National Exams May 2019

04-Agric-A5, Principles of Instrumentation

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
Any non-communicating calculator is permitted.

3. Questions 1, 2 and any other THREE (3) questions constitute a complete exam paper. Only questions 1, 2 and the first THREE (3) other questions as they appear in your answer book will be marked.

4. All questions are of equal value.

Question 1. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

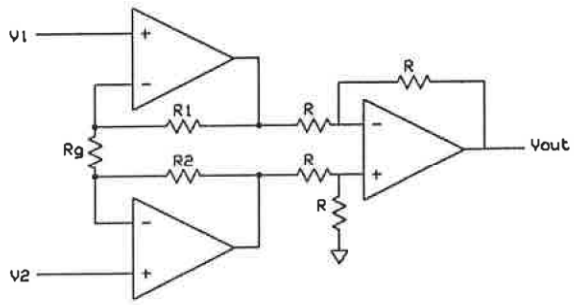
a) (2 marks) Why does taking a derivative enhance the noise in a signal?

b) (2 marks) Why does low pass filtering a signal reduce its noise content?

c) (2 marks) What is the source of semiconductor shot noise?

d) (2 marks) What is the difference between interference and noise?

e) (2 marks) A three op-amp instrumentation amplifier is shown in the schematic at the right. What are the two main features of this type of amplifier



f) (2 marks) What is the maximum cut off frequency of an anti-aliasing filter?

g) (2 marks) Why can't bias errors be determined statistically?

h) (2 marks) What is the most common source of instrument drift?

i) (2 marks) Why does subtracting two similar measurement values result in a very high error?

j) (2 marks) If a 13 bit (the Intersil 7109) analog to digital converter has a ±10 volt input, what is the voltage resolution?

Question 2. (20 marks)(You must answer this question. Each part is worth 2 marks.)

Answer the following short answer questions very briefly. Point form, graphs or sketches may be used as appropriate.

a) (2 marks) Is the sensitivity of a Pitot tube highest at high or low air speeds? Explain very briefly.

b) (2 marks) A pH sensor consists of a pH electrode and a reference electrode. What is a reference electrode?

c) (2 marks) Semiconductor gas detectors are sometimes limited by the rate of diffusion of the gas from the ambient air to the sensor surface. How would you specify the speed of this type of detector?

d) (2 marks) Cantilever load cells based on strain gages vibrate. How can you reduce the vibration without affecting the load reading?

e) (2 marks) Piezoelectric vibration sensors are very fast. How do these sensors detect vibration?

f) (2 marks) To measure electric current, moving coil meters are the most common instrument. How do these instruments measure current?

g) (2 marks) Why does a thermocouple require a reference junction?

h) (2 marks) Why is a phototransistor more sensitive than a photodiode?

i) (2 marks) Why are optical sensors sometimes cooled to liquid nitrogen temperatures?

j) (2 marks) What is a Hall effect sensor?

Question 3. (20 marks)(You only have to do three questions from questions 3 to 7.)

To track an object in motion, an inertial measurement unit (IMU) consisting of accelerometers and gyroscopes may be used. Each answer requires a brief explanation.

a) (5 marks) How would you use accelerometers to determine the velocity and position of an object in space?

b) (5 marks) What errors would affect position and velocity measurements based on accelerometers?

c) (5 marks) How many gyroscopes would be required to determine the attitude (orientation in space) of an object? Here a sketch would be useful in explaining your answer.

d) (5 marks) Why is an initial reference required for both the accelerometer and gyroscope systems?

Question 4. (20 marks)(You only have to do three questions from questions 3 to 7.)

Household smoke detectors use an ionization chamber to detect combustion products. Here, a radio-isotope, Americium 241, emits α particles which ionize the air in a chamber. The presence of the combustion products react with the ions, greatly reducing the ionization level.

a) (5 marks) Why are α particles more effective than β particles or γ rays in ionizing the air in the chamber?

b) (5 marks) How is the ionization in the chamber measured?

c) (5 marks) Another type of smoke detector is based on light scattering by smoke particles. Describe the mechanism of this detection system.

d) (5 marks) Since smoke detectors may be considered as 'life support' systems, discuss the liability issues faced by the designers and manufacturers of smoke detectors.

Question 5. (20 marks)(You only have to do three questions from questions 3 to 7.)

Consider a non-linear measurement system which has a calibration equation of the form:

$$S = aM^b$$

where S is the signal from the system, M is the measured quantity and a and b are fitted coefficients. To fit the coefficients, a logarithmic transform is often used:

$$\text{Log } S = \log a + b \log M.$$

This transform may be used in some cases but not in others. To determine if its use is appropriate, the error structure of the system must be considered.

a) (4 marks) What are absolute error and relative errors?

b) (4 marks) How is error included in fitting the calibration equation?

c) (4 marks) Does a constant absolute error allow the use of the logarithmic transform? Explain your answer briefly.

d) (4 marks) Does a constant relative error allow the use of the logarithmic transform? Explain your answer briefly.

e) (4 marks) Why should you plot the error in each measurement against the signal value to determine if the error is absolute or relative?

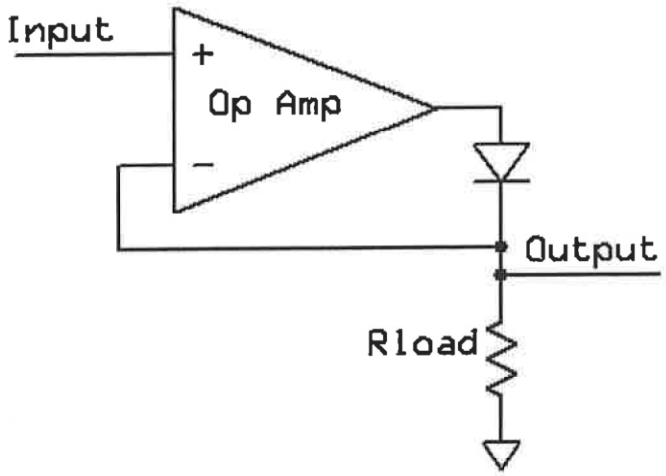
Question 6. (20 marks)(You only have to do three questions from questions 3 to 7.)

Electrical conductivity provides a measure of the concentration of ionic solutes in water solution. An excitation voltage is applied to a cell of known geometry with two inert electrodes. The impedance of the cell is measured with the cell as part of a voltage divider.

a) (3 marks) Why does the excitation voltage have to be AC (alternating current)?

b) (2 marks) What ions in the solution are detected?

To measure the voltage, the AC must be converted to DC by a rectifier. One problem here is the 0.7 volt drop across a silicon diode. To solve this problem, a precision rectifier is used. The following schematic shows a simple precision rectifier:



c) (7 marks) Explain the operation of this circuit.

d) (2 marks) What type of filter is required at the output?

e) (3 marks) What factors are important in choosing the AC frequency to be used in designing this instrument?

f) (3 marks) How would you estimate the filter time constant to be used in designing this instrument?

Question 7. (20 marks)(You only have to do three questions from questions 3 to 7.)

Fluid flow rates can be measured in a number of ways. The most common is based on Bernoulli's equation. Here, a velocity change in the fluid passing through a restriction gives a pressure change across the restriction.

a) (3 marks) What is the relation between the pressure change and the fluid flow rate?

b) (4 marks) List several flow meter types based on this principle.

Thermal flow meters can be configured to add heat to the fluid and calculate the flow from the temperature rise at a thermometer downstream from the heater.

c) (3 marks) What assumptions are necessary to make this calculation.

d) (5 marks) What design steps can be taken to justify these assumptions?

An alternate form of a thermal flow meter is one where the cooling of a heated sensor is measured. The cooling is a function of the square root Reynolds number (fluid velocity) going past the sensor.

e) (5 marks) If the sensor is heated electrically by a Wheatstone bridge circuit as shown in the following schematic where the amplifier keeps the bridge balanced, what is the relationship between the output voltage and the fluid speed?