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

Problem Set 4: Due on Tuesday, 23-Feb-99 at begin of lecture.
Discussion on Wednesday, 24-Feb-99 at 12 – 1 PM in 347 LeConte.
Office hours: Mondays, 3 – 4 PM in 420 LeConte

1. If within a given time interval the average number of events is $\bar{n}$, the probability of measuring *n* events is given by the Poisson distribution

$$P_n = \frac{(\bar{n})^n}{n!} e^{-\bar{n}}$$

Plot the probability distributions for $\bar{n}$ = 1, 2, 3, 5, 10. What is the probability of measuring zero events? Where does the distribution become approximately Gaussian?

2. A silicon detector is fabricated using 300 μm thick *n*-type material with a donor concentration of 1.8×10^{12} cm^{-3}. The *p*-region is highly doped with a concentration of $>10^{16}$ cm^{-3}.

   a) What is the voltage required for full depletion?

   b) What are the collection times for electrons and holes when the detector is operated at 50, 100 and 200 V?

   c) The detector is exposed to 20 keV x-rays. At 50 V the detector system yields a signal-to-noise ratio of 5. What is the noise level of the system? What is the signal-to-noise ratio at 100 and 200 V?

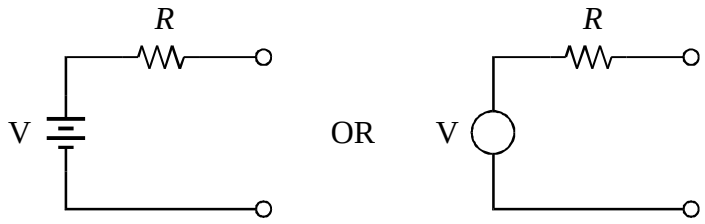
   d) Using the same electronics the detector is exposed to minimum ionizing particles, which have an energy loss dE/dx = 265 eV/μm. What is the signal at 50, 100 and 200 V? What is the signal-to-noise ratio?

3. Consider an *RC* integrator driven by a voltage amplifier, i.e. the source impedance is low. The resistance R = 10 K and the capacitance C = 100 pF.

   a) Plot the magnitude and phase vs. frequency of the transmitted voltage. What is the signal bandwidth of this system? Calculate the noise bandwidth and compare it with the signal bandwidth.

   b) Derive the pulse response to a step input with negligible rise time. What is the time constant of the output pulse? What is the relationship between the time constant and the rise time measured as a difference between the times when the output attains 10% and 90% of the peak signal?

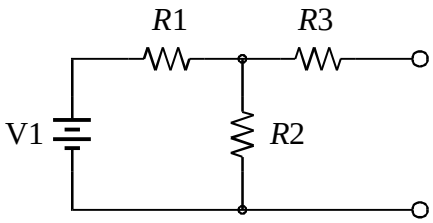
4. Although an ideal voltage source provides an output voltage that is independent of the current drawn, real voltage sources exhibit a finite source resistance. Over a restricted range of load currents voltage sources can be represented by the equivalent circuit,



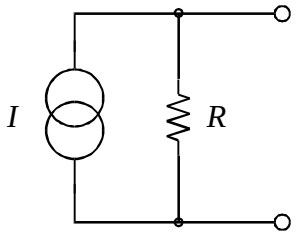
where the battery is an ideal voltage source (i.e. with zero source resistance) providing the voltage V (Thévenin equivalent circuit).

a) What is the dependence of output voltage on load current?

b) Draw the equivalent circuit of the following network showing the component values.

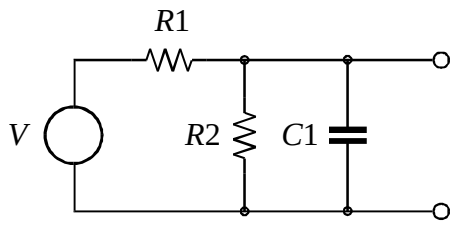


c) The equivalent circuit of a voltage source can also be constructed with a current source (Norton equivalent circuit). This is useful in nodal analyses where currents must be summed. An ideal current source forces a constant current into the load, independent of the load resistance (i.e. independent of the voltage across the load).



What is the equivalent circuit of the network shown in b) when using a current source?

5. In the circuit below the voltage generator provides either an alternating voltage (sine wave) in problem a) or a step impulse in problem b).



a) Plot the magnitude and phase of the output voltage as the frequency of the voltage generator is varied.

b) What is the output waveform if the source generates a voltage step?

Hint: First derive the equivalent circuit for the network *V*, *R*1, *R*2 and then consider the effect of *C*1..