Homework 2, due February 28th 5pm CST

Handin at 1102 DCL. Slide under door if TA not present.

Important: Please type or *neatly* write your solutions. Anything we can't read will receive no credit. You must show work to receive full credit.

1. (20 points) Suppose that interrupt number `40H` has not been used. Its new ISR starts at memory location `30000H`. Code segment starts at `28CC0H`. Complete the C function below using *Intel* inline assembly code (we used extended AT&T inline assembly in lab) that will install the ISR address to the interrupt vector table.

```
Load_ISR()
{
    asm {
        ... /* insert code here */
    }
}
```

Solution:

```
Load_ISR()
{
    asm {
        PUSHA
        MOV AX, 0
        MOV DS, AX      /* DS should be 0, but we cannot MOV DS, 0      */
        MOV AX, 7340H   /* Instruction Pointer: 30000H - 28CC0H = 7340H */
        MOV [100H], AX  /* Put the IP at address 4 * 40H = 100H         */
        MOV AX, 28CCH   /* Code Segment: 28CC0H >> 4 = 28CCH            */
        MOV [102H], AX  /* Put the CS at address 100H + 2H = 102H       */
        POPA
    }
}
```

2. (10 points) Suppose that we have a signal with frequency components in the range of 40 to 70 Hz and noise in the range of 257 to 325 Hz. According to Nyquist's theorem on sampling, what is the minimum bound for the sampling rate if the noise is filtered out …

   (a) digitally? (5 points)

   (b) with an analog low-pass filter? (5 points)

Solution:

(a) The Nyquist minimum sampling frequency is twice the highest frequency content. In this case, 325Hz is the highest out of both the signal and the noise. Therefore, the answer is **650Hz**.

(b) In this case the noise component has been filtered out by the analog filter prior to sampling. So the highest frequency content remaining is 70Hz. Two times 70Hz is **140Hz**.

3. (15 points) In a system with nested interrupts, how does an ISR of high priority prevent interrupts from an ISR of lower priority?

Solution:
When the high priority ISR executes, it sets the priority mask to its own level. All ISRs of lower priorities will be disabled.

4. (40 points) The 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 θ is the attenuated signal (as a percentage of the original).

$$\frac{1}{\sqrt{\left(\frac{\omega}{\omega_{cutoff}}\right)^{2n}+1}} = \theta \tag{1}$$

Suppose that we have a signal with a frequency of $2x$ and noise with a frequency of $6x$. Compute the cutoff frequency and the *minimal* number of stages of the filter such that, after filtering, more than 90% of the signal is left and at most 10% of the noise is left? Note that your cutoff frequency will be in terms of x.

Solution:
We solve for ω_{cutoff} in equation (1):

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

$$\left(\frac{\omega}{\omega_{cutoff}}\right)^{2n} = \theta^{-2} - 1 \tag{3}$$

$$\left(\frac{\omega}{\omega_{cutoff}}\right) = \left(\theta^{-2} - 1\right)^{\frac{1}{2n}} \tag{4}$$

$$\omega_{cutoff} = \frac{\omega}{\left(\theta^{-2} - 1\right)^{\frac{1}{2n}}} \tag{5}$$

Using equation (5), we can then plug in our target attenuations and original frequencies.

Order	Signal	Noise
1	$\omega_{cutoff} > \frac{2x}{(.9^{-2}-1)^{\frac{1}{2}}} \approx 4.129x$	$\omega_{cutoff} < \frac{6x}{(.1^{-2}-1)^{\frac{1}{2}}} \approx .603x$
2	$\omega_{cutoff} > \frac{2x}{(.9^{-2}-1)^{\frac{1}{4}}} \approx 2.873x$	$\omega_{cutoff} < \frac{6x}{(.1^{-2}-1)^{\frac{1}{4}}} \approx 1.902x$
3	$\omega_{cutoff} > \frac{2x}{(.9^{-2}-1)^{\frac{1}{6}}} \approx 2.546x$	$\omega_{cutoff} < \frac{6x}{(.1^{-2}-1)^{\frac{1}{6}}} \approx 2.789x$

Thus a 3rd order filter with a cutoff frequency between $2.546x$Hz and $2.789x$Hz will meet our requirements.

5. (15 points) The best way to get rid of errors and noise in data is to prevent them from entering the system in the first place. List 2 items that will help you reduce random noise and another 2 items that will help you minimize deterministic error.

   Solution:
   To reduce random noise:

   - Check the grounding condition of equipment and signal line.
   - Identify strong noise sources (EMI) near you and remove them.
   - Use differential input or shield signal lines to avoid EMI.

   To minimize deterministic errors:

   - Re-calibrate equipment or compensate for bias in software.
   - Use appropriate signal amplitude range and data representation resolution to avoid quantization errors.
   - Use a sampling rate high enough to avoid aliasing.