Problem 1

a) Without any filtering, white noise is limited only by the preamp. We can calculate the current noise referred to the input to directly compare it with the continuous-wave current signal coming from the photosensor. I_{S_MIN}= $\sqrt{(\frac{S_V}{(50\Omega)^2} + S_I + \frac{4kT}{50\Omega}) * \frac{\pi}{2} * f_{PA}} = 151nA$. In terms of power: P_{S_MIN}=(151n/0.226) W= 668nW corresponding to a $P_{,LASER\_MIN}$ = 668nW/0.05 = 13.3µW.

b) Since R varies over a few tens of ms range, we can consider a bandwidth of the signal of about 100Hz. To improve the sensitivity of the system, we can use a RC filter with a pole at 1kHz. We obtain I_{S_MIN}= $\sqrt{(\frac{S_V}{(50\Omega)^2} + S_I + \frac{4kT}{50\Omega}) * \frac{\pi}{2} * f_{P,RC}} = 1.07nA$. In terms of power: P_{S_MIN}=(1.07n/0.226) W= 4.73nW corresponding to a $P_{,LASER\_MIN}$ = 4.73nW/0.05 = 94.6nW.

c) The ambient light has the same characteristics of the signal both in terms of wavelength and bandwidth. Therefore, we need to measure it in absence of signal. To this aim, we need to switch off the signal: we can either switch on/off the laser diode, if possible (the text does not specify if the laser features this operation mode or not), or we can use a chopper in front of the laser. In both cases, the light delivered to the target is modulated on/off (optical square wave). By using a square wave +1/-1 to demodulate and exploiting the same RC of point b, we filter the ambient light, but we collect the same white noise of point b and only half of the signal, thus the SNR obtained in point b is here reduced by $\sqrt{2}$. In conclusion, $P_{,LASER\_MIN}$ = 94.6nW * $\sqrt{2}$ = 133.8nW.

d) In the conditions of point b, 1/f noise contribution is infinite unless a zero setting is performed before the measurement. For example, we can consider a maximum duration of the measurement as long as 30minutes; we can use an integration window with duration much longer than the RC used in point b to avoid noise doubling. In these conditions, fi= 1/(2*π*30min) = 88µHz and $n_{,I,1/f}$ dominated by the voltage contribution of the preamp, is equal to $\sqrt{(\frac{S_V}{(50\Omega)^2} f_C * \ln(f_i / f_{P,RC})} = 2.54nA$ which is quite high with respect to the white noise contribution.

   In the conditions of point c, we can make 1/f noise contribution negligible with a proper selection of the modulating/demodulating frequency. For example, we can modulate at 10kHz which is well above the noise corner frequency, thus making 1/f negligible.

Problem 2

a) At λ=850nm the photodiode can provide a high photon detection efficiency while the phototube can't. Therefore, the photodiode is preferable.
At 850nm, L_0≈10µm; reasonable parameters for a photodiode are R=0.1, width of the neutral region t_N=0.3µm and PDE=50% at the wavelength of interest. Since $PDE = (1-R)e^{-\frac{t_N}{L_0}}(1-e^{-\frac{t_D}{L_0}})$, a t_D=8.5µm is required.

b) With an APD, if the electronics noise is dominant, the result can be computed by simply dividing the result of Problem 1 point b by the gain of the APD, i.e. $I_{S\_MIN}=\frac{1.07nA}{100} = 10.7pA$. We can consider the same S of Problem 1 (reasonable for an APD), corresponding to $P_{,LASER\_MIN}$ = 947pW, or compute an alternative S. We must verify that the contribution of shot noise is indeed negligible; considering a noise factor F=2, we obtain: $\sqrt{2qI_{MIN} * G^2 * F} = \frac{262fA}{\sqrt{Hz}}$ that is much lower than dominant contributions (preamp voltage noise and resistor noise).
c) We can consider a PMT with G=10^6 , F=2 and dark counts=10^3 e/s (corresponding to a dark current of 0.15fA). Considering the overall noise contribution due to electronics, the PMT and shot noise, we get $I_{S\_MIN}=1.74fA$. The detection efficiency of a PMT at 850nm is limited to few percent. With η=5% we have $P_{,LASER\_MIN}$ = 1 pW.
d) Refer to lesson 22 (PD_04), pages 20-21.