Tutorial – 13

Exam Text of 24/02/2005

Problem 1

The temperature of a biochemical reaction in a test tube varies from 30°C to 40°C and we want to measure the temperature variation with high precision once per second. A Platinum RTD (Resistive Temperature Detector) featuring R_{T0}=100Ω at the reference temperature of 20°C is exploited. A Wheatstone bridge readout configuration with 3 resistors and the RTD is exploited. The power dissipation on the sensor has to be kept below 1μW. The power supply of the bridge V_A is a pulsed periodical voltage with a duration T_A=100ms and period Tr=1s. The signal is readout by means of a voltage preamplifier featuring a bandwidth limited by a single pole fp=100kHz. The noise referred to the input of the preamp is given by the following contributions, expressed in terms of unilateral noise spectral densities: current white noise $\sqrt{S_I} = 1pA/\sqrt{Hz}$, voltage noise $\sqrt{S_V} = S_W + K/f$ with $\sqrt{S_W} = 10nV/\sqrt{Hz}$ and corner frequency f_C=5kHz.

First of all, sketch and describe the configuration of the setup. Then:

a) Select a simple filtering stage that limits the 1/f noise contribution and considering only this filter and the preamp evaluate the noise affecting this measurement.

b) Evaluate the precision that can be achieved with the setup of point a in terms of minimum temperature that can be measured.

c) Select an additional filtering stage to improve the sensitivity of the system. Repeat the evaluations of point a) and b).

Problem 2

Consider the same setup of problem 1 with a sinusoidal voltage having maximum amplitude V_A and frequency f_A=500Hz applied to the Wheatstone bridge.

a) Select a simple filtering stage that limits the 1/f noise contribution. Considering only this filter and the preamp, evaluate the noise affecting this measurement and the minimum temperature that can be measured.

b) Now add a resonant filter tuned at f_A and having quality factor Q=5. Repeat the evaluations of point a).

c) In order to improve the precision of the measurement, how would you change the bias of the Wheatstone bridge and/or the filtering stage following the preamp? Paying attention to comply with the requirements of Problem 1, describe the new setup and repeat the evaluations of point a.

A) To filter the $\mathbf{1/f}$ component we can use a high-pass CR filter, to avoid effects on the signal we choose $\boldsymbol{f_{HPF} = 0.1\ Hz}$, the total noise is equal to:

$$\boldsymbol{\sigma_v = \sqrt{(S_W + S_I R^2)\cdot\frac{\pi}{2} f_P + S_W \cdot f_c \cdot \ln\left(\frac{f_P}{f_{HPF}}\right)} \cong 4.75\ \mu V}$$

B) To find the minimum variation measurable we need to know the value of the power supply:

$$\boldsymbol{P_{sensor} = \left(\frac{V_A}{2}\right)^2 \cdot \frac{1}{R}\cdot\frac{T_A}{T_R} \rightarrow V_A = \sqrt{4P_{sensor}R\frac{T_R}{T_A}} \cong 63.2\ mV}$$

The minimum variation of the temperature measurable by the system is:

$$\boldsymbol{\Delta T_{min} = \sigma_v \cdot \frac{4}{V_A \alpha} \cong 75\ mK}$$

C) We can further improve the measurement using a Gated integrator of duration $\boldsymbol{T_G = T_A = 100\ ms}$ and a sync signal synchronous to the power supply, in this case, the noise is equal to:

$$\boldsymbol{\sigma_v = \sqrt{(S_W + S_I R^2) \cdot \frac{1}{2T_G} + S_W \cdot f_c \cdot \ln\left(\frac{f_{GI}}{f_{HPF}}\right)} \cong 1.4\ \mu V}$$

The minimum variation of the temperature measurable by the system is:

$$\boldsymbol{\Delta T_{min} = \sigma_v \cdot \frac{4}{V_A \alpha} \cong 22\ mK}$$

SECOND PROBLEM

A) To filter the $\frac{1}{f}$ component we can use a high-pass CR filter, given the signal is modulated around $\boldsymbol{f_A = 500\ Hz}$ we can use a $\boldsymbol{f_{HPF} = 50\ Hz}$, the total noise is equal to:

$$\boldsymbol{\sigma_v = \sqrt{(S_W + S_I R^2) \cdot \frac{\pi}{2} f_P + S_W \cdot f_c \cdot \ln\left(\frac{f_P}{f_{HPF}}\right)} \cong 4.41\ \mu V}$$

To find the minimum variation measurable we need to know the value of the power supply:

$$\boldsymbol{P_{sensor} = \frac{1}{2}\left(\frac{V_A}{2}\right)^2 \cdot \frac{1}{R} \rightarrow V_A = \sqrt{8 P_{sensor} R} \cong 28\ mV}$$

The minimum variation of the temperature measurable by the system is:

$$\boldsymbol{\Delta T_{min} = \sigma_v \cdot \frac{4}{V_A \alpha} \cong 156\ mK}$$

B) Using a resonant filter tuned around $\boldsymbol{f_A}$ we obtain a bandwidth of:

$$\boldsymbol{BW = \frac{\pi}{2}\frac{f_A}{Q} \cong 157\ Hz}$$

The total noise is equal to:

$$\boldsymbol{\sigma_v = \sqrt{(S_W + S_I R^2) \cdot BW + S_W \cdot f_c \cdot \ln\left(\frac{f_P}{f_{HPF}}\right)} \cong 415\ nV}$$

The minimum variation of the temperature measurable by the system is:

$$\boldsymbol{\Delta T_{min} = \sigma_v \cdot \frac{4}{V_A \alpha} \cong 15\ mK}$$

C) To further improve the system, we can increase f_A beyond the noise corner frequency of the noise, for example, we can use $\boldsymbol{f_A = 10\ KHz}$, then we can use a LIA with a low-pass filter (i.e. $\boldsymbol{f_{LPF} = 10\ Hz}$) to extract the measurement.
The total noise is equal to:

$$\boldsymbol{\sigma_v = \sqrt{\left(S_W + S_I R^2 + S_W \cdot \frac{f_c}{f_A}\right) \cdot \frac{\pi}{2} f_{LPF}} \cong 69\ nV}$$

The minimum variation of the temperature measurable by the system is:

$$\boldsymbol{\Delta T_{min} = \sigma_v \cdot \frac{4}{V_A \alpha} \cong 2.4\ mK}$$