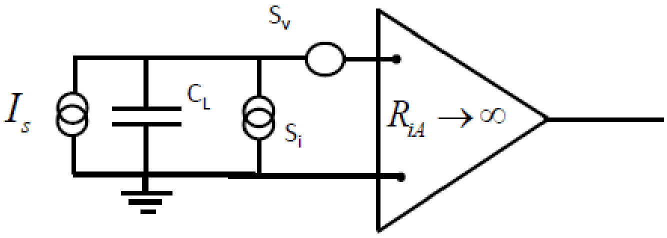
Problem 1



Piezoelectric Sensor of Force A_q=10pC/N force-to-charge conversion C_L= 500pF total capacitance of sensor and electronic circuit connected (I_s represents the piezoelectric effect in the sensor)	**Force F applied** Case 1: step-pulse waveform Case 2: rectangular pulse waveform with duration T_p = 5ms
Voltage Preamplifier Input resistance R_{iA} very high > 500 MΩ , to be considered → ∞ Bandlimit f_{pa}=20MHz set by single pole $\sqrt{S_{v,u}} = 20nV/\sqrt{Hz}$ wide-band voltage noise (unilateral) $\sqrt{S_{i,u}} = 0,2pA/\sqrt{Hz}$ wide-band current noise (unilateral); only where explicitly stated take into account in S_i also a component *1/f* with corner frequency f_c=1KHz	

A piezoelectric force sensor connected to a voltage preamplifier with the characteristics above reported is employed for measuring the force applied to the sensor in the cases below specified. A suitable electrical filtering is applied to the sensor-amplifier output for improving the S/N.

A) Without considering *1/f* noise components, in each one of the cases specified indicate and illustrate the filtering that gives the optimum result in the measurement. Compute the optimum S/N value thus obtained and evaluate the minimum measurable force. Compare the results of the two cases and explain in intuitive terms the reasons of the difference between them.

B) For each one of the cases of force, point out and explain a suitable **constant parameter linear filter** and a measurement procedure by which the overall filtering obtained in practice is an approximation of the optimum filter seen in (A).

C) Consider now also the *1/f* component. With the filtering seen in (B), the output noise has now an additional contribution due to the *1/f* noise component. It it is required to keep this contribution lower or at least comparable to that of the wide-band noise previously computed in (B). To this aim, a further linear filtering can be employed at the output of the filter seen in (B). For each one of the two cases of force, evaluate first whether such additional filtering is necessary for meeting the noise limitation requirement or not. In case it is necessary, select the type of additional filter to be employed, compute the noise contribution due to the *1/f* component with the additional filter, compare it with that of the wide-band noise and explain in intuitive terms the results.

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

Problem 2

Optical Signal rectangular with duration T_P as specified amplitude (optical power) P_S wavelength λ_a = 600 nm **Optical background** Steady light with power P_F	**Silicon PIN Detector** quantum efficiency η_{Dd} = 0,30 at λ_a = 600 nm dark current I_{bd} = 0,05 pA capacitance $C_D \approx$ 1pF
Current Preamplifier (transimpedance amplifier) Band limited by simple pole with f_{pa} = 100 MHz Current noise referred to preamp input $S_{ip}^{1/2}$ = 0,05 pA/Hz$^{1/2}$ (unilateral) (the input voltage noise generator $S_{pv}^{1/2}$ has negligible effect in this circuit configuration and therefore it is not specified)	**PMT detector with S11 photocatode** quantum efficiency η_{Dm} = 0,025 at λ_a = 600 nm: dark current at the cathode I_{bk} = 0,16 fA gain $G = 10^5$ excess noise factor F= 2

It is required to measure the amplitude (i.e. the optical power) of the optical signals above specified. The signals are generated by a remote laser and attenuated by the atmosphere in the transmission to the detector. The photodetectors and preamplifiers to be employed are above specified. As specified in the following, in some cases also a steady background light arrives to the detector with power P_F and wavelength equal to the λ_a of the signal. It is required to evaluate the minimum detectable optical signal power P_{Smin} in every case considered (*Hint: in the evaluation of the mean square value of a fluctuation with various contributions, neglect those contributions that can be preliminarly recognized to be a small percentage of the total*)

A) Consider first cases without optical background (P_F =0) and pulses with duration T_P =1µs. Select an electrical filtering suitable for improving the S/N and evaluate the minimum optical signal power P_{Smin} that can be measured in the two cases, namely with the PMT and with the PIN. Compare the results obtained and explain them in intuitive terms.

B) Still without optical background P_F =0, consider now cases where for obtaining better sensitivity optical pulses of longer duration are employed with the same type of filtering employed in (A), but with modified parameters suitable for the new conditions. Evaluate the results obtained with the PMT and with the PIN operating 1) with pulse duration T_P =10 µs and 2) with pulse duration T_P =10 ms. Compute the factor of improvement of P_{Smin} obtained in each case, compare the two cases and explain in intuitive terms the results obtained.

C) Consider now cases where the optical background P_F is not negligible and the optical pulses have duration T_P =10 ms. Explain how the optical background modifies the limit in the measurement P_{Smin} in the two cases with the PMT and with the PIN.

For each of the two cases evaluate the background light power P_{Fm} that makes the mean square value of the total measured fluctuation 2 times greater than that measured without background. Evaluate in these conditions the minimum measurable optical signal power P_{Smin} and explain the results in intuitive terms.