05/02/2025 – solution draft

Pb1)

A) The signal bandwidth can be estimated with roughly 1/Tp (first zero of the sync^2) corresponding to 20MHz. Therefore a suitable preamplifier features a single pole at 200MHz. The optimization of SNR requires a gated integrator with TG=4/3 Tp, leading to $V_{P,min} = 41\mu V$

B) The information carried by multiple pulses within a burst can be used to reduce the impact of wideband noise. Nonetheless, some high-pass filtering action is also required to limit 1/f noise. The exploitation of a correlated double sampling allows to limit 1/f noise but in order to avoid noise doubling an integration window on noise longer than the one on the signal is necessary. Since there is not enough time between pulses (in the worst case scenario), the noise can be collected before each burst leading to a center to center distance of the two integration windows (for the last pulse) of Tw=(4/3Tp)/2+(40/3Tp)/2+9*200ns+Tp/3=2.18μs.
At first approximation we can consider the same 1/f noise contribution on each pulse (conservative estimation) and that it does not scale with averaging on N pulses. At the same time, white noise contribution is reduced by sqrt(N). Overall, with the same GI of point a on the signal, a CDF (Tn=10*Tg) and averaging out 10 pulses we obtain $V_{P,min} = 13.35\mu V$.

C) See theory.

Pb2)

A) At 400nm a phototube can feature a PDE of 20% (with a S20 photocathode) while the PDE of a photodiode is limited by La=100nm. With a thickness of the neutral region of 100nm and of the depleted region of $1\mu m$, we can obtain a PDE=30%. Therefore the photodiode is preferrable.
A reasonable value for its dark current is 2fA. The total noise referred to the input is $\sqrt{S_{i,tot,IN}} =$ 44pA/sqrt(Hz). Assuming that the overall electronics noise is dominant with respect to the noise signal and using the optimum filter we obtain

$$\frac{S}{N} = \frac{I_P}{\sqrt{\frac{S_{i,tot,IN}}{2}}}\sqrt{T_P}.$$

Leading to $I_{P,min} = 220nA$ and $P_{min} = \frac{220nA}{0.097A/W} = 2.27\mu W$. Shot noise of signal is indeed negligible.

B) With a PMT (G=10^6, F=2), the shot noise of signal becomes more relevant. A simple filter is a RC low-pass filter with optimized sizing: $\tau_P = 0.8Tp$. Assuming that the shot noise of signal is dominant

$$\frac{S}{N} = \frac{I_P\left(1 - e^{-\frac{T_P}{\tau_P}}\right)}{\sqrt{2qI_P F \frac{1}{4\tau_P}}}$$

Leading to $I_{P,min} = 20pA$ and $P_{min} = \frac{20pA}{0.064A/W} = 310pW$. Shot noise of signal is indeed dominant.

C) See theory.