Laboratory Instruction on Ionizing Detectors

“Silicon Sensor and Read Out Electronics”

by Richard Brenner (may 2005)

Introduction

Near intrinsic n-type silicon with a metallised p-doped region, is the most frequently used semiconductor structure for detecting charged tracks in high-energy physics experiments. A polarisation voltage is applied reverse biasing the diode structure, which depletes the silicon from charge carriers. Charged particles or photons interacting with the silicon will create electron-hole pairs that drift along the electric field lines to the contacts located on the silicon surface.

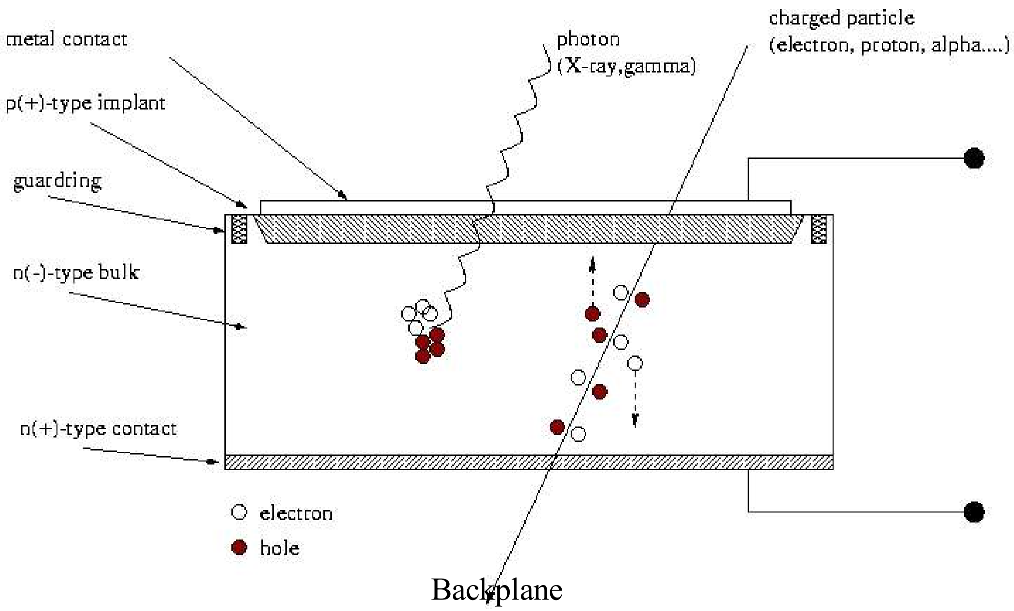

Illustration 1. A schematic drawing of a silicon sensor diode.

A first step in constructing a particle detector based upon a silicon sensor is to characterize the sensor without readout electronics attached. The static characteristics of a sensor are usually adequate to determine if the sensor can be used for particle detection. The leakage current behavior as a function of voltage and the voltage needed to fully deplete the sensor are two important parameters. The voltage needed to deplete the sensor can be determined by measuring the capacitance between the diode implant and the backplane of the sensor. In the final particle detector system, both the capacitance and the leakage current will influence the performance of the readout electronics.

The capacitance and leakage current depend on the geometry of the sensor and the quality of the material and manufacturing process. In a well controlled and uniform process sensors with the same geometrical layout, processed on the same substrate, should have the same behavior. In reality, there may be variation both in the process and in the material and therefore there may be sensors which differ largely from what we naively would expect. When constructing an experiment consisting of many sensors we have to measure them in the laboratory to find the good sensors that can be used in the experiment. It is not unusual that preamplifiers are sold separately. Especially in systems with many channels and odd geometries one want to use hybrid preamplifiers. The advertise shown in figure 1 shows a hybrid preamplifier that looks very much like the one you will study in this lab, however your originates from the late 80' .

In this exercise you will characterize separately a silicon sensor and a preamplifier. You will finally connect the silicon sensor to the preamplifier.

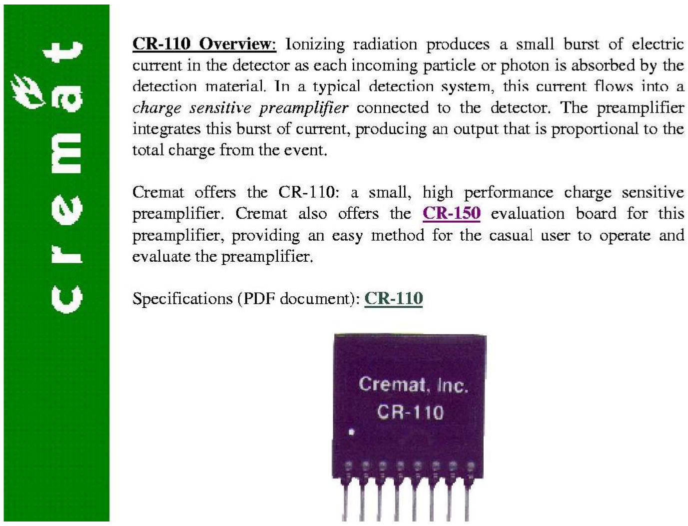

Illustration 2. Advertisement published in 2005 on a hybrid preamplifier.

Characterization of the preamplifier

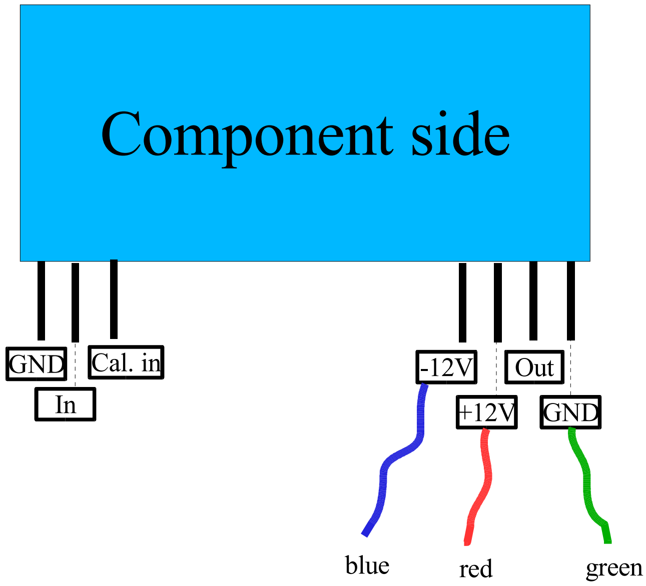

Illustration 3. Layout of the preamplifier hybrid board.

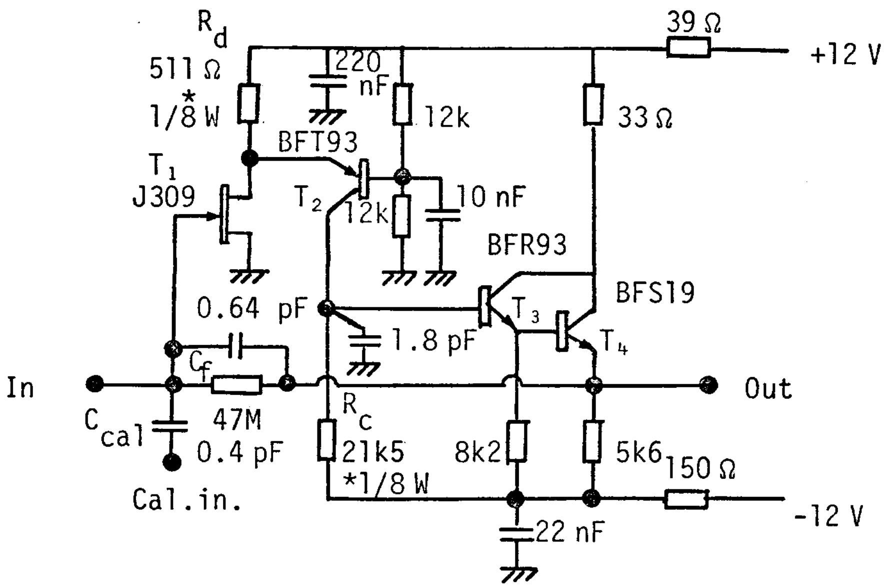

Illustration 4. Schematics of the preamplifier hybrid board.

Task:

- Get familiar with the Vero board.
- Study the amplifier gain, rise time and noise as a function of load capacitance (between input and ground) .
  - Determine the size of the calibration charge injected by a square pulse over the calibration capacitance C_{cal}. Select an injected charge between 1-2 MIP in 300 micrometer silicon (between 25000 electrons and 50000 electrons).
  - Plot the gain, rise time and noise vs. input capacitance.
  - Plot the ENC vs. capacitance, fit the data with a straight line and extract the ENC noise at 0pF and the noise slope in ENC/pF.

Characterization of the silicon sensor.

The silicon sensor is characterized by measuring its leakage current and capacitance. A small mezzanine board with a sensor has been prepared for the exercise. The backplane of the sensor is glued with conductive glue to the copper strip. The copper strip, the four diodes and the guard ring is bonded by a 25 micron thick aluminum wire to the conductors on a kapton foil. The sensor is 300 μm thick, n-type bulk (crystal orientation <111>) and has a resistivity around 6 kΩcm.

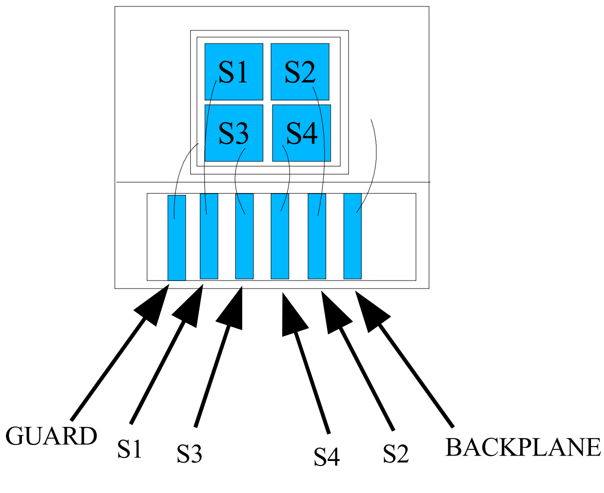

Illustration 5. Mezzanine board with the sensor.

Task:

- Measure the IV-characteristics (leakage current vs. depletion voltage) for all four sensors.
- Calculate the theoretical depletion voltage for the sensor.
- Determine from the CV-measurement the depletion voltage.
- What is the leakage current at full depletion?
- Explain what you measure and can the measurement be improved by defining the potential on the guard ring or the unmeasured diodes.

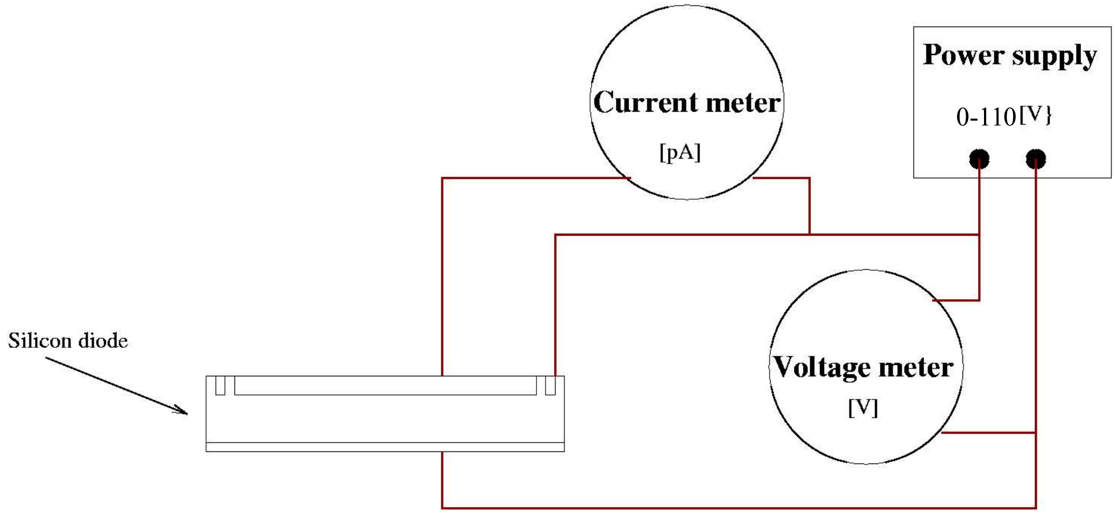

Illustration 6. A schematic drawing of the setup for IV measurement.

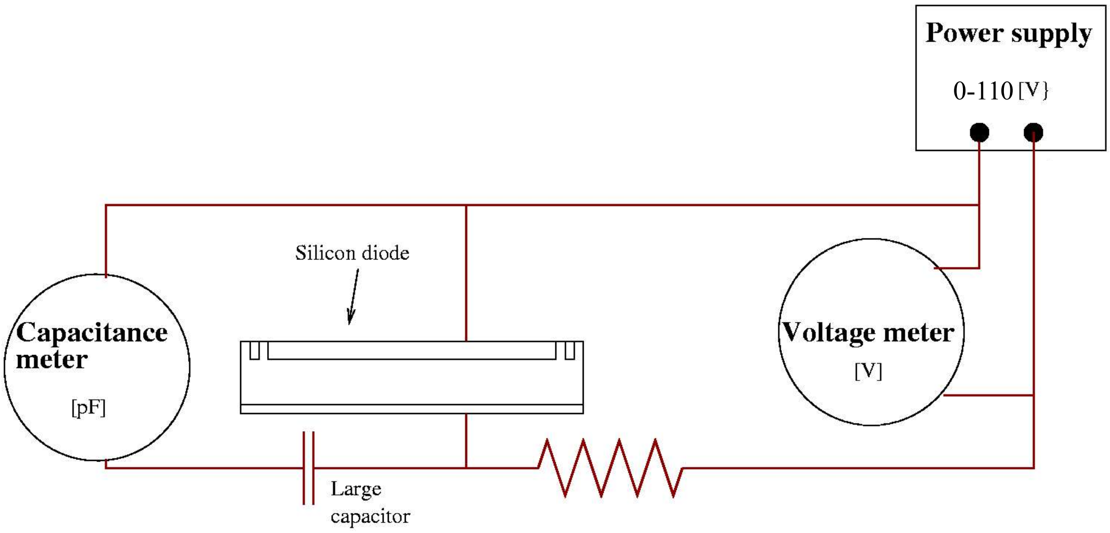

Illustration 7. A schematic drawing of the setup for CV-measurement.

Measurement of full chain sensor + amplifier=detector

Task:

- Measure the performance with the sensor DC-coupled to the preamplifer with test pulse. Determine noise, rise time, .
- Measure the performance with the sensor AC-coupled to the preamplifer.

    - Decide on magnitude of the coupling capacitance and bias resistor

Draw in both cases a schematic diagram of the circuit and identify the serial and parallel noise sources and if possible the magnitude of the sources.

With the data from the characterization of the two parts separately, what performance do you expect from the combined parts?

- Expose the detector to beta particles from a ^{137}Cs source - what do you expect to see and what do you see?

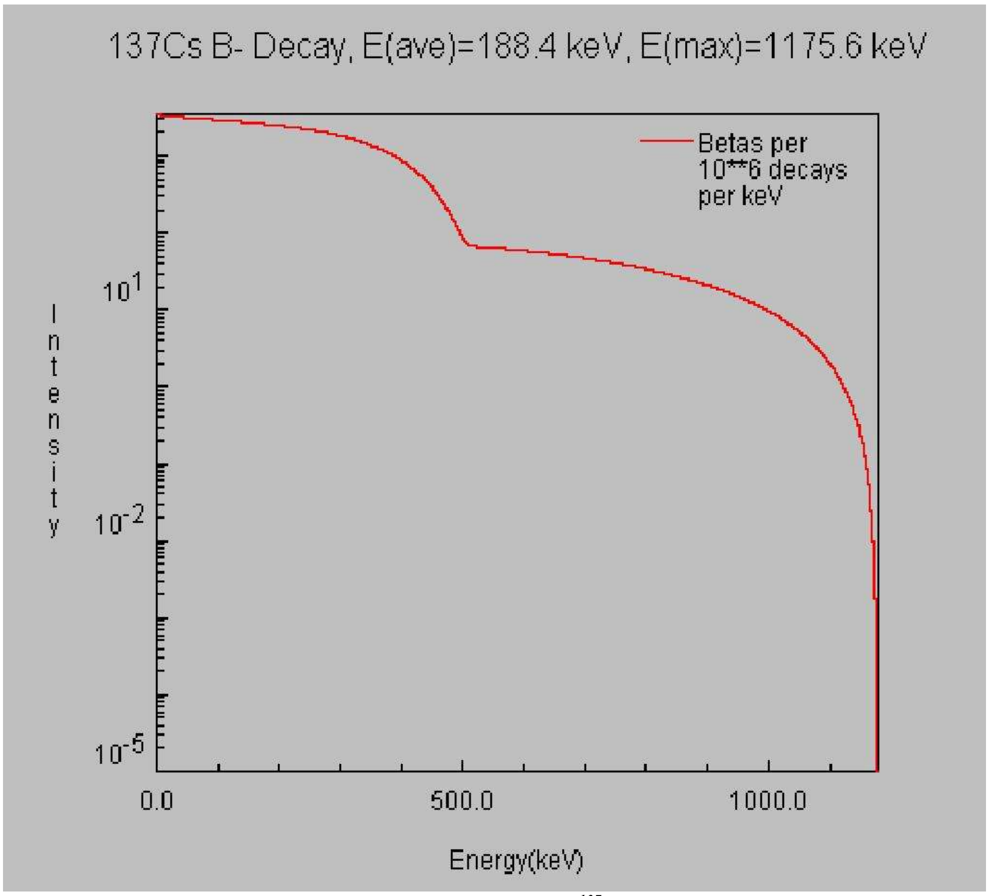

Illustration 8. Energy spectrum of beta particles from ^{137}Cs.

- Study the signal at very low bias and compare it to the signal at full depletion voltage
- How can the the detector be improved ?