Problem 1

1) The duration of the GI could be equal to Tp (one rectangle) or 2.5Tp (two rectangles plus the interval). With T_G=Tp and A=1, Vp_{MIN}=8.9µV; with T_G=2.5Tp and A=1, Vp_{MIN}=7µV.
Therefore, the best choice is collecting the whole signal.

2) A whitening filter to get only white noise is necessary. The filter also acts on the signal producing 4 exponential signals corresponding to the 4 edges (two rising and two falling ones); the time constant is 318ns. With an ideal optimum filter we'd obtain Vp_{MIN}=35µV.

3) At the output of the whitening filter of point 2) we obtain a noise spectrum consisting of white noise and 1/f noise with fc=10kHz. The ideal optimum filter already provides a high pass filtering action thanks to the subtraction of exponential signals with opposite polarity. The additional contribution of 1/f noise can be estimated considering an upper bandwidth limitation equal to 1/(4Tc) and a lower bandwidth limitation equal to 1/(2πTp). The overall noise is therefore $\sqrt{4S_V f_C \ln\left(\frac{\pi T_P}{2T_C}\right)} \approx 31\mu V$. As a result, the SNR is reduced by almost 9% with respect to point 2 (and Vp_{MIN}=38.5µV).

Problem 2

1) The basic configuration of the detector-preamplifier assembly consists of an equivalent current generator with a capacitor in parallel both modeling the p-i-n photodiode. The signal is collected by means of a resistor in parallel to the generator, followed by a preamplifier.
Reasonable values for the parameters are:
   - Photodiode:
     - PDE(800nm)=55% (R=0.1, tn=200nm, td=10µm) [Resulting S_D= 0.35A/W]
     - C=1pF
   - Preamplifier:
     - Gain 1 (for simplicity)
     - $\sqrt{S_V} = \frac{4nV}{\sqrt{Hz}}$
     - $\sqrt{S_I} = \frac{1pA}{\sqrt{Hz}}$
   - Resistor:
     - 1kΩ

The phototube has an extremely low efficiency at 800nm (at most around 2% with a S25 photocathode).

2) It is convenient to use a simple low pass filter with a pole at 100Hz to avoid signal loss. In this case the noise equivalent bandwidth is π/2 * f_P (detailed theory is required here).
The minimum transmitted power that can be measured is P_{MIN}=206pW.
Photosensor with internal gain: we could use an APD (not a PMT because of poor PDE at 800nm).
Reasonable APD (additional) parameters:
     - G = 100
     - F = 2
     - I_D=0.15fA

The dominant noise contribution is still the electronics noise but its impact on the SNR is reduced by the gain. P_{MIN}=1.42pW

3) The best solution is to modulate and demodulate the signal with a square-wave reference at 100kHz. (detailed theory on square wave modulation and demodulation is required here).

P_{MIN} is the same of point 2.