E3.02
AC4

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

MSc and EEE PART III/IV: M.Eng., B.Eng. and ACGI

INSTRUMENTATION

Monday, 12 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Corrected Copy

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : C. Papavassiliou
Second Marker(s) : S. Lucyszyn

1. The voltage from a measurement instrument depends linearly both on magnetic field and temperature, as shown below:

$$V = aH + bT + c$$

This instrument needs to be calibrated. A number of measurements are performed, resulting to the following table (Table 1.1):

H_1	T_1	V_1
H_2	T_2	V_2
...	...	...
H_N	T_N	V_N

Table 1.1: Calibration measurements performed for instrument in Question 1.

Please note that all measurements have equal errors.

(a) What is the minimum number of calibration measurements required to determine the coefficients *a, b* and *c*? Why? Can all these measurements be performed at the same temperature?

[2]

The coefficients *a, b* and *c* can be determined more accurately by performing a least squares procedure on a number of measurements exceeding the minimum number of measurements determined in question (1.a) .

(b) Write the objective function, X^2 , for this problem.

[3]

(c) Derive the equations needed to solve so that the parameters *a, b* and *c* can be determined by minimising X^2.

[12]

(d) Define the cross-sensitivity for this instrument. Write an expression for the cross-sensitivity in terms of the coefficients *a, b* and *c.*

[3]

2.

(a) With the aid of a diagram, describe the operation of 2 different phase detectors that can be used in a phase locked loop (PLL). Plot the transfer function and state the input range and the gain of each detector.

[6]

(b) Draw block diagrams for a PLL frequency multiplier and a frequency multiplier not based on a PLL.

[6]

(c) Design the simplest possible PLL frequency multiplier with multiplication factor N. What is your choice for phase detector and filter? Compute the steady-state phase error of this loop for a step phase and a step input frequency disturbance. Can this loop track a continuously changing input frequency?

[6]

(d) What is the simplest type of PLL loop filter that allows simultaneous control of acquisition speed and phase margin?

[2]

3.

(a) Define the Noise Factor, Noise Figure and Noise Measure of an amplifier. **[3]**

(b) Write an expression for the noise factor of a cascade of 3 amplifiers in terms of their individual gains and noise factors. **[2]**

(c) Three low noise amplifiers are available in an instrumentation laboratory. Their characteristics are summarised in table 3.1. A gain of 30 dB and the minimum possible noise figure is required in a measurement. What is the optimum connection order? Explain your reasoning and show all necessary calculations.

Identification	NF db	Gain dB
A1	2	5
A2	2.2	10
A3	2.4	15

10:00 am,

Table 3.1: Gain and Noise figure data for amplifiers of question 3.

[10]

(d) Describe how you would account for 0.2 dB cable loss in the 2 intermediate interconnection cables. Write any necessary formulae, but do not do the calculations. **[5]**

4.

(a) With the aid of a diagram, describe the operation of the horizontal sub-system of an oscilloscope having a dual timebase, so that it is equipped with intensified and delayed sweep features. **[10]**

(b) Design a frequency compensated 5:1 attenuating oscilloscope probe. The oscilloscope has input impedance of 1 $M\Omega$ and input capacitance of 5 pF. What is the input impedance at the probe tip? What is the minimum probe attenuation required so that the probe tip capacitance is less than 0.1 pF? **[4]**

(c) Explain how a digital oscilloscope may be used to display signals at a frequency higher than its sampling rate. Draw a diagram to support your argument. What condition must the sampling frequency satisfy relative to the frequency of the signal observed? What is the ultimate limitation for the maximum frequency a digital scope can display? How must the input signal be filtered? **[6]**

5. (a) Describe three ways a real D/A converter deviates from ideality. **[3]**

(b) An ideal 3-bit A/D converter is available This has a maximum conversion rate of 3.5×10^6 samples/s . Calculate the output noise power for this converter at its maximum operating frequency, if the input signal is a full scale sinusoid having 10 mW average power. Calculate and plot against frequency the noise power spectral density of the noise power. What condition must the input signal satisfy? **[4]**

(c) Calculate the sampling frequency necessary to perform a 10-bit A/D conversion on signals of frequency lower than 50 kHz using ideal 3-bit converters. Do not use feedback, and do not comment on any necessary signal processing . **[5]**

(d) Limitations in manufacturing limit the performance of available D/A and A/D converters to a maximum resolution of 3 bits and a maximum conversion rate of 3.5 MHz. These converters can be considered to be otherwise ideal. With the aid of a diagram explain how these 3-bit 3.5 MHz converters can be used together to obtain 10 bits resolution A/D conversion on signals of frequency up to 50 kHz. **[5]**

(e) Qualitatively explain how your circuit in question (5.d) must be modified in order to obtain resolution of 15 bits on signals of frequency up to 50 kHz. **[3]**

6.

(a) With the aid of a diagram, describe one analogue frequency measurement instrument. Calculate its sensitivity as well as its output ripple as a function of the input frequency. Design an analogue frequency meter based on the instrument you described so that it can be used to measure frequencies up to 50 kHz with 1% accuracy. What is the maximum reading rate supported by this instrument?

(**hint:** To calculate the ripple consider the ripple spectrum and filter required. Note that the total power in a signal before any filtering is the sum of the power of all its spectral components!) **[10]**

(b) With the aid of a diagram, describe one digital frequency measurement instrument for frequencies up to 50 kHz. If a local oscillator at 100 kHz is available, design the instrument for 1% accuracy. What is the maximum reading rate supported by this instrument? **[10]**