YOUR NAME: ______________________ ID:_s__________ DOB: ____/____/19__

Department/Program: TN / N / TBK / BMT / ...

Final Exam
Principles of Measurement Systems
(NAPMS.2008-2009.1a)
Friday, February 6, 2009 (14:00-17:00)

Please write your name, student ID number and date of birth on this or the first page, only your name on all subsequent pages, and number the pages. Don't forget to hand in all relevant paperwork.

This is not an open-book exam, so please remove all other documents.

Read carefully. Pay attention to units. A numerical result without, or with wrong units, will be considered incorrect. You may assume that I know the answer to the questions posed; Therefore, give derivations and/or motivate your answers as appropriate! If you cannot answer the first part of a question, make a (educated) guess, and continue with the rest... Success!

You may use the following table:

time-domain $f(t)$	s-domain $\tilde{f}(s)$
$\delta(t)$	1
1	$\frac{1}{s}$
t	$\frac{1}{s^2}$
e^{at}	$\frac{1}{s-a}$
$1-e^{-at}$	$\frac{a}{s(s+a)}$
$\sin(\omega t)$	$\frac{\omega}{s^2+\omega^2}$
$\cos(\omega t)$	$\frac{s}{s^2+\omega^2}$
$e^{at}g(t)$	$\tilde{g}(s-a)$
$g(at)$	$\frac{1}{a}\tilde{g}\left(\frac{s}{a}\right)$
$f(t)$	$\int_{0^-}^{\infty} f(t)e^{-st}dt$ *)
$f'(t)$	$s\cdot\tilde{f}(s)-f(0^-)$

*) Note: The lower bound of the integral being equal to 0^- signifies that the origin is fully included in the evaluation of the integral.

Question 1 (Chapter 3)
A simple temperature measurement system consists of a specialized temperature sensor (the AD592 from Analog Devices) operating from a power supply voltage of 12V and generating a current proportional to the temperature in degrees Kelvin. The current is converted to a voltage reading by a resistor and buffer amplifier combination. The output is interpreted by a microcomputer with display. The system is represented in Figure 2, and characterized by the following steady-state parameters for an input temperature T of 30 °C:

$Ms = 10^{-4}\ \mu A/K^2$	$\sigma_{Ms} = 0\ \mu A/K^2$
$K_s = 1\ \mu A/K$	$\sigma_{Ks} = 0\ \mu A/K$
$H_s = 0.1\ \mu A$	$\sigma_{Hs} = 10^{-3}\ \mu A$
$M_a = 10^4\ \Omega$	$\sigma_{Ma} = 30\ \Omega$
$K_a = -150\ mV/mA^{0.5}$	$\sigma_{Ka} = 0\ mV/mA^{0.5}$
$H_a = -3\ mV$	$\sigma_{Ha} = 0\ mV$
$K_d = 100\ K/V$	$\sigma_{Kd} = 0\ K/V$
$H_d = -0.5\ K$	$\sigma_{Hd} = 0\ K$

The sub-systems are described by the following equations: $i = H_s+K_s \cdot T+M_s \cdot T^2$, $V = H_a+K_a \cdot i^{0.5}+M_a \cdot i$, and $T_M = H_d+K_d \cdot V$.

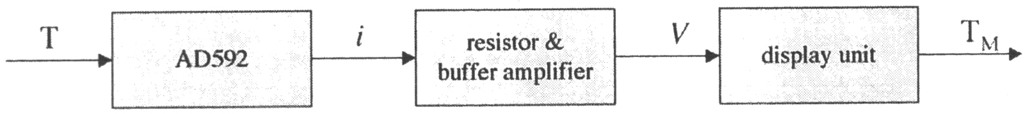

Figure 1. Block diagram of the temperature measurement system

a) Calculate the mean of the output reading T_M when the input temperature is $T =$ 30 °C.
b) Calculate the standard deviation of the output reading T_M when the input temperature is $T =$ 30 °C.
c) Determine the accuracy and the precision of the measurement at 30 °C in terms of the results of a) and b).
d) Identify the one parameter of the above system that dominates the uncertainty in the temperature reading.

Question 2 (Chapter 6)

A pressure sensor with built-in current transmitter (characterized by its Norton equivalent circuit: current source i_N with shunt resistance R_N) is read out by a recorder with load resistance R_L. The capacitive coupling to a nearby power cable and earth plane (same as the recorder ground) can be described by the parasitic capacitors C_1, C_2, C_3, and C_4, as shown in Figure 2.

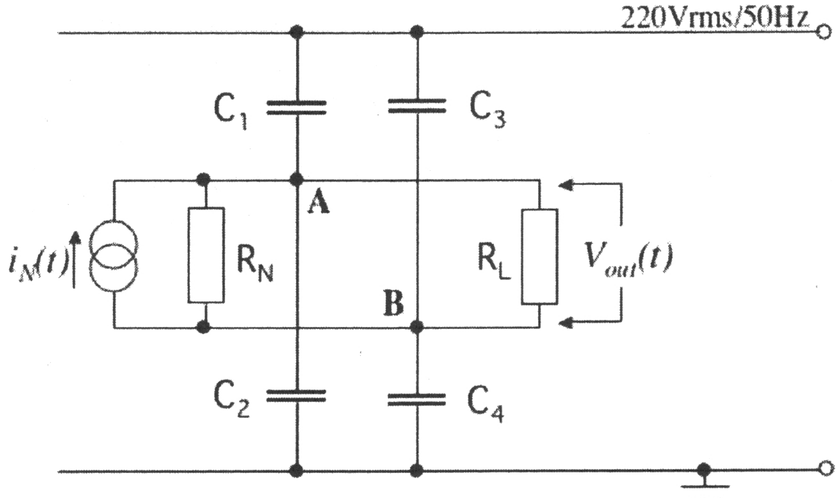

Figure 2. Equivalent circuit of pressure transducer and recorder, showing capacitive coupling to power cable and earth plane. R_N=100 kΩ, R_L=1 kΩ, C_1=50 pF, C_2=55 pF, C_3=80 pF, C_4=85 pF

Assume for the moment that $i_N = 0$ A and $R_N = R_L = \infty\ \Omega$.

a. Derive an expression for the common mode voltage (rms) seen by the recorder, and evaluate it numerically.

b. Derive an expression for the series mode voltage (rms) seen by the recorder, and evaluate it numerically.

The current is given by $i_N(t) = c \cdot \sin(\omega t)$, with c = 6.3 mA and ω=1 kHz.

c. Ignoring the influence of the capacitive coupling, calculate the rms signal registered by the recorder.

d. Discuss strategies for reduction of the capacitive coupling (considering the physical characteristics that are at the origin of the capacitive coupling).

e. Estimate the signal-to noise ratio of the measurement, provided that the recorder has a CMRR=60 dB and that the sole source of noise is the capacitive coupling to the power cable.

Question 3 (Chapter 4)
A second-order system with transfer function $G(s)$ is subjected to a unit step function (i.e., the Heaviside function $H_0(t)$) at the input x.

$$G(s) = \frac{2}{s^2 + 2s + 2}$$

a) Give the expression for $\Delta\tilde{y}(s) = G(s) \cdot \Delta\tilde{x}(s)$.
b) Apply the final value theorem to calculate the steady-state value of the output (numerical result only is insufficient!).
c) Expand $\Delta\tilde{y}(s) = G(s) \cdot \Delta\tilde{x}(s)$ in relevant partial fractions.
d) Derive the unit step time response function $\Delta y(t)$ for this system.
e) Sketch $\Delta y(t)$.

Question 4 (Chapter 8)

Figure 1 gives the schematic diagram of a thermocouple temperature sensor. The thermocouple is made up of Ni-Cr lead wires, a copper thermocouple wire (A, with Seebeck coefficient S_A), and a constantan thermocouple wire (B, with Seebeck coefficient S_B). The reference junction is kept in a bath of melting ice. Table I lists the Seebeck coefficients of a number of common materials.

a) Derive an integral expression for the voltage V_{out} at the measurement terminals.

b) What is the predicted output voltage at a tip temperature of 100 °C (measured with an ideal voltmeter)?.

c) The length of the thermocouple wires A and B is increased from 5 to 50 cm. The accuracy of the measurement improves. Give a plausible explanation.

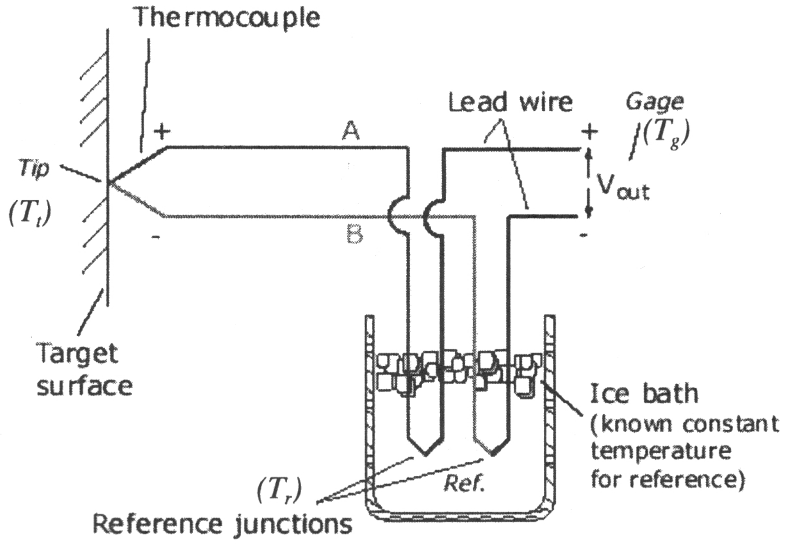

Figure 1. *Thermocouple arrangement.*

Table I. Seebeck coefficients of various metals at 0 °C.

Material	Seebeck Coeff. [µV/°C]		Material	Seebeck Coeff. [µV/°C]		Material	Seebeck Coeff. [µV/°C]
Aluminum	3.5		Gold	6.5		Rhodium	6.0
Antimony	47		Iron	19		Selenium	900
Bismuth	-72		Lead	4.0		Silicon	440
Cadmium	7.5		Mercury	0.60		Silver	6.5
Carbon	3.0		Nichrome	25		Sodium	-2.0
Constantan	-35.1		Nickel	-15		Tantalum	4.5
Copper	7.6		Platinum	0		Tellurium	500
Germanium	300		Potassium	-9.0		Tungsten	7.5

... End of the Exam.