ENGINEERING TRIPOS PART IIB

Monday 7 May 2007 2.30 to 4

Module 4B13

ELECTRONIC SENSORS AND INSTRUMENTATION

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 Bread is baked on an industrial scale by being transported in tins along a conveyor belt, which passes through a large oven. In order to monitor the baking process, it is desired to pass a temperature logging device through the baking process to record its temperature - time profile and also to measure the surface temperature of the bread as it exits the oven.

(a) The data logger comprises a thermistor and interface circuitry linked to a micro-processor with a built-in ADC, covering the range 0 - 5 V. Design an interface circuit to provide a suitable analogue signal in response to a temperature range of 20 - 120 °C. A semiconductor thermistor with the following properties is available: $R = 1000\ \Omega$ at 0 °C and $\beta' = 3100$. [35%]

(b) In order to monitor how crusty the bread is, an engineer sets up a pyrometer system to observe the top of the bread, just after it leaves the oven. A ZnSe focussing lens of diameter 50 mm, located 0.5 m above the bread, is used to focus the radiant energy onto a LM35 temperature sensor of diameter 5 mm placed 75 mm behind the lens. The sensor has a thermal rating of 120 ° C/W and a sensitivity of 10 mV/K and the emissivity of the bread crust = 0.90.

What change in signal from the pyrometer is seen if the bread surface temperature changes from 120 °C to 130 °C, and what area of bread crust does it monitor at any one time ? [35%]

(c) It is required for quality control purposes to weigh the loaves of bread in their tins, as they pass along a section of conveyor supported on the end of a cantilevered beam. The stainless steel cantilever beam is 25 cm long and has a full-bridge set of metal strain gauges attached 25 mm from its fixed end. If the beam is 10 mm wide and 5 mm deep and the strain gauge bridge is powered by 10 V ; what is the change in raw output from the strain gauges when a loaf of bread 100 g underweight passes along the conveyor ? [30%]

State all assumptions and approximations made.

2 (a) List three important reasons, explaining each briefly, why a Transformer Bridge is such an important technique in comparing two resistances to a high precision. [15%]

(b) Draw the outline circuit of a transformer bridge to compare a resistor of unknown value R_X with a standard resistor of known value R_S. Put brief notes round your diagram. Say why the effect of the capacitance of the coaxial cables between each of the resistors and the bridge enclosure can be made very small and how the best sensitivity of the balance point can be obtained.

What one disadvantage does the simple transformer bridge have ? [30%]

(c) A certain new resistive temperature sensor with a nominal $25\ \Omega$ value is measured by comparing it to a $25\ \Omega$ reference standard using a bridge. This was carefully done by 5 different operators and the following values were obtained for the new sensor:-

24.996, 24.993, 24.997, 24.994, 24.997 Ω

From past calibrations, the reference resistor was found to be changing by $+\ 0.0020\ \pm\ 0.0004\ \Omega$ per year and it was last calibrated *2* years ago and found to be exactly correct. No corrections were needed for other influences but their uncertainties are shown in the table below :-

Source of Uncertainty	Value $\pm\Omega$	Probability Distribution	Divisor K	Standard Uncertainty
Calibration of Reference Resistor	*0.0010*	Normal	*2*	
Drift since last calibration				
Linearity of Reference	*0.0010*	Rectangular	$\sqrt{3}$	
Resolution of readings	*0.0005*	Rectangular		
Power Dissipation Errors	*0.0015*	Rectangular		
Measurement Uncertainty				

Copy out and complete the table to determine an *Expanded Systematic Uncertainty,* using $K = 2$, to provide a level of confidence of *95 %*. State a value for the new sensor. [45%]

(d) If it was desired in the future to try to improve the measurement accuracy, what features of the measurement would you suggest were investigated? Briefly say what might be done to make an improvement. [10%]

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3 (a) Describe what is meant by *surface micromachining* and *bulk micromachining*. Use diagrams to describe how components are made using each of these technologies. [30%]

(b) The layout of a MEMS accelerometer is shown in Fig 1. Name and *describe* the function of the components labelled *A*, *B*, *C* and *D* in Fig. 1. Why are holes designed into part D ? [20%]

(c) What is meant by *open loop* and *closed loop force feedback* operation of the accelerometer? [10%]

(d) Part *D* is made from 5μm thick poly-silicon with a density of 2300 kg/m^3. What is the output voltage per *g* of acceleration ? Assume that the accelerometer is operating in force feedback mode, where half of its electrodes are used for sensing and the other half for force feedback. Assume also that the force feedback applied is used to cancel the entire acceleration experienced by the accelerometer. Use $\varepsilon_0 = 8.9 \times 10^{-12}$ F/m. [40%]

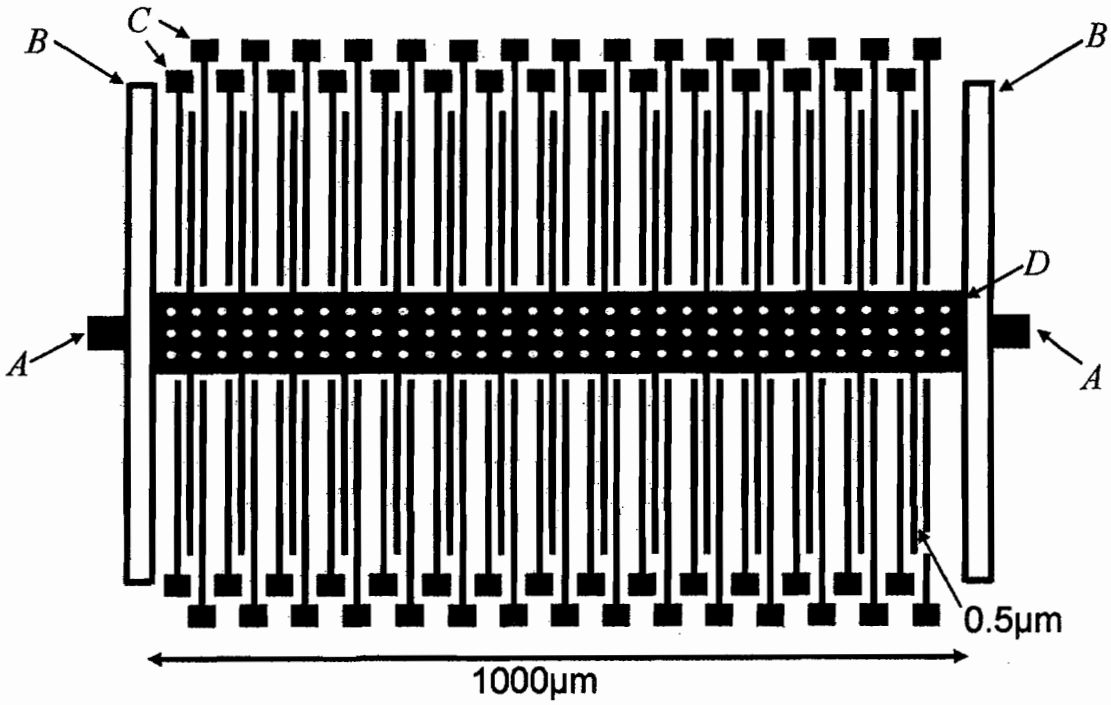

Fig. 1

4 A remote weather station uses a pair of ultrasonic transducers to measure wind speed. The transducers are mounted to face each other 30 cm apart on a vane, which rotates so that the line between the transducers is always aligned with the wind direction.

(a) If the transducers operate at 120 kHz, how many wavelengths separate the two transducers and what difference in the ultrasound transit times will be observed when the wind speed is 2 m/s ? What relative phase shift does this represent ? [15%]

(b) If the ultrasonic transducers have a diameter of 2 cm, a full beam angle of 15°, an acoustic impedance of 8×10^5 kg m^{-2} s^{-1} and an efficiency of 15 %, what amplitude of signal will be seen at the receiving transducer across a matched load of 500 Ω when the transmitting device is driven by a sine-wave of amplitude 9 Vpp ? [40%]

(c) In the winter, after a period of light snow fall, the system is still found to be working after coverage by 1 cm of snow. By what factor has the amplitude of the electrical signal been changed by the layers of snow and how has it affected the accuracy of the wind speed sensor ? [45%]

	Density (kg m^{-3})	Speed of sound (m s^{-1})	Attenuation @ 120 kHz (dB m^{-1})
Air	1	340	-
Snow	500	950	72

Table 1: Physical properties of materials

State all assumptions and approximations made.

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5 A weather vane for indicating wind direction is mounted on a freely rotating vertical shaft with a small magnet attached to its base. A flux-gate magnetic sensor is located in a weather-proof plastic box, a small distance away directly under the magnet, such that it experiences a variation in magnetic field of 100 μT dependent on the angle of the vane.

(a) Briefly describe the principles of operation of a flux-gate magnetometer and indicate some of the advantages and disadvantages of this technique over other magnetic sensor technologies for this application. [25%]

(b) Design a flux-gate sensor system suitable for this application, based on a high permeability core of diameter 1 mm and length 30 mm wound with a coil of 200 turns, to produce an analogue output of 5 V in response to a magnetic flux density of 100 μT. You may assume that a 20 kHz square-wave oscillator is available. [55%]

(c) Calculate the small signal self-inductance of the flux-gate sensor. [20%]

Note: the demagnetising factor, D, of a core of diameter, d, and length, ℓ, may be approximated by: $D = (d/\ell)^2 [\ln(2\ell/d) - 1]$

State all assumptions and approximations made.

END OF PAPER