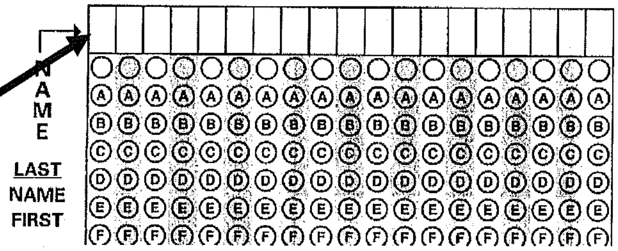
MAE334 - Introduction to Instrumentation and Computers

Midterm Examination

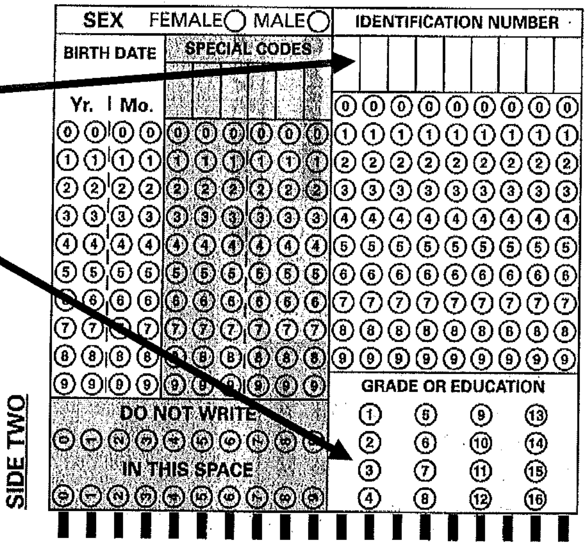
October 29, 2008

- **USE A #2 Pencil**
- **Closed Book and Notes**
- **No Calculators**



1. **Fill in your name** on side 2 of the scoring sheet (Last name first!)
2. **Fill in your 8-digit person number** on your scoring sheet.
3. **Fill in circle 3 under GRADE OR EDUCATION** on your scoring sheet. This is your test number! You will receive a ZERO if you do not indicate your test number.

- For each question, choose **THE BEST ANSWER** and mark the corresponding answer on the scoring sheet.



The terms *lab 1, lab 2*, and *lab 3* refer to: **Lab 1 Static and Dynamic Calibration of Thermocouples** and **Lab 2 Basics of A to D Conversion** and **Lab 3 Transient Thermal Behavior with Work and Heat Loss.**

All multiple choice questions are worth 2 points.

All short answer questions are worth 5 points.

Total 25x2 + 6x5 = (80 points) midterm + Quizzes (20 points)

1. The value of the integral of the delta function over the interval from t = -∞ to -1, $A = \int_{-\infty}^{-1} \delta(t)dt$, is
   - [✓ a.] 0
   - b. 1
   - c. ∞
   - d. None of the above
2. The discrete Fourier transform of a signal sampled once every hundredth of a second (δt = 1/100 sec) for 5 seconds would have a maximum frequency of
   - a. 100 Hz
   - [✓ b.] 50 Hz
   - c. 1/5 Hz
   - d. 1/10 Hz
   - e. None of the above

   $f_s = \frac{1}{\delta t} = 100$ samples/sec

   $f_N = f_s/2 = 50$ Hz
3. What is the equation relating the confidence interval that a single temperature measurement, T_i, is within 5% of the mean if the data set contains 36 points and has a standard deviation of 1 °C?
   - [✓ a.] $T_i = \bar{T} \pm t_{35,5\%} 1$
   - b. $T_i = \bar{T} \pm t_{35,95\%} 1$
   - c. $T_i = T' \pm t_{35,5\%} \, {}^{1}\!/\!{\sqrt{36}}$
   - d. $T_i = T' \pm t_{35,95\%} \, {}^{1}\!/\!{\sqrt{36}}$
   - e. None of the above
4. A 4 bit ADC with an input range of 16 volts and an input signal gain of 4 has a quantization step size of
   - a. 1 volt
   - b. 0.5 volts
   - [✓ c.] 0.25 volts
   - d. 0.125 volts
   - e. None of the above

   $Q = {}^{16/4}\!/\!{}_{2^4} = 0.25V$ ✓
5. A very small, very sensitive thermocouple will reach a steady state value sooner for a small step input than a large step input.
   - a. True
   - [✓ b.] False
6. An instrument's precision is a measure of the random fluctuations in output for repeated applications of the same input.
   - [✓ a.] True
   - b. False
7. The settling time in seconds of the second order system response (a) plotted in Figure 1is approximately
   - a. 0.25
   - b. 0.70
   - c. 1.05
   - [✓ d.] 1.5
   - e. 4.0
8. Of the two second order system responses plotted in Figure 1 which system has the largest damping ratio, ζ.
   - a. response (a)
   - [✓ b.] response (b)
9. The damped natural frequency, ω_d, of response (a) is higher than that of response (b) of the second order systems plotted in Figure 1.
   - [✓ a.] True
   - b. False
10. The ADC architecture normally associated with the highest precision and slowest conversion rate is
    - a. Flash
    - b. Pipelined
    - c. Successive Approximation
    - [✓ d.] Sigma-Delta

11. Randomization is used to break-up the effects of interference from either continuous or discrete extraneous (i.e. uncontrolled) variables.
    [✓ a.] True b. False

12. A discrete Fourier transform of the data plotted in Figure 1 would have a frequency spacing, df, of
    a. 4 Hz
    b. 2 Hz
    c. 1 Hz
    [✓ d.] 0.25 Hz
    e. None of the above

$\Delta f = \frac{1}{T} = \frac{1}{4 sec} = 0.25\ Hz$

13. What sampling rate would be required to accurately represent the wave form shape of the second order system response function plotted in Figure 1?
    a. 1 Hz
    b. 2 Hz
    c. 4 Hz
    [✓ d.] 15 Hz
    e. None of the above

At least 10 times faster than the highest frequency.

14. Heat loss to the laboratory surroundings from the calorimeter used in lab 3 was modeled with the equation, $Q = H(T_{calorimeter} - T_{lab})$
    [✓ a.] True b. False

15. The fundamental frequency of the Fourier series $y(t) = \sum_{n=1}^{\infty} \frac{3n}{2} \sin nt + \frac{5n}{3} \cos nt$ is
    a. 1 Hz
    [✓ b.] 1 rad/sec
    c. 3/2 Hz
    d. 3/2 rad/sec
    e. None of the above

16. What is the twos complement binary representation of -8 as an 8 bit number?
    a. 00001000
    b. 11110111
    [✓ c.] 11111000
    d. 11111001
    e. none of the above

	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
8→	0	0	0	0	1	0	0	0
1's comp→	1	1	1	1	0	1	1	1
Add 1								1
2's comp→	1	1	1	1	1	0	0	0

17. What are the units of the static sensitivity of the thermocouple calibrated in the first lab used to convert the ADC output to temperature?
    a. Volts/C°
    b. milliVolts/C°
    c. C°/microVolts
    [✓ d.] C°/Volts
    e. none of the above

ADC output is in Volts

$(Volts)\left(\frac{°C}{Volt}\right) = °C$

18. When modeling the dynamic response of the thermocouple probe to a step input change in temperature only the initial temperature and the time constant are used.
    a. True [✓ b.] False

also need a final temperature or step size.

19. The time constant of the thermocouple plotted in Figure 2 is approximately
    [✓ a.] 2 seconds.
    b. 5 seconds.
    c. 10 seconds
    d. 12 seconds

20. What portion of the repeated sampling of a static temperature signal are within two standard deviations of the data set's mean value?
    [✓ a] 95.5%
    b. 99.7%
    c. 68.3%
    d. 50%
    e. None of the above

Short Answer Section Name:

Person Number:

21. What is the approximate variance of the data set whose probability density function is plotted in Figure 3?
    - a. 1
    - b. 2
    - c. 3
    - [✓ d. 4]
    - e. 6

$3\sigma = 6 \therefore \sigma = 2$ Variance $= \sigma^2 = 2^2 = 4$

22. The frequency bandwidth of a first order instrument is defined as the frequency below which $M(\omega)=0.707$, or output/input power is -3 dB.
    - [✓ a. True]
    - b. False

23. The smallest quantization step size, as plotted in Figure 4, of the ADC used in the lab is?
    - [✓ a. 24.4 micro-Volts]
    - b. 2.44 milli-Volts
    - c. 4.88×10^{-5} Volts
    - d. 2.44×10^{-4} Volts
    - e. None of the above

24. The polynomial equation, $y(x) = a_0 + a_1x + a_2x^2 + a_3x^3$, fit to a data set with 25 points has how many degrees of freedom?
    - [✓ a. 21]
    - b. 22
    - c. 23
    - d. 24
    - e. None of the above

4 unknowns $\therefore \nu = 25 - 4 = 21$

25. It can be determined from the probability density function plotted in Figure 3 that the maximum allowable gain used by the ADC in the lab to collect this data would be?
    - [✓ a. 1]
    - b. 2
    - c. 20
    - d. 200

ADC range is ±10 Volts, data range is ±6

26. What is ADC quantization step size as defined in terms of the input range, E_{FSR}, *Gain* and the number of ADC bits, M, for the ADC hardware in the lab with the maximum gain

$$Q = \frac{E_{FSR}/Gain}{2^M} = \frac{20\text{ Volts}/200}{2^{12}}$$

27. What is the equation used to find the standard deviation of a data set?

$$S_x = \left[\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})^2\right]^{1/2}$$

28. Given a data set with 20 points what is the equation used to find the confidence interval within which 95% of the data is expected to lie?

$$x_i = \bar{x} \pm t_{19,95\%} S_x \text{ or } CI = \pm t_{19,95\%} S_x$$

29. What is the 90% confidence interval of a linear fit $y = a_0 + a_1x \pm CI$ to a 15 point data set?

$$CI = \pm t_{13,90\%} S_{yx}/\sqrt{15}$$

30. What is the equation for the error function, $\Gamma(t)$, used in lab 3 to linearize the cooling data to determine the calorimeter time constant?

$$\ln[\Gamma(t)] = \ln\left[\frac{T_\infty - T(t)}{T_\infty - T_0}\right] = -t/\tau$$

31. What is the equation used to calculate the damped or ringing frequency, ω_d, of an under damped second order sensor like the one plotted in Figure 1 in terms of natural frequency, ω_n, and the damping ratio, ζ?

$$\omega_d = \omega_n\sqrt{1-\zeta^2}$$

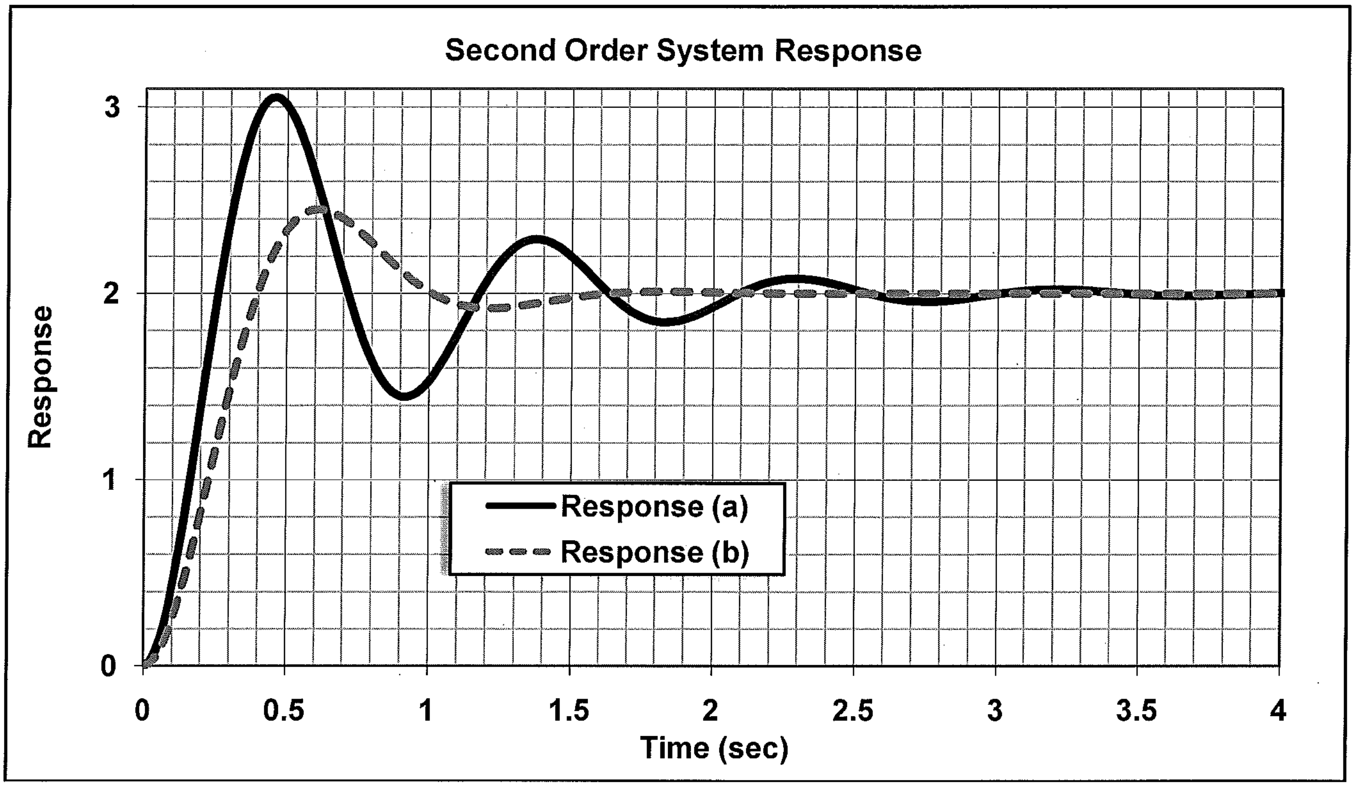


Figure 1. Second order system response to a 2 unit step input function.

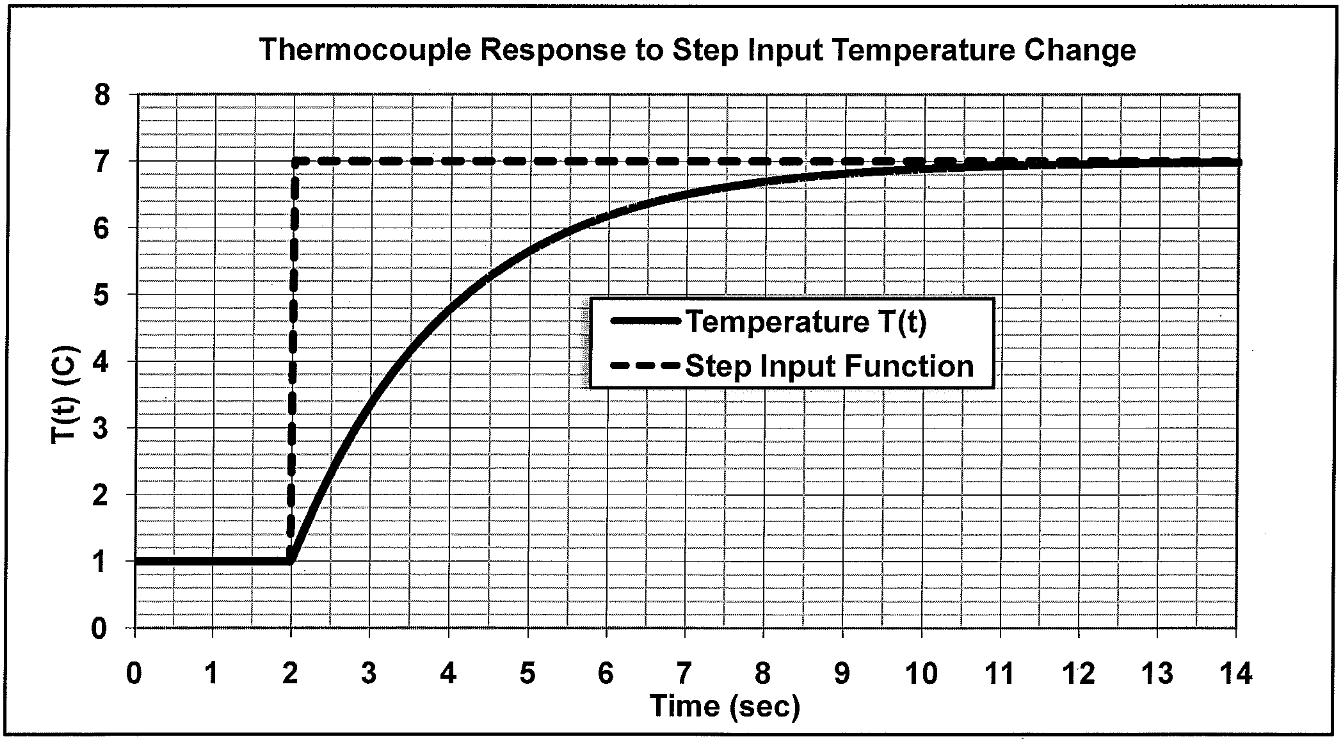


Figure 2. Thermocouple response to a 6 degree C step input temperature change.

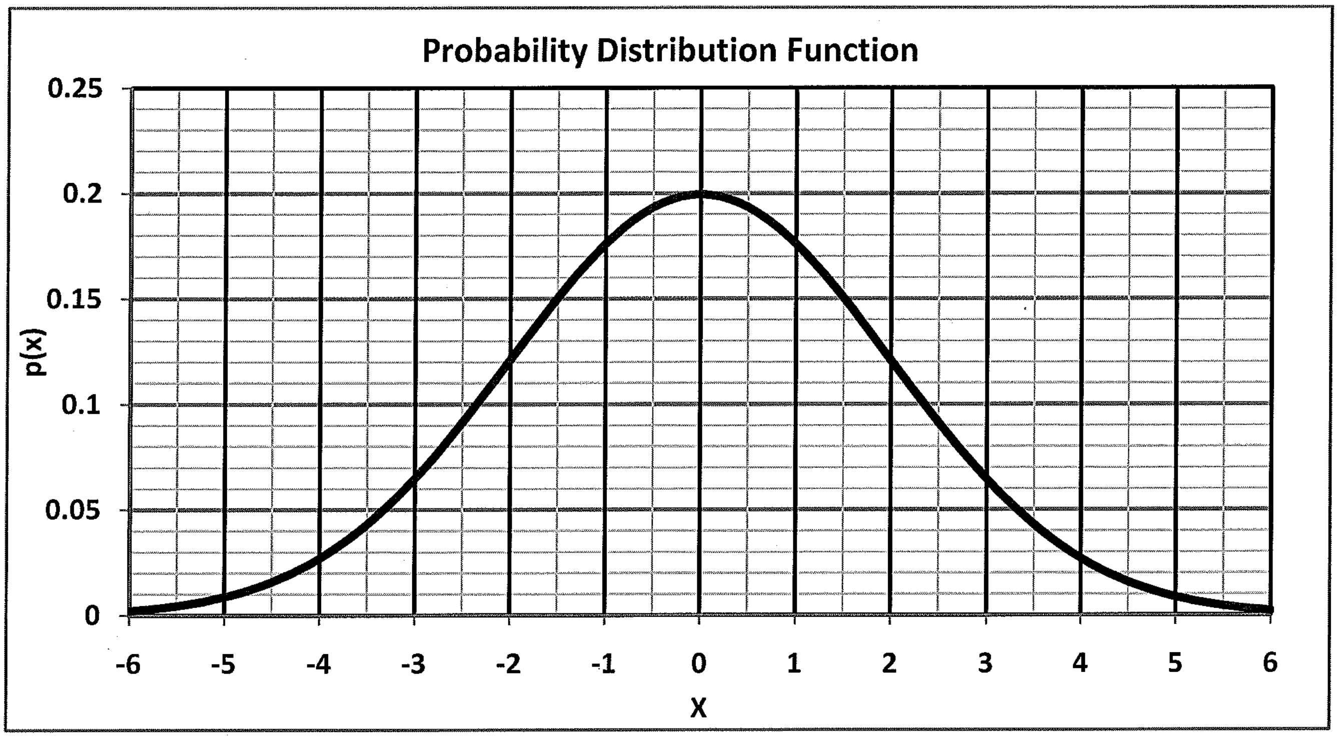


Figure 3. Probability density function of a normally distributed data set.

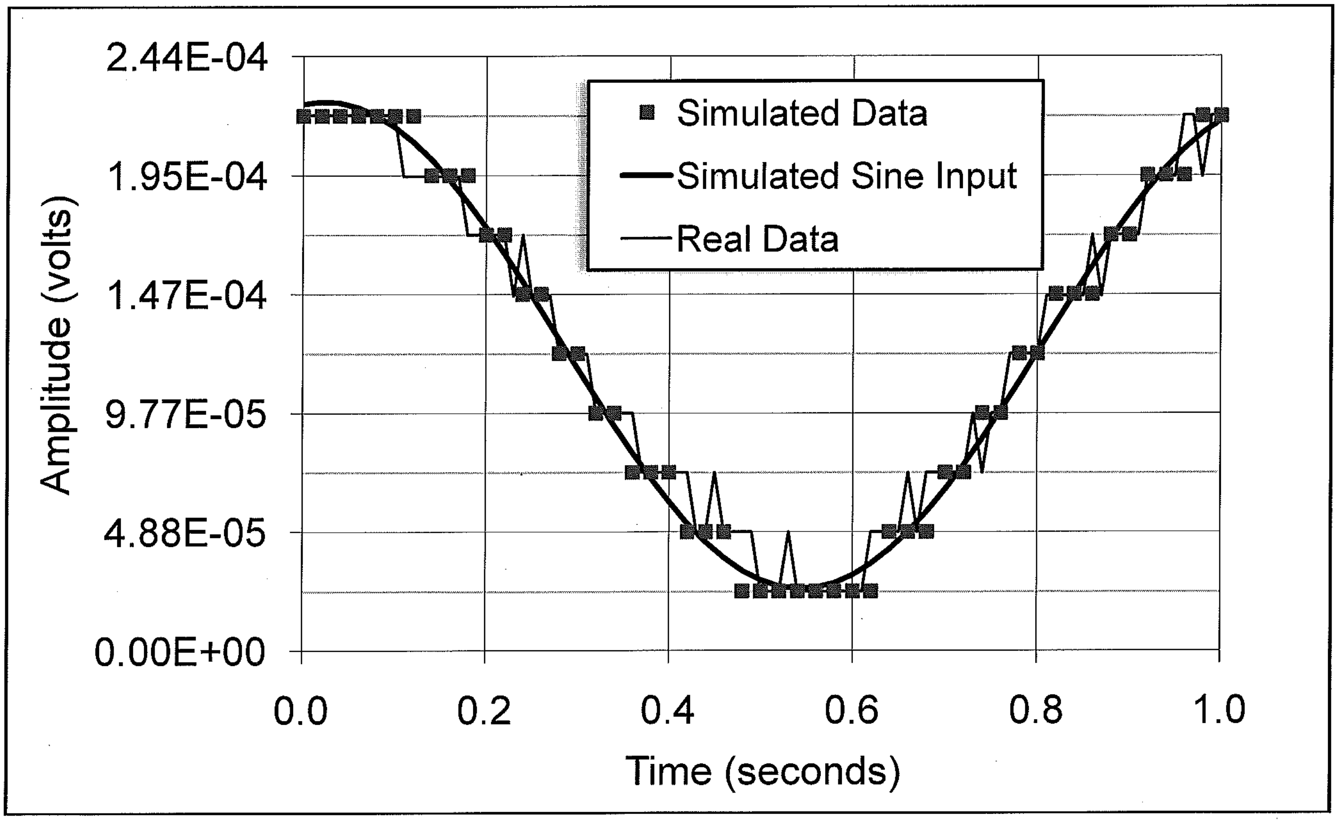


Figure 4. Sample data collected during lab 2 with simulated data superimposed on plot.