14/06/2024 – solution draft

Pb1)

A) The signal shape is preserved by the preamplifier, so all samples will have the same amplitude Vp. The noise at the output of the preamplifier features a Lorentzian spectrum with correlation time constant $\tau_{pa} = 1.6ns$.
With a sampling frequency of 100MHz noise samples are spaced by 10ns, thus they are uncorrelated. Acquiring N=11 samples, the SNR is improved by sqrt(N) with respect to the single sample, thus the minimum amplitude that can be measured is $V_{P,min} = 37.9\mu V$.
With a sampling frequency of 500MHz noise samples are spaced by 2ns, thus some of them are correlated. The noise can be computed by integrating the product of the autocorrelation function of noise by the autocorrelation of the weighting function. The latter is a train of 51 samples. Considering a unitary weight of each sample, the autocorrelation function features a triangular shape with peak amplitude in zero corresponding to a value of 51. Overall, $N^2 \cong 90 * R_{xx}(0)$, while the signal is $51 * V_P$. In this case, the minimum amplitude that can be measured is $V_{P,min} = 23\mu V$.

B) With a repetition rate of 1MHz multiple pulses can be acquired providing an exponential weighting function. Since noise is not correlated from pulse to pulse, in both cases the same improvement factor can be obtained. To ensure a maximum duration of the weighting function equal to 1s, a time constant of 1s/5=200ms is needed, resulting into $IF = \sqrt{2 * 1MHz * 200ms} = 632$. In this scenario,
@fs1, $V_{P,min} = \frac{37.9\mu V}{632} = 60nV$

@fs1, $V_{P,min} = \frac{23\mu V}{632} = 36nV$

C) See theory.

Pb2)

A) The signal can be modulated at 20KHz to avoid the 1/f noise component and a LIA can be used to recover the signal. With a chopper placed very close to the laser, only the signal is modulated while the constant background reaches the photodetector and its mean value is filtered out along with the DC component of the signal. The dominant noise contribution in this case is given by the electronics noise, leading to $I_{P,min} = 25pA$, $P_{P,min} = \frac{I_{P,min}}{S_D} = \frac{25pA}{0.04A/W} = 625pW$.

B) With a PMT (G=10^6, F=2), the shot noise of signal, dark counts and background becomes dominant. The shot noise associated with the modulated signal is not stationary: for the sake of simplicity, it can be approximated with a constant spectrum equal to $2qI_PF$. In this case, $I_{P,min} \approx 0.6fA$ and $P_{P,min} = 15fW$.

C) See theory.