

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
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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?

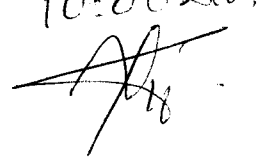
[2]

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

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

10:00 am  


- (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]

[10]

[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  $1\text{ M}\Omega$  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]

[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  $3.5 \times 10^6$  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]

