**Physics 198, Spring Semester 1999** Helmuth Spieler
**Introduction to Radiation Detectors and Electronics**

Problem Set 7: Due on Tuesday, 16-Mar-99 at begin of lecture.
Discussion on Wednesday, 17-Mar-99 at 12 – 1 PM in 347 LeConte.
Office hours: Mondays, 3 – 4 PM in 420 LeConte

Compare the time resolution obtainable in a scintillation detector using either a photodiode or a photomultiplier. As an example, consider a scintillator array, as was shown in the lecture on March 4, V.5. Semiconductor Detectors – Examples. An 8 x 8 array of crystals is coupled either to a PMT with a 1 x 1 in$^2$ faceplate or to an array of photodiodes on the other side. The light output of the scintillator as a function of time is given by

$$\frac{dN(t)}{dt} = N_0 \frac{e^{-t/\tau_2} - e^{-t/\tau_1}}{\tau_2 - \tau_1}$$

where $N_0$ is the total number of photons, $\tau_1$ is 5 ns and $\tau_2$ is 200 ns. The number of scintillation photons from a 511 keV gamma incident on the detector is 15000.

1. First consider the photomultiplier system. Its quantum efficiency is 20%.

   a) Integrated over the light pulse, how many electrons will reach the first dynode?

   b) What is the photoelectron current vs. time?

   c) In a photomultiplier system the instantaneous fluctuation of the signal is not due to electronic noise, but to photoelectron statistics. For the purposes of this analysis, assume that the electron-multiplication structure provides a constant gain and mean transit time, but that the transit time jitter is such that the structure effectively integrates over 500 ps. What is the fluctuation of the anode current pulse as a function of time? (Subdivide the pulse into 500 ps intervals and determine the number of photoelectrons and their statistical fluctuation in each interval).

   d) What is the timing jitter for various trigger levels $I_T/I_0$, where $I_0$ is the peak current?

Turn page for Problem 2.

2. Now consider a photodiode readout. The photodiode array is fabricated on a 300 μm thick *n*-type substrate with a donor concentration of $1.0 \cdot 10^{12}$ cm$^{-3}$. It has the usual asymmetric structure with a thin, highly-doped *p*-layer. Light is incident on the n$^{+}$-contact, which has been formed by a special technique to make it very transparent to scintillation light. The detector is operated at 100 V and the reverse bias current is 0.4 nA/cm$^{2}$. The quantum efficiency is 90%, which means that for 90% of the incident photons a scintillation photon will form an electron-hole pair.

a) What is the depletion voltage? Sketch the field profile in the detector.

b) What is the capacitance of an individual photodiode?

c) The absorption coefficient of the scintillation light is about $10^{4}$ cm$^{-1}$. Which carrier type dominates the detector signal? What is the collection time $t_c$?

d) A current sensitive amplifier is used to sense the instantaneous signal current. The signal current due to *n* charges traversing the detector is

$$i_s = \frac{nq_e}{t_c}$$

Estimate the optimum trigger level.

e) What is the optimum rise time of the amplifier? What is the electronic noise current level required for a time jitter of 300 ps?

f) A realistic spectral noise current density referred to the input of the amplifier is 20 pA/Hz$^{1/2}$. Is this adequate for a time jitter of 300 ps? What is the noise contribution from the detector bias current?

g) Compare the current fluctuations due to electronic noise with the current fluctuations due to photon statistics.