Tutorial for Industrial Instrumentation (EE60031/EE41001)

1. For an instrument, the maximum positive value of its only modifying input ($I_{M,max}$) causes a +5% change in its sensitivity to the measured input. If during a measurement the modifying input is assumed to be a Gaussian random variable of mean $+0.5I_{M,max}$ and standard deviation $0.01I_{M,max}$, compute the limits of instruments output, for an input value of half the FS input range, in terms of the FS output range, with more than 99% confidence. Consider the instrument is ideal in all other respects than what is mentioned above regarding the modifying input.

2. The data sheet of an IC accelerometer sensor ADXL335 is attached. The basic description of the sensor is given in Page 1. The sensor specification parameters are given in Page 3. Assume a particular sensor having the 'typical' values of specification parameters mentioned in Page 3 is used to measure the acceleration sensed during single axis motion of a body. Assume the sensor to have a bandwidth of 10Hz and the supply voltage Vs to be 3V. Interpretation of bandwidth, noise statistics etc. are given in Page 11. Assume an ambient temperature variation in the range 5-45°C. Assume the acceleration of the body to be limited in bandwidth to less than 0.5Hz. It is also limited in amplitude not to cause the output of the sensor to exceed its input range.
   a) Calculate a specification of the total measurement error of the sensor under the conditions of usage mentioned, as x% of FS output ± y% of measured output
   b) Calculate an estimate of the resolution of the sensor.
   c) Define all the specification parameters derived or used in your calculations clearly to explain and justify your usage.

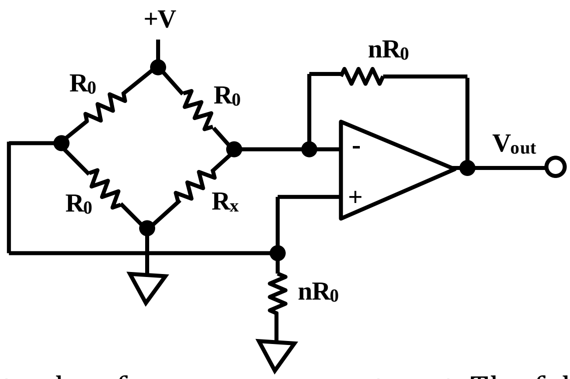
3. Consider the specifications for a bonded strain gage transducer given below. Derive the steady state sensor model relating the desired, modifying and interfering inputs to the output with and without making the available adjustments. Characterise the worst case errors.

Specifications:

Materials	Case and electrical fitting-304L and 316L stainless steel. Pressure fitting and pressure cavity – 17- 4ph stainless steel. Options available.
Full Scale Output	4-20 mA dc corresponding to 0-FS pressure.
Span	16.00 ±0.16 mAdc at 24 Vdc. (±2% adjustment available as an option).
Zero Balance	4.00 ±0.16 mAdc at 24 Vdc. (±5% adjustment available as an option.)
Accuracy	Within ±0.25% of span measured by best fit straight line method to include combined effects of linearity, hysteresis and repeatability at +70°F (+21°C). Within ±0.50% of span for 15 PSI units.
Resolution	Infinite.
Proof Pressure Rating	0-15 thru 0-50 PSI ranges: 5.0 times range. 0-100 thru 0-20k PSI ranges: 2.0 times range. Application of proof pressure will not cause any change in performance characteristics.
Burst Pressure Rating	0-15 thru 0-50 PSI ranges: 10 times range. 0-100 thru 0-20k PSI ranges: 4 times range.
Compensated Temperature Range	-30°F to +170°F (-34°C to +77°C).
Operating Temperature Range	-65°F to +200°F (-54°C to +93°C).

Thermal Sensitivity Shift	Less than ±0.010% of span per °F over compensated temperature range (±0.018% per °C).
Thermal Zero Shift	Less than ±0.010% of span per °F over compensated temperature range (±0.018% per °C).
Shock	30 G's for 11 milliseconds will not cause change in transmitter performance characteristics.
Excitation	15-40 Vdc unregulated at transmitter with performance unaffected by power supply reversal. Any loop resistance is acceptable provided excitation at transmitter is between 15-40 Vdc. Span and zero sensitivity to excitation at the transmitter is less than 0.05% of span per volt. Calibrated at 24 Vdc.
Insulation Resistance	1000 megohms at 50 Vdc between both leads in parallel and case at +70°F (+21°C).
Pressure Connection	1/2-14 NPT internal. Maximum recommended applied pressure with this fitting is 25.000 PSI. For applications where higher pressures are expected, the AE F250-C cone is recommended and is available as an option.
Mounting	By pressure fitting. Unit is not position sensitive.

4. Compute the common mode and differential gains of the resistive transducer–based measurement system (V_0/α) shown below. Let $R_x = R_0(1+\alpha)$. Fine the outputs for V=10V, R_0 = 250Ω, n=100 and α = 0.1 and 0.01



5. Two instruments are used in tandem for a measurement expt. The full scale input ranges of the instrument are R_1 and R_2. Their nominal sensitivies are K_1 and K_2. Each has an accuracy figure quoted as x_i% of f.s. Give specs for ranges sensitivity and accuracy of the composite instrument.

6. For a single op-amp differential amplifier shown in fig. P4, the op-amp is an ideal one, but there is a mismatch in the values of the resistances. Find the CMRR of the configuration. Comment on the result.

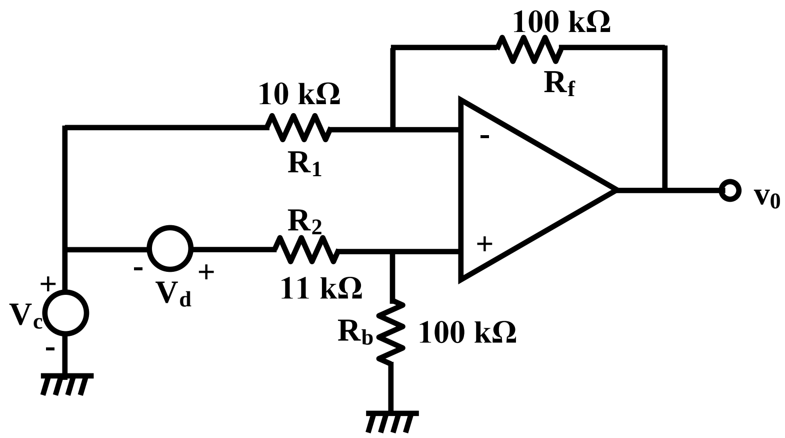


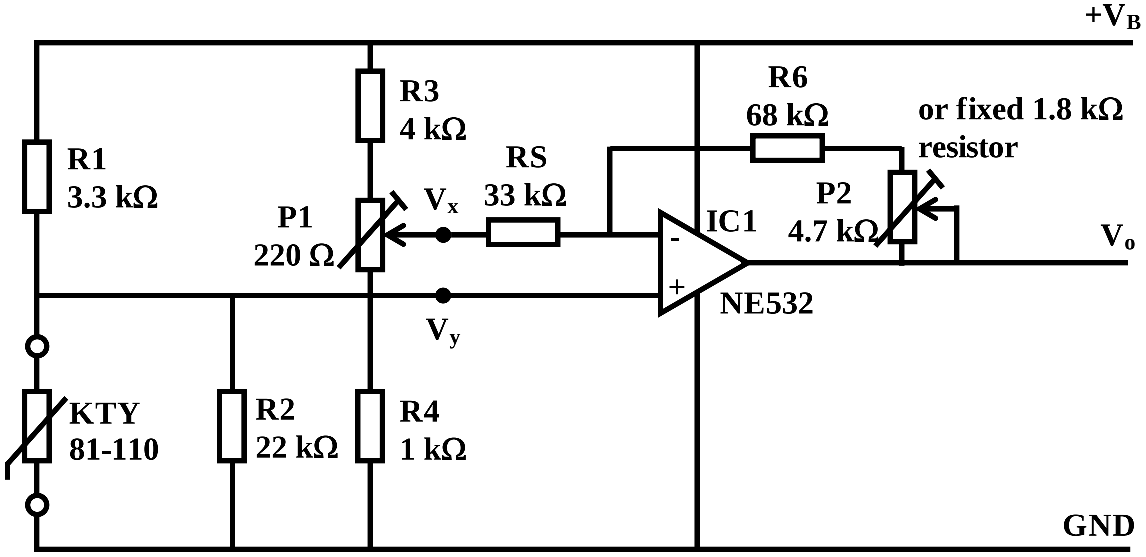
Fig. P-4

7. Below find the resistance characteristics of a silicon temperature sensor. For the temperature measurement circuit shown below, and using the characteristics provided, answer the following.

(a) Compute the range of voltage across $V_x - V_y$ and Vo-GND for a temperature range of 0-100°C and a supply voltage V_B = 5V.

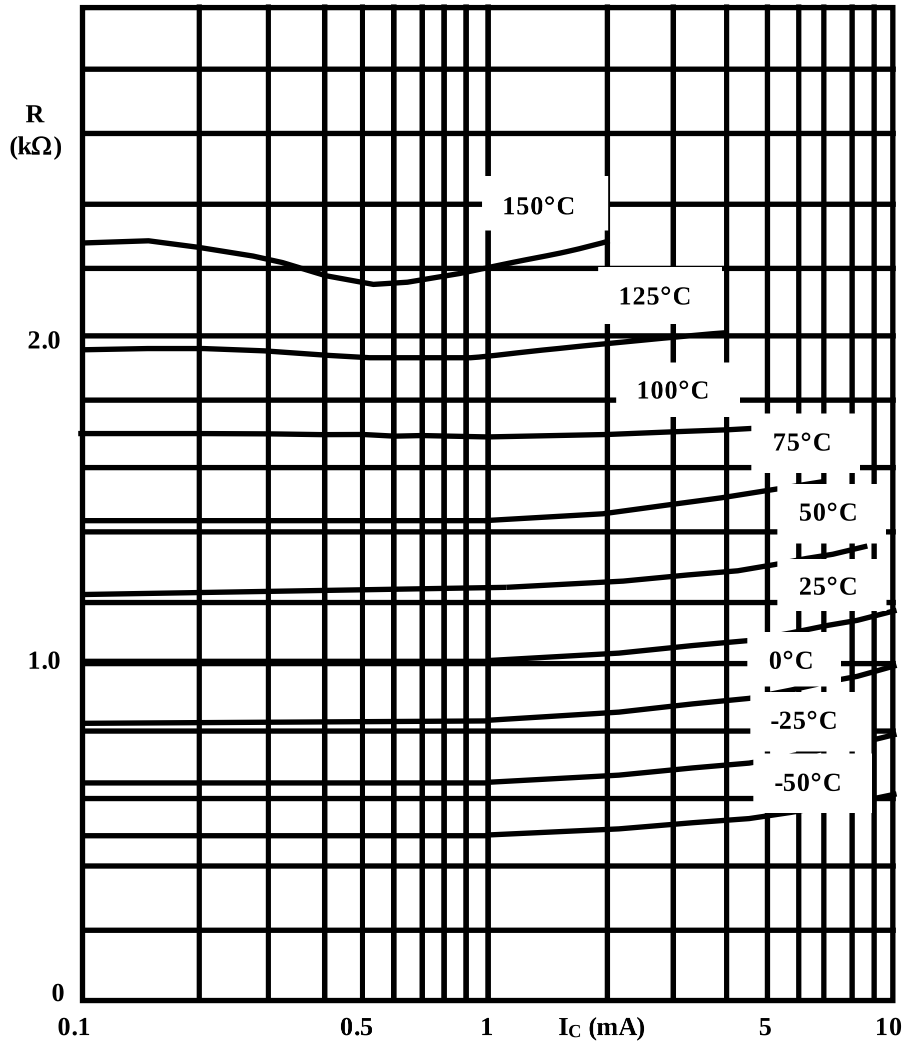
(b) Comment on the non-linearity of the sensor, the sensor $-R_2$ combination and its impact on the non linearity of the voltage $V_x - V_y$.

(c) For a given sample of the KTY-31 sensor describe a method of adjusting zero and sensitivity in the circuit so that the output signal varies over a given fixed range for temperature variation of 0-100°C. compute the range of adjustment possible with the given components in the circuit.



T_{amb} °C	Resistance Ω	T_{amb} °C	Resistance Ω
50	1209	-55	490
60	1299	-50	515
70	1392	-40	567
80	1490	-30	624
90	1591	-20	684
100	1696	-10	747
110	1805	0	815
120	1915	10	886
130	2023	20	961
140	2124	25	1000
150	2211	30	1040
		40	1122

Ambient temperature and corresponding average resistance values of sensor (I_C = 1 mA).



Sensor resistance as a function of operating current

8. a) In a single arm strain gauge bridge for force measurement on a brass member, the circuitry is 5m away maintained in a temperature controlled enclosure and connected by copper leads with the gages. The bridge and amplifier together has an overall sensitivity of 10-5 V/N. The resistance of the gauge is 100Ω and the gauge current which may approximately be measured constant is 25mA. Calculate the limits of error induced by ambient temperature variation in the sensor and the leads in the range 0-50°C. the following specification of the strain gauge are given

Tempco of gauge factor	:	+0.75% 100°F
Tempco of gauge resistance		: Matches the member on which the gauge is bonded for zero temperature induced strain
Tempco of copper	:	43×10^{-4} / °C
Tempco of brass	:	20×10^{-4} / °C
Young's modulas of brass	:	2×10^{11} N / m^2
Resistance of lead	:	2m / ohm.

b) Let a dummy lead of equal length be laid along with the sensor lead and connected in series with the resistance in the arm opposite to the sensor arm of the bridge. Compute the improvement in error specification.

c) A better solution to the lead compensation problem is known to be a 3 wire circuit. Compare this with the solution of part (b) of the problem.

9. A Wheatstone bridge circuit which is actually used for strain measurement is shown in fig. P7. Explain the uses of the resistances/potentiometers R_z, R_{z1}, R_{z2} and R_c. Suggest their range of values for 120Ω strain gages and supply voltage E = 10v.

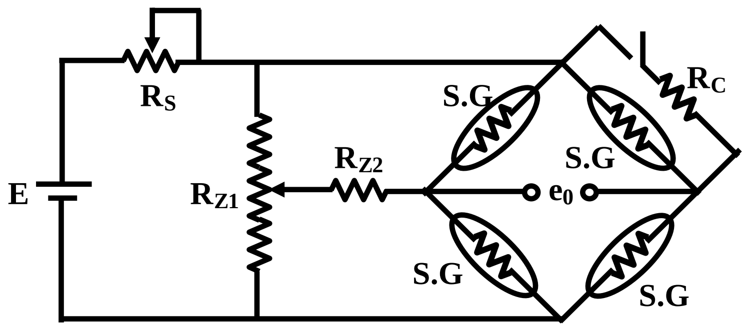


Fig. P-7

10. Consider the strain gage measuring circuit in fig. P6, with only one strain gauge of marked value 120Ω in arm 4 and all other bridge arms are fixed resistances of 120Ω each. The calibration switch is kept open. If R_{z1} = 15KΩ and R_{z2} = 10KΩ, determine the minimum and maximum values of the strain gage resistance for which the bridge can be balanced by adjusting the potentiometer R_{z1}.

11. Consider fig. P6 with only one strain gage of 120Ω (G.F. = 2) in arm 1 and all other bridge arms being fixed resistances of 120Ω each. The calibration is carried out by closing the switch in series with R_c. Calculate the values if R_c to obtain equivalent microstrain level of a) 300 and b) 1000 μs.

12. In fig. P10, let the transducer be a platinum RTD of temperature co-efficient α_0 = 0.00392/ºC and resistance R_0 = 100Ω. Let V_{ref} = 15V.

    (a) Specify the values of R_1 and amplifier gain A to achieve an output sensitivity of 0.1v/ºC. To limit the self heating of the RTD, restrict its power dissipation to less than 0.2 mw.

    (b) Compute V_0 at 100ºC and estimate its equivalent error in ºC due to the nonlinearity of the bridge. Assume the CMRR of the Instrumentation Amplifier to be very high.

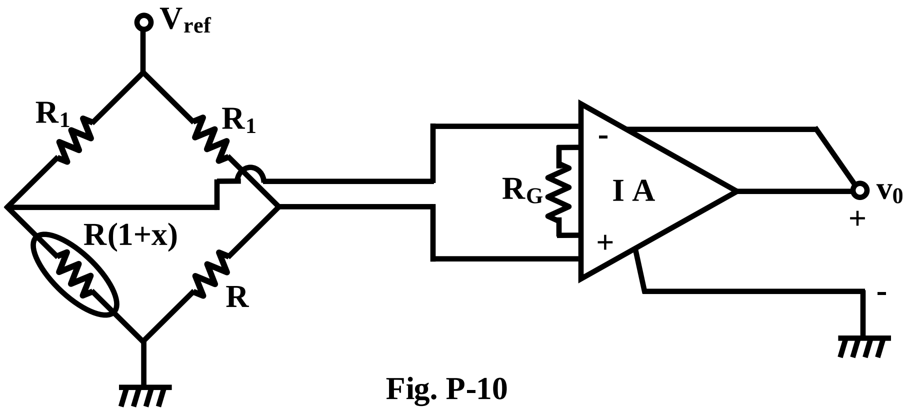


Fig. P-10

13. Consider a calibration output data of a sensor at 0, 20, 40, 60, 80 and 100% of inputs. Consider the nominal characteristics of the sensor to be the straight line joining the (input, output) pair of values for 0% and 100% inputs. Let e_{20}, e_{40}, e_{60}, e_{80} be the deviations of the outputs at the corresponding value of inputs from the nominal straight line. Let e_i {i = 20, 40, 60, 40} be expressed as x_i % of FSD and as y_i % of reading. From this data develop a procedure for arriving at a specification of the form "x % if FSD or y % of reading whichever is greater".