Problem 1

<table>
<tr><td colspan="2">RECTANGULAR OPTICAL PULSE
- $T_p = 100ns$ duration
- $r_p = 100kHz$ pulse repetition rate
- electrical signal synchronous to light pulse available
- I_e photocurrent at PMT photocathode and n_e photoelectron emission rate, variable</td></tr>
<tr><td>PHOTOMULTIPLIER TUBE
- Gain G=·10^6 , negligible Excess Noise F≈1
- Detection efficiency η=0,10
- Background at PMT cathode (dark current and environment light): $n_B = 2500\, el/s$ electron emission rate i.e. $I_B = 0,4\, fA$ current</td><td>CURRENT PREAMPLIFIER
- Noise (unilateral) at amplifier input
$\sqrt{S_{iA}} = 1\, pA/\sqrt{Hz}$</td></tr>
</table>

For optical pulses with the features above specified, it is required to measure in various conditions the amplitude in terms of photon rate employing as analog photodetector the photomultiplier tube (PMT) and the preamplifier above specified.

A) Consider first to measure a single pulse. (1) Select a filter suitable for obtaining the best possible signal-to-noise ratio, explaining the reasons of your choice. Evaluate the minimum measurable photocurrent pulse amplitude, pointing out the noise components and their relative role, possibly finding out a dominant component (2) Evaluate in this condition the actual minimum measurable pulse in terms of photoelectrons and the corresponding minimum measurable photon rate.

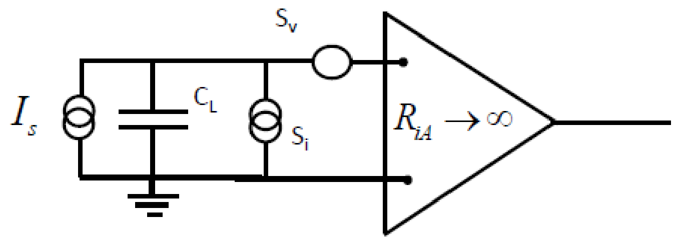
B) Consider now to measure the amplitude by averaging over a moderate number of pulses, namely N_{m1}=100 pulses. (1) Evaluate the minimum measurable photocurrent pulse amplitude, pointing out the time taken by the measurement in this case and the relative role of the noise components, possibly finding out a dominant component. (2) Obtain the equation that shows how the minimum amplitude decreases as the moderate averaged number N_{m1} is increased

C) Consider now to measure the amplitude by averaging over a high number of pulses, namely $N_{m2}=10^6$ (one million) pulses. (1) Evaluate the minimum measurable photocurrent pulse amplitude attained, pointing out the time taken by the measurement in this case and the relative role of the noise components, possibly finding out a dominant component. (2) Obtain the equation that shows how the minimum amplitude decreases as the high averaged number N_{m2} is increased; in particular, evaluate the factor of the improvement obtained with respect to the measure of a single pulse.

D) The background current I_B is a baseline of finite value added to the measured photocurrent I_e . For each one of the three cases above considered, analyze quantitatively whether it is necessary or not to measure and subtract this baseline. In the cases where it turns out to be necessary to subtract the baseline, evaluate how the minimum measurable amplitude is changed by the baseline subtraction.

(NB: see text also on the other side of the sheet)

Problem 2



Piezoelectric force sensor - A_q=10pC/N force-to-charge transduction factor - C_L= 500pF total capacitance, sensor and circuit - generator I_s represents the piezoelectric effect	**Applied Compression Force** - Rectangular pulse with constant amplitude F and duration $T_p = 5ms$
Preamplifier - R_{iA} high input resistance, to be considered infinite - Wide Band-limit f_{pa}=50MHz - $\sqrt{S_{v,u}} = 20nV/\sqrt{Hz}$ (unilateral) wide band - $\sqrt{S_{i,u}} = 0,2pA/\sqrt{Hz}$ (unilateral) wide band - 1/f noise components have not to be considered	**Sinusoidal Electromagnetic Interference** - f_d=20kHz frequency, known with uncertainty ±1%, - Amplitude at preamplifier input $V_d \approx 100\mu V$

A piezoelectric quartz sensor is connected to a preamplifier and subject to a pulsed compression force, with the features above specified. The force has to be measured, employing a suitable filtering of the preamplifier output for maximizing S/N and obtaining high sensitivity and resolution.

A) Describe and explain the optimum filtering that gives the best possible result in the force measurement. Evaluate the minimum force thus measurable.

B) Explain intuitively how to select a constant-parameter filter that can be considered an approximation of the optimum filter. Select this filter and explain how the measurement has to be carried out employing it. Evaluate the minimum force measurable in this way, compare it with the optimum result and explain intuitively the difference.

C) Select now a variable-parameter filter that can be considered an approximation of the optimum filter. Explain how the measurement has to be carried out employing it and evaluate the minimum force measurable in this way. Compare it with the previous results (optimum filter and constant-parameter filter) and comment.

D) A strong disturbance is now added to the preamplifier output by the electromagnetic interference signal above specified. Discuss the possibility of eliminating or strongly reducing the disturbance on the measurement by means of a simple modification of the filter after the preamplifier. Analyze the suitability to this purpose of the filters employed and select the most suitable solution, explaining it in intuitive terms. Evaluate the residual level of disturbance attained with the modified filter, taking into account that the frequency of the interference is known with uncertainty ±1%, and compare it with the filtered noise level.