Exam of 20200618 – short solution

Problem 1

1) Both PD and PT are easily limited by the electronics noise having no internal gain. Therefore, it is crucial to maximize the current signal by maximizing the PDE
PT: PDE ≈ 15% at 500nm (S20 or S11 photocathode)
PD: PDE ≈ 65% at 500nm with R=0.2, t_N=200nm, t_D=5µm.

   A PD is much better than PT for this application for PDE, size, ruggedness. Also, the SER can be of few tens of ps.

   Summarizing:

   PDE = 65%, reasonable dark current 2fA, S_D=0.26A/W

   Setup: 50Ω resistor, voltage preamp with $\sqrt{S_V} = 2nV/\sqrt{Hz}$, $\sqrt{S_I} = 0.5pA/\sqrt{Hz}$
   BW must be > 1/TP = 50MHz.
   We can use a preamp with f_{PA} = 400MHz.

   Overall <u>electronics</u> noise referred to the input $\sqrt{S_{\text{iTOT,I}}} = 44pA/\sqrt{Hz}$

   By using this setup, single shot measurement:
   S= I_P
   N≈ $\sqrt{(2qI_P + S_{\text{iTOT,I}}) * {}^{\pi}/_{2}\, f_{PA}}$

   The minimum signal is I_P= 1.1µA corresponding to $P_{P,\,min}$ = 4.23µW.

2) A) use multiple pulses
B) use a better filter on the single pulse, e.g. a GI
(C) combination of A) and B))

   With a GI, for simplicity T_G=2T_P and A=1, we obtain $I_{P,MIN}$= 0.44µA and $P_{P,\,min}$ = 1.69µW.

   By using multiple pulses the SNR improves by sqrt(N). For example, to obtain the same result of the GI, i.e. an improvement factor of 2.5, we need ≈6 measurements.

3) The exploitation of a detector with internal gain reduces the contribution of the electronics noise by a factor G^2F.
For example, a Si-APD with the same PDE of the PD, G=100 and F=2 can be used. With a single shot measurement we can reach $I_{P,MIN}$= 7.6nA and $P_{P,\,min}$ = 29nW.

Problem 2

1) If the signal was a rectangular signal, most of its frequency content would have been within 1/2T_P = 16.7MHz.
To preserve the signal we need a preamp with a BW much higher than that.
For example, with f_{PA}=180MHz, $V_{P,MIN}$= 672.4µV
2) Now the exact shape of the signal is known. Half signal is described by the following equations:

   t*10V_P/T_P for 0<t<T_P/10

V_P for $T_P/10<t<T_P$

With the optimum filter we could ideally obtain $V_{P,MIN}$= 119.5µV

A practical filter can be a GI. If we collect the whole signal, for simplicity, we obtain $V_{P,MIN}$= 121.5µV. This result is so close to the optimum filter that an optimization of the duration of GI is not necessary.

3) The maximum duration of the burst is $T_B = 10*2T_P + 9d_{MAX}$, where d_{MAX} = 30ns (maximum duration between consecutive pulses in the same burst).

   A possible solution to filter 1/f noise is to perform a zero setting before each burst. The worst SNR is for the last pulse and the time distance is so long that it is convenient to have an integration window for the zero setting with a duration >> $1/T_P$ to avoid noise doubling.
   Time distance for equivalent high pass filter is 1.14µs in the worst case (last pulse of the burst). Nevertheless, this solution already makes the 1/f noise is negligible and $V_{P,MIN}$= 121.5µV.

   Comment: the SNR could be further improved by using all the pulses in one burst leading to $V_{P,MIN}$=38.26µV