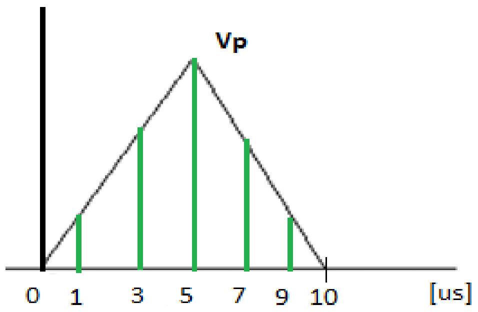
Exam text July 10, 2020 – short solution

Problem 1

1) The Fourier transform of the triangular signal is a square sync with the first zero in 1/Tp = 1/5µs=200kHz. Most of the frequency content of the signal is within 200kHz.
To be conservative, we can use a preamplifier with f_{pA}= 10 * 200kHz = 2MHz.
A reasonable value for input referred voltage noise is $\sqrt{S_V} \;= 10nV/\sqrt{Hz}$.
Given the preamplifier bandwidth limitation, the output noise has a Lorentzian spectrum with τ=80ns. This time is much lower than the minimum sampling time of the microcontroller so noise samples are always **uncorrelated.**
To implement a GI in the digital domain, we must give the same weight to each sample. Exploiting the maximum sampling frequency of the microcontroller, we can acquire 5 samples. To maximize the SNR we must acquire the signal peak, so we must acquire the samples corresponding to the green lines shown in the following figure:



The first half of the signal can be described as follows:
S_{ANALOG}= Vp/Tp * t for 0<t<Tp

$S_{DIGITAL}$= Vp/Tp * k * Ts/2 k ϵ {0,1,2,3,4,5}

Therefore, giving the same weight A to all samples we get

S = Vp/Tp * A * Ts/2 * (1*2+3*2+5), where 1 and 3 have been doubled to take into account the second (descending) part of the signal.

N = $\sqrt{5 * \ A^2 * \ Sv * \ \frac{\pi}{2} \ fpa}$, where 5 is the number of acquired samples.

As a result we obtain V_{pmin} = 15.2µV.

2) Being able to choose any weight for each sample, we can design a filter that has the same shape of the signal in order to implement a digital version of the optimum filter.
In this case the weighting function is equal to 1, 3,5,3,1 for the 5 samples.
S = Vp/Tp * Ts/2 * (1^2*2+3^2*2+5^2) = Vp/Tp * Ts/2 * 45
N= $\sqrt{(1^2 * 2 + \ 3^2 * 2 + 5^2) \ * Sv * \ \frac{\pi}{2} \ fpa}$
In this case, V_{pmin} = 13.2µV.

3) The digital weighting function tends to its analog counterpart as the sampling frequency tends to infinite. See theory for more details.

Problem 2

1) Wheatstone bridge configuration with 4 Strain Gauges (SGs): 2 SGs are used to collect as much signal as possible, while the remaining 2 are used for temperature compensation (see theory for the placement of the SGs on the component under test).
   With a SG featuring a R_0=100Ω, we can use a bias Va=10mV exploiting the whole power budget.
   A typical Gauge factor G for the SG is 2.
   The differential signal at the input of the preamp is Va * G/2 * ε, where ε is the applied strain.

2) A filter is necessary. Being the signal intrinsically modulated (it's a square wave centered around zero) we can use a LIA. The best solution is demodulating with +/- 1 square wave (f_{demod}=500Hz, duty cycle 50%) and a LPF with f_P=10BW_S = 100Hz. As a result, ε_{MIN} = 5 microstrain.

3) 1/f noise affects the first and the third harmonic of the signal. To minimize its effect we must change the bias of the Wheatstone bridge to modulate the signal, i.e. fa=20kHz to avoid 1/f noise; by using +/-Va we keep the same power dissipation.
   In this case we need two nested LIAs to extract the signal: the first one with +/-1 demodulation and f_{demod}=20kHz followed by the same acquisition scheme of point b) thus obtaining the same ε_{MIN} of point b).