ENGINEERING TRIPOS PART IIB

Monday 2 May 2005 2.30 to 4.00

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 to this paper.

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

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1 (a) Clearly show, with the aid of a block diagram, how a timer-counter is organised and switched internally to make both period and frequency measurements. If the internal crystal reference is 10 MHz , what would you set to get best resolution and a new reading at least every 3 seconds for:-

(i) a source of 400 Hz , and (ii) a source of 100 kHz . [35%]

(b) In a laboratory where a group of 5 timer-counters are to be maintained, describe the steps used both before and after a calibration of one of the units and allowing its value to be traced to the other 4 units. [25%]

(c) A researcher with a double beam oscilloscope has checked the internal reference frequency of a timer-counter against an accurate 10 MHz frequency standard and believes the former to be 0.025 ppm (parts per million) below the frequency of the standard. You are asked to check this result. How would you expect to see the equipment connected and what readings and calculations would you use ? [25%]

(d) If your results show that the timer-counter internal reference is indeed low but in 6 repeated measurements you get figures of:

0.022 , 0.024 , 0.022 , 0.023 , 0.027, 0.022 ppm.

What would you quote as the value and expanded uncertainty of your measurement using a 95% confidence for the uncertainty ? If you prefer, give both answers in parts per billion (ppb) . [15%]

2 A system for measuring the surface temperature of pottery in a kiln uses a 3 cm diameter ZnSe lens, of focal length 5 cm, to focus infra-red radiation onto one of a pair of 100 Ω platinum resistance elements, mounted closely back to back.

(a) How should the pair of platinum resistors be connected to give an output signal related to the pottery temperature and what is the advantage of using a pair of devices over a single device ? [15 %]

(b) If the platinum resistors each have a thermal rating of 200 °C/W and a diameter of 3 mm, what % change in resistance is seen when the pottery temperature reaches 850 °C ? You may assume that the surface emissivity is 0.7 . [35 %]

(c) Design an interface circuit, using an op-amp, to give an output voltage of 1 V for 1000 °C and estimate the errors introduced by the surface emissivity of different pots varying from 0.6 to 0.8 . The circuit rise-time should be ≈ 2 s. [35 %]

(d) Estimate the electrical noise at the output of your circuit if the op-amp has an input noise level of 6 nV/√Hz . How much noise in the temperature measurement does this correspond to ? [15%]

State all assumptions and approximations made.

Note: Stefan-Boltzman constant = 5.6×10^{-8} W m^{-2} K^{-4}

Temperature coefficient of resistance for platinum = 0.00385 K^{-1}

3 (a) Outline briefly the advantages and disadvantages of micromachining silicon for sensors, making particular reference to pressure sensors. [25%]

(b) Figure 1 shows outline cross sections of a bulk micromachined silicon pressure sensor made by bonding wafers A and B together, and a second sensor made by bonding wafers C and D. If the sensors have piezo-resistive strain gauge readout, explain the construction of the sensors and outline the fabrication process and mode of operation. Discuss the performance of the sensors and how to compensate for the possible effects of temperature. [25%]

(c) In a particular pressure sensor, the ratio of the bending moment, M, to the second moment of area, I, for the beam sections carrying the readout piezo-resistive strain gauges is 2×10^{13} N m^{-3}. If the gauge factor for the devices is 60 and the beam section is 5 μm thick and the elastic modulus of the material is 110×10^{9} N m^{-2}, calculate the output voltage from a full bridge circuit using four such strain gauges if it is powered from 4 V. [30%]

(d) Comment briefly on the performance and application of piezo-resistive pressure sensors, and compare them with other technologies. [20%]

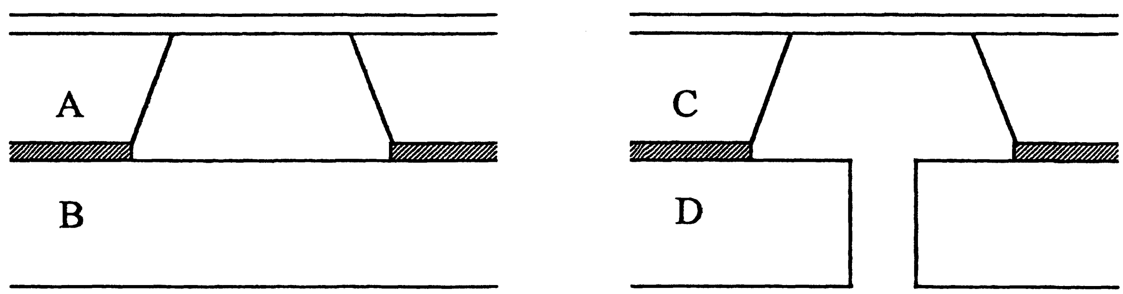

Fig. 1

4 The load sensor inside a set of digital bathroom scales is based on a steel cantilever beam situated between a pair of 'U-cores' forming two identical, variable reluctance inductors. This arrangement is illustrated as an end view in fig. 2 below.

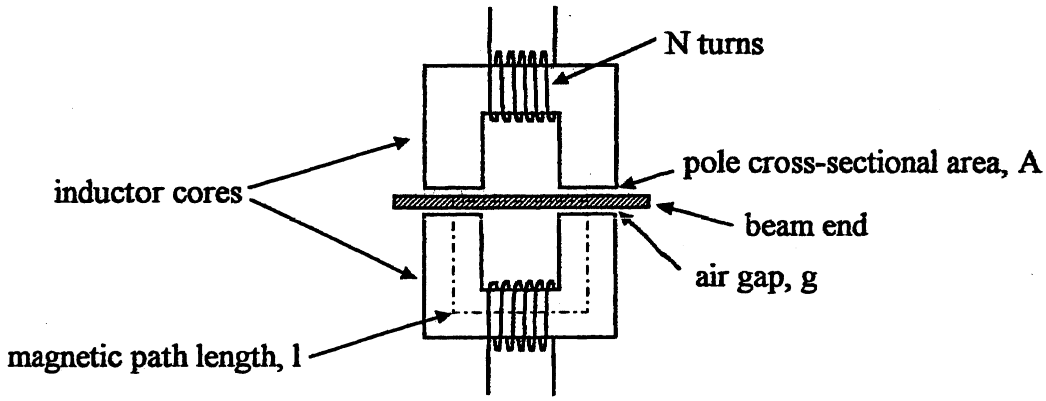

Fig. 2

Under zero load, the end of the beam is positioned symmetrically between the inductor cores. As the beam deflects under an end load, the air gap increases one side and decreases correspondingly the other side.

(a) Derive an expresssion for the inductance of the sensors as a function of the air gap, assuming the solid materials in the flux path have a relative permeability of 1200. [45 %]

(b) The load sensor is to have a measurement range of 0 to 15 kg force, so that with a suitable 10:1 lever arrangement, the scales have a capacity up to 150 kg. If the air gaps at zero load are 1 mm and the beam is 3 mm thick, determine suitable dimensions for the length and width of the beam for each pole cross-section to be 0.5 cm^2. [15 %]

(c) If the inductors have 400 turns, a magnetic path length of 35 mm and are each to be resonant with a parallel capacitor at approximately 1 kHz under zero load, determine the capacitor value required. If the load is to be derived from the frequency difference between the upper and lower resonant circuits, what will be this difference with sensor loads of 5 kg and 10 kg force ? Comment on the linearity of the scales. [40 %]

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5 An electronic system to measure the speed of go-karts on an indoor track is based on an ultrasonic Doppler system, indicating the speed along a straight section of track on a digital display for spectators. The system is to operate at 65 kHz, using transducers with the following properties: diameter 5 cm, electrical impedance 1 kΩ, conversion efficiency 10 %, cone half-angle 15 ° and acoustic impedance 1800 kg m^{-2} s^{-1}.

(a) Sketch a block diagram of a system to produce an electrical output at the Doppler frequency and determine this frequency for a go-kart travelling at 50 km/hr. [20 %]

(b) If the transmitter transducer is driven with a 24 $V_{pk\text{-}pk}$ sine wave, what is the open-circuit amplitude of the signal detected by the receiver transducer when the go-kart is at a range of (i) 5 m and (ii) 15 m ? [55 %]

(c) To enable compensation for the variation of the speed of sound in air with temperature, a sensor is used to monitor the air temperature. A 5 mA constant current source drives a semiconductor NTC themistor to produce a voltage signal. The thermistor has the following properties:

$$\text{nominal resistance} = 2\ \text{k}\Omega\ \text{at}\ 0\ °\text{C}, \quad \beta' = 3280.$$

Calculate the voltage across the thermistor at 20 °C and the non-linearity of the signal when measuring over the range 10 °C to 30 °C. [25 %]

State all assumptions and approximations made.

Note: 65 kHz ultrasonic attenuation coefficient in air = 0.2 dB m^{-1}

Speed of sound in air = 340 m s^{-1}

Density of air = 1.29 kg m^{-3}

END OF PAPER