Reseach Course on Detector technology - Semiconductor detector

group 1

November 12, 2018

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1 Introduction

2 Description of the experiment

We worked on a p-type silicon detector. The device was exposed to a soft X-ray source and operated under a bias that ensured depletion of the entire chip. Depletion means that there are no intrinsic charge carrier left on the device, so all the signal measured will come from photoexcitation plus noise from the electronics. The silicon chip was provided without any connection between the top and bottom electrodes. To make these connections, the chip was sent to a clean room where wires were ultrasonically bonded to the top of the chip and the side electrode contacts.

Once the wire bonding was done, the sensor was placed inside a dark room workstation and its basic performances were evaluated. First, a calibration run measures the parasitic capacitance between the two contacts (in this case needles) of the sensor. Next, a voltage bias scan is performed, and the leakage current is measured with a pico amp-meter until we reach a plateau that corresponds to the depletion voltage. Finally the capacitance of the sensor is measured as a function of voltage and the parasitic capacitance is subtracted, to get the correct value of the capacitance of the silicon detector.

Before attaching the sensor to the rest of the circuit to perform measurements, the response of the pre-amplifier was calibrated using different capacitances between 1 pF and 100 pF put in parallel to the capacitance of 0.4 pF at the calibration input. To do this, the amplifier was supplied with two voltage biases of + and -12V from a DC workbench power supply. The RMS of the baseline noise was measured while no pulse was injected. The circuit was fed with a square pulse and the rise time of the output signal was measured directly on the oscilloscope between the 10% and 90% of the rising signal. The amplitude of the signal was noted as well. During these measurements, the circuit and the cables were coated with aluminium foil (grounded through a cable to the HV power supply), in order to shield the system from radiations, which would cause additional noise to the output signal.

After the calibration measurements were completed, the silicon detector was introduced in the circuit by connecting it to the pre-amplifier. A voltage of around 60 V was fed to the sensor, in order to fully deplete it, through a low-pass filter consisting of a 100 nF capacitance and of a 300 kΩ resistor, see

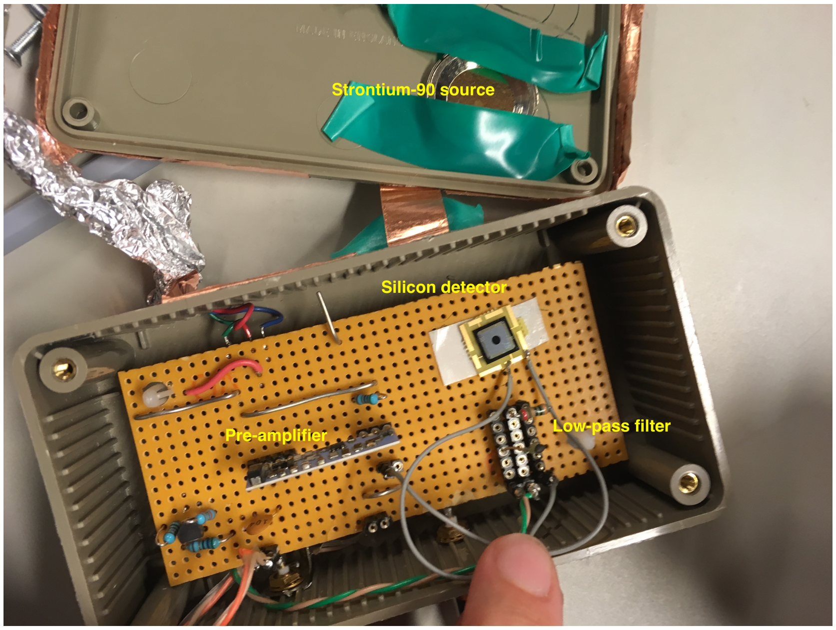


Figure 1: Silicon detector experimental setup.

Figure ??. The resulting circuit is schematically shown in Figure 2. Finally the Strontium-90 source was attached with tape to the lid of the box containig the entire circuit. By closing the lid and covering it with aliminium foil, external radiations were shielded. The measurement of the pulses induced in the silicon detector by the particles radiated by the Strontium decay were registered from the oscilloscoper for further analysis.

3 Equivlent Noise Charge

The *Equivalent Noise Charge*, or ENC, is the amount of charge one would have to inject into the preamp in order to match the recorded noise level of the output. In other words, we want to figure out, for a given capacitance, what the RMS noise signal would look like if it were an unamplified input signal.

$$ENC = \frac{V_{rms} \cdot C_{calibration}}{G} \tag{1}$$

The gain is given by the ratio of output-to-input voltage:

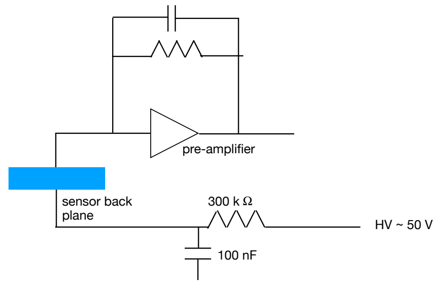


Figure 2: Silicon detector circuit with low-pass filter, pre-amplifier and silicon diode.

$$ENC = \frac{V_{rms}}{V_{out}} \cdot (C_{calibration} \cdot V_{in}) \tag{2}$$

During the calibration test, the input voltage is fixed to 20mV, so the only thing that varies in this expression should be the capacitance

4 Study of Silicon detector

Before integrating the silicon detector inside the rest of the circuit, a few measurements were undertaken to understand its properties: the depletion voltage and the capacitance at depletion. All curves were measured 4 times, in order to have an estimate of the uncertainty of each measurement.

The IV curve measures the leakage current as a function of voltage and it is useful for measuring the deplation voltage. As it is visible from Figure 3, the depletion voltage for this particular silicon diode is of ≈ 50 V. The current going through the diode at full depletion is of around -15 nA. The errorbars are found by taking the standard deviarion between the four measurements performed for each point.

The CV curve measures the capacitance of the diode as a function of the voltage and can be seen in Figure 4 for the diode used in this experiment. Before measuring the capacitance of the silicon diode though, we measured the capacitance of the measuring instrument, called "Open needle" in Figure 4. We then measured the diode capacitance and finally we subtracted the instrument capacitance, to have the actual measurement in red in Figure 4.

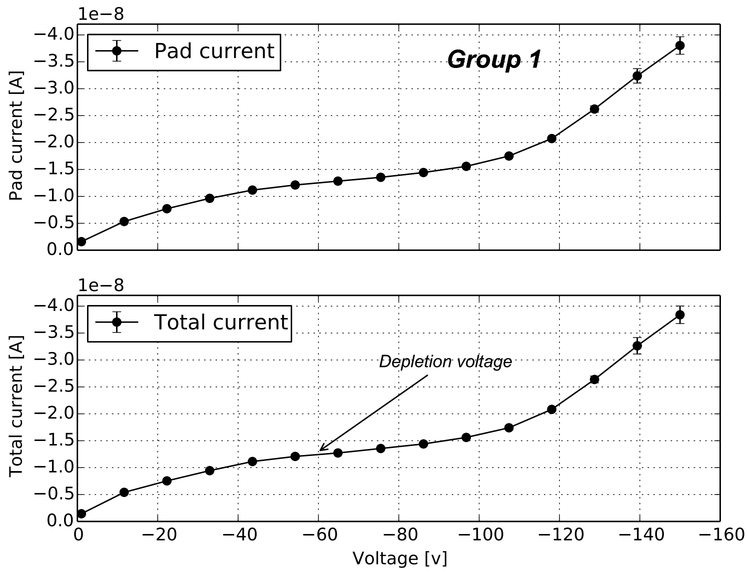


Figure 3: IV curve for the silicon detector of p-type. The upper plot shows the current per pad for the 4 different pads, while the lower plot shows the total current

Again each measurement was performed 4 times and the plotted results are the mean of the experiments, while the errorbars are found by calculating the standard derivation of the measurements. In this case, the standard deviation is very small and the errorbars are hence smaller than the data points. The capacitance of the diode at full depletion voltage (above 50 V) is measured to 11.20 ± 0.02 pF, see Figure 4.

5 Pre-amplifier calibration

The response of the pre-amplifier was studied with a calibration signal consisting of a square pulse over the calibration load capacitance, which was between 1 and 100 pF. Before injecting the square pulse, the noise of the circuit with the different capacitors was measured as the RMS of the noise oscillations. The measurements were recorded and plotted on Figure 5a. As it is clearly visible, the noise RMS increases as a function of the input load capacitance.

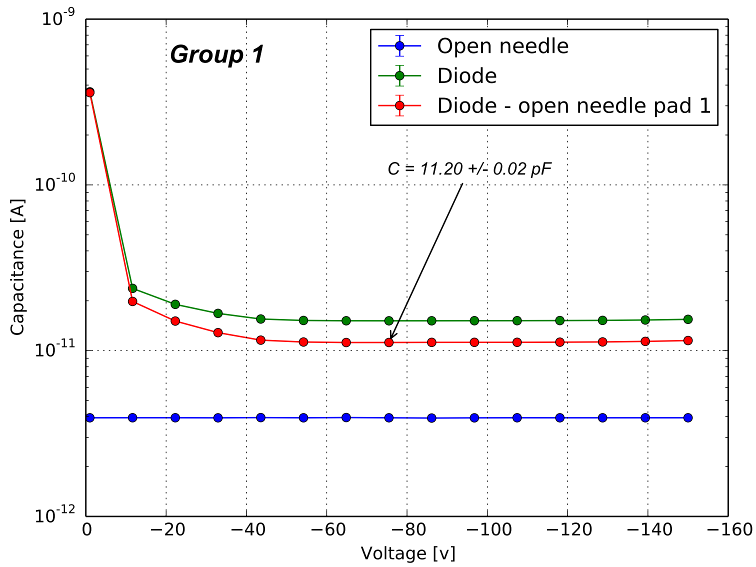
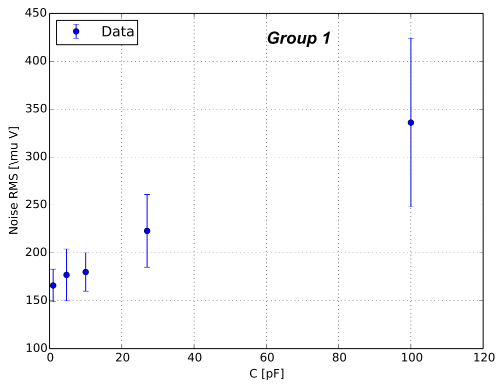


Figure 4: Parasitic capacitance of the instrument (blue), capacitance of the system plus the silicon diode and capacitance of the diode as a function of voltage.

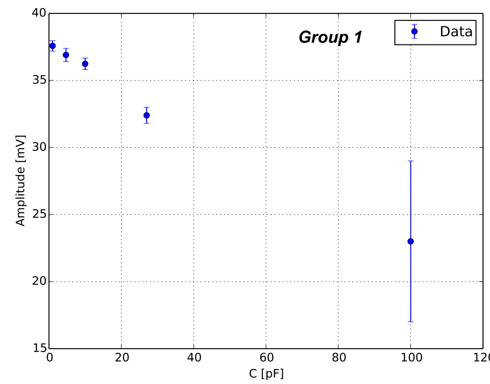
After feeding the square pulse through the preamplifier, the amplitude and the rise time of the pulse were noted and plotted in Figure 5b and Figure 6 respectively. The amplitude decreases as a function of load capacitance, while the rise time increasese, which means that the pulse reacts slowlier and looses some of its power as a functio of capacitance. The rise time was measured by finding the time interval between the 10% and 90% of the rising pulse. Additionaly, the measurements with higher capacitances are affected more by the noise, as it is visible by the errorbar size for C = 100 pF for example. The rise time measurement was fitted to a 2nd degree polynomial and the resulting paramters are shown in Figure 6

6 Results and Discussion

After soldering the silicon diode to the rest of the circuit with the pre-amplifier (see Figure 2), we closed the Strontium-90 source and the diode in a box, shielded it with aluminium foil and we connected the pre-amplifier



(a) Noise RMS vs capacitance measurement



(b) Amplitude vs capacitance measurement

Figure 5: Calibration measurements for the pre-amplifier.

to the ± 12 V source and we applied ≈ 50 V to diode to fully deplete it. When one of the product decays of the radioactive source hit the diode, it induced a signal, which was observed on the oscilloscope. A few of these signals were saved and are visible in Figure 7 and 8. Several measurements were extracted from these data. First of all the noise RMS was measured by taking the standard deviation of all the measured points before the pulse (until Time $= -0.5\mu$ s, which is a cut-off that is valid for all the datasets). The mean noise RMS and its uncertainty are 1.0 ± 0.1 mV. The rising pulse is then fitted to find the rise time using the equation:

$$V = V_0(1 - \exp^{-t/\tau}) + V_{noise} \tag{3}$$

where V_0 is the starting amplitude, V_{noise} is the background amplitude and τ is the rising time. The rising time from the fit and the rising time from the calibration of the pre-amplifier are though not exactly the same rising time, as the first one is measured for the entire rising slope and the second one is measured only between 10% and 90% of the slope. In order to relate the two to each other, this relation exists:

$$t_r = \ln(9) \cdot \tau = 2.197 \cdot \tau \tag{4}$$

where t_r is the time interval between 10% and 90%, while $\tau = RC$. The mean rise time found with the fits is of $/tau = 38.9 \pm 9.7$ ns and if we multiply this by 2.197 to get the time interval we get $t_r = 85.5 \pm 21.3$ ns.

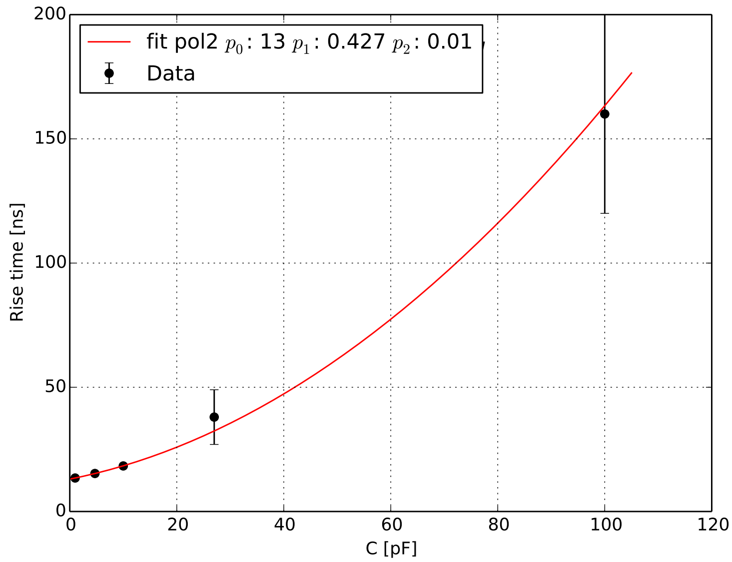


Figure 6: Calibration of the rise time as a function of capacitance

7 Conclusion

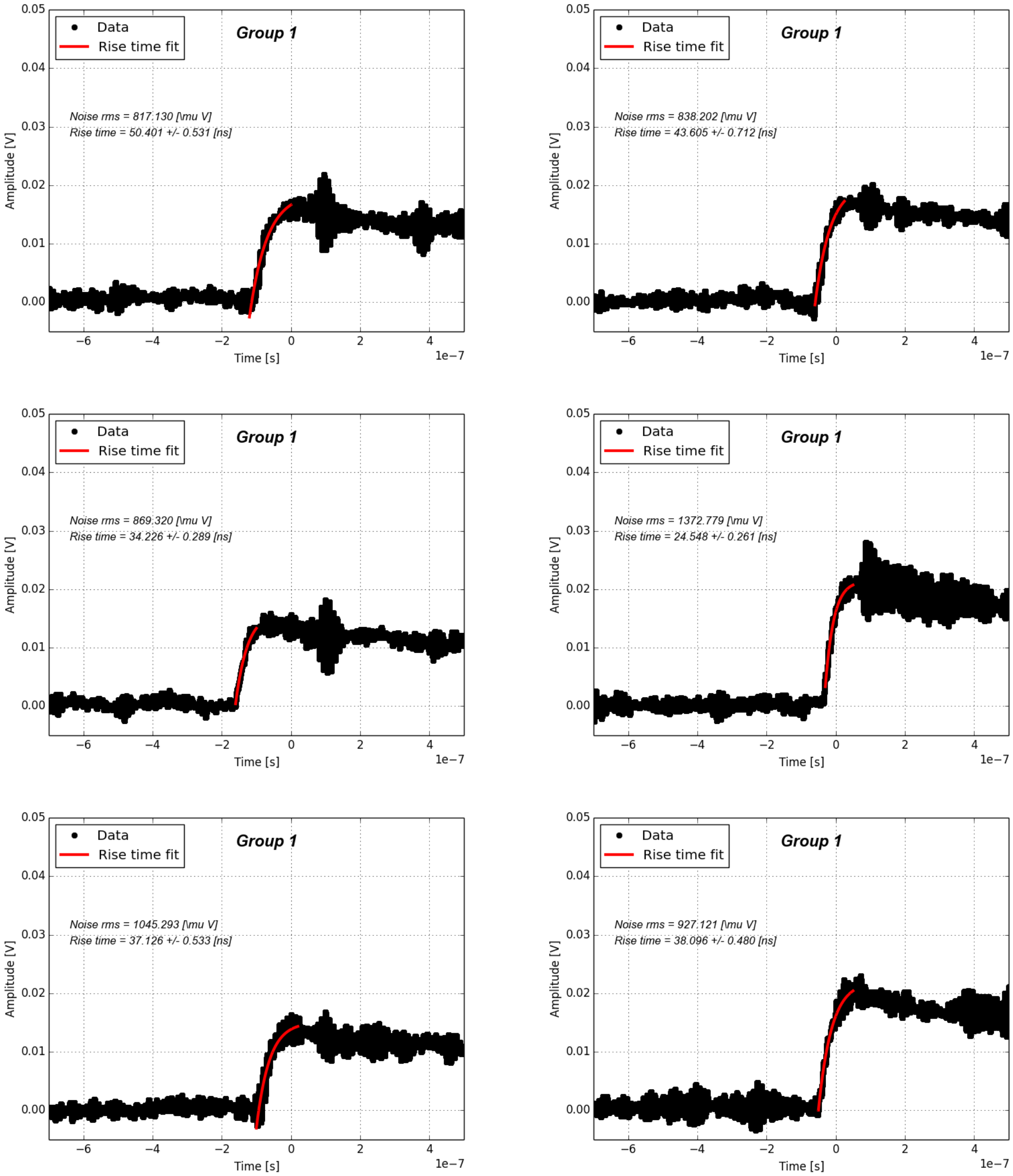


Figure 7: Measurement of the rise time from the Strontium-90 decay

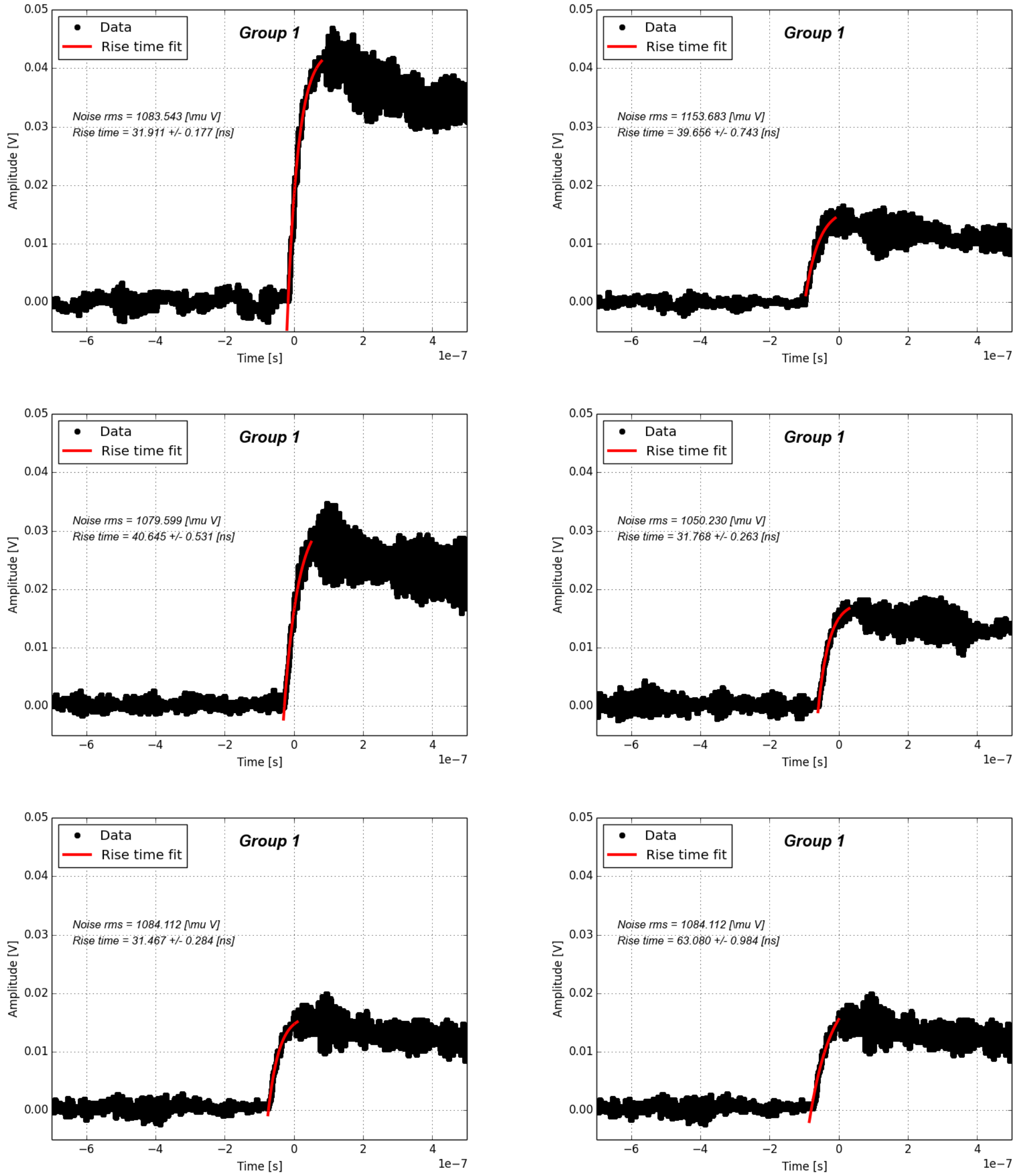


Figure 8: Measurement of the rise time from the Strontium-90 decay

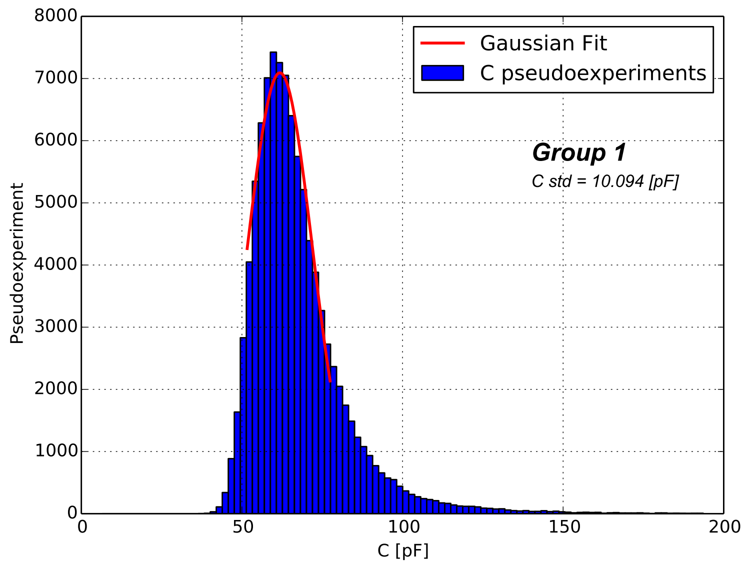


Figure 9: Statistical error on C from MC pseudoexperiments