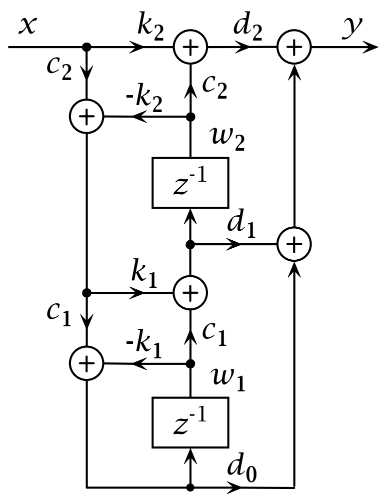

Figure 2: Normalized ladder biquad stage.

The normalized ladder coefficient values do not have a simple relationship with the coefficients of the transfer function polynomials. In compensation for this inconvenience the k and c coefficient values are bounded by ± 1.

Looking at the block diagram it is seen this is a canonical form.

(a) Write the state variable matrices, **A**, **B**, **C** and **D**, for the normalized ladder biquad section.

(b) Draw the block diagram of the transposed version of the normalized ladder biquad section shown in Figure 2.

17. (5 pts) For the first order Delta-Sigma 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.

18. (5 pts) Assume a B-bit A/D converter. The analog input voltages can go plus and minus. The converter generates digital output values using the two's complement number format.

    The most negative input analog input is $-V_m$ volts (mid-tread) and produces digital output value -2^{B-1}.

What is the voltage change (Δ) at the input that produces precisely a one count change in the digital output?

19. (5 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?

$$\sigma_e^2 =$$

20. (5 pts) Using the above result an expression was derived in lecture that relates the signal-to-noise ratio of a signal waveform and the quantization noise to the number of the bits in am amplitude quantizer.

    A change of one bit in the size of the quantizer results in a change of how many dBs in the signal-to-noise ratio?

21. (5 pts) For the direct form biquad section shown in Figure 3 what is the transfer function between the input x and the delay stage output w_4?

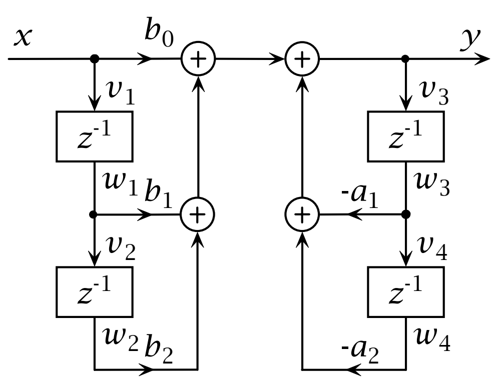

Figure 3: A direct form biquad section.

22. (10 pts) Draw the block diagram of the transposed direct form two (TDF2) biquad section. Remember to label the coefficients.

23. (5 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 $N > P$)?

24. (2 pts each)

    (a) The sample rate normally used on the DSP56303EVM CODEC is _____ kHz.

    (b) The sample rate normally used on the C5402DSK CODEC is _____ kHz.

    (c) The total on-chip memory of the DSP56303 is _____ words.

    (d) The total on-chip memory of the C5402 is _____ words.

    (e) The word size on the DSP56303 is _____ bits.

    (f) The word size on the C5402 is _____ bits.

    (g) The technical name for the norm that we used to scale for overflow in our IIR filter designs is the "_______________ norm".

    (h) The name of the SigLab program that we used in lab to measure transfer functions is _______________.

    (i) John Backus was responsible for the creation of the programming language named _______________.

(j) The ____________________ has a protected execution pipeline.

25. (6 pts) In the realtime FFT lab exercise using the DSP56303EVM we used three window functions to demonstrate the use of windowing to reduce leakage. The names of these three windows are:

(a) ____________________________

(b) ____________________________

(c) ____________________________

26. (10 pts) What is the transfer function of the filter shown in Figure 4?

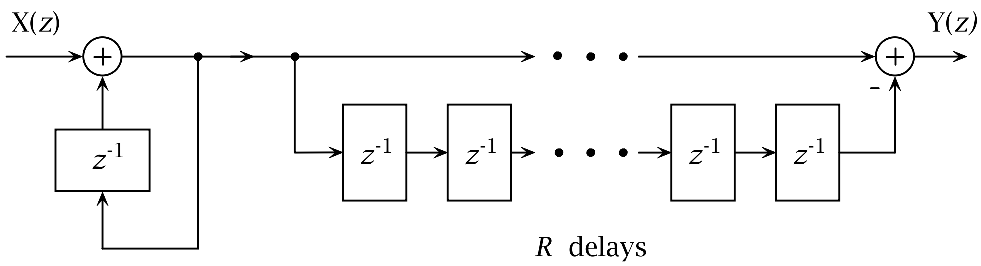

Figure 4: Filter block diagram.

27. (10 pts) For the direct digital frequency synthesizer shown in Figure 5 we have update clock, $f_s = 10^6$ Hz, accumulator bit size, B_A, of 16 bits, and sine table size of 256 values.

(a) What is the frequency tuning value, FTV, that results in an output frequency as close as possible to 1000 kHz?

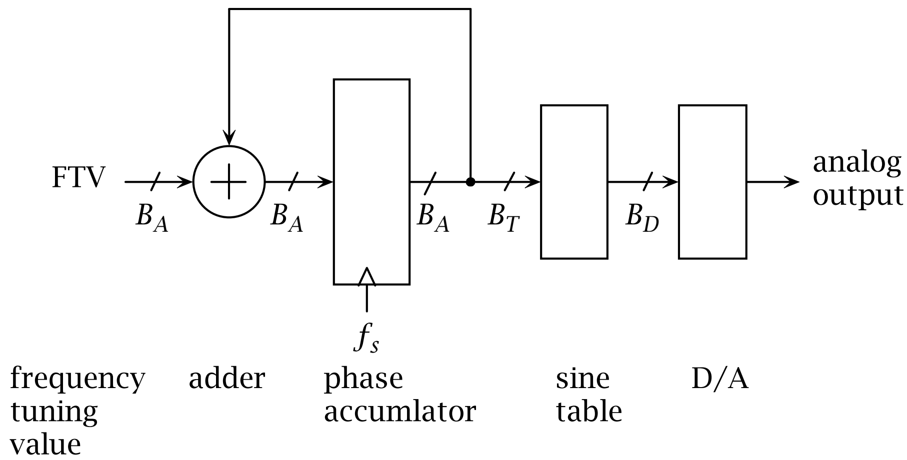

Figure 5: Direct digital frequency synthesizer block diagram.

(b) What is the smallest increment in Hz that can be made in the output frequency?

28. (8 pts) When doing arithmetic calculations using assembly language on the C5402 our results are affected by the settings of bits in the status words. What are the functions of the following bits?

(a) SXM

(b) OVM

(c) SST

(d) FRCT

29. (5 pts) What settings (0 or 1) of the SXM, OVM, SST, and FRCT bits cause the C5402 arithmetic to most closely model that of the DSP56303?

    SXM _____

    OVM _____

    SST _____

    FRCT _____

30. (6 pts) The concept of a stack is so important that TI provides a hardware stack pointer and has several instructions that make use of the stack. When developing programs and functions there are four uses of a stack that we often make. List three.

    (a)

    (b)

(c)

31. (20 pts) The C5402 possess 16 “indirect” addressing modes. These have the following syntactic forms:

a) *ARx
b) *ARx-
c) *ARx+
d) *+ARx
e) *ARx-0B
f) *ARx-0
g) *ARx+0
h) *ARx+0B
i) *ARx-%
j) *ARx-0%
k) *ARx+%
l) *ARx+0%
m) *ARx(lk)
n) *+ARx(lk)
o) *+ARx(lk)%
p) *(lk)

Match the above syntax descriptions to the following descriptions (where IA=indirect address, BR=bit reverse):

____ IA post subtract c(AR0) circular

____ pre-increment IA

____ pre-increment IA pointing to C(ARn) + lk

____ IA post decrement circular

____ use absolute memory address lk

____ IA post add c(AR0)

____ IA pointing to C(ARn) + lk

____ IA post subtract c(AR0)

____ IA post decrement by 1

____ IA post BR add c(AR0)

32. (10 pts) If we multiply a Q0.15 format fractional number by a Q3.12 on the TI C5402 with the FRCT bit set to 0.

    (a) The result in the **full** accumulator is a Qm.n number. What are the values of m and n?

    (b) The result is moved from the middle word of the accumulator. What are the m and n values for the moved 16-bit value?

33. (10 pts) Figure 6 shows the pole and zero locations for the Elliptic filter design we used for the IIR lab exercise. The letters a through d identify

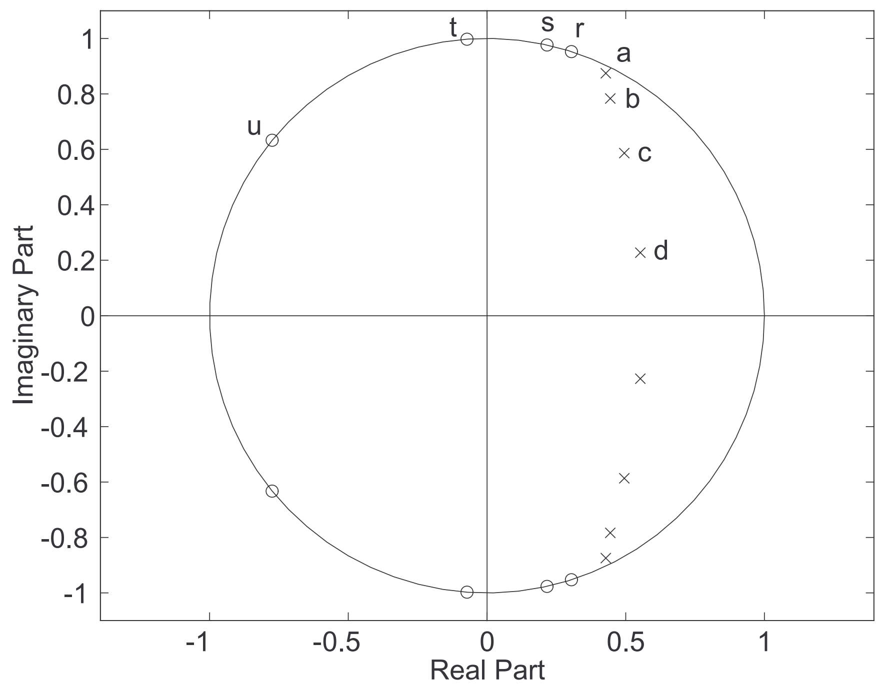

Figure 6: Elliptic filter pole-zero locations in the z-plane.

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.