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

Problem Set 13: Due on Tuesday, 04-May-99 at begin of lecture.
Discussion on Wednesday, 05-May-99 at 12 – 1 PM in 347 LeConte.
Office hours: Mondays, 3 – 4 PM in 420 LeConte

1. A gas ionization chamber is used to detect 5.9 keV x-rays from an ^{55}Fe source.

   a) How large is the charge signal provided by the detector?

   Assuming $\varepsilon_i = 30$ eV, the number of electron-ion pairs N is 5900/30 ≈ 200.

   b) What is the statistical fluctuation of the charge signal?

   The Fano factor in gases typically ranges from 0.2 to 0.3. Assume $F = 0.3$, so

$$\Delta Q_{\rm det} = \sigma_N = \sqrt{FN} = 7.8\ \text{el}$$

   For $F = 1$ the fluctuation is 14 el.

   c) What is the allowable electronic noise level, if the overall resolution is to be within 10% of the intrinsic resolution of the detector?

   The total signal fluctuation

$$\Delta Q_{tot}^2 = \Delta Q_{\rm det}^2 + Q_n^2$$

   so for $\Delta Q_{tot} = 1.1\ \Delta Q_{det}$, the allowable electronic noise is $Q_n = 0.46\ \Delta Q_{det} = 3.6$ el. If you assumed a Fano factor of 1 in the preceding problem, $Q_n = 0.46\ \Delta Q_{det} = 6.5$ el.

   d) The chamber capacitance is 10 pF. You have an amplifier whose input JFET has a transconductance of 5 mS and an input capacitance of 5 pF. Using a CR-RC shaper, what is the minimum shaping time that will provide the required noise level? Assume that the noise current sources are negligible.

   The white noise level was calculated in last week's problem 1.a.
   For $\gamma_n = 1$, $T_0 = 300$ K and $g_m = 5$ mS, $v_n^2 = 3.3 \times 10^{-18}$ V^2/Hz.

   The total input capacitance is the sum of the detector capacitance and the input capacitance of the FET $C_{det} + C_{FET} = 15$ pF, so the equivalent noise charge

$$Q_n = C_i v_n \sqrt{\frac{F_v}{T_s}} = 15 \cdot 10^{-12} \times 1.8 \cdot 10^{-9} \sqrt{\frac{0.9}{T_s}} = \frac{2.6 \cdot 10^{-20}}{\sqrt{T_s}}$$

   A noise level of 3.6 el is equal to 0.58 aC, so the resulting shaping time is 2.0 ms, long enough to obtain the full ion signal. For a noise level of 6.5 el ($F = 1$), the calculated shaping time is about 620 µs.

However, at these long shaping times 1/*f* noise will dominate. For a JFET with the characteristics used here, a typical 1/*f* noise coefficient $A_f \approx 4 \times 10^{-15}$ V^2, so the 1/*f* noise contribution (from lecture notes V.3., p. 12)

$$Q_{nf} = eC_{tot}\sqrt{\frac{A_f}{2}} = 1.8 \cdot 10^{-18} \text{ As } = 11 \text{ el} .$$

The total resolution $(\Delta Q_{det}^2 + Q_n^2 + Q_{nf}^2)^{1/2}$ becomes 14 el, about twice the intrinsic chamber resolution. Better resolution requires a lower chamber capacitance.

2. An MSGC is to be used as a tracking detector. The gas is CH_4 at standard temperature and pressure (not necessarily the best choice, but it keeps the calculation simple).

   a) Minimum ionizing particles have a differential energy loss $dE/dx \approx 2$ MeV g^{-1} cm^2. The drift space where the primary energy is deposited is 4 mm thick. How large is the primary signal charge for a track at normal incidence?

   The density of CH_4 gas at standard temperature and pressure is 6.7×10^{-4} g/cm^3. You can either look it up or simply estimate it knowing that one mole of gas (16 g of CH_4) at STP occupies a volume of 22.4 l (2.24×10^4 cm^3). Multiplying by the density translates $dE/dx = 2$ MeV g^{-1}cm^2 to $dE/dx = 1.34$ keV/cm. For an ionization energy of 30 eV per ion pair, this yields 18 electron-ion pairs in 4 mm.

   b) The anode strip pitch is 200 µm. What is the signal per readout strip for tracks at 45° incidence?

   The signal per strip is provided by the portion of deposited energy subtended by the anode strip pitch. At 45° incidence the path length subtended by the 200 µm strip pitch is $p/(\cos 45°) = 283$ µm, so the number of primary charge pairs is 1.3.

   c) A bipolar input transistor is used in the preamplifier. The transistor's current gain is 150 and the total capacitance of a readout strip is 10 pF. What is the obtainable noise level?

   From last week's problem 3.a. $Q_n = 732$ el.

   d) How much gas gain is required if a signal-to-noise ratio of 10 is to be achieved at normal incidence? How much gain is required if $S/N = 10$ is to be maintained at track angles up to 45° (relative to normal incidence)?

   For a signal-to-noise ratio of 10, the signal must be $10 \times Q_n = 7320$ el. At normal incidence 18 primary electrons are formed, so the necessary gas gain is 7320/18 = 407.

   At 45° incidence only 1.3 primary electrons are available, so the required gas gain is 5600.

   Assume a counting experiment. If a theshold-to-noise ratio of 4 is used to limit the number of noise hits, the threshold level is about 3000 el, so at least twice the gas gain is needed for good efficiency.