30/08/2024 – solution draft

Pb1)

A) The RC network integrates the ultrafast pulse producing a step-like signal (exponential decay with time constant 100us). Analogously, the current noise gets integrated producing a $1/f^2$ component. The best theoretical filter consists of a whitening filter plus a matched filter. At the output of the whitening filter the signal features an exponential decay: $\frac{Q_S}{C}e^{-\frac{t}{1\mu s}}$. By applying the ideal matched filter $Q_{S,min} = 0.1fC$. Replacing the matched filter with a sampler it is convenient to apply a weight that is proportional to the amplitude of the samples. By doing this and since noise samples are uncorrelated we obtain $Q_{S,min} = 0.8fC$.

B) Since the duration of the integration window is 100 times lower than the signal time constant, the signal can be considered constant within the integration window. The value acquired in each integration window is then exponentially weighted following the signal shape, obtaining the following SNR: $\frac{S}{N} = \frac{\frac{Q_S}{C}}{\sqrt{\frac{S_V}{2}}}\sqrt{T_G\frac{\tau_C}{2T_S}}$, where $T_G = 10ns, \tau_C = 1\mu s, T_S = 100ns$. As a result, $Q_{S,min} = 0.32fC$.

C) See theory.

Pb2)

A) Reasonable values for a silicon photodiode suitable for the described application: R=0.2, t_N=200nm, t_D=15µm, dark counts: 1000cps. As a results, the PDE is 61% and the radiant sensitivity S_D=0.39A/W. To limit the impact of 1/f noise a CDF is exploited with T_G =1.25 τ and (integration window on noise) = 50ns to avoid noise doubling. The dominant noise contributions are given by the electronics (preamp and resistor) leading to $I_{S,MIN}$=16.4nA and $P_{S,MIN}$=42nW
B) An APD with the same characteristics of the photodiode except for G=100 and F=2 can be used. The APD gain changes the SNR. In particular by keeping the same CDF of point A) the 1/f noise contribution becomes negligible. In this case $I_{S,MIN}$=0.2nA and $P_{S,MIN}$=0.51nW.
C) See theory.