CS 331: Embedded Systems, Spring 2003 Midterm

Name:
NetID:

- Do **NOT** open the test until told to do so.
- Print your name and NetID in the boxes above. Also print your NetID on the upper right corner of every page.
- You may use one $8\frac{1}{2}'' \times 11''$ double-sided handwritten sheet of notes and a calculator.
- Please turn in your cheat sheet when you hand in your exam.
- If anything is unclear, write down your assumptions.
- Show your work when appropriate. Clearly indicate your answers by circling them.
- You have exactly 1 hour and 15 minutes to complete the exam.
- Good luck!

#	Points	Score	Grader
1	8		
2	10		
3	12		
4	16		
5	12		
6	14		
7	12		
8	16		
Total	100		

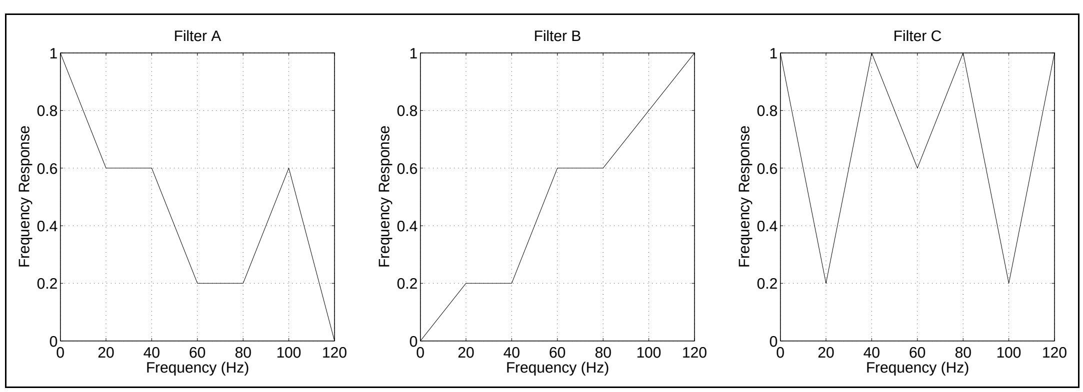
1. (8 points) The following figure shows the first eleven 2-byte values in an Interrupt Vector Table. What is the starting memory address of the Interrupt Service Routine for interrupt number 3? (Hint: be careful with hexadecimal arithmetic.)

Address	**Value**
0 H	5776 H
2 H	8104 H
4 H	5609 H
6 H	9462 H
8 H	3646 H
A H	9404 H
C H	1328 H
E H	8356 H
10 H	2090 H
12 H	7229 H
14 H	3205 H

Solution:
For each interrupt number ($0 - 255$), the Interrupt Vector Table stores a 2-byte Instruction Pointer value followed by a 2-byte Code Segment value. For interrupt number 3, the IP is 1328 H (from address C H) and the CS is 8356 H (from address E H). Therefore, the ISR starts at memory address 83560 H + 1328 H = 84888 H.

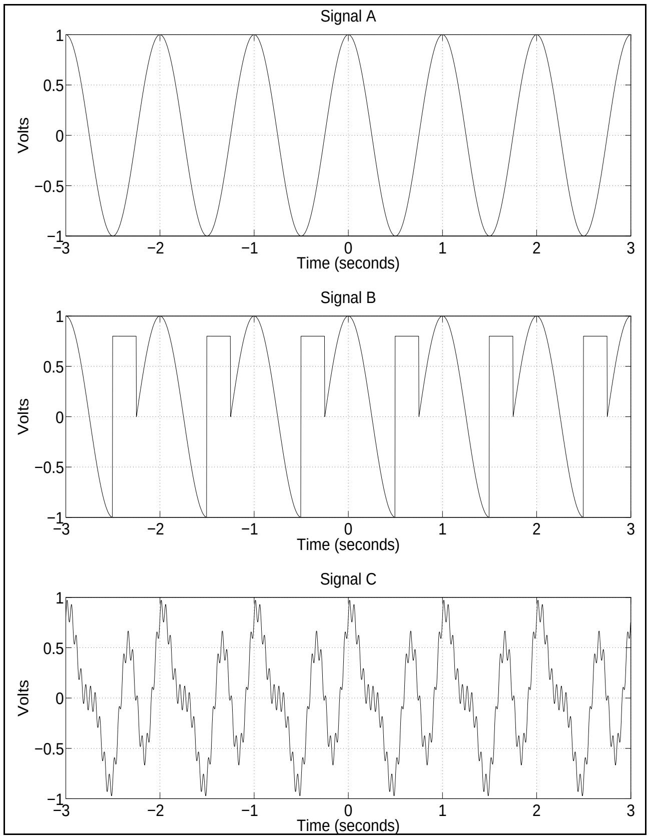
2. (10 points) Signal processing.

   (a) (5 points) Three filters (A, B, and C) described by the following frequency response plots are cascaded together such that the output of filter A goes into B and the output of filter B goes into C.



   What percentage of a 50 Hz cosine wave put into filter A comes out of filter C?
   Solution:
   $0.4 \times 0.4 \times 0.8 = 0.128 = 12.8\%$

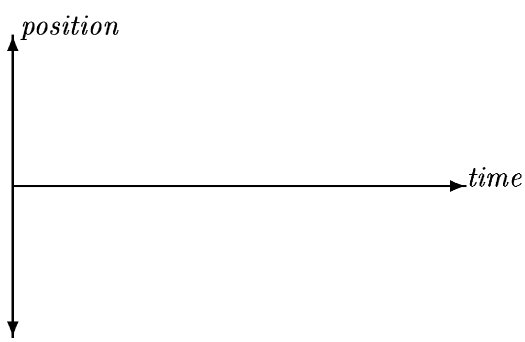
   (b) (5 points) The following three periodic signals (A, B, and C) are observed on an oscilloscope. Among these signals, which one has the highest bandwidth? Explain your reasoning.



Solution:
Signal B has the highest bandwidth because the sharp corners are made of very high frequency components.

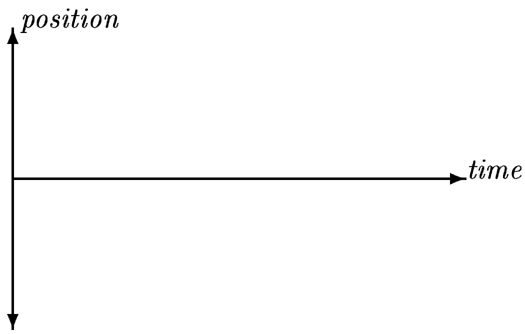
3. (12 points) For each of the following differential equations, determine the stability of the described system and sketch a graph of its behavior. Show your work.

   (a) $x'' + 3x' + 2x = 0$ Stability (circle one): Stable Marginally Stable Unstable



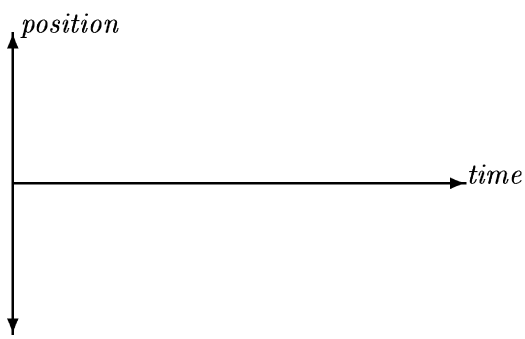
Solution:
Laplace transform: $s^2 + 3s + 2 = (s+1)(s+2) = 0 \quad \Rightarrow \quad s = \{-1, -2\}$
The eigenvalues are all real and negative, so the system is stable and the sketch is a decaying exponential with no oscillations.

(b) $x'' + 4x = 0$ Stability (circle one): Stable Marginally Stable Unstable



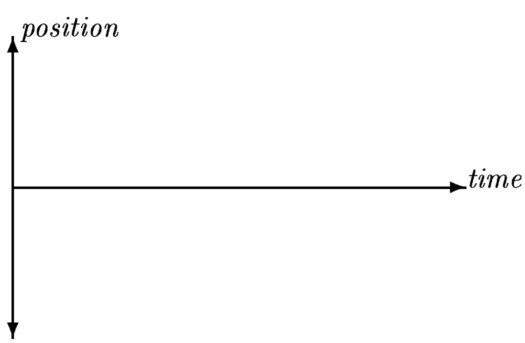
Solution:
Laplace transform: $s^2 + 4 = 0 \quad \Rightarrow \quad s = \pm 2j$
The eigenvalues are all purely imaginary, so the system is marginally stable and the sketch oscillates with constant amplitude.

(c) $x'' - 6x' + 13x = 0$ Stability (circle one): Stable Marginally Stable Unstable



Solution:
Laplace transform: $s^2 - 6s + 13 = (s - 3 + 2j)(s - 3 - 2j) = 0 \quad \Rightarrow \quad s = 3 \pm 2j$
The eigenvalues are all imaginary with positive real parts, so the system is unstable and the sketch is an oscillating exploding exponential.

(d) $x'' + 10x' + 26x = 0$ Stability (circle one): Stable Marginally Stable Unstable



Solution:
Laplace transform: $s^2 + 10s + 26 = (s + 5 + j)(s + 5 - j) = 0 \quad \Rightarrow \quad s = -5 \pm j$
The eigenvalues are all imaginary with negative real parts, so the system is stable and the sketch is an oscillating decaying exponential.

4. (16 points) In Lab 2 you used a POSIX timer to generate square waves with a 50% duty cycle (the voltage was high during the first 50% of the period and low during the rest of period). Recall that the POSIX timer had a frequency of 100 Hz.

   Suppose that you now need to generate 15% duty cycle square waves at 10 Hz, 20 Hz, and 25 Hz using a POSIX timer. What is the *minimum* frequency of the POSIX timer such that the three square waves can all be generated exactly? Show your work.

   Solution:
   There are six different periods that the POSIX timer must deliver exactly to produce the desired waves. These periods are listed in the last two rows of the following table.

Frequency	10 Hz	20 Hz	25 Hz
Period	100 ms	50 ms	40 ms
15% Period	15 ms	7.5 ms	6 ms
85% Period	85 ms	42.5 ms	34 ms

   The problem is then to find the greatest common divisor of $(15, 85, 7.5, 42.5, 6, 34)$. We multiple everything by 10 to make them integers: $(150, 850, 75, 425, 60, 340)$. It's obvious that 5 will divide all of them, but 10 will not. Therefore, the gcd must be a multiple of 5 but not 10. After some testing using Euclid's algorithm, we can also see that the gcd of 425 and 60 is only 5. Thus, we can conclude the gcd of the entire set is 5 or $0.5ms$. This corresponds to a POSIX timer frequency of $\frac{1}{0.5} = 2$ KHz.

5. (12 points) The function `cmr3()`, which uses extended AT&T inline assembly, is defined below. What will be printed to the screen when "`cmr3(75, 10, 50, 15)`" is called?
   Hint: Note the positions of the colons and their meaning for read-only ("input") and write-only ("output") variables.

```
void cmr3(int a, int b, int c, int d)
{
      __asm__ ("subl %3, %2\n\t"   /* %2 = %2 - %3 */
               "movl %2, %1\n\t"
               "addl %1, %3\n\t"
               "movl %3, %0\n\t"
               : "=r" (a), "=r" (b)
               : "r" (c), "r" (d));

      cout << "a=" << a << endl;
      cout << "b=" << b << endl;
      cout << "c=" << c << endl;
      cout << "d=" << d << endl;
}
```

   Solution:
   a=50
   b=35
   c=50
   d=15

6. (14 points) The *high-pass* Butterworth filter will decrease the magnitude of a signal according to the formula below; where ω is the original frequency, ω_{cutoff} is the cutoff frequency, n is the order of the filter, and H is the attenuated signal (as a percentage of the original).

$$H = \frac{1}{\sqrt{\left(\frac{\omega}{\omega_{cutoff}}\right)^{-2n} + 1}} \qquad (1)$$

Suppose that we have a signal with *data* components between 300 Hz and 500 Hz, and *noise* components between 10 Hz and 100 Hz. Given that $\omega_{cutoff} = 225$ Hz, compute the *minimal* number of stages of the filter such that, after filtering, more than 90% of the signal is left and at most 5% of the noise is left. Show your work.

Solution:
Evaluate equation (1) at the target frequencies for various n values until the desired attenuations are reached.

Order	Noise	Data
1	$H = \frac{1}{\sqrt{\left(\frac{100}{225}\right)^{-2}+1}} \approx 0.406$	$H = \frac{1}{\sqrt{\left(\frac{300}{225}\right)^{-2}+1}} = 0.8$
2	$H = \frac{1}{\sqrt{\left(\frac{100}{225}\right)^{-4}+1}} \approx 0.194$	$H = \frac{1}{\sqrt{\left(\frac{300}{225}\right)^{-4}+1}} \approx 0.871$
3	$H = \frac{1}{\sqrt{\left(\frac{100}{225}\right)^{-6}+1}} \approx 0.087$	$H = \frac{1}{\sqrt{\left(\frac{300}{225}\right)^{-6}+1}} \approx 0.921$
4	$H = \frac{1}{\sqrt{\left(\frac{100}{225}\right)^{-8}+1}} \approx 0.039$	$H = \frac{1}{\sqrt{\left(\frac{300}{225}\right)^{-8}+1}} \approx 0.953$

Thus a 4th order filter will meet our requirements.

7. (12 points) Suppose you're trying to control the water seesaw in lab using the PID controls discussed in class. In the following situations, describe which gain(s) you would change and how would you change them.

   (a) (4 points) The water seesaw keeps settling at +5.
   Solution:
   Slowly increase integral gain, but watch out for overshoot and oscillation.

   (b) (4 points) The water seesaw keeps bouncing from one side of the table to the other, never settling at any particular point.
   Solution:
   Either decrease proportional gain or increase derivative gain.

   (c) (4 points) The water seesaw is moving too slowly towards 0.
   Solution:
   Increase proportional gain or decrease derivative gain.

8. (16 points) Suppose you just purchased an A/D – D/A card from eBay, but the careless seller forgot to include the user's manual. You managed to figure out the following information:

- Each port address holds an 8-bit value.
- The resolution is 10 bits. (Voltages are represented by a 10-bit value.)
- The card uses a $-5 \ldots +5$ volt range for both input and output.
- To do a D/A output, the 10-bit voltage value is somehow split up and written to port addresses 500H and 501H.
  - The 10-bit voltage value is split into either the high 2 bits and low 8 bits, or the high 8 bits and low 2 bits. You are not sure which.
  - The 8-bit block is written to either 500H or 501H. You are not sure which. The 2-bit block is written to the other port address.
  - When writing the 2-bit block, the 2 bits are either the most significant bits in the byte or the least significant bits in the byte. You are not sure which.

In an attempt to find out the exact configuration of the card you write hex values `5F` and `CF` into port addresses 500H and 501H respectively. You then measure the voltage on the card to be 4.53 volts.

Do you now have enough information to figure out exactly how the 10-bit voltage value is stored in port addresses 500H and 501H? If so, list the configuration. If not, explain why. Show your work.

Solution:
Hex value `5F` is equal to binary value `0101 1111` and `CF` is equal to binary value `1100 1111`. The 10-bit binary value corresponding to 4.53 volts is:

$$\frac{4.53+5}{10} \times (2^{10}-1) = 974.919 \approx 975 = (11\,1100\,1111)_2$$

By inspection, `0xCF` (which was written to port 501H) must be the low 8 bits of the 10-bit voltage value.

Writing `0x5F` to port 500H causes the two most significant bits to be `01` and the two least significant bits to be `11`. Therefore, the high 2 bits of the 10-bit voltage value are the least significant two bits at 500H.

To summarize, the 10-bit voltage value $b_9b_8b_7b_6b_5b_4b_3b_2b_1b_0$ is mapped as follows:

500H							b_9	b_8
501H	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0

No other mappings are possible.