MAE334 - Introduction to Instrumentation and Computers

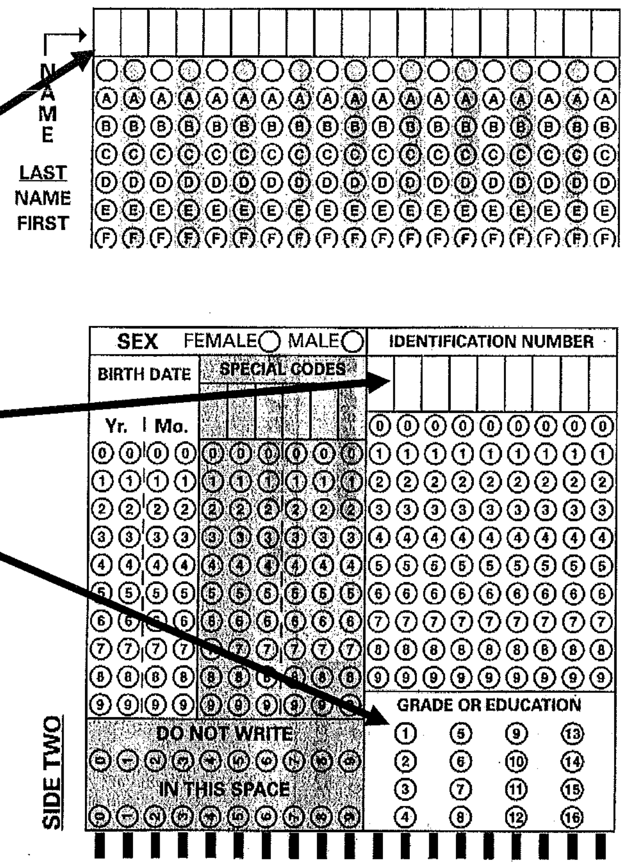
Final Examination

December 11, 2007

- **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 1 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.



Given: a normally distributed data set containing 500 points spanning 0.5 seconds with a Excel standard deviation, STDEV(data), of 2 units and a mean value, AVERAGE(data), of 5 units. [For use with the next 9 questions!]

$T = 0.5$ s

$\Delta f = 1/.5$ Hz $= 2$ Hz

SR = 1000 sam/s

1. What is the Nyquist frequency of the data set?
   - a. 250 Hz
   - b. 500 Hz
   - c. 1000 Hz
   - d. None of the above

2. What is the frequency spacing, Δf, of this data set after a Fourier transform?
   - a. 1/1000 Hz
   - b. 1/500 Hz
   - c. 1 Hz
   - d. 2 Hz
   - e. None of the above

3. What is the lowest frequency that can be captured by this data set?
   - a. 0.5 Hz
   - b. 1 Hz
   - c. 4 Hz
   - d. None of the above 2 Hz

4. What range should 19 out of 20 of the data points be between?
   - a. $\bar{x} \pm t_{500,95\%} S_x$
   - b. $\bar{x} \pm t_{500,95\%} S_{\bar{x}}$
   - c. $\bar{x} \pm t_{499,95\%} S_x$
   - d. $\bar{x} \pm t_{499,95\%} S_{\bar{x}}$
   - e. None of the above $\bar{x} \pm t_{N-1,95\%} S_x$

5. What percentage of the data fall in the range of 3 to 5 units?
   - a. 34 %
   - b. 48 %
   - c. 50 %
   - d. 68 %
   - e. 95 %

   $-\sigma + \bar{x}$ to $\bar{x}$

6. If the input signal contained a periodic signal at 525 Hz at what frequency would it appear in the data set?
   - a. 525 Hz
   - b. 475 Hz
   - c. 25 Hz
   - d. None of the above

7. How would you define your estimate of the true mean value, x'?
   - a. $x' = \bar{x} \pm t_{500,P\%} S_x$
   - b. $x' = \bar{x} \pm t_{499,P\%} S_x$
   - c. $x' = \bar{x} \pm t_{500,P\%} S_{\bar{x}}$
   - d. $x' = \bar{x} \pm t_{499,P\%} S_{\bar{x}}$

8. The standard deviation of the means, $S_{\bar{x}}$, for this data set is
   - a. $2/\sqrt{500}$ $= \frac{S_x}{\sqrt{N}}$
   - b. $\frac{1}{500}\sum_{i=1}^{500} x_i$
   - c. $\sqrt{\frac{1}{499}\sum_{i=1}^{500}(x_i - 5)^2}$
   - d. None of the above

9. If this data set was collected from a stationary signal. Would you expect repeating the data collection using the same parameters to
   - a. increase the precision of your estimate of the mean value, $\bar{x}$.
   - b. have mean values normally distributed about x'.
   - c. increase the frequency resolution in the Fourier domain.
   - d. have no effect on your estimation of the signal statistics.
   - e. Both a. and b.

Given: An infrared image captured with a digital camera with a 1000 x 1000 pixel sensor. From this image we are able to determine the surface temperature of the material being photographed. The lens magnification results in each pixel recording a 1 mm x 1 mm area. [For use with the next 7 questions!]

10. What is the highest spatial frequency that can be resolved?
    a. ½ cycle/mm
    b. 1 cycles/mm
    c. 1 cycle/m
    d. 2 cycles/m
    e. None of the above

11. This type of temperature sensor behaves like a first order system.
    a. True
    b. False

12. The lowest spatial frequency that can be captured in this image is
    a. ½ cycle/mm
    b. 1 cycle/mm
    c. ½ cycle/m
    d. 1 cycle/m
    e. None of the above

13. If the temperature resolution of this particular camera setup is ½ degree Celsius what is the zero order uncertainty in the measurement?
    a. ± ½ °C
    b. ± ¼ °C
    c. ± 1 °C
    d. None of the above

14. The manufacturer lists the linearity error associated with this camera as ± 1% of the reading in degrees Kelvin. What would the design stage uncertainty be in determining a single pixel temperature reading at 400 °K?
    a. $u_d = \sqrt{(u_0^2 + 2^2)}$ (95%)
    b. $u_d = \sqrt{(u_0^2 + 4^2)}$ (95%)
    c. $u_d = \sqrt{(u_0 + 4^2)}$ (95%)
    d. $u_d = \sqrt{(u_0 + 8^2)}$ (95%)
    e. None of the above

15. Is this camera setup going to give accurate measurements of thermal gradients, ΔT/Δx in the range of 2 °C/1 mm at 400 °K?
    a. Yes
    b. No
    c. Insufficient information

16. The input impedance of this type of temperature sensor is very low.
    a. True
    b. False

17. Temperature is an effort variable.
    a. True
    b. False

18. The area under a properly normalized probability distribution function is 100.
    a. True
    b. False

19. The static sensitivity of a thermocouple is constant regardless of the convective heat transfer coefficient.
    a. True
    b. False

20. Bias error is effectively eliminated by a proper static calibration.
    a. True
    b. False

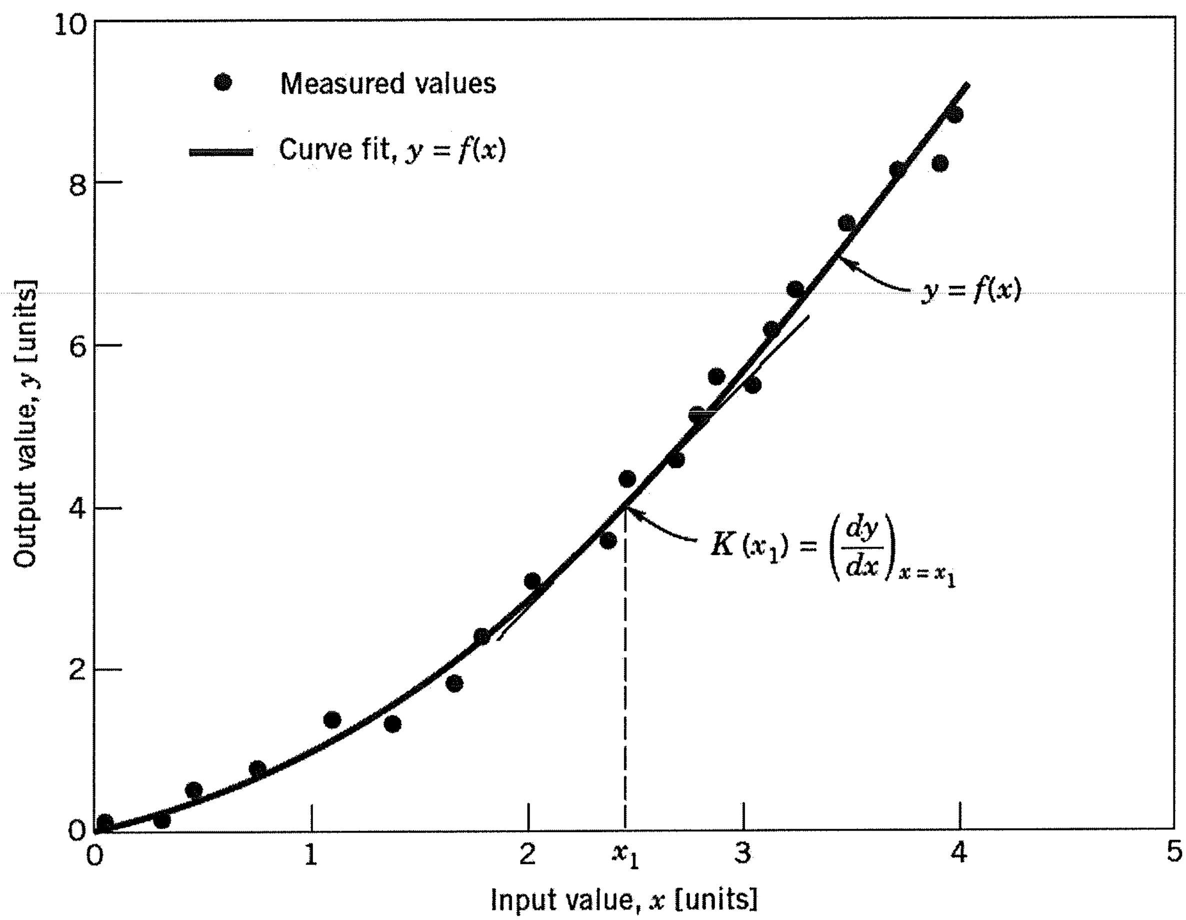


Figure 1.6 Representative static calibration curve.

21. Using the static calibration data from Figure 1.6 above it can be stated that the static sensitivity of the instrument is greater at an input value of 1 [units] than at a value of 3 [units].
    a. True   b. False

22. There are 21 measured values in the calibration data set. How many degrees of freedom are there in the 2nd order calibration curve y = Ax + Bx^2?
    a. 18   c. 20
    b. 19   d. 21
    N-2

23. The calibration of Figure 1.6 could be used for data spanning the range of 0 to 5 input units.
    a. True   b. False
    0-4

24. The uncertainty interval around the computed value, y_c, from the curve fit is defined as
    a. $\pm t_{\nu,P\%} S_{yx}$ c. $\pm t_{\nu,P\%} S_y$ e. NONE OF ABOVE
    b. $\pm t_{\nu,P\%} S_{\bar{x}}$ d. $\pm r^2$ (where r is the correlation coefficient)

25. Calibration hysteresis error is made worse by random application of the input signal.
    a. True   b. False
    (reduced

26. A zero order sensor will delay the output signal with respect to the input signal.
   a. True
   b. False

27. The frequency bandwidth in radians/sec of a first order sensor is 1/(time constant), $1/\tau$.
   a. True
   b. False

28. A Bourdon Tube pressure transducer is modeled as a first order sensor.
   a. True
   b. False
   Second

29. The standard deviation of a signal is also known as its variance.
   a. True
   b. False
   $\sigma = \sqrt{\sigma^2}$

30. What portion of a data set is within 2 standard deviations of the data set mean value.
   a. 50 %
   b. 68 %
   c. 75 %
   d. 95 %
   e. 99 %

31. The polynomial, $y = a_0 + a_1x + a_2x^2 + a_3x^3$, fit to a data set with N points has how many degrees of freedom?
   a. N-3
   b. N-2
   c. N-1
   d. None of the above
   N-4, 4 unknowns

32. A correlation coefficient of 0.5 for a linear fit to a data set indicates a good quality fit.
   a. True
   b. False

33. The ADC architecture normally associated with the highest precision is
   a. Flash
   b. Sigma-delta
   c. Pipelined
   d. Successive approximation

34. A large thermocouple will reach a steady state value sooner if subjected to a small step input than a large step input.
   a. True
   b. False
   τ does not change

35. A null device has ~~zero~~ ∞ input impedance.
   a. True
   b. False

36. Which of the following are effort variables
   a. temperature, voltage, heat flux, pressure
   b. current, pressure, heat flux
   c. voltage, pressure, force
   d. velocity, force, voltage

37. A 65 Hz sine wave sampled at 100 Hz will result in a sampled data set with what frequency
   a. 15 Hz
   b. 65 Hz
   c. 45 Hz
   d. 30 Hz
   e. None of the above

35 Hz

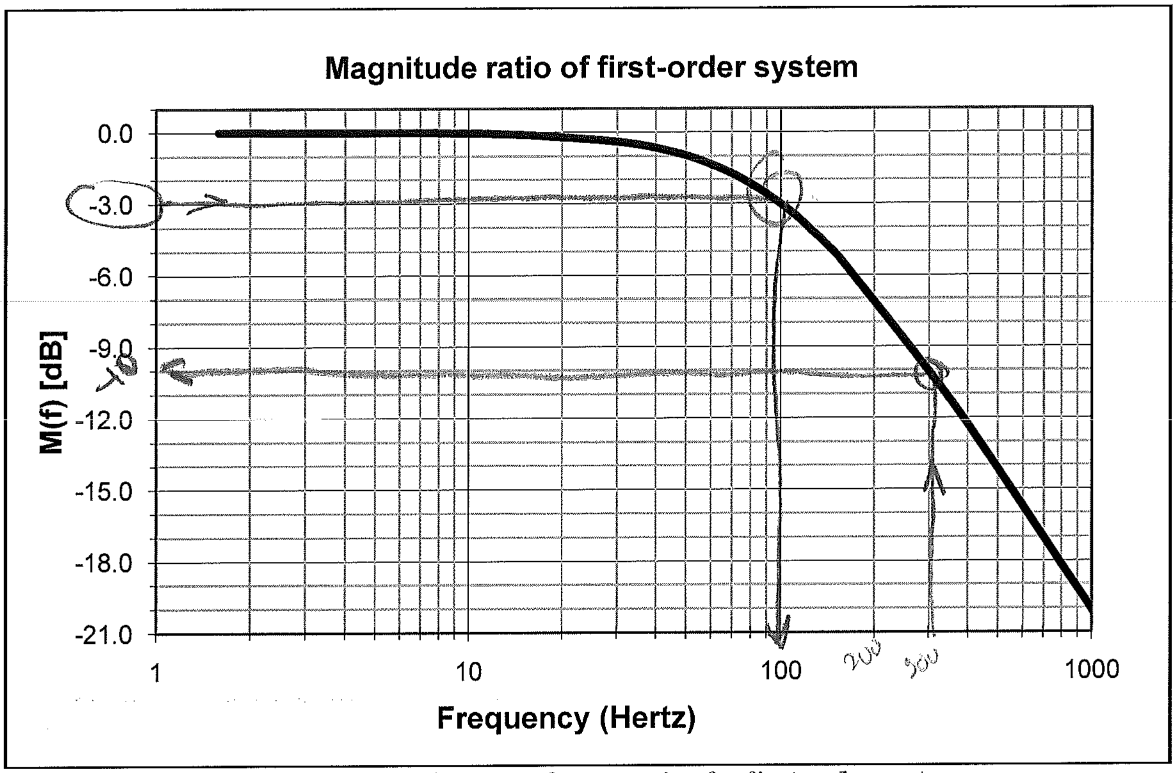


Figure 1. Magnitude ratio, (output/input vs. frequency), of a first-order system.

38. The bandwidth of the first-order system response plotted in Figure 1 is
    a. 10 Hz
    b. 50 Hz
    c. 80 Hz
    d. 100 Hz
    e. None of the above

39. If you needed to make a simple single pole RC filter to match the magnitude response plotted in Figure 1 you would pick RC to equal
    a. $1/(2\pi f_c)$
    b. $1/f_c$
    c. $1/\tau$ where τ is the time constant
    d. None of the above

40. Can you determine the value of the time constant, τ, from a magnitude response function of a first order system like the one plotted in Figure 1?
    a. Yes
    b. No

41. If the first order system whose magnitude response function is plotted in Figure 1 was subjected to a 1 [units] magnitude 300 Hz input signal what would the amplitude of the output signal be?
    a. 0.1 units
    b. 20 log(-10) units
    c. $10^{(-10/20)}$ units
    d. Cannot be determined from Figure 1
    e. None of the above

42. The thermocouple connection pictured in Figure 8.40 would output a signal proportional to what temperature?
    a. T_1
    b. T_1 - 21.5 ± 0.2 °C
    c. T_1 + 21.5 ± 0.2 °C
    d. None of the above

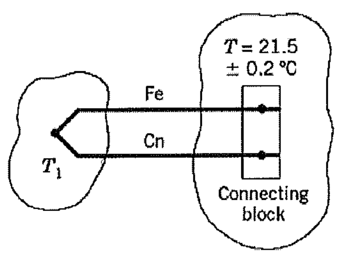


Figure 8.40 Thermocouple circuit for Problem 8.24.

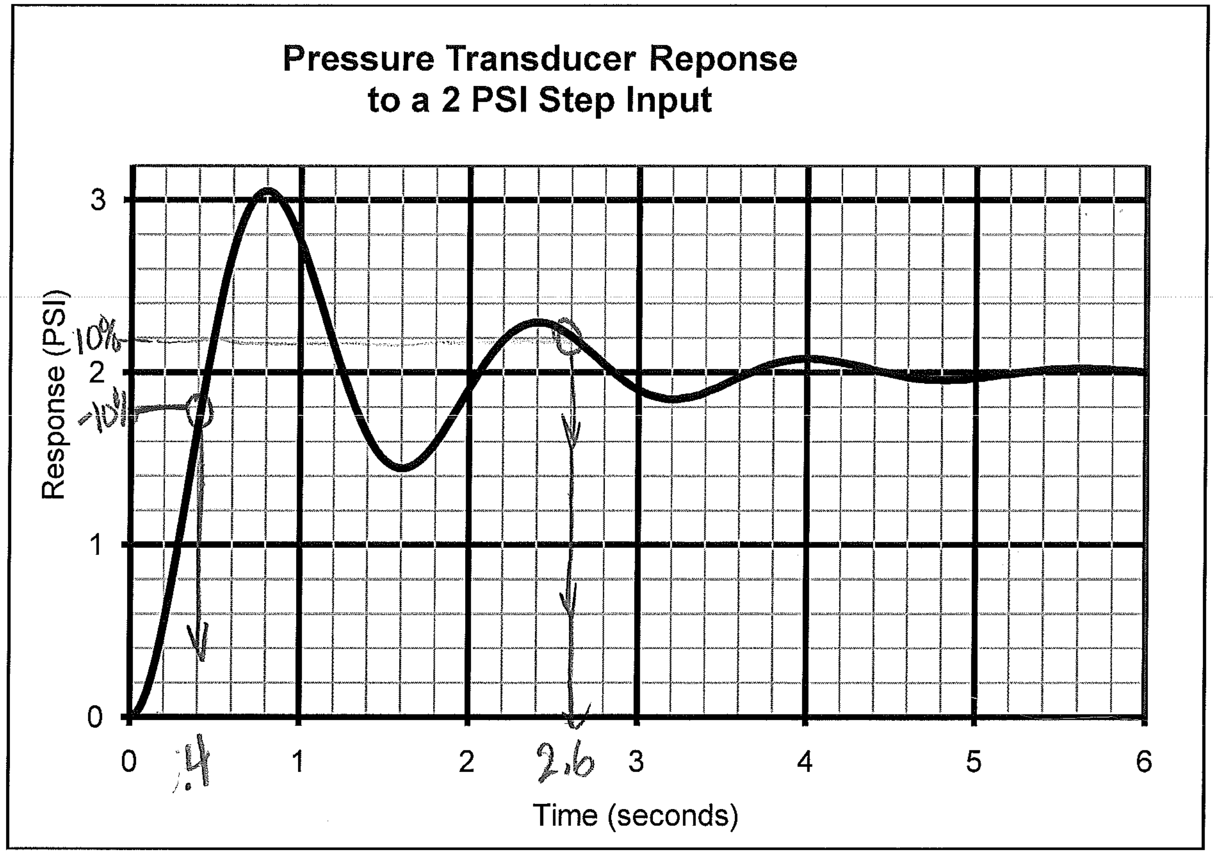
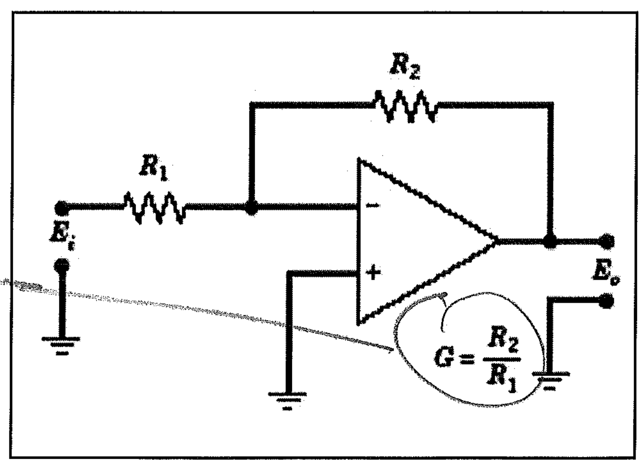


Figure 2. Second order system response to a step input signal.

43. The rise time and settling time of the pressure transducer plotted in Figure 2 is
    a. 0.4 and 1.1 seconds respectively.
    b. 0.4 and 3.4 seconds respectively.
    c. 0.45 and 6+ seconds respectively.
    d. 0.8 and 2.6 seconds respectively.
    e. None of the above

44. The damped natural frequency, ω_d, of the second order system plotted in Figure 2 is
    a. 1.6 Hz
    b. 1/0.8 Hz
    c. 5/8 Hz
    d. 0.8 Hz
    e. None of the above



45. What is the gain of the amplifier circuit diagramed to the right?
    a. R_1/R_2
    b. $-R_1/R_2$
    c. $R_1R_2/(R_1 + R_2)$
    d. R_2/R_1
    e. $-R_2/R_1$

46. The area under a delta function goes to zero as the width of the function approaches zero.
    a. True
    b. False

47. An ideal operational amplifier has the following characteristics
   a. zero input and output impedance
   b. infinite input and output impedance
   c. zero input and infinite output impedance
   d. infinite output impedance and infinite bandwidth
   e. infinite bandwidth and infinite input impedance

48. What is the uncertainty of a normal analog car speedometer with a ±4% accuracy and 5 MPH gradations at an average speed of 60 MPH?
   a. ± 2.4 MPH
   b. ± 2.5 MPH
   c) $\pm\sqrt{2.5 + 2.4^2}$
   d) $\pm\sqrt{2.5^2 + 2.4^2}$

49. If a 10 Hz sine wave is sampled for 3 seconds at 52 Hz would the spectra have Fourier component spectral leakage into several frequencies?
   a. Yes
   b. No
   c. Not enough information to determine

50. In designing an instrument system to achieve a given level of precision, it is usually most economical to choose components
   a. each of which contributes about the same amount to the overall precision error.
   b. such that most of the precision error is contributed by one of the components.
   c. such that the data acquisition system has the lowest precision error.
   d. such that the sensor has the lowest precision error.

51. The zero order uncertainty of a 4 ½ digit voltmeter with a range of 0 to 200 volts is
   a. ± 0.5 V
   b. ± 0.005 V
   c. ± 0.0005 V
   d. ± 0.05 V

The accelerometer in a Nintendo Wii Remote (ADXL330, Analog Devices) lists the following specifications: Typical Bandwidth 1.6kHz, Range +/- 3g, Sensitivity 300 mV/g, Sensitivity Accuracy ±10%, Nonlinearity Error ±1%. It is connected up to a 12 bit ADC (ADμC7020) with a range of ±3 V.

52. What is the zero order uncertainty, u_0, of the Wii Remote in engineering units [g].
   a. $\pm 3/2^{12}/0.3$ g
   b. $\pm 5/2^{12}$ g
   c. $\pm 10/2^{12}$ g
   d. $\pm 1.5/2^{12}/0.003$ g
   e. None of the above

53. What is the Wii Remote accelerometer uncertainty, u_c, for a nominal 1 g acceleration?
   a. $\pm\sqrt{(0.03)^2 + (0.003)^2}$ g
   b. $\pm\sqrt{(30)^2 + (3)^2}$ g
   c. $\pm\sqrt{(0.1)^2 + (0.01)^2}$ g
   d. $\pm\sqrt{(0.03)^2}$ g
   e. None of the above

54. What is the design stage uncertainty, u_d, of the Wii Remote?
   a. $\pm\sqrt{u_0^2 + u_c^2}$
   b. $\pm\sqrt{u_0 + u_1^2 + u_2^2}$
   c. $\pm\sqrt{u_0 + u_c^2}$
   d. None of the above

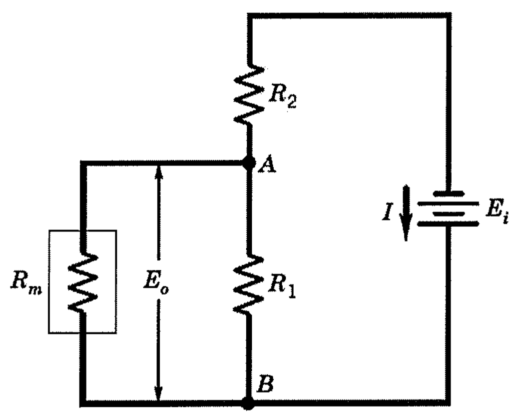
55. A single pole Butterworth low pass filter made with a simple resistor and capacitor will have what cutoff frequency?
   a. RC
   b. 1/(2πRC)
   c. $1/\sqrt{1 + RC^2}$
   d. 1/RC
   e. None of the above

56. What is the magnitude ratio of an single pole Butterworth RC filter at 20π Hz?
   a. $1/\sqrt{1+(10RC)^2}$
   b. $1/\sqrt{1+RC^2}$
   c. $1/\sqrt{1+\left(\frac{1}{RC}\right)^2}$
   d. $20\pi/RC$
   e. None of the above

57. What is the magnitude ratio of a 3-pole Butterworth filter at the cutoff frequency?
   a. -3 dB
   b. -9 dB
   c. 0.3
   d. 2/3
   e. None of the above

58. Which filter has a linear phase shift?
   a. Butterworth
   b. Chebyshev
   c. Elliptic
   d. None of the above

59. What is the fundamental frequency of $y = 5\sin(20\pi t) + 8\sin(12\pi t) + \cos(25\pi t)$?
   a. 1 Hz
   b. 6 Hz
   c. 12.5 Hz
   d. 5 Hz
   e. 8 Hz



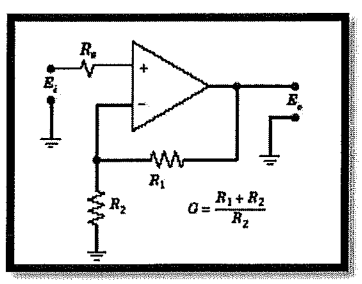
60. Referring to the figure to the right, as the supply voltage, E_i, gets larger the % error introduced by the meter, R_m, gets smaller.
   a. True
   b. False

61. Referring to the figure to the right, if R_m is the meter resistance and R_1 is an RTD what is the output impedance of the curcuit?
   a. R_m
   b. $R_1R_m/(R_1+R_m)$
   c. $R_2 + R_1R_m/(R_1+R_m)$
   d. R_1
   e. None of the above

62. Heat flux should be measure with a very high input impedance sensor.
   a. True
   b. False

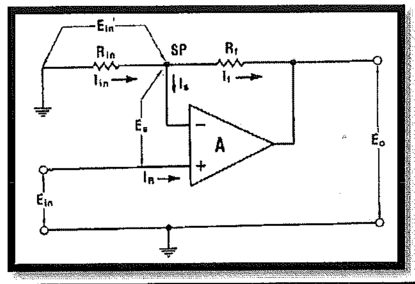
63. The input impedance of a volt meter should be very large.
   a. True
   b. False

64. In the circuit to the right, if $R_1=R_2$ this is
   a. an inverting amplifier
   b. a non-inverting amplifier
   c. a voltage follower
   d. a differential amplifier
   e. None of the above



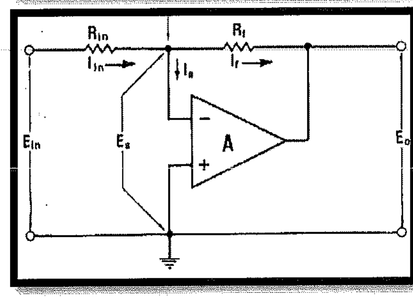
65. The voltage E_s in this op amp circuit to the right is

a. E_{in}
b. E_o
c. $I_{in}R_{in}$
d. Zero
e. E_o/E_{in}



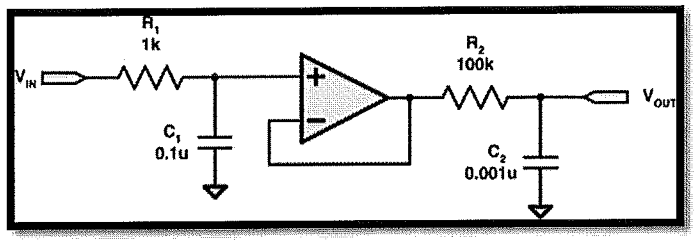
66. The gain of this op amp circuit is

a. R_f/R_{in}
b. R_{in}/R_f
c. $(R_{in}+R_f)/R_{in}$
d. None of the above



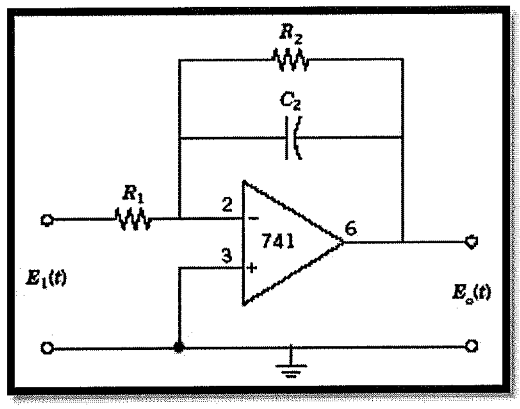
67. The circuit to the right is

a. a 2-pole passive high pass filter
b. an active 2-pole high pass filter
c. a 2-pole passive low pass filter
d. a band pass filter
e. a notch filter



68. The circuit to the right is

a. a high pass filter b. a low pass filter
b. an inverting amplifier c. a differentiator



69. In lab 4s, Strain Gage Experiences, a strain gauge was placed on a cantilevered beam. The input impedance of the strain gauge should have been very high.

a. True b. False

70. A strain gage does not require material deformation to sense force.

a. True b. False

71. The output of an accelerometer like the one used in the last lab, can be integrated to accurately obtain velocity and ultimately position information for very long periods of time.

a. True b. False

72. The best signal to noise ratio that can be achieved with an 8 bit ADC is

a. ±½Q where Q is the resolution c. log(256)
b. 20 log(256) d. None of the above

73. If a sensor's performance can be modeled with the equation, $y(t) = 4 + 12F(t)$, where $F(t)$ is the input to the sensor, it is

a. a zero order sensor
b. a first order sensor
c. a second order sensor

74. If you are given the time constant of a thermocouple can you determine the attenuation of a 10 Hertz input temperature signal?
   a. Yes   b. No - need more information

75. The area under a probability density function (PDF) from $-\sigma$ to $+\sigma$ is 0.68.
   a. True   b. False

76. If you are given only the PDF of a data set then you can determine
   a. the first and second moments
   b. the frequency response of the system
   c. the accuracy and precision of your measurement
   d. None of the above

77. The ringing of an under damped second order system in response to a step input will decay exponentially.
   a. True   b. False

78. The ringing frequency of any damped second order system is $\omega_d = \omega_n\sqrt{1-\zeta^2}$.
   a. True   b. False

79. The magnitude of the deflection of a sensor is proportional to its impedance.
   a. True   b. False

80. The magnitude of the deflection of a sensor is proportional to its sensitivity.
   a. True   b. False

81. Piezoelectric pressure transducer is a null device.
   a. True   b. False

82. The frequency spectra of a square wave has only odd harmonics.
   a. True   b. False

83. A sine wave is an even function.
   a. True   b. False

84. The accuracy of the mean value of a discretely sampled signal is linearly proportional to the number of data points sampled.
   a. True   b. False

85. Amplitude ambiguity in the Fourier Transform of a signal can be reduced by sampling longer.
   a. True   b. False

86. An elliptic low pass filter has a steep roll off and a linear phase shift.
   a. True   b. False

87. The units of static sensitivity of the thermocouple used in lab 2 is Volts/°C.
   a. True   b. False

88. Given two second order systems with the same natural frequency the one with a damping ratio of 0.5 will have a shorter settling time than one with a damping ratio of 0.707.
   a. True   b. False

89. Quantization error can be reduced by signal amplification.
   a. True   b. False

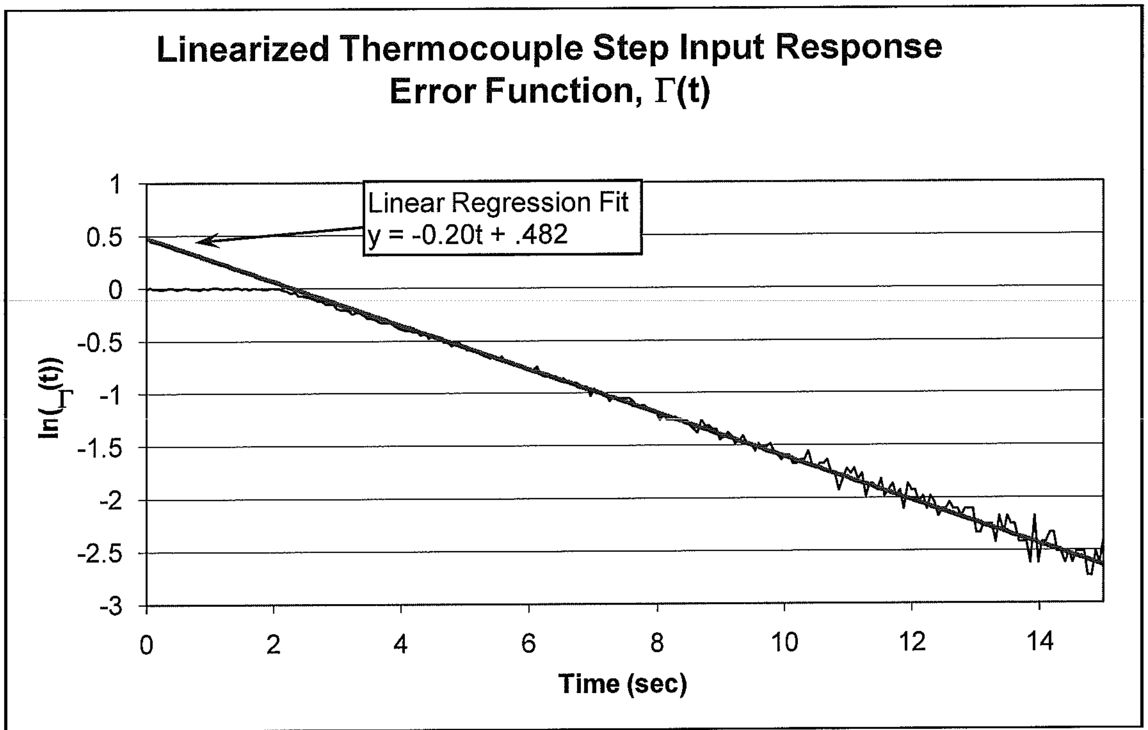


Figure 3. Linearized error function obtained from the dynamic calibration of a thermocouple.

90. The time constant of the thermocouple step input response is plotted in Figure 3 is 0.2 seconds.
    a. True
    b. False

91. What is the highest frequency air temperature fluctuation that could be accurately tracked using the thermocouple from lab 2.
    a. 1 cycle/hour
    b. 1 cycle/minute
    c. 1 Hz

92. Careful calibration of an instrument
    a. requires an accurate calibration reference input.
    b. should cover the entire range of the data to be collected.
    c. can correct for bias error.
    d. all of the above are correct.
    e. only A and C are correct.

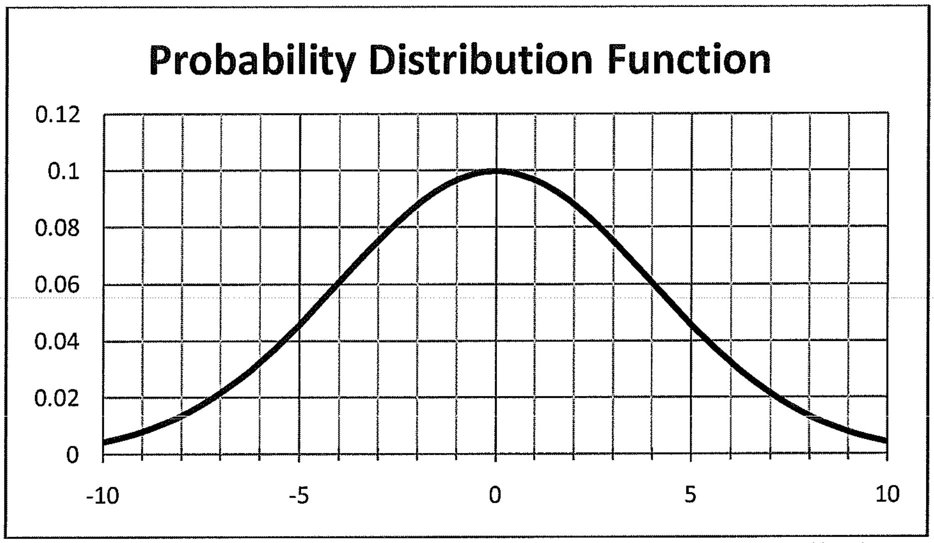


Figure 4. PDF plot of a data set with a Gaussian (normal) distribution.

93. The normally distributed data set whose PDF if plotted in Figure 4 has a standard deviation of approximately
    a. 2
    b. 4
    c. 7
    d. 10

94. To estimate the 95% confidence interval for a linear curve fit of 15 data points you would use the formula
    a. $C.I. = \pm t_{15,95} S_{xy}$
    b. $C.I. = \pm t_{13,95} S_x$
    c. $C.I. = \pm t_{13,95} S_{\bar{x}}$
    d. $C.I. = \pm t_{13,95} S_{xy}$
    e. None of the above

95. To estimate the 90% confidence interval of the sample mean value, $\bar{x}$, about the true mean value, x' from a 50 point normally distributed data set you would use the formula
    a. $C.I. = \pm t_{50,90} S_x$
    b. $C.I. = \pm t_{49,90} S_x$
    c. $C.I. = \pm t_{48,90} S_{\bar{x}}$
    d. $C.I. = \pm t_{49,90} \dfrac{S_x}{N^{1/2}}$
    e. None of the above

96. Given a 50 point normally distributed data set. If a 51st data point where taken, x_i, there is a 90% probability that its value would lie within what confidence interval of the data set's mean value, $\bar{x}$.
    a. $C.I. = \pm t_{50,90} S_x$
    b. $C.I. = \pm t_{49,90} S_x$
    c. $C.I. = \pm t_{48,90} S_{\bar{x}}$
    d. $C.I. = \pm t_{49,90} \dfrac{S_x}{N^{1/2}}$
    e. None of the above

97. Careful calibration of an instrument
    a. can minimize the effect of precision error.
    b. requires constant values of extraneous variables.
    c. can eliminate the effect of bias error.
    d. All of the above
    e. Only B and C are correct.

Student Number: ____________________ Your Name: ____________________

98. If a -0.3 volt signal was applied to the ADC used in the lab what would the binary output be if the quantization step size was 1 millivolt? $\frac{-0.3}{0.001} = -300$

X	X	X	X	0	0	0	1	0	0	1	0	1	1	0	0
				1	1	1	0	1	1	0	1	0	0	1	1
														+1	1
X	X	X	X	1	1	1	0	1	1	0	1	0	1	0	0

You have a 2 year old inexpensive 3 digit digital thermometer with XX.X °C display. If it is to be used to check normal body temperature (~40 °C) find the anticipated design stage errors given the following manufacturers specifications.

Range: 15 to 55 °C
Linearity: 1 %
Bias Error: ± 0.1 °C
Stability: 0.1% per year

You do not need to perform the math, but must neatly and clearly write out the applicable equations and then insert the appropriate values into the equations. You will get 1 point for stating the correct equation and 1 point for correct application of the specified errors.

99. (2 pts) Find the zero order error.

(1 PT) $u_0 = \pm\frac{1}{2}Q = \pm\frac{1}{2}\,0.1 = \pm 0.05\,°C$ (1 PT)

100. (4 pts) Find each of the elemental instrument errors

$u_1 = \pm 1\%\ 40\,°C$ — (1 PT)

$u_2 = \pm 0.1\,°C$ — (1 PT)

$u_3 = \pm(0.1\%)(2)(40)\,°C$ — (1 PT)

(1 PT)

101. (2 pts) Find the design-stage uncertainty of the thermometer

(1 PT) $u_d = \pm\sqrt{u_0^2 + u_c^2}$

(1 PT) $\sqrt{0.05^2 + (1\%\,40)^2 + 0.1^2 + [(.1\%)(2)(40)]^2}$