Name:____________________

Person Number:______________

Department of Mechanical and Aerospace Engineering

MAE334 - Introduction to Instrumentation and Computers

Final Examination

December 14, 2005

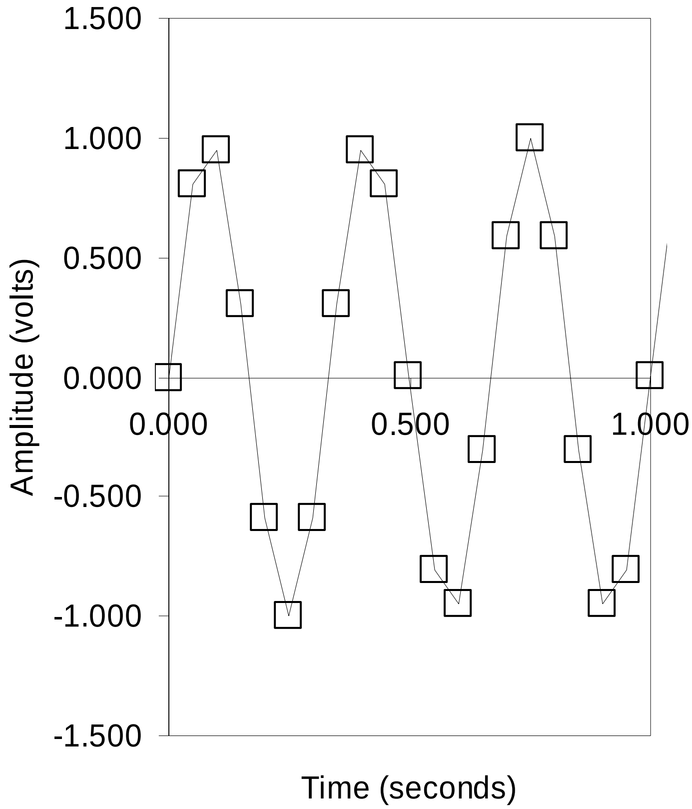
Closed Book and Notes

1. Be sure to fill in your name <u>and</u> 8 digit person number (starting from the left and with no gaps or hyphens) on side two of the scoring sheet and also on this questioner.
2. Be sure to fill in circle number 1 under the "Grade or Education" box on side two of the scoring sheet. This is your exam number. There are 4 different exams!
3. For each question, choose the <u>best</u> answer and place a mark corresponding to that answer on the machine scoring form.
4. All questions are weighted equally.

Failure to correctly complete steps 1 and 2 above will most likely result in a grade of ZERO!

1) Add the two 4 bit binary numbers 1100 and 0010. A negative number is in 2's complement binary representation.

a) 14
b) 6
c) 2
d) -2
e) None of the above



2) With no other knowledge about the voltage signal which was discretely sampled using an ADC and plotted in the graph on the right you can determine the highest frequency in the voltage signal was

a) 1 Hz
b) 2 Hz
c) 3 Hz
d) None of the above

3) The best signal-to-noise ratio that can be achieved with the analog to digital converters used in the lab is 20 log(4096) decibels.

a) True
b) False

4) A typical dynamic calibration is used to obtain both the static sensitivity and frequency response characteristics of a sensor.

a) True
b) False

5) Which extraneous variable most contributed to the discrepancy in the PV = constant assumption used in "Lab #4 Studying the Behavior of a Compressed Gas."

a) Quantization error
b) Electronic interference noise
c) Temperature change of the compressed gas
d) Pressure transducer accuracy
e) Potentiometer accuracy

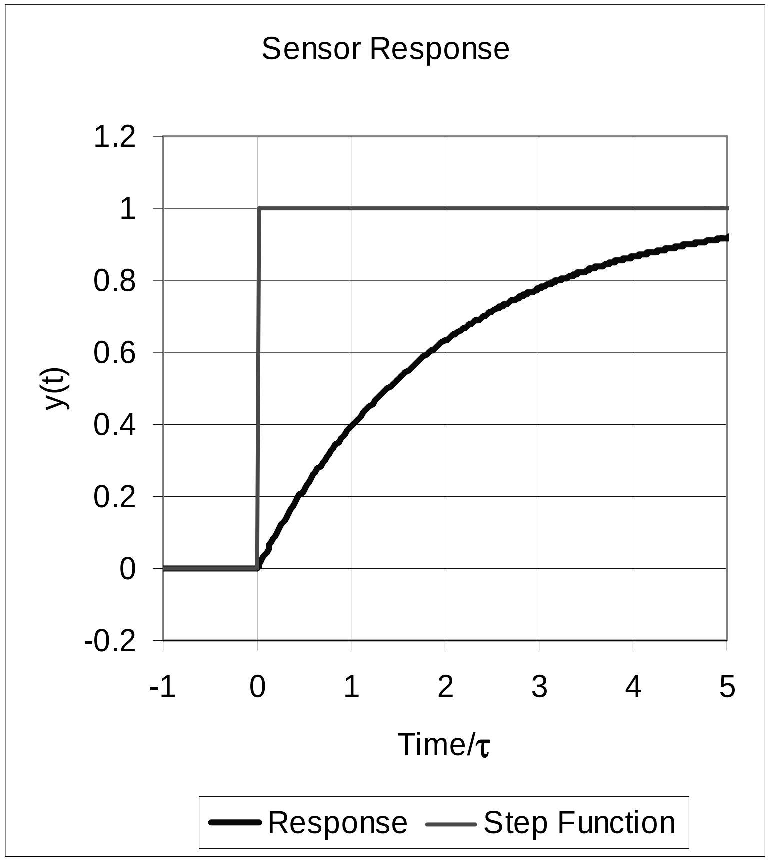
6) If the sensor output, $y(t)$, is a linear function of the input, $y(t) = KF(t)$, then

a) The static sensitivity is frequency dependent
b) The sensor could be a thermocouple
c) The sensor behaves as a zero-order system
d) All of the above
e) None of the above

7) If a system can be modeled with the equation, $\text{Output} = mc_v dT(t)/dt$, where m and c_v are constants and T is a function time, t, it is referred to as a first order system.

a) True
b) False

8) Is the plot on the right representative of a first order system response? (τ is the time constant)



   a) True
   b) False

9) If you know the time constant, τ, of a first order system you can uniquely define the frequency response characteristics of the system.
   a) True
   b) False

10) If the transfer function magnitude ratio of a first order system is $M(\omega) = 1/[1+(\omega\tau)^2]^{1/2}$ then to avoid aliasing of a fluctuating temperature signal with a range of 1 °C recorded using a thermocouple you could sample at what rate? Given: $\tau = 1/(2\pi)$ seconds and the measurement resolution is 0.1 °C. (Hint: at what frequency is the response of the thermocouple to a 1 °C fluctuation less than the resolution of your measurement device?)
   a) $\sqrt{99}$ Hz
   b) $\sqrt{99}/2\pi$ Hz
   c) 2π Hz
   d) 1 Hz
   e) None of the above

11) Using the information from the previous question. The output magnitude ratio at 1 Hz is $M(\omega) = \frac{1}{\sqrt{2}}$.
   a) True
   b) False

12) The total area under a probability density function is
   a) Related to the variance of the data set
   b) Always equal to 1
   c) Related to the number of data points
   d) All of the above
   e) None of the above

13) The standard deviation is equal to the square of the variance.
   a) True
   b) False

14) Approximately 68% of the measurements of normally distributed variable are within one standard deviation of the mean value.
   a) True
   b) False

15) If we know the probability density function of a measurement variable then one can

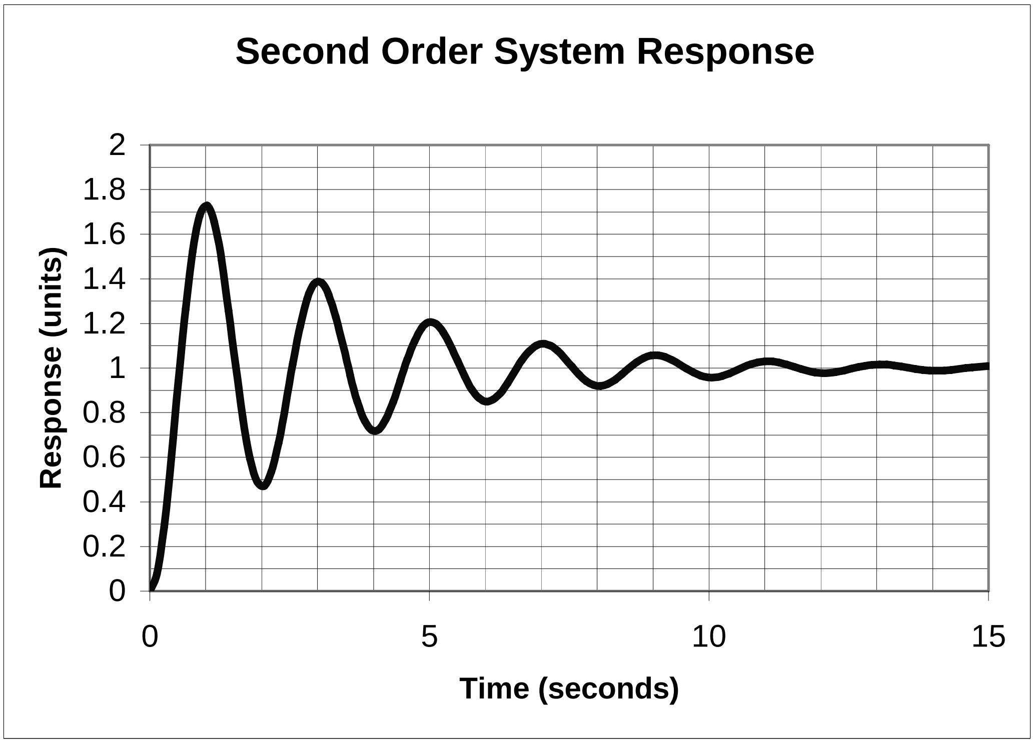
a) Figure out the mean value
b) Figure out the variance
c) Estimate the probability of recording a particular range of values
d) All of the above
e) None of the above

16) A large data set (N>1000) has a mean value of 9.2 units and a standard deviation of 1.1 units. Determine the range of values in which 50% of the data set should be found, assuming a normal probability.

a) 9.2 ±(0.674 x 1.1)
b) 9.2 ± ½(0.674 x 1.1)
c) ±(9.2 x 0.674)
d) None of the above

17) For all of the static calibrations of linear transducers performed in the lab this semester the number of degrees of freedom of the calibration curve was, $\nu = N - 2$, where N is the number of static calibration points collected.

a) True
b) False



18) The Power Spectrum of the second order system response plotted above would have a marked peak at 2 Hz.

a) True
b) False

19) The time constant of the second order system response plotted above is approximately 0.5 seconds.

a) True
b) False

20) The settling time of the second order system response plotted above is approximately 7 seconds.

a) True
b) False

21) If the response of a system can be modeled with the equation, $y(t) = y(0) + C\left[\frac{A}{B}\sin(Bt) + \cos(Bt)\right]e^{-At}$, where *A*, *B* & *C* are constants, then it is

a) an over damped second order system
b) a critically damped second order system
c) an under damped second order system
d) None of the above

22) The damped natural frequency of an under damped second order system can be expressed in terms of the natural frequency and the damping ratio as, $\omega_d = \omega_n \sqrt{1 - \zeta^2}$.

a) True
b) False

23) If the damping ratio of a second order system is below 0.5 then the output amplitude will be greater than the input amplitude if it is subjected to a sinusoidal input at the natural frequency.

a) True
b) False

24) For a second order system the frequency response phase shift will be 90 degrees at the natural frequency no matter what the damping ratio is.

a) True
b) False

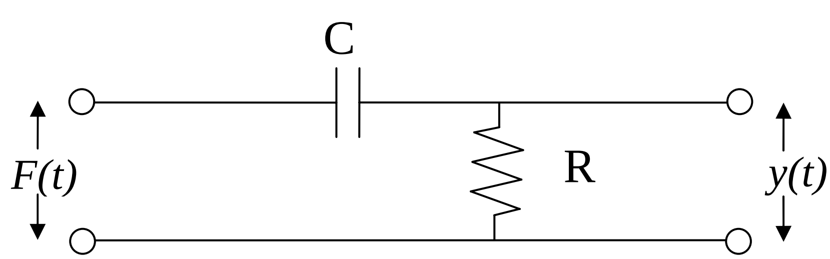
25) A pressure transducer which is not a null device has a static sensitivity which is proportional to the deflection it undergoes due to a change in pressure.

a) True
b) False

26) The pressure transducer used in the lab was based on a diaphragm and strain gauge principle.

a) True
b) False

27) To accurately measure the output voltage *y(t)* in the circuit on the right your meter should have an input impedance of approximately twice *R*.



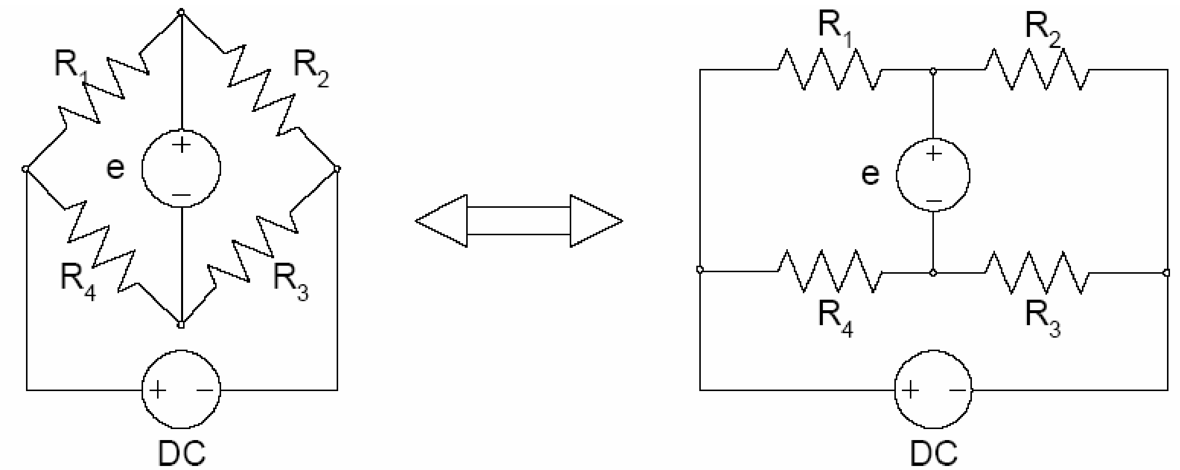
a) True
b) False

28) Pressure is considered to be an effort variable and should be measured with a low input impedance sensor.

a) True
b) False

29) The temperature gage in your car should have a low input impedance.

a) True
b) False



30) The Wheatstone bridge pictured above would be called “balanced” *only* if all the resistances were equal.

a) True
b) False

31) If R_1 in the Wheatstone bridge pictured above is a strain gauge then varying a well calibrated potentiometer at R_4, would be a method of allowing one to use a sensitive D'Arsonval meter to accurately measure the bridge voltage.

a) True
b) False

32) An optical interferometer used to measure displacements has an inherent precision on the order of the wavelength of the light source.

a) True
b) False

33) A linear potentiometer as used in the fourth lab has a position measurement zero order uncertainty of __________ where K is the static sensitivity of the position vs. voltage calibration and Q is the resolution of the ADC.

a) ± ½ (K Q)
b) ± (K Q)
c) ± ½ Q
d) ± Q
e) None of the above

34) The full scale resolution, E_{FSR}, of the ADC used in the lab is

a) 20/4096
b) 10/4096
c) Range/2^{10}
d) Both a) and c)
e) None of the above

35) If the desired quantity is a function of 3 measurements, M_1, M_2 & M_3, in the form of, $y = 2M_1 + 4M_2 + 10M_3$, then the uncertainty in y can be expressed as a function of the uncertainty associated with each measurement, U_1, U_2 and U_3 as

a) $U_d = \pm\sqrt{U_1^2 + U_2^2 + U_3^2}$

b) $U_d = \pm\sqrt{2U_1^2 + 4U_2^2 + 10U_3^2}$

c) $U_d = \pm\sqrt{(2U)_1^2 + (4U)_2^2 + (10U)_3^2}$

d) $U_d = \pm\sqrt{\left(\frac{2}{2}U\right)_1^2 + \left(\frac{4}{2}U\right)_2^2 + \left(\frac{10}{2}U\right)_3^2}$

e) None of the above

Design Stage Uncertainty Problem

An ADC is to be used to measure the output from a thermocouple. The nominal temperature expected will be about 20 °C. Estimate the design-stage uncertainty in this combination. The following information is available:

ADC	
Gain:	1
Range:	±1 volt
Resolution:	10 bits
Accuracy:	within 0.001% of reading
Thermocouple	
Sensitivity:	10^{-4} V/°C
Linearity:	within 1 mVolt/°C over range
Repeatability:	within 2 mV/°C over range
Resolution:	negligible

36) The voltage measurement design stage uncertainty of the ADC is

a) $u_0 = \pm\frac{1}{2}\left(\frac{2}{2^{10}}\right)$

b) $(u_d)_E = \pm\sqrt{\left(\frac{1}{2}\left(\frac{2}{2^{10}}\right)\right)_E^2 + \left(2\times10^{-8}\right)_E^2}$

c) $(u_d)_E = \pm\frac{1}{2}\sqrt{\left(\frac{2}{2^{10}}\right)_E^2 + \left(2\times10^{-8}\right)_E^2}$

d) None of the above

37) The design stage uncertainty of the thermocouple can be assumed to be

a) $\pm\sqrt{\left[(1\text{ mV/}^\circ\text{C}) \times 20\ ^\circ\text{C}\right]^2 + \left[2\text{ mV/}^\circ\text{C} \times 20\ ^\circ\text{C}\right]^2}$

b) $\pm\frac{1}{2}\sqrt{\left[(1\text{ mV/}^\circ\text{C}) \times 20\ ^\circ\text{C}\right]^2 + \left[2\text{ mV/}^\circ\text{C} \times 20\ ^\circ\text{C}\right]^2}$

c) $\pm\sqrt{[1\text{ mV}]^2 + [2\text{ mV}]^2}$

d) None of the above

38) The Fourier Transform of a square wave will contain infinite frequencies.

a) True
b) False

39) The step input response function can be used to characterize the dynamic response of a system because the step input contains uniform frequency content from 0 to infinity.

a) True
b) False

40) The delta function integral $\int_{-\infty}^{+\infty} \delta(t)dt$ is defined to be

a) 1
b) ½
c) 0
d) None of the above

41) The lowest resolvable frequency in a sample data set is

a) The Nyquist frequency
b) 1/record length
c) ½ the sampling rate
d) (½ the sampling rate) x number of samples
e) None of the above

42) The minimum sampling rate required to resolve the fundamental frequency of a 100 Hz *square* wave would be

a) > 50 Hz
b) > 100 Hz
c) > 200 Hz
d) > 300 Hz
e) > ~ 1000 Hz

43) If t is in seconds, the frequency in Hertz of $y(t) = 12\sin(18\pi t)$ is:

a) 9
b) 18
c) 18π
d) 36
e) none of the above.

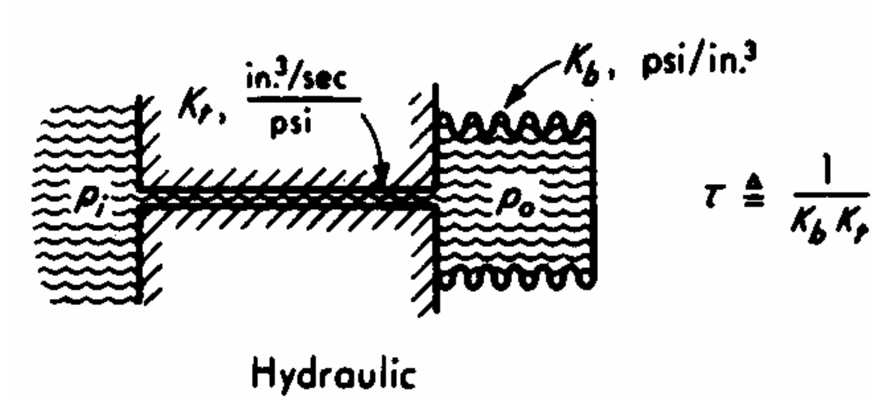
44) The error function of a thermocouple subjected to a step input will vary from

a) 1 to 0
b) 0 to -∞
c) T_0 to T_∞
d) -1 to 0
e) None of the above

45) Amplitude ambiguity in the Fourier Transform of a signal can be reduced by

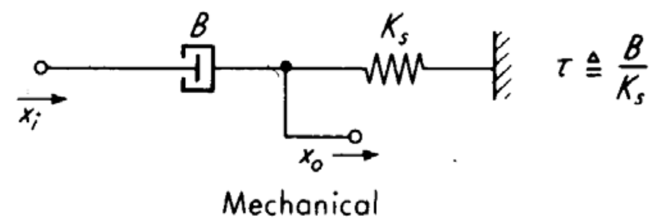
a) sampling long enough
b) sampling for an integer multiple of the signal period.
c) Sampling much faster than the twice the highest frequency in the signal
d) All of the above
e) Both a) and b)

46) The figure to the right is an example of a hydraulic high pass filter.



a) True
b) False

47) The mechanical system in the schematic to the right is a high pass filter.



a) True
b) False

48) The key features of a Bessel low pass filter are

a) Simple construction, moderate roll off and non-linear phase shift
b) Simple construction, gradual roll off and non-linear phase shift
c) Gradual roll off and linear phase shift
d) Steep roll off and linear phase shift
e) Steep roll off and non-linear phase shift

49) A high order elliptic filter would be effective for

a) Sound recording systems
b) Anti-aliasing signal conditioning
c) Simultaneous sampling of multiple channels
d) None of the above

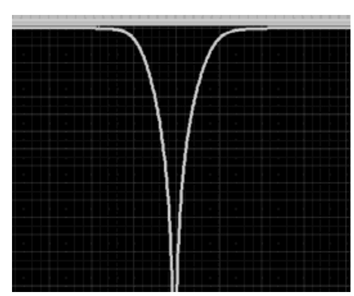
50) A Butterworth filter with a cut-off frequency of 5,000/π Hz could be fabricated with

a) 10^3 ohm resistor and 1 μF capacitor
b) 10^4 ohm resistor and 1 μF capacitor
c) 10^4 ohm resistor and 1 pF capacitor
d) 10^3 ohm resistor and 1 pF capacitor
e) None of the above

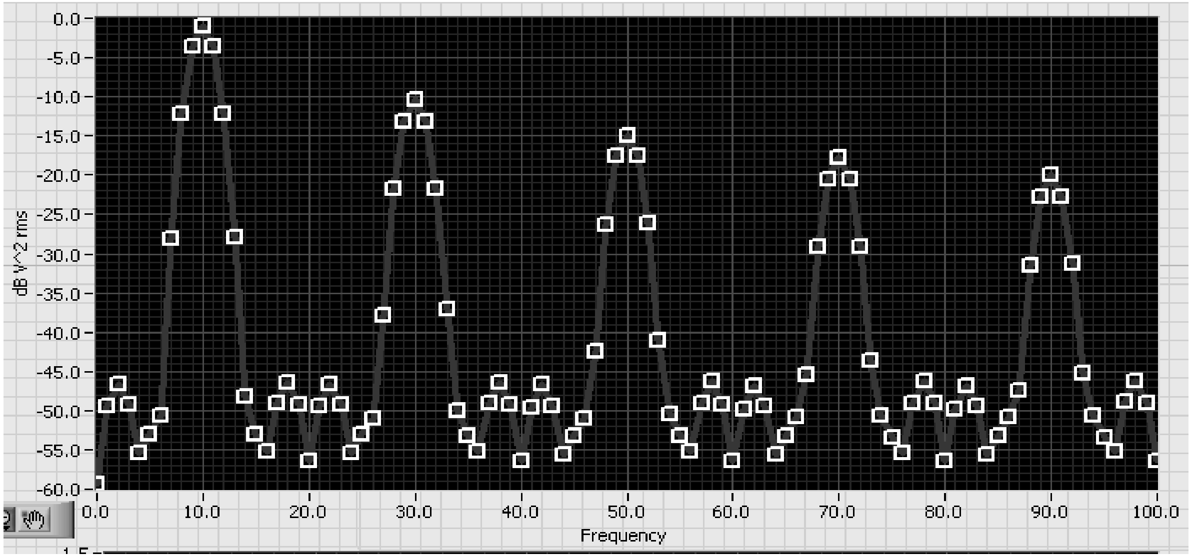
51) When describing the amplitude reduction of Butterworth lowpass filter, the -3 dB frequency, the half-power frequency and filter cut-off frequency all refer to the same frequency.

a) True
b) False

52) The magnitude of the filter transfer function plotted to the right is of a notch filter.

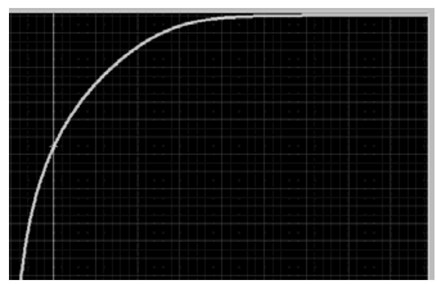


a) True
b) False



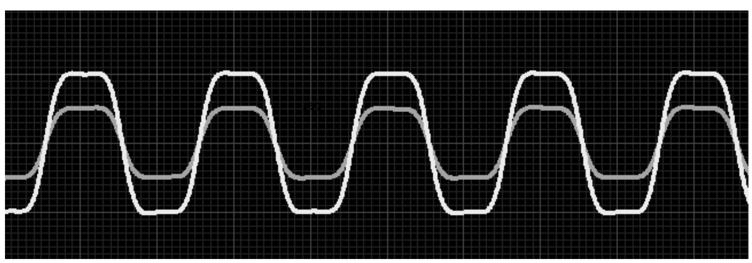
53) The frequency spectra plotted above is of a complex periodic waveform with both even and odd harmonics.

a) True
b) False



54) The magnitude of the filter transfer function plotted to the right is of a band pass filter.

a) True
b) False

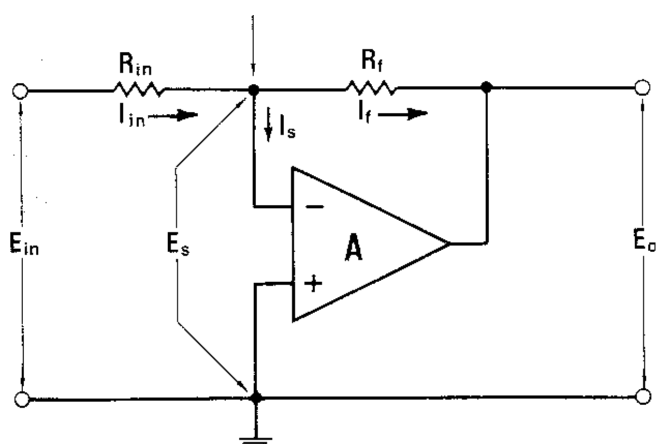


55) The signal plotted above is that of a square wave passed through a low pass filter.

a) This output signal indicative of a Bessel filter
b) This output signal is indicative of a Butterworth filter
c) This output signal is indicative of a Elliptic filter

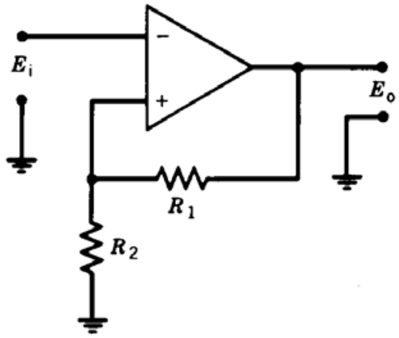
56) The operational amplifier circuit pictured to the right has a gain of

a) Gain = $-R_f/R_{in}$
b) Gain = R_f/R_{in}
c) Gain = $-R_f/(R_{in} + R_f)$
d) Gain = $R_f/(R_{in} + R_f)$
e) None of the above

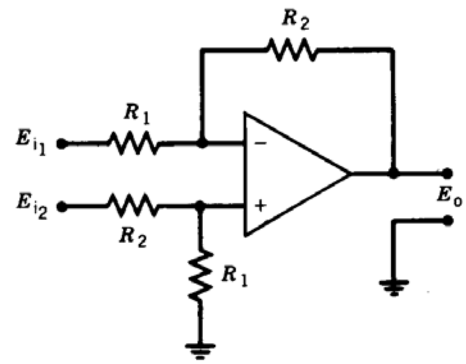


Use the following answers for the next 5 questions

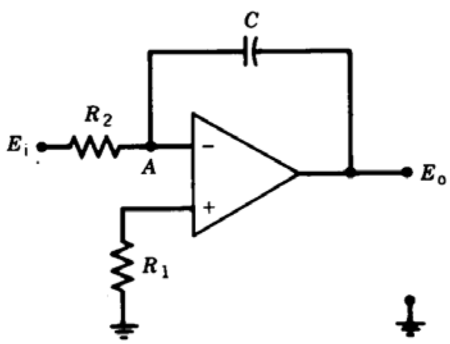
a) Integrator
b) Differential Amplifier
c) Differentiator
d) Non-inverting Amplifier
e) Inverting Amplifier



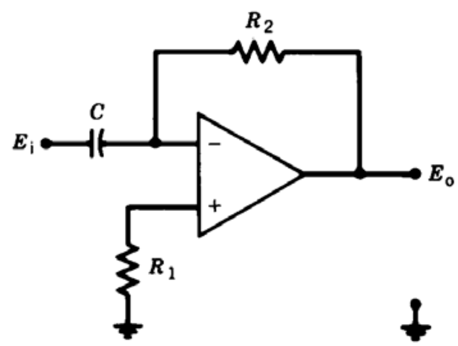
57) Figure 1. Op-Amp Circuit is a:



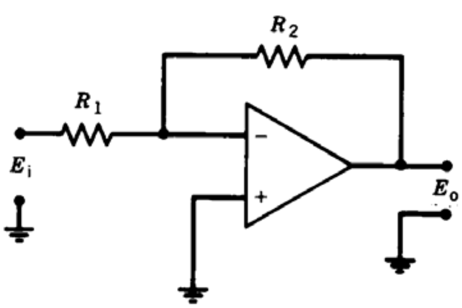
58) Figure 2. Op-Amp Circuit is a:



59) Figure 3. Op-Amp Circuit is a:



60) Figure 4. Op-Amp Circuit



61) Figure 5. Op-Amp Circuit is a:

62) The gain of the amplifier circuit in Figure 1 is

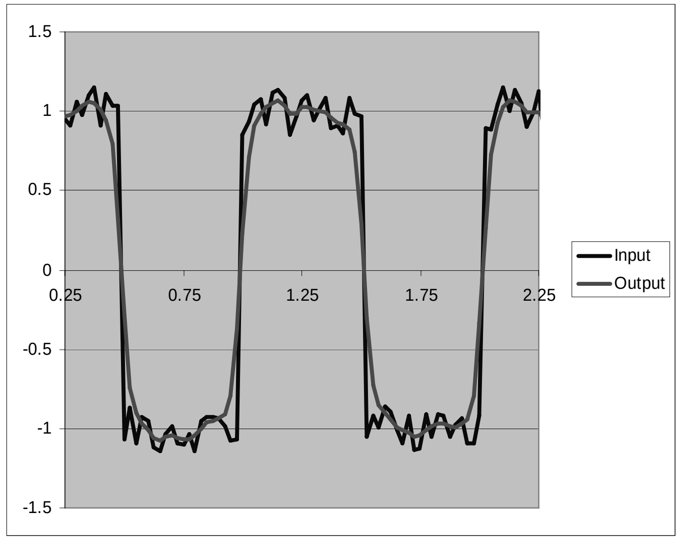
a) $-R_1R_2$
b) $-R_1/R_2$
c) R_1R_2
d) R_2/R_1
e) $-R_2/R_1$

63) Which of the following never depends on the sampling rate?

a) Frequency of the sampled signal
b) Magnitude of the sampled signal
c) Nyquist frequency
d) Shape of the sampled signal
e) None of the above

64) Which low pass filter type produces a constant time delay between the input and output signals?

a) Bessel
b) Butterworth
c) Chebyshev
d) Elliptic



65) The input data is digitally filtered in Excel using a weighted averaging algorithm to produce the output data in the figure to the right. As demonstrated in class a simple weighted averaging algorithm always produces a linear phase shift of the input data.

a) True
b) False

66) What type of thermocouple did we use in the second lab?

a) K-type Chomel-Aluminum
b) J-type Iron-Constantan
c) T-type Copper-Constantan
d) G-type Tungsten-Rhodium

67) Voltage is

a) an effort variable
b) a flow variable

68) In Lab #3 "Transient Thermal Behavior with Work and Heat Loss" given a constant work input, the calorimeter temperature would reach a steady state temperature

a) When the temperature was equal to the lab air temperature
b) When the heat transfer to the lab air equaled the work input
c) After approximately 2 minutes of work input
d) None of the above

69) As the temperature of the calorimeter in Lab #3 increased the thermistor circuit output voltage increases.

a) True
b) False

70) The static sensitivity in units of °C/volt of the thermocouple used in the second lab is much larger than the thermistor used in the third lab.

a) True
b) False

71) The natural frequency of the pressure transducer used in Lab 4 was found to be several kilohertz by analyzing the resonant frequency of the step input response function.

a) True
b) False

72) For an adiabatic compression PV = constant, where P and V are the pressure and volume respectively.

a) True
b) False

73) It was found that the pressure volume relationship in Lab 4 matched that of a polytropic compression.

a) True
b) False

74) Which of the following does not indicate the linearity of a static calibration?

a) The correlation coefficient, R
b) Slope of the regression line
c) The 95% confidence interval
d) Standard error of the fit, S_{xy}
e) None of the above

75) What kind of elastic element was used in the pressure transducer of our experiment #4.

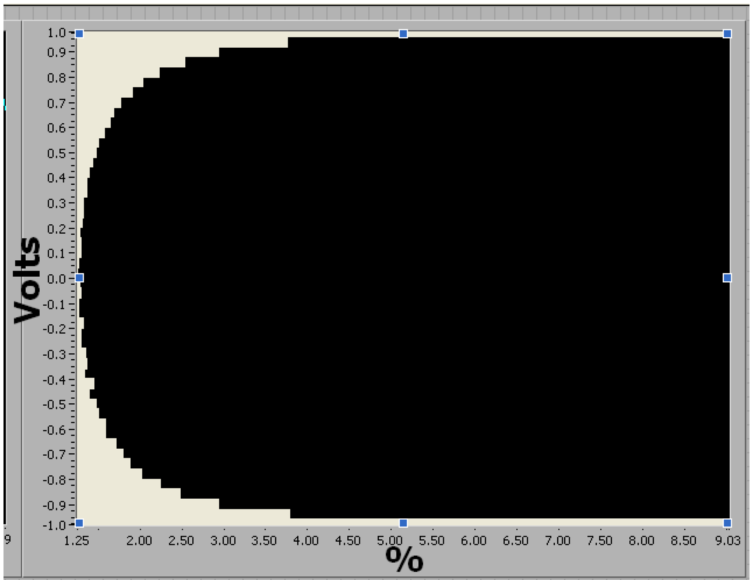
a) a strain gage bonded to the diaphragm
b) a capacitive sensor detecting diaphragm movement
c) a piezoresistive semiconductor
d) none of the above

76) A histogram of repeated measurements of a static value

a) is useful for determining if the extraneous variables are randomly distributed.
b) provides an approximation of the bias error
c) provides an approximation of the precision error
d) all of the above are correct
e) only a) and c) are correct

77) If the output impedance of an operational amplifier is zero it is an infinite source of power.

a) True
b) False

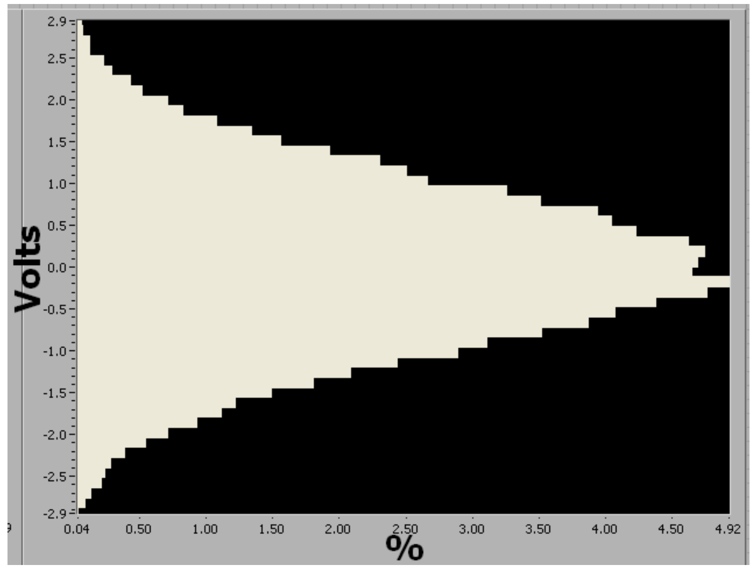


78) The histogram plotted to the right is indicative of a sinusoidal signal.

a) True
b) False

79) The signal from which the histogram to the right is calculated spends approximately 18% of the time near its extremes.

a) True
b) False



80) The histogram plotted to the right is appears to be of a randomly distributed data set.

a) True
b) False

81) By jumping off the bumper of a car and observing the step input response of the suspension you recognize the ideal single oscillation as

a) An over damped second order system
b) A critically damped second order system
c) An under damped second order system

82) Velocity should be measured with a low input impedance sensor.

a) true
b) false

83) Given a second order system with a damping ratio of 1, a reduction in the mass of the system will cause it to oscillate at a higher frequency.

a) True
b) False

84) Given a second order system with a damping ratio of 1, a reduction in the mass of the system will reduce the settling time.

a) True
b) False

slope	23502	16.400	**intercept**
Standard error for the slope	110.32	0.1242	**Standard error for the intercept**
R Square	0.9991	0.7225	**S_{yx}, Standard error for the y estimate**
The F statistic	45381	43	**ν, Degrees of freedom**
regression sum of squares	23686	22.44	**D, residual sum of squares**

Table 1. Microsoft Excel LINEST output from a thermocouple static calibration data set.

85) Using the output from the LINEST function in Table 1 determine the 90% confidence interval of the fit.

a) $y_{ci} = \pm (0.9991)(1.681)$
b) $y_{ci} = \pm (0.7225)(1.681)$
c) $y_{ci} = \pm (16.4)(1.681)$
d) $y_{ci} = \pm (0.1242)(1.681)$
e) none of the above

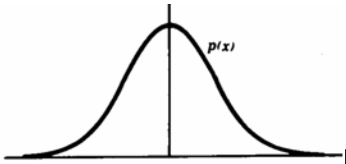
86) More than 99.9% of the variance in *y* is accounted for by the fit in Table 1.

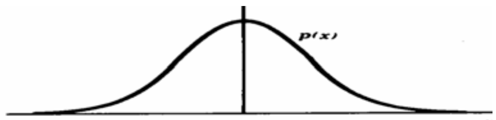
a) True
b) False

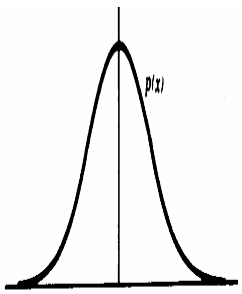
87) A 49 Hz sine wave sampled at 100 Hz will result in a sampled data set with what frequency

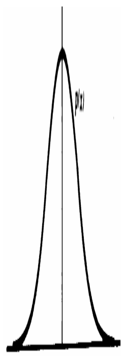
a) 1 Hz
b) 2 Hz
c) 49 Hz
d) none of the above

88) Given the following probability density functions. Which signal has the largest standard deviation?

a.


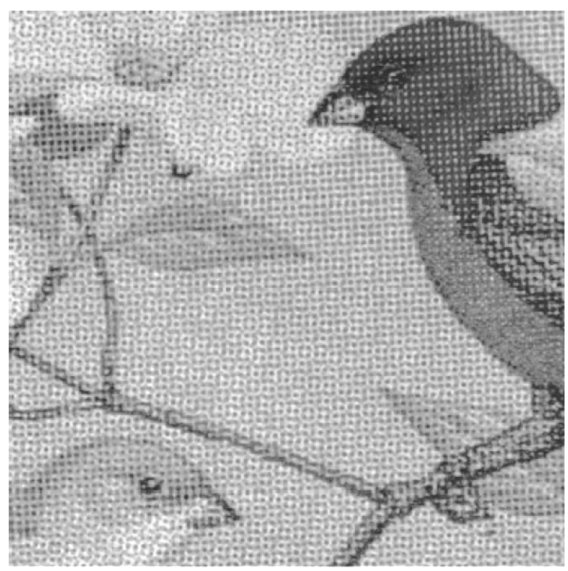
b.


c.


d.


89) In this class we refer to the true mean value of a continuous function as x'.

a) True
b) False


a

90) The half-tone pattern in the image to the right could be removed with Fourier transform filtering.

a) True
b) False

91) Accuracy is a measure of the ability to represent a true (known) value.

a) true
b) false

92) Two resistors are combined to form an equivalent resistance of R = 1000 ohms. Readily available are two common resistors at 500 +/- 50 ohm and 2000 +/- 100 ohm.

a) Combining the 500 ohm resistors in series produces the most accurate result
b) Combining the 2000 ohm resistors in parallel produces the most accurate result

93) The quantization size of an ADC is related to:

a) the speed of the A/D conversion.
b) the gain of the input single.
c) the amplitude of the input signal relative to the full range of the A/D converter.
d) all of the above are correct.
e) only B and C are correct.

94) As the standard error of the fit, S_{xy}, decreases the confidence limits on a linear regression line will decrease in magnitude as well.

a) True b) False

For the next 3 questions: Given an analog pressure gauge like that used in the lab with a resolution of 5 psi and an accuracy of ±4% of the reading.

95) Find the zero order uncertainty, u_0, at 100 psi.

a) $u_0 = \pm 2$ psi
b) $u_0 = \pm 4$ psi
c) $u_0 = \pm 5$ psi
d) $u_0 = \pm 2.5$ psi
e) none of the above

96) Find the uncertainty error, u_c, at 60 psi

a) $u_c = \pm 5$ psi
b) $u_c = \pm 2.5$ psi
c) $u_c = \pm 2.4$ psi
d) $u_c = \pm 1.2$ psi

97) The design stage uncertainty, u_d, at 60 psi can be found using the formula

a) $u_d = \pm (u_c + u_0)^{0.5}$
b) $u_d = \pm 1/2(u_c + u_0)^{0.5}$
c) $u_d = \pm (u_c^2 + u_0^2)^{0.5}$
d) $u_d = \pm 1/2(u_c^2 + u_0^2)^{0.5}$
e) none of the above

98) Given a data set with 50 values, a sample mean of 2.0 and a sample standard deviation of 0.2. Approximately 99% of the data points will lie in the range of

a) 2.0 ± (0.2)(2.678)
b) 2.0 ± (0.2)(2.680)
c) 2.0 ± (0.2)(2.682)
d) none of the above

99) If the source of the precision error in a measurement is the instrument resolution, the precision error can be assumed to have Gaussian distribution

a) True
b) False

100) In a design-stage uncertainty analysis, the zero-order uncertainty estimate for each component of the instrument system is estimated from

a) preliminary measurements using the component.
b) the manufacturer's estimates of all sources of instrument error.
c) the instrument resolution.
d) a combination of A and C.
e) a combination of B and C.

Representative values of the Student-t estimator are as follows:

ν	$t_{\nu, 50\%}$	$t_{\nu, 90\%}$	$t_{\nu, 95\%}$	$t_{\nu, 99\%}$
40	0.681	1.684	2.021	2.704
41	0.681	1.683	2.020	2.701
42	0.680	1.682	2.018	2.698
43	0.680	1.681	2.017	2.695
44	0.680	1.680	2.015	2.692
45	0.680	1.679	2.014	2.690
46	0.680	1.679	2.013	2.687
47	0.680	1.678	2.012	2.685
48	0.680	1.677	2.011	2.682
49	0.680	1.677	2.010	2.680
50	0.679	1.676	2.009	2.678
∞	0.674	1.645	1.960	2.576