**Problem 1**

A)

- because of $1/f^2$ component, noise is divergent if no filter is used. Therefore $V_{P,MIN}$ is infinite.
- To obtain the best possible SNR a whitening filter followed by a matched filter has to be used. Whitening filter : CR with $f_P$=20KHz. Time constant of the filter is much lower than the duration of the rectangular pulse. As a result, the signal shape is modified. Output of the whitening filter: positive exponential pulse followed by a negative exponential pulse both of amplitude $V_P$. Time constant of the two exponential pulses: 7.95µs given by the CR filter. Matched filter same shape of the signal (two exponential pulses with opposite sign). $V_{P,MIN}$ = 2.5µV.

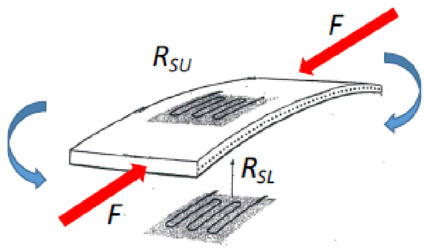
B) a suitable practical filter that is a good approximation of the optimum filter is the Gated Integrator. It can be demonstrated that the best choice for the integration window in this case is Tg=1.25τ. we use **two gated integrators with opposite sign** for the two exponential pulses (i.e. we subtract the two acquisitions). With this solution $V_{P,MIN}$ = 2.8µV.

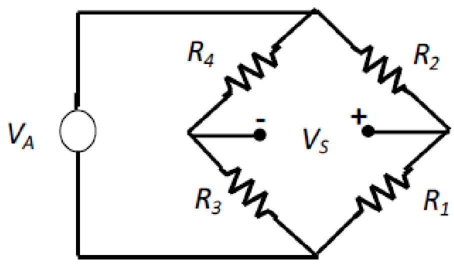
C) white noise at the output of the whitening filter is filtered by the preamp. Therefore, the time constant of the noise autocorrelation function is $1/(2\pi f_{PA})$=15.9ns. With a $T_{Sample}$=80ns noise samples are substantially uncorrelated. We use an exponential weighting function for both exponential signals. With this solution $V_{P,MIN}$ = 4µV.

D) at the output of the whitening filter, the residual noise consists of a 1/f noise component and a white noise component. With the solution of point B) we already have a high pass filtering action thanks to the subtraction of the two integration windows used for the two exponential pulses with opposite sign. This is equivalent to a HPF with fi=1/(2π100µs)=1.59kHz, where 100µs is the distance between the two gated integrators. The low pass filtering action is provided by the gated integrator with $fs=1/(2T_G)$=62.9kHz. considering the quadratic contribution, the contribution of the white noise is $2*S_V*1/(2T_G)=10^{-11}\ V^2/Hz$. The contribution of 1/f noise is $2*S_V*f_C*\ln(fs/fi)$. The latter is negligible if it is 10 times lower than the contribution of white noise. Therefore $f_{CMAX}$=1.35kHz.

**Problem 2**

A) with two strain gauges $R_{SU}$ and $R_{SL}$ in the following configuration it is possible to measure only the compression/extrusion strain and reject the bending strain:




Where $R_4=R_{SU}$ and $R_1=R_{SL}$ or viceversa and $R_2=R_3=R$=300Ω.
$V_A$ <= 60mV to meet power requirements of each strain gauge.
$V_S=V_A/2 * G * \varepsilon$. with $V_A$ = 60mV, F=60nV/microstrain.

B) Typical thermal coefficient: $\alpha=4*10^{-3}$/K. with G=2. $\varepsilon_T$=2000*ΔT[in K] < 50 microstrain. ΔT<25mK.

Temperature issues can be mitigated replacing $R_2$ and $R_3$ (see picture above) with two additional strain gauges. The two additional strain gauges have to be placed near $R_{SU}$ and $R_{SL}$ and orthogonal to them.

C) See theory.

D) To avoid 1/f noise affecting the measurement we can modulate $V_A$, for example at 50KHz. Because of power constraints, with a sinusoidal bias we can use $V_A$=84.8mV and with a sinusoidal reference the white noise is doubled. With a square wave bias (+$V_A$, - $V_A$) we can use $V_A$=60mV but white noise is not doubled. Therefore we can obtain the same SNR with the two solutions. If we want to measure the signal every 10ms (for example), we can use a LPF with cutting frequency 1kHz. $\varepsilon_{MIN}$=6.6microstrain.