Exam in Sensor system, 7.5 credits.
Course code: et2009
Date: 2010-08-21

Allowed items on the exam:
Tables of Mathematical formulas.
Calculator.

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Maximum points: 28.
In order to pass the examination with a grade 3 a minimum of 12 points is required.
To get a grade 4 a minimum of 17 points is required, and to get a grade 5 a minimum of 23 points is required.

Give your answer in a readable way and motivate your assumptions.

Good Luck!

Questions of 2 points.

1.
A non-linear temperature sensor has an input range of 0 to 400 ˚C and an output range of 0 to 20 mV. The output signal at 100 ˚C is 4.5 mV. Find the non-linearity in millivolts and as a percentage of span.

2.
A pressure transducer has an input range of 0 to 10^4 Pa and an output range of 4 to 20 mA at a standard temperature of 20 ˚C. If the ambient temperature is increased to 30 ˚C, the range changes to 4.2 to 20.8 mA. Find the values of the environmental sensitivities K_I and K_M.

3.
A force measurement system consists of four elements with sensitivities 10^{-2}, 5 x 10^{-2}, 10^3 and 1.9. Find the system error for a true value input of 10 kN.

4.
A linear thermocouple with a sensitivity of 0.04 mV/˚C and resistance of 100 Ω is connected to a load with a resistance of 1 kΩ. Find the voltage across the load for a temperature of 250 ˚C.

5.
A pressure transducer consists of a Bourdon tube elastic element connected to a potentiometer displacement sensor. The input range of the Bourdon tube is 0 to 10^4 Pa and the output range is 0 to 1 cm. The potentiometer has a length of 1 cm, a resistance of 10 kΩ and a supply voltage of 10 V. If the input pressure is 5 x 10^3 Pa, calculate:
a) the displacement of the potentiometer wiper (assume a linear Bourdon tube)
b) the open circuit transducer output voltage
c) the voltage indicated by a voltmeter of resistance 10 kΩ connected across the potentiometer.

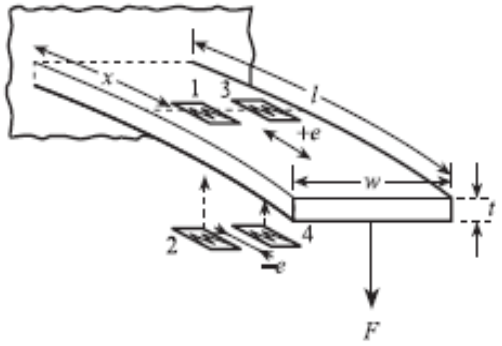
6.
Use the table for the type T thermocouple (reference junction at 0˚C, included in this exam) to calculate:
a) the percentage non-linearity at 150 ˚C if the temperature range is 0 to 300 ˚C
b) the temperature inside a vessel if an e.m.f. of 11.5 mV is measured relative to a reference junction of 20 ˚C.

7.
A variable reluctance tachogenerator consists of a ferromagnetic wheel with 20 teeth rotating close to a bar magnet and coil. If the wheel is rotating at 6000 rpm, what is the frequency of the a.c. voltage induced in the coil?

8.
An AD-converter has an input range of 0 to 5 V. Calculate the resolution error both as a voltage and as a percentage of f.s.d. if the output digital signal is 8-bit binary.

Questions of 4 points.

9.
A simple weight sensor consists of a steel cantilever clamped at one end with a free end subject to a downward force F.



a) Four identical strain gauges (specified below) are to be bonded onto the cantilever halfway along its length as shown in above figure.
Sketch the four-element strain gauge bridge where the gauges are connected for highest sensitivity and to get a temperature compensated bridge and find the expression for the bridge output voltage. (3p)

b) If F=250 N, use the data given below to calculate the bridge output voltage corresponding to the above conditions. (1p)

Data:

Strain $e = \dfrac{6(l-x)F}{wt^2E}$

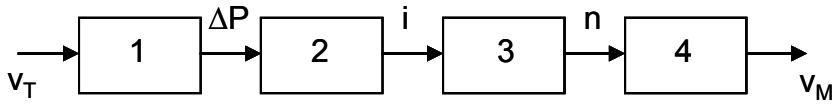
Cantilever: length l=150 mm
width w=50 mm
thickness t=3 mm

Young's modulus E=2.0 x 10^{11} N/m^2

Gauge factor G=2.0

Bridge supply voltage V_S=15 V

10.
A fluid velocity measurement system consists of a pitot tube, a differential pressure transmitter, an 8-bit AD-converter and a microcontroller with display facilities.
The microcontroller calculates the measured value of velocity assuming a constant density ρ.



Estimate the mean and standard deviation of the error distribution assuming the true value of velocity v_T=14.0 m/s.
Uncertainty of each element is modelled by error bands. Treat the rectangular distributions from the error band model as normal with $\sigma = \frac{h}{\sqrt{3}}$.
The model equation and parameters for each element in the system are presented below.

Pitot tube (1):
Model equation: $\Delta P = \frac{1}{2}\rho v_T^2$ [Pa].
Mean value: ρ=1.2 [kg/m^3].
Error bandwidth: h_1=9.8 [Pa].

Differential pressure transmitter (2):
Model equation: $i=K_1\Delta P+a_1$ [mA].
Mean values: K_1=0.064 [mA/Pa], a_1=4.0 [mA].
Error bandwidth: h_2=0.15 [mA].

AD-converter (3):
Model equation: $n=K_2 i+a_2$ [n is a number].
(n is rounded off to nearest integer)
Mean values: K_2=12.80 [1/mA], a_2=0.0.
Error bandwidth: h_3=0.5.

Microcontroller (4):
Model equation: $v_M = K_3\sqrt{n-51}$ [m/s].
Mean values: K_3=1.430 [m/s].
Error bandwidth: h_4=0.0 [m/s].

11.
A sinusoidal signal of amplitude 1.4 mV and frequency 5 kHz is "buried" in Gaussian noise with zero mean value. The noise has a uniform power spectral density of 100 pW/Hz up to a cut-off frequency of 1 MHz.

a) The signal is passed through a band-pass filter with centre frequency of 5 kHz and bandwidth 1 kHz. What is the signal-to-noise ratio in dB before and after the filtering? (1.5p)

b) The filtered signal is then passed through a signal averager which averages corresponding samples of 100 sections of signal. What is the signal-to-noise ratio in dB now? (1.5p)

c) Which of the two noise reduction methods in a) and b) was most powerful?
You must motivate your answer. (1p)

Help:
The relations between the autocorrelation, root-mean-square(rms)-value and the total power of a signal x are:
$R_{xx}(0)=x^2_{rms}=W_{TOT}$.

Signal-to-noise ratio $SNR = \frac{s_{rms}}{n_{rms}}$.

Standard deviation $\sigma = x_{rms}$ if x is a zero mean signal.

Root-mean-square value of a sinusoidal with amplitude A is $\frac{A}{\sqrt{2}}$.

Table Prob. 22 e.m.f. in mV for type T thermocouple (measured junction at T °C, reference junction at 0 °C).

Temp. °C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.351	0.391
10	0.391	0.430	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.789
20	0.789	0.830	0.870	0.911	0.951	0.992	1.032	1.073	1.114	1.155	1.196
30	1.196	1.237	1.279	1.320	1.361	1.403	1.444	1.486	1.528	1.569	1.611
40	1.611	1.653	1.695	1.738	1.780	1.822	1.865	1.907	1.950	1.992	2.035
50	2.035	2.078	2.121	2.164	2.207	2.250	2.294	2.337	2.380	2.424	2.467
60	2.467	2.511	2.555	2.599	2.643	2.687	2.731	2.775	2.819	2.864	2.908
70	2.908	2.953	2.997	3.042	3.087	3.131	3.176	3.221	3.266	3.312	3.357
80	3.357	3.402	3.447	3.493	3.538	3.584	3.630	3.676	3.721	3.767	3.813
90	3.813	3.859	3.906	3.952	3.998	4.044	4.091	4.137	4.184	4.231	4.277
100	4.277	4.324	4.371	4.418	4.465	4.512	4.559	4.607	4.654	4.701	4.749
110	4.749	4.796	4.844	4.891	4.939	4.987	5.035	5.083	5.131	5.179	5.227
120	5.227	5.275	5.324	5.372	5.420	5.469	5.517	5.566	5.615	5.663	5.712
130	5.712	5.761	5.810	5.859	5.908	5.957	6.007	6.056	6.105	6.155	6.204
140	6.204	6.254	6.303	6.353	6.403	6.452	6.502	6.552	6.602	6.652	6.702
150	6.702	6.753	6.803	6.853	6.903	6.954	7.004	7.055	7.106	7.156	7.207
160	7.207	7.258	7.309	7.360	7.411	7.462	7.513	7.564	7.615	7.666	7.718
170	7.718	7.769	7.821	7.872	7.924	7.975	8.027	8.079	8.131	8.183	8.235
180	8.235	8.287	8.339	8.391	8.443	8.495	8.548	8.600	8.652	8.705	8.757
190	8.757	8.810	8.863	8.915	8.968	9.021	9.074	9.127	9.180	9.233	9.286
200	9.286	9.339	9.392	9.446	9.499	9.553	9.606	9.659	9.713	9.767	9.820
210	9.820	9.874	9.928	9.982	10.036	10.090	10.144	10.198	10.252	10.306	10.360
220	10.360	10.414	10.469	10.523	10.578	10.632	10.687	10.741	10.796	10.851	10.905
230	10.905	10.960	11.015	11.070	11.125	11.180	11.235	11.290	11.345	11.401	11.456
240	11.456	11.511	11.566	11.622	11.677	11.733	11.788	11.844	11.900	11.956	12.011
250	12.011	12.067	12.123	12.179	12.235	12.291	12.347	12.403	12.459	12.515	12.572
260	12.572	12.628	12.684	12.741	12.797	12.854	12.910	12.967	13.024	13.080	13.137
270	13.137	13.194	13.251	13.307	13.364	13.421	13.478	13.535	13.592	13.650	13.707
280	13.707	13.764	13.821	13.879	13.936	13.993	14.051	14.108	14.166	14.223	14.281
290	14.281	14.339	14.396	14.454	14.512	14.570	14.628	14.686	14.744	14.802	14.860
300	14.860	14.918	14.976	15.034	15.092	15.151	15.209	15.267	15.326	15.384	15.443
310	15.443	15.501	15.560	15.619	15.677	15.736	15.795	15.853	15.912	15.971	16.030
320	16.030	16.089	16.148	16.207	16.266	16.325	16.384	16.444	16.503	16.562	16.621
330	16.621	16.681	16.740	16.800	16.859	16.919	16.978	17.038	17.097	17.157	17.217
340	17.217	17.277	17.336	17.396	17.456	17.516	17.576	17.636	17.696	17.756	17.816