

National Exams May 2017

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) What is the definition of instrument sensitivity?
- b)(2 marks) Why are sensitivity and selectivity often conflicting goals?
- c)(2 marks) What is the difference between noise and electrical interference?
- d)(2 marks) Why is the signal to noise ratio more important than the absolute signal level?
- e)(2 marks) Why does noise not affect the accuracy of a measurement?
- f)(2 marks) Why should repeated measurements be part of a calibration procedure?
- g)(2 marks) How would you check for hysteresis when calibrating an instrument?
- h)(2 marks) When is a one point calibration valid?
- i)(2 marks) Why is the RMS error used to describe the quality of a measurement?
- j)(2 marks) What defines the 'lowest detectable limit' of a measurement?

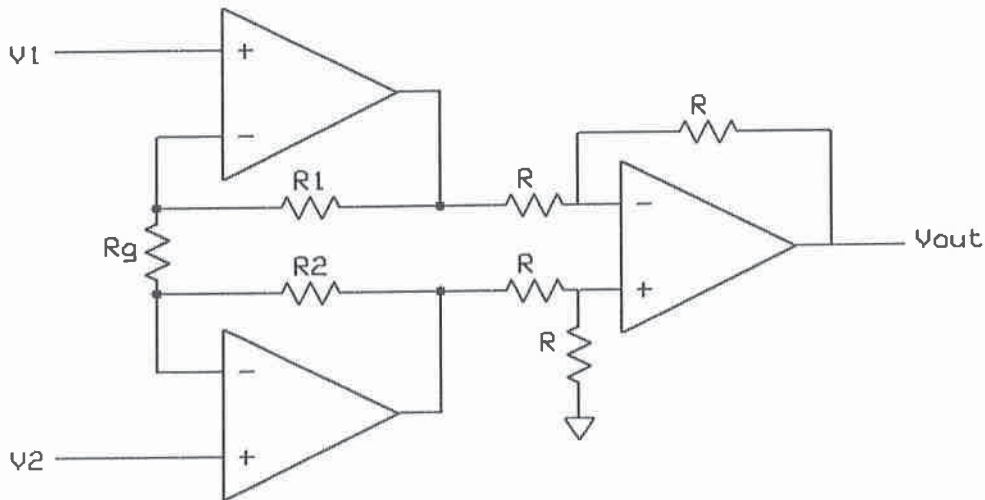
Question 2. (20 marks)(You must answer this question. Each part is worth 2 marks.)

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

- a)(2 marks) What are the advantages of a 4 - 20 mA data transfer channel over a 0 - 10 V channel?
- b)(2 marks) Why is a differential amplifier used with a shielded twisted pair signal cable?
- c)(2 marks) How would you connect the shield of a shielded twisted pair cable?
- d)(2 marks) What are the advantages of optical data transmission over electrical data transmission?
- e)(2 marks) What is the main advantage of digital data transmission over analog data transmission?
- f)(2 marks) What are aliasing errors?
- g)(2 marks) In choosing an analog to digital converter for a specific application, what converter specifications must be considered?
- h)(2 marks) Why is a sample and hold unit required with most analog to digital converters?
- i)(2 marks) What must be considered when choosing a wireless data transfer system?
- j)(2 marks) What is an isolation amplifier?

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

Operational amplifiers are the basis of signal processing and data acquisition systems. The following schematic shows the classic three operational amplifiers in a differential amplifier configuration.



- a)(3 marks) What characteristics of the operational amplifiers make sure that the gain is set only by the external resistors?
- b)(4 marks) For high impedance sensors such as pH electrodes, an extremely high input impedance is required. If the pH electrode impedance is 500×10^6 Ohms, what amplifier input impedance is required to give a reading within 0.1% of the actual sensor voltage?
- c)(3 marks) What type of operational amplifiers should be used in the first stage to obtain this extremely high impedance?
- d)4(marks) What is an operational amplifier input bias current? If V1 in the figure above is connected to a pH electrode and V2 to a reference electrode, why is an input bias current return path required?
- e)(3 marks) Why do the four resistors labelled R in the above circuit have to be matched (the same value)?
- f)(3 marks) In signal processing operations, integration and differentiation operations are sometimes required. How do these operations affect the signal to noise ratio of the output?

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

In measuring the density of a granular material such as grain, two values may be obtained. One is the bulk density and the other is the real density of a single granule.

- a)(2 marks) Why are these different?
- b)(4 marks) How would you account for the size and shape of the container used in the bulk density measurement?
- c)(4 marks) How would you measure the real density of a single granule?
- d)(4 marks) To obtain the moisture content, the electrical capacity of a sample of grain placed in a specified container is measured. What sources of error affect this measurement system?
- e)(2 marks) Why is the capacity a strong function of the moisture content?
- f)(4 marks) If a sample of the granular material is taken from a large drying bin, what steps must be taken to be sure that the sample is representative of the entire contents of the bin?

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

Thermocouples are likely one of the most used type of temperature sensor. Their response is very close to linear but the signal voltage is very low and they require cold junction compensation.

- a)(4 marks) What is cold junction compensation and how would you provide cold junction compensation without ice?
- b)(4 marks) Although the signal is small, why is there is very little noise in a thermocouple temperature measurement.
- c)(8 marks) What is the time constant of a small cylindrical thermocouple used to measure air temperatures? The thermocouple has the following characteristics:

Length	2	cm
Diameter	0.5	cm
Density	5000	kg/m ³
Heat Capacity	350	J/(kg K)
Heat Transfer coefficient	50	J/(sec m ² K)

- d)(4 marks) How long (in time constant units) does it take for a reading to reach 95% of its ultimate response?

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

The response of a spectrophotometer follows Beer-Lambert's law:

$$-\log T = \epsilon Cl$$

where T is the fraction of light transmitted through the sample, ϵ is an absorption coefficient which depends on the wavelength of the light and the sample material, C is the concentration of the absorbing substance and l is the optical path length through the sample. The measurement output is a voltage directly proportional to the fraction of light transmitted:

$$v = kT$$

where v is the output voltage and k is the electrical equipment gain.

- a)(10 marks) Sketch the curve relating the output voltage to the concentration of the absorbing substance in the sample. Indicate where in the concentration range the output is most sensitive to changes in the concentration and where the concentration data is most affected by electrical measurement noise.
- b)(5 marks) At zero concentration the transmission is at its highest value. To get the absorbance, the measured transmittance with a sample must be subtracted from a baseline measured with a blank sample. Why does this greatly increase the measurement error for dilute solutions?
- c)(5 marks) What determines the highest concentration that can be measured by a device of this type?

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

Both analog and digital filters can be used to remove unwanted frequency components from a measurement signal. These frequency components can occur due to mechanical resonances, radio interference from motors and weak coupling to the 60 Hz. power wiring.

- a)(5 marks) A low pass filter removes high frequency components such as vibrations in a weigh scale or the blade tip pulses from a blower. However, it also slows the measurement process. How would you optimize the cutoff frequency and filter order for a particular problem?
- b)(5 marks) Simple averaging is often used to reduce the error due to noise in a measurement. A special case of this uses the average of a large number of samples taken over a sixtieth of a second (1/60 seconds). How does this eliminate the power line interference in North America?
- c)(5 marks) When a digital filtering system is used, an analog anti-aliasing filter is required before the data is converted to a digital form. Why is this required and what cutoff frequency should be used?
- d)(5 marks) A second order low pass filter has a cutoff frequency of 30 Hz. How much is a 150 Hz noise signal reduced?